# SAVANNAH HARBOR EXPANSION PROJECT CHATMAN COUNTY, GEORGIA AND JASPER COUNTY, SOUTH CAROLINA: FINAL GENERAL RE-EVALUATION REPORT AND ENVIRONMENTAL IMPACT STATEMENT JANUARY 2012

## COMMUNICATION

FROM

## THE ASSISTANT SECRETARY OF THE ARMY, CIVIL WORKS, THE DEPARTMENT OF DEFENSE

TRANSMITTING

THE CORPS' FINAL GENERAL RE-EVALUATION REPORT AND ENVIRONMENTAL IMPACT STATEMENT

## PART 4 OF 15

NOVEMBER 9, 2012.—Referred to the Committee on Transportation and Infrastructure and ordered to be printed

U.S. GOVERNMENT PRINTING OFFICE

81–593 WASHINGTON : 2013

FINAL

# GENERAL RE-EVALUATION REPORT

## SAVANNAH HARBOR EXPANSION PROJECT

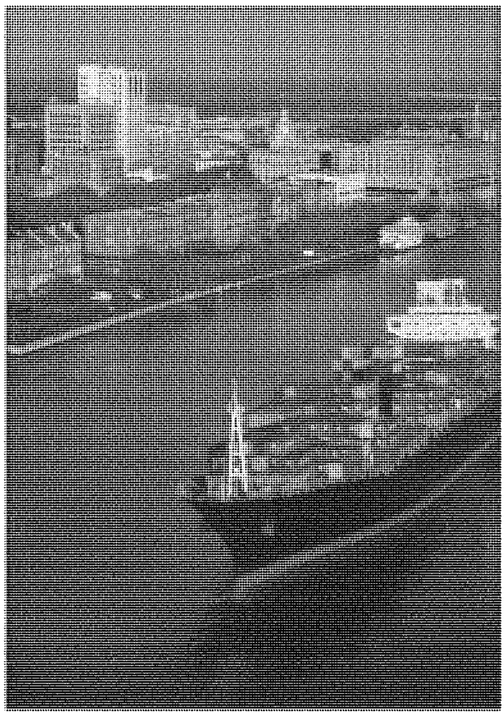
Chatham County, Georgia and Jasper County, South Carolina

**January 2012**

**(Revised July 2012)**

Appendix C
Attachment 3
Parts 16-26

Volume 4



**US Army Corps of Engineers**
*Savannah District*
*South Atlantic Division*

ERDC/CHL TR-11-X

Coastal and Hydraulics Laboratory

US Army Corps
of Engineers®
Engineer Research and
Development Center

*DRAFT*

# Vertical Ship Motion Study for Savannah, GA Entrance Channel

Michael J. Briggs and William G. Henderson

June 28, 2011

Program Title [Business Area or Work Unit Title Optional if Work Not Direct-Funded]

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# Vertical Ship Motion Study for Savannah, GA Entrance Channel

Michael J. Briggs and William G. Henderson

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

DRAFT Final report



Prepared for Commander, U.S. Army Engineer District, Savannah (CESAS-EN-H)

Under Work Unit 33143

Monitored by U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

**Abstract:** The Savannah District (SAS) is finalizing the engineering appendix pending the economics study for the "Savannah Harbor Expansion Project: Extension of Entrance Channel." Some shallower offshore shoals were discovered that might influence the safety and efficiency of navigation if the project proceeds as originally proposed. The U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), conducted a vertical ship motion study to evaluate three proposed channel alignments S-1, S-3, and S-8. These alignment changes (doglegs) are proposed to allow ships to reach deeper water in less distance, with reduced dredging costs. The Channel Analysis and Design Evaluation Tool (CADET) was used to predict vertical ship motions due to wave-induced heave, pitch, and roll. PIANC and Ankudinov ship squat were calculated and compared with the Beck, Newman, Tuck (BNT) squat predictions used in CADET. The CADET days of accessibility, vertical ship motion allowances, and net underkeel clearance were calculated based on these vertical ship motion components to provide a risk-based method of evaluating different channel depths. This output was used to make a educated engineering judgment of the optimum channel depth for the two ship loading conditions and three channel alignments.

# Contents

# Figures and Tables

## Figures

## Tables

# Preface

This report describes procedures and results of a vertical ship motion study for the entrance channel at Savannah, GA. The study was performed in support of the "Savannah Harbor Expansion Project: Extension of Entrance Channel." 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, Savannah (SAS). The study was conducted during the period January through May 2010 as part of a larger study that included use of the Ship Tow Simulator (STS) in the horizontal channel design. Mr. Wilbur Wiggins, U.S. Army Engineer District, Savannah, was the study manager and point of contact.

The investigation reported herein was conducted by Dr. Michael J. Briggs of the Coastal Harbors and Structures Branch, CHL. The final report was written by Dr. Briggs with assistance from Mr. William Henderson. We gratefully acknowledge the support of Mr. Andrew Silver and Mr. Paul Kopp of the Naval Surface Warfare Center, Carderock Division, for discussion and review.

This study was performed under the general supervision of Dr. William Martin, Director, CHL. Direct supervision of this project was provided by Dr. Jackie Pettway, Chief, Coastal Harbors and Structures Branch. At the time of publication of this report, Dr. Jeffery P. Holland was Director of ERDC, and COL Kevin J. Wilson, EN, was Commander and Executive Director.

# Unit Conversion Factors

| Multiply | By | To Obtain |
|---|---|---|
| acres | 4,046.873 | square meters |
| cubic feet | 0.02831685 | cubic meters |
| cubic inches | 1.6387064 E-05 | cubic meters |
| cubic yards | 0.7645549 | cubic meters |
| degrees (angle) | 0.01745329 | radians |
| fathoms | 1.8288 | meters |
| feet | 0.3048 | meters |
| hectares | 1.0 E+04 | square meters |
| inches | 0.0254 | meters |
| knots | 0.5144444 | meters per second |
| miles (nautical) | 1,852 | meters |
| miles (U.S. statute) | 1,609.347 | meters |
| miles per hour | 0.44704 | meters per second |
| pounds (force) per square foot | 47.88026 | pascals |
| pounds (force) per square inch | 6.894757 | kilopascals |
| pounds (mass) | 0.45359237 | kilograms |
| pounds (mass) per cubic foot | 16.01846 | kilograms per cubic meter |
| pounds (mass) per cubic inch | 2.757990 E+04 | kilograms per cubic meter |
| pounds (mass) per square foot | 4.882428 | kilograms per square meter |
| pounds (mass) per square yard | 0.542492 | kilograms per square meter |
| square feet | 0.09290304 | square meters |
| square inches | 6.4516 E-04 | square meters |
| square miles | 2.589998 E+06 | square meters |
| square yards | 0.8361274 | square meters |
| tons (force) | 8,896.443 | newtons |
| tons (force) per square foot | 95.76052 | kilopascals |
| tons (long) per cubic yard | 1,328.939 | kilograms per cubic meter |
| tons (2,000 pounds, mass) | 907.1847 | kilograms |
| tons (2,000 pounds, mass) per square foot | 9,764.856 | kilograms per square meter |
| yards | 0.9144 | meters |

# 1 Introduction

## Savannah entrance channel

Savannah is an important deep-draft commercial harbor on the U.S. Atlantic coast with containerships comprising a major part of the commercial trade (Figure 1). The natural nearshore water depth in the vicinity of the Savannah is relatively shallow. Large shoals protrude 4-5 miles seaward from the entrance on either side of the channel, eventually dropping down to a broad, flat bottom area with depth of 40-50 ft.

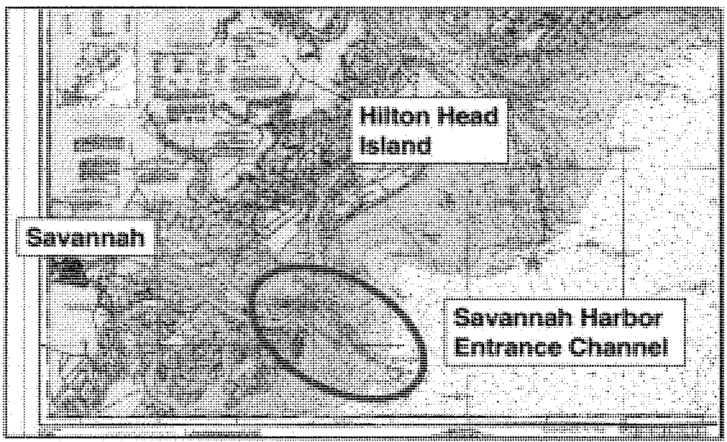



Figure 1. Location map of Savannah study.

The entrance channel of the Port of Savannah, Georgia consists of two sections: an Outer Channel subject to waves and a sheltered Inner Channel. The existing channel project depth is 44 ft Mean Lower Low Water (MLLW) for the Outer or Offshore Channel and 42 ft MLLW for the Inner Channel (i.e., 2 ft difference). The proposed dredging is 2 to 6 ft for both channels with a maximum project depth of 50 ft for the Outer Channel and 48 ft for the Inner Channel. Typical high tide adds another 7 to 8 ft of useable depth for deeper draft vessels. However, the durations of these high tide water levels is always less than 24 hr per day and 365 days per year. Design gross underkeel clearance (UKC) is 4 ft in the Outer Channel and 2 ft in the Inner Channel.

Based on the separate economic study for the Savannah Harbor Expansion Project, final proposed project depths of 49 ft for the Outer Channel and 47 ft for the Inner Channel were selected. This represents a 1 ft reduction in the original project depth of 50 ft for the Outer Channel that was used in this engineering study. However, because of the tidal range and durations of those water levels, transit times are easily accommodated within the Savannah Channel for the range of ship drafts and speeds in this study. Comments have been included in this report to this effect as necessary.

The existing Outer Channel has a length of 10 nm (60,000 ft) and a width of 600 ft. The offshore 5.8 nm section is typical of an unrestricted channel cross-section, but with a finite width at the bottom of 600 ft. The inshore part of this outer channel is more like a restricted channel cross-section with a length of 8.2 nm, a width of 600 ft, side slopes of 1:5, and trench heights above the bottom $h_T$ of 10 to 25 percent of the depth. Channel cross-sections are not symmetric about the centerline of the channel and usually are different on each side of the channel. In this study the channel cross-section is assumed to be unrestricted or open for the entire Outer channel.

The Inner Channel is 17 nm long and 500 ft wide. It has a restricted channel cross-section with side slopes of 1:3 and $h_T$ from 10 to 100 percent of the depth. The inner 5.5 nm section near the port becomes congested and ship traffic is required to go much slower. The inner channel was not modeled in this study.

## Design ship

The *Susan Maersk* Post-Panamax containership (Figure 2) is the design ship for this study. It was completed in 1997 with a TEU capacity of 8,680 and a length overall $L_{OA}$ of 1,138 ft. Typical ship speeds $V_k$ range from 8 kt in the inner channel to 14 kt in the outer channel. In addition to the fully-loaded draft of $T$ = 47.5 ft, a light-loaded draft of $T$ = 46 ft was also investigated in this study. This is necessary since the lighter ship (with less draft) will respond to waves differently than the fully-loaded ship. Table 1 lists ship particulars for these two design drafts of the *Susan Maersk*.

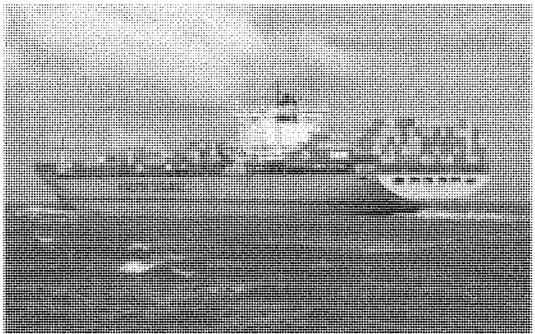


Figure 2. *Susan* Maersk design ship for Savannah Channel.

Table 1. *Susan Maersk* containership parameters.

| Description | Symbol | Units | Light-loaded | Fully-loaded |
|---|---|---|---|---|
| Length between perpendiculars | $L_{PP}$ | ft | 1087.9 | 1087.9 |
| Beam | B | ft | 140.4 | 140.4 |
| Draft | T | ft | 46.0 | 47.5 |
| Block coefficient | $C_B$ | — | 0.65 | 0.65 |
| Longitudinal center of gravity | $L_{CG}$ | ft | 563.0 | 563.7 |
| Vertical center of gravity (from keel) | $V_{CG}$ | ft | 62.8 | 62.2 |
| Metacentric height | GM | ft | 1.97 | 2.48 |
| Roll damping factor, fractional percent | R | — | 0.04 | 0.08 |
| Roll Gyradius | $k_4$ | ft | 57.6 | 57.6 |
| Pitch Gyradius | $k_6$ | ft | 272.0 | 272.0 |

## Purpose

The Savannah District (SAS) is finalizing the engineering appendix pending the economics study for the "Savannah Harbor Expansion Project: Extension of Entrance Channel." Some shallower offshore shoals were discovered that might influence the safety and efficiency of navigation if the project proceeds as originally proposed. Several additional channel extensions are now being considered based on length, dredging requirements, and pilot considerations. These alignment changes (doglegs) are proposed as they will allow the ships to reach deeper water in less distance, with reduced dredging costs.

Figure 3 shows the three proposed channel alignment options. For this study, the Existing Channel starts at Station 0 and ends at Station 60 (i.e., 60,000 ft). Option S-1 is a proposed extension of the Existing Channel to Station 123 (123,000 ft). Option S-3 runs east-west from Station 98 (98,000 ft), intersecting the Existing Channel at Station 82 (82,000 ft). The S-8 option is the preferred option for the pilots since it is an easier transition to the Existing Channel and has a similar alignment. It also begins at Station 98 and intersects the Existing Channel at Station 60.

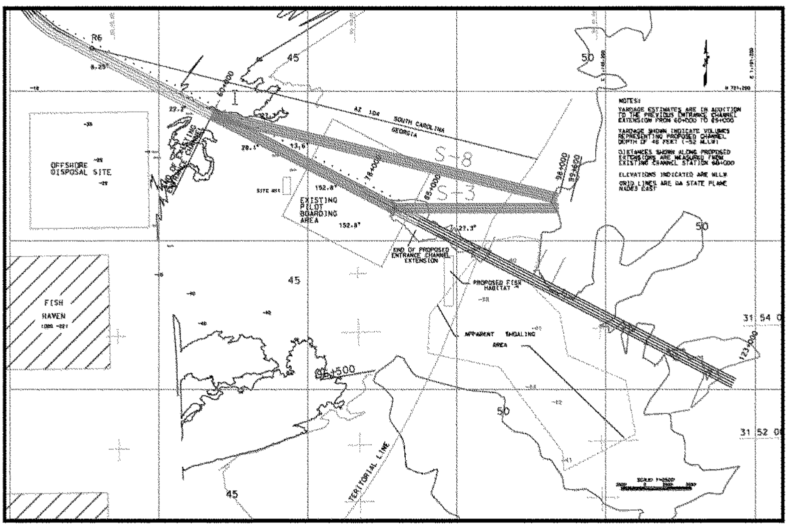



Figure 3. Savannah Entrance Channel proposed channel alignments showing Option S-1 extension to Existing, Option S-3, and Option S-8.

## 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 SAS planning and design for the Savannah entrance channel. This study consisted of wave and vertical ship motion information that was part of a larger effort by CHL that included horizontal channel design using the Ship Tow Simulator (STS). The approach consisted of the following tasks:

- Characterize incident wave climate from available sources.

- Provide wave conditions along existing and optional channel alignments to the STS.
- Apply the Channel Analysis and Design Evaluation Tool (CADET) vertical ship motion model to the study areas.
- Provide PIANC, Ankudinov, and CADET ship squat estimates. CADET squat predictions are based on the methodology of Beck, Newman, and Tuck (BNT).
- Provide CADET vertical ship motion allowances that reflect wave-induced ship motions.
- Provide CADET days of accessibility that reflect UKC due to both ship squat and vertical wave-induced ship motions.

Port designers have historically relied on deterministic approaches with large safety factors for channel design. Risk-based models are now recommended to define a useful lifetime with an acceptable level of risk of accidents or groundings. CADET is a program to determine the 'optimum' dredge depth for the offshore portions of entrance channels. This 'optimum' dredge depth is defined as the depth that provides the greatest accessibility for the least amount of dredging and is determined by predicting ship UKC for different wave, ship, and channel combinations. It is based on probabilistic risk analysis techniques to evaluate the accessibility of a series of channel reaches for multiple vessel geometries, loading, and wave conditions.

## Report organization

In this report, the CADET numerical model is briefly described in Chapter 2. Chapter 3 contains a description of the PIANC, Ankudinov, and CADET/BNT ship squat predictions. The characterization of the waves for the CADET and STS simulations is described in Chapter 4. Results from the ship squat calculations are compared in Chapter 5. Chapter 6 presents the days of accessibility from the CADET model. The wave-induced, vertical ship motions and corresponding UKC are discussed and presented in Chapter 7. These results will indicate vertical ship motions and levels of accessibility as a function of the full range of proposed channel project depths from 48 to 64 ft, including the tidal advantage. The reader will be able to select the optimum dredge depth based on the percentage of time the channel could be safely transited each year. Finally, a summary and conclusions is presented in Chapter 8.

# 2 CADET Numerical Model

## Background

CADET (Kopp and Silver 2005) was developed by the Naval Surface Warfare Center, Carderock Division (NSWCCD) under contract to the US Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL). CADET is an expansion of the technology developed to determine the depth of entrance channels to new homeports for Nimitz-class Aircraft Carriers (CVN 68). The technology used in CADET (Silver 1992, Silver and Dalzell 1997) was initially developed for the Environmental Monitoring and Guidance System (EMOGS). EMOGS provides operational guidance on the expected UKC of a vessel given real time wave and water level measurements or observed conditions at a particular port. For each UKC prediction, it also calculates the uncertainty and risk of touching the channel bottom for those conditions. EMOGS evaluates clearance and risk for a single specified ship at one channel depth, using a single wave spectrum, for a transit in one direction at a specific date and time. Astronomical tide effects on the water level are included and take into account the duration of transit for a given ship speed and entrance channel configuration. Meteorological effects on water level due to barometric pressure are also included. EMOGS is installed at naval stations in the United States and has been in operation for over 20 years. During this time, no known incident of bottom touching or grounding has occurred, and the users have not complained that the results are too restrictive.

CADET differs from EMOGS in several respects. It is more of a design tool as it evaluates clearance and risk for a range of possible water depths. In addition, it evaluates the entrance channel depths for any channel cross-section. Annual local wave statistics are used to determine the accessibility of the transit channels, expressed in days per year. Astronomical and meteorological tide effects are not explicitly included since, for design purposes, a transit could occur in either direction at any time. Water level changes can be included by varying the project depth relative to ship draft. A tide calculator is a post-processor option that can be used to indicate additional days of accessibility due to hindcast of 20-year tidal cycles for a particular location.

## Vertical UKC calculation

CADET calculates the vertical UKC of a specific ship, commercial or naval, at a specified channel location, and provides information to aid in determining the optimum dredge depth. This optimum depth is defined as the shallowest depth that allows the maximum days of access for any given year at that location. The accessibility of the channel is determined by calculating the vertical UKC and the risk of the vessel touching the channel bottom under all wave conditions that are present. The general rule is that if the risk α of the ship touching a flat channel bottom is less than 1 in 100 (i.e., $\alpha = 0.01$) for each wave in a climatology during a given transit, then the channel is considered accessible for that depth. The Navy is comfortable with this level of risk and corresponding accessibility. The number of days per year the channel is accessible is dependent on the persistence of the local wave conditions obtained from the local wave climatology.

The dynamic UKC of the vessel is influenced by five major parameters that include:

- Static draft and trim of the ship at rest,
- Underway sinkage and trim,
- Wave-induced vertical motions,
- Hydrologic factors of channel depth at Mean Lower Low Water (MLLW) project depth, and
- Change in water level due to the astronomical tides.

Because CADET is primarily a channel-depth design tool, ephemeral parameters such as meteorological tides are not factored into the calculation. As mentioned previously, CADET does have a post-processing option for tidal effects. Otherwise, the user can input equivalent tides in the range of water depths used for the predictions. CADET does not explicitly include channel width or bank effects.

Figure 4 shows the major parameters considered when calculating the vertical clearance of the ship in a channel. The static UKC is the difference between the nominal channel depth and the static at-rest draft of the vessel. Static trim must also be taken into account. As the ship travels at speed along the channel, the ship both sinks and trims (i.e., squat or midship sinkage and trim by the bow or stern) due to a pressure field between the hull of the vessel and the channel bottom. The net $UKC_j$ at location $j$ (i.e.,

$j^{th}$ control point on a hull corresponding to the lowest points, usually at the bow, stern, rudder, and bilges) is given by

$$UKC_j = D_c + E_t - (T_j + S_j + A_j) \tag{1}$$

where:

$D_c$ = nominal channel depth at MLLW
$E_t$ = water level due to tide relative to MLLW
$T_j$ = static draft
$S_j$ = ship squat
$A_j$ = vertical motions allowance.

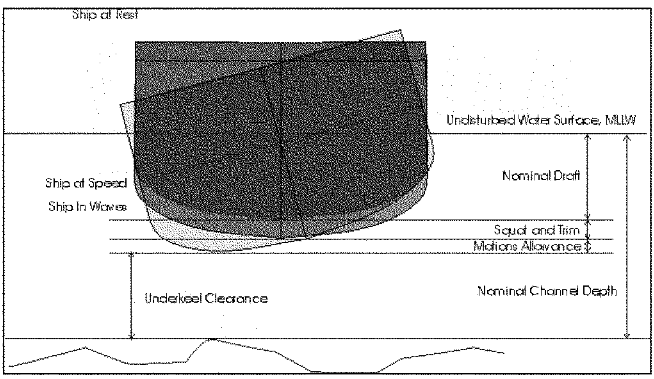



Figure 4. Cross-section of a ship in a channel.

The $A_j$ is determined from the vertical wave-induced ship motions of heave, pitch, and roll. The magnitude of the vertical displacement at a point on the ship is dependent upon the height and period of the waves in the channel, the ship speed, the relative ship heading to the waves, and the channel depth. For the coupled heave and pitch motions, a vertical displacement transfer function $H_j(f,\theta)$ is calculated as

$$H_j(f,\theta) = Z + X_j\Theta(f,\theta) \tag{2}$$

where:

$j$ = corresponds to the $j^{th}$ control point location
Z = vertical heave motion transfer function
$X_j$ = longitudinal distance from the ship's center of gravity to the $j^{th}$ control point
$\Theta(f,\theta)$ = pitch transfer function.

A similar transfer function is calculated for the coupled heave, pitch, and roll motions to determine the vertical displacement on the sides of the ship. These transfer functions are then used in the calculation of the RMS (root mean square) displacement $\sigma_j$ given by

$$\sigma_j = \sqrt{\sigma_j^2} = \sqrt{\sum_f \sum_\theta S(f,\theta)\left|H_j(f,\theta)\right|^2 \Delta f \Delta \theta} \tag{3}$$

where:

$\sigma_j$ = RMS displacement at $j^{th}$ control point location, ft
$S(f,\theta)$ = directional wave spectrum, $ft^2$/Hz/deg
$\left|H_j(f,\theta)\right|^2$ = square of the modulus of the transfer function, known as the Response Amplitude Operator (RAO)
$\Delta f$ = increment in frequency, Hz
$\Delta\theta$ = increment in direction, deg.

Because of phase differences, $\sigma_j$ calculated from individual wave conditions may not provide the largest vertical excursion the ship can experience during a transit. Therefore, higher order extremal statistics (Ochi 1973) are used to define an expected extreme motion allowance $A_j$ during a given transit as

$$A_j = \sigma_j \sqrt{2 \ln\left[\frac{T_d \sigma_{vj}}{2\pi\alpha\sigma_j}\right]} \tag{4}$$

where:

$T_d$ = exposure time in the channel (i.e., reach length/ship speed), sec
$\sigma_{vj}$ = vertical velocity of the vertical motion (i.e., time derivative of $\sigma_j$) at location $j$, ft/sec
$\alpha$ = risk parameter, normally taken to be 0.01 (i.e., 1/100) in CADET. If $\alpha$ = 0.01, then the ship has a risk of 1 in 100 that the

predicted motions allowance $A_j$ will be exceeded for the given set of wave conditions.

## Uncertainty and risk analysis

Each of the parameters in Eq. 1 has inherent uncertainties. As an example, Table 2 lists the uncertainty (i.e., bias and variability) in each of the major parameters that make up $UKC_j$ for a large naval vessel. First, the channel depth for CADET has no bias or variability because it is a deterministic parameter. Second, the uncertainty in the static and dynamic drafts comes from the estimation of the draft at the pier, from the draft marks, and the method that calculates the sinkage and trim. The error band in the static draft is assumed to be known within a range of ±1 percent. The critical points of the bow, stern, and bilge (i.e., port and starboard amidships on the keel) therefore have an error band within 4.5 percent of the actual value at the bow and stern and 1.5 percent of the actual value at the bilge. The sinkage estimate is usually based on an analytical method or model test results. The uncertainty in the sinkage stems from the scatter of the data from model tests and how well the calculated results fit the model test results. This gives a variability of the sinkage parameter of 1 percent with no bias, as shown in Table 2.

Table 2. Uncertainty in major CADET parameters (All values represent ±2σ range).

| Parameter | Bias | Variability |
|---|---|---|
| Channel depth | None | None |
| Static Draft | | |
| Bow and stern | None | 4.5% |
| Bilge | None | 1.5% |
| Squat (sinkage & trim) | None | 1.0% |
| Transformed wave spectra | 0.2m (0.6ft) | 80% |
| Wave-induced motions based on measured wave data | 20% over predicted | 34% |

The final two parameters in Table 2 are the wave statistics and the wave-induced motions. The wave statistics are usually generated from hindcast wind models, and then transformed from offshore to the channel with a shallow water wave model. Most models are validated with buoy data. The bias and variability shown in Table 2 for the transformed wave spectra assumes a measurement bias and large variability in the wave input. The usual models for global ocean wave prediction using wind hindcast data introduce a bias of ±0.2 m (0.6 ft) and an average RMS error of 0.8 m (2.6 ft) that translates to an error band of about 80 percent. The variability of the wave input, especially wave height, is the main driver of the variability in the motions estimates. There are also uncertainties in the calculation method of the response amplitude operators.

The shallow water motions calculation for Navy ships was based on a software program that was a hybrid of the Navy Standard Ship Motion Program (SMP). This hybrid was validated by both model tests and comparisons of predicted motions with full-scale measurements (Silver and Dalzell 1991). The motions of the commercial ships used in CADET were computed through the shallow-water version of SCORES (Kaplan 1996a, 1996b). The bias and uncertainty shown in Table 2 reflect those of a large Navy ship. As more experience using CADET is attained for commercial ships, the bias and variability could change. However, a large component of the uncertainty and bias in the motions calculation comes from the uncertainty in the wave measurement. Therefore, the difference in the uncertainty of the motions between commercial and Navy ships may be small.

The primary objective for calculating uncertainty is to provide a measure of risk of the vessel touching the various project depths being considered. Risk is defined as that proportion of all possible transits under statistically constant conditions in which the minimum channel clearance would be negative. The risk model accounts for the uncertainty in each of the parameters by assuming a Gaussian distribution for static ship draft, and underway sinkage and trim, and a Rayleigh distribution for the vertical motion and velocity variances. The Rayleigh distribution reflects the most likely probability distribution of the waves. Using these distributions, the probability density of the largest motion excursion or the minimum UKC is determined and its area up to a minimum clearance of zero is calculated.

Under this definition of risk, it is necessary to compute the probability density of the net effective clearance and determine the area up to zero net effective clearance. The net effective clearance, therefore, is defined as the difference between the random variables that make up the effective channel depth and the effective vertical displacement of the ship. These random variables are a function of the uncertainty in each of the major parameters that make up the net effective clearance.

Thus, a risk analysis is performed to determine the probability of any one of the critical points of the deep draft vessel touching the channel bottom for inbound and outbound transits. The critical locations on the vessel usually are the bow at the keel, the rudder(s), and the port and starboard bilges at amidships. The risk analysis is performed for each of the wave conditions in a wave climatology for the port. The significant wave height, the peak or modal period, primary wave direction, and distribution of energy in frequency and direction (i.e. directional wave spectrum) define the wave condition. The result of the risk analysis provides a probability of the vessel touching the channel bottom under each of the wave conditions for a specified project depth. It is assumed that if the risk is greater than some threshold value (normally 1 in 100), then the channel is inaccessible by the vessel. The days of accessibility of the channel are calculated by determining the persistence of the wave condition that produces the risk of 1 in 100 or greater. The risk calculation is performed for each wave condition and a range of project depths. When complete, the optimum channel depth is the one with the greatest number of days of accessibility per year and the least amount of dredging.

## CADET organization

CADET is the interface to a set of computer programs that calculates net UKC and bottom touching risk probability for any number of ships and loading conditions over a range of multiple project depths. CADET manages the necessary internal data flow among the component programs and provides an interface structured in four basic modules for defining and performing calculations and actions relative to (a) Ship, (b) Project, (c) Analyses, and (d) Results. These modules are written in FORTRAN and $C^{++}$. English units (i.e., ft, $ft^2/Hz$, etc.) are the standard for the program, although metric equivalents can be converted for some inputs.

### Ship module

The first module contains all of the ship parameters to define a ship relative to geometry and loading. Figure 5 shows the nine categories for defining the ship that include (a) static draft and trim, (b) ship speeds, (c) loading parameters, (d) motion risk parameter, (e) water depths, (f) wave frequencies, (g) sinkage and trim, (h) critical point locations, and (i) ship motion transfer functions.

The most critical input is the ship geometry file that is represented by the "ship lines" drawing in Figure 5. Ships are defined by a hull geometry file that is independent of loading condition. The geometry file represents the ship in terms of hull offsets, from the keel to the deck-at-edge, at 21 equally-spaced stations between the forward and aft perpendicular. These geometry data files can be prepared externally (manually or by conversion from other representations) and imported into CADET, or they can be created using a built-in graphical geometry editor. The spacing between these 21 stations is determined by the ship's waterline length or the length between the forward and aft perpendiculars, $L_{pp}$. Figure 6 shows an example of the station cross-sections. The ship's beam $B$ represents the width at the waterline. It is a deterministic geometric parameter that is used to document the ship and to calculate some hydrostatic properties. The offsets do not necessarily have to correspond to $B$ exactly as CADET calculates beam at the waterline using the offsets in the ship lines. Points defining the $x$, $y$, and $z$ coordinates along the ship lines have specific "types" to properly identify the ship lines at beginning and ending points and discontinuities. The origin of the ship geometry is defined in CADET as follows. The $x$-location identifies the station number starting at zero at the forward perpendicular and increasing to the aft perpendicular with each station equidistant from each other. The $y$-location is referenced from the centerline of the ship, with no real distinction for port or starboard. The z location is positive upward from the baseline of the ship.

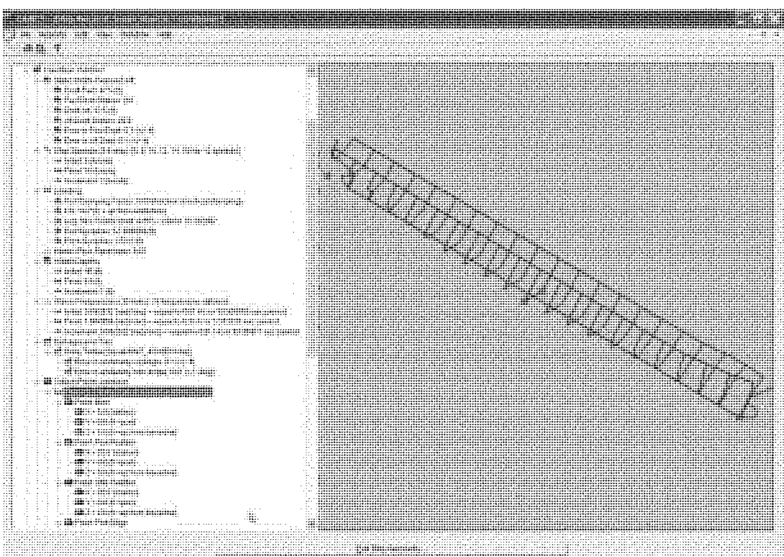


Figure 5. Example CADET ship record with red dots denoting the critical point locations.

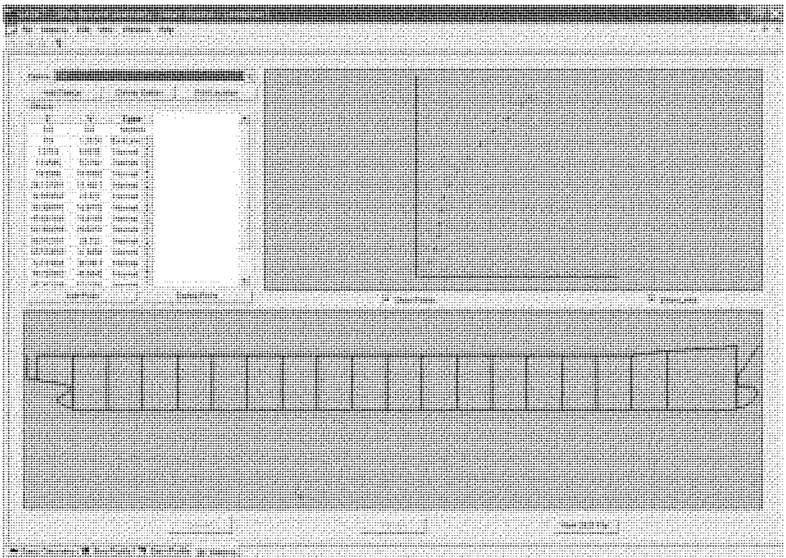


Figure 6. Example CADET ship record geometry for stations. The green highlighted station ship line cross-section is shown in the upper right plot.

*Draft and Ship Speed*

The static draft and trim are defined at either (a) the forward ($T_{FP}$) and aft ($T_{AP}$) perpendiculars or (b) draft at some longitudinal position and a trim angle in degrees. Up to 8 ship speeds in knots can be entered. These speed values must be whole integers.

*Loading*

Multiple loading conditions can be defined for each ship in CADET. The ship loading parameters that affect the three vertical motions of heave, pitch, and roll include (a) longitudinal center of gravity $L_{CG}$, (b) vertical center of gravity $KG$, (c) roll damping factor, (d) roll mass radius of gyration $k_4$, and (e) pitch mass radius of gyration $k_6$. Figure 7 is an example of the built-in calculated hydrostatics that provides some insight into the properties of the loading condition.

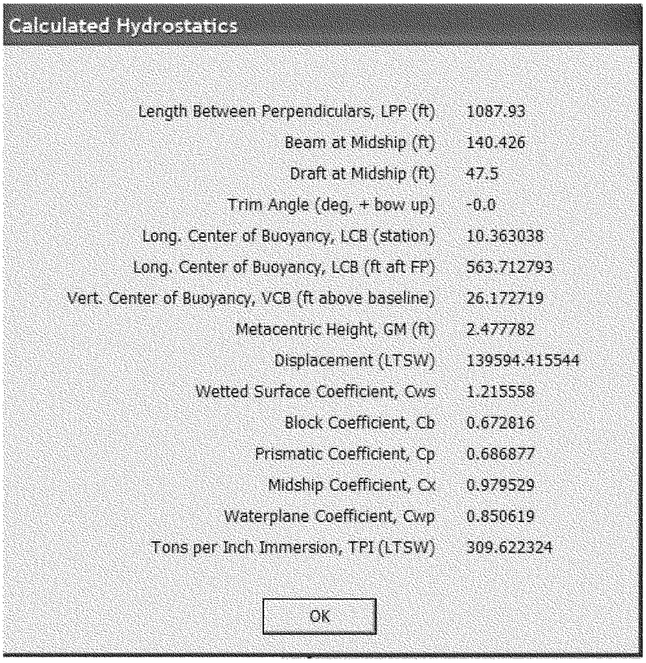



Figure 7. Example CADET hydrostatics.

Figure 8 illustrates ship stability for static equilibrium and free unresisted rolling. Static equilibrium is based on Archimedes Principle where the weight $W$ of the ship and cargo is balanced by the weight $B$ of the water displaced by the ship. The longitudinal center of gravity $L_{CG}$ is usually located midway along the longitudinal axis of the ship. The center of buoyancy is the center of gravity of the fluid displaced by the ship. In the static condition, the longitudinal center of buoyancy $L_{CB}$ (as shown in the calculated Hydrostatics in Figure 7) is coincident with the $L_{CG}$. The vertical center of gravity $KG$ is located along the vertical axis of the ship, approximately midway in the cargo as measured from the keel. In CADET the vertical center of gravity, $V_{CG}$, is entered as a vertical location relative to the waterline (positive up) and varies with the type of ship. Tankers typically have negative values around -5 to -20 ft since there cargo is lower in the ship. Containerships, however, have positive values of approximately 5 to 15 ft since their cargo is stacked on top of the deck as well as in the holds.

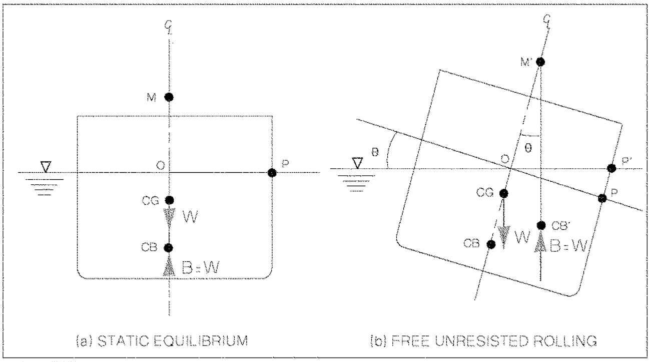



Figure 8. Equilibrium conditions for a ship.

For stability the metacenter M needs to be above the CG. The metacentric height $\overline{GM}$ is the distance from the CG to M. When the ship rolls, the CB moves to a new position which is no longer in line with the CG and the vertical axis of the ship. The intersection of the vertical from the new CB' with the upright vertical axis defines the location of M. The righting moment of the ship is thus a function of the angle of roll, the weight of the ship and cargo, and the $\overline{GM}$. CADET also requires the roll damping factor to account for the ship's dynamic roll characteristics. This factor is the fraction of critical damping and is typically equal to 0.08 to as large as 0.4 for containerships. Finally, the mass distribution properties of the ship are defined by the roll and pitch gyradii $k_4$ and $k_6$ approximations given by

$$\begin{aligned} k_4 &= 0.41B \\ k_6 &= 0.25L_{pp} \end{aligned} \tag{5}$$

*Motion risk parameter α*

The motion risk parameter $\alpha$ typically has a value of 0.01 for most design applications.

*CADET sinkage and trim*

The CADET sinkage and trim module is discussed in Chapter 3 with the PIANC and Ankudinov ship squat formulas.

*Critical point locations*

The red dots on Figure 5 correspond with the critical point locations *j* previously discussed. The five primary control points are located on the centerline at the $T_{FP}$ and $T_{AP}$ to examine the effects of pitch at the bow and rudder(s), and along the port and starboard bilge to include the effects of roll. Four alternative (optional) control points can be added anywhere along the hull and they may include a minimum vertical standoff distance from the channel bottom.

*Wave frequencies*

A total of 30 wave frequencies are input to define the range of frequencies containing significant wave energy that will be used to calculate the ship motion transfer functions or response amplitude operators (RAOs) for heave, pitch, and roll. The user should input initial, final, and increment values of frequency in Hz. Although the RAOs at a particular frequency can be interpolated to match the specific wave frequency in the project module, it is important that the final frequency value match the highest frequency with significant wave energy to insure highest accuracy in the RAOs. These RAOs are used in Eq. 3 to determine the CADET predictions.

*Ship motion transfer functions*

Finally, ship motion heave, pitch, and roll RAOs are calculated using a frequency-domain, shallow water, strip-theory program SCORES (Kaplan 1996a & b). In a manner similar to that used to calculate sinkage and trim, CADET generates SCORES input files from the defined hull geometry, draft and trim, ship speeds, water depths, roll damping coefficient, and wave frequencies. SCORES is run in the background by CADET, and the motion transfer functions are extracted from the SCORES output files. The extracted transfer functions are written to compressed binary files for later use in determining the $A_j$ from Eq. 4. Plotting of the transfer functions can be performed with different representations as needed (real/imaginary or amplitude/phase versus frequency, frequency of encounter, or non-dimensional wave length). Figure 9 is an example of a roll RAO showing amplitude and phase for the range of ship speeds and ship headings as a function of frequency at a particular water depth.

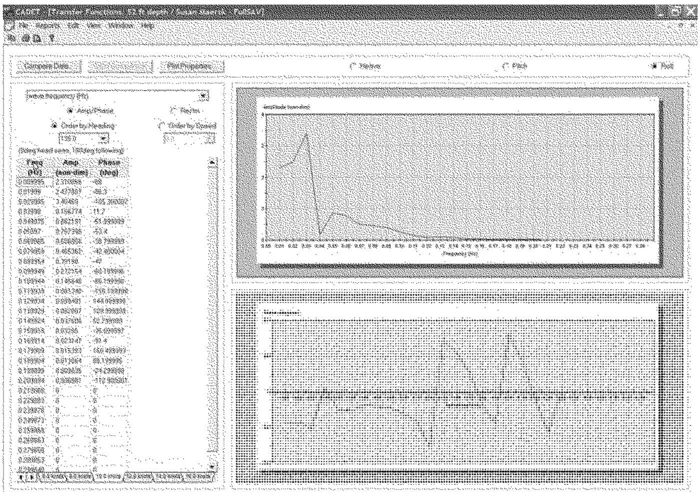


Figure 9. Example CADET roll ship motion transfer function.

## Project module

A project in CADET includes channel reaches, waves, ships, tides, and comments. While CADET keeps track of all of these direct and logical associations between projects, channel reaches, wave spectra, ships, loading conditions, and sinkage and trim data; the user is responsible for ensuring that these associations are coherent.

### *Reaches*

Reaches should be defined whenever the depth, width, cross-section, or alignment of the channel changes significantly. They can be defined from offshore to inshore or vice versa. Figure 10 is an example of the reaches input. It includes (a) reach number, (b) description. (c) length, (d) direction, (e) width, (f) bottom type, (g) begin depth, (h) terminal depth, (i) increment depth, (j) outer water depth, (k) over-dredge, (l) dredge variability, and (m) wave coefficient of variation. Reach numbers are automatically increased as new reaches are added. The description, bottom type (i.e., sandy, rock, etc.) and width (feet) are purely for documentation. The length input is in nautical miles. The reach direction is in degrees measured clockwise from north as with a compass. East, therefore, would be $90^{o}$, south $180^{o}$, and west $270^{o}$. It is good convention to define the channel according to the direction of an outbound ship if the reaches begin inshore and increase offshore or for an inbound ship if the reaches begin offshore and increase inshore. The beginning, terminal, and increment depth are in feet and should correspond with the water depths selected in the ship module used to calculate ship squat (see Chapter 3) and RAOs. The outer water depth can be defined as a fixed or variable value for the range of water depths. A "-1" in this parameter will insure that an unrestricted channel cross-section is used for all depths. The next two inputs account for bottom variability. Over-dredge is the amount of additional clearance assumed due to advance maintenance or dredging tolerance. Typical values are 2 ft. The dredge variability is a tolerance for dredging execution tolerance to account for unevenness (i.e., non-horizontal level) of the bottom. While the project depth is assumed to be flat with no variability or unevenness, a typical value of 0.85 ft is specified for the over-dredge variability. The wave coefficient of variation is an indication of the reliability of the waves with a typical value of 0.4.

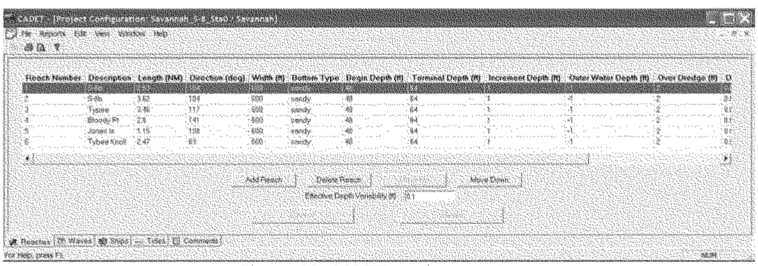


Figure 10. CADET reach example.

*Waves*

CADET requires directional wave spectra to predict vertical ship motions. The user can input one or more files as necessary for the project goals. Only one or two files might be necessary for validating CADET predictions with measured field or laboratory data for a particular ship, time, and transit direction. More than one file may be required to properly bracket transit times for validation. Design life predictions of channel accessibility, however, would require many spectra to properly represent the statistical variation in wave conditions over a 20-year design life.

In the typical application of CADET for design life predictions, it is customary to use something like a 20-year hindcast. The Wave Information Study (WIS) is a good source of data for coasts around the U.S (http://chl.erdc.usace.army.mil/wis). The user selects the WIS station that is closest to the project site and sorts it into joint distribution tables of wave height and period for fixed wave directions. The WIS outputs data in 22.5 deg bins, so this is a good directional increment to use in CADET (although other values can be used). As before, if the WIS station is greater than about 5 nm from the project site, the data should be transformed to the site. Also, if the channel is long, waves may transform from one end to the other, so the STWAVE type of program can be used to predict ratios relating incident wave conditions to output stations along the reaches of the channel (Stauble et al. 2001, Thompson 2002). Except for reflections, waves do not travel offshore from land. Therefore, the user can reduce the number of waves in this database by eliminating waves that are not possible due to blockage from land features. Wave directions should cover the full directional exposure of the channel.

Once the 20-year hindcast database has been transformed to the project site, a final post-processing step is performed to compute statistical information. In this case, the user will want to minimize the number of individual cases according to combinations of wave height, period, and direction that are representative of the site and would significantly influence ship motions. Since deep draft ships are relatively large, one might want to limit the number of waves to those with longer wave periods and larger wave heights that would actually affect the vertical ship motions. One might think that since the largest vertical ship motions occur for wave periods that coincide with the natural oscillation periods in heave, pitch, and roll that are typically of the order of 8 sec or larger; it is reasonable to ignore wave spectra with peak wave periods below 5 or 6 sec. Similarly, one might think that it is reasonable to ignore the insignificant ship motions due to waves with heights less than 2 to 3 ft. Of course, this would be dependent on the size of the ship(s) in the study.

However, a better procedure is to retain all of the data, but set up "bins" for the sorting that tend to isolate the "tails" data on the low and high ends of wave period and height. The CEDAS (**C**oastal **E**ngineering **D**esign and **A**nalysis **S**ystem) has a NEMOS (**N**earshore **E**volution **Mo**deling **S**ystem) program that does sorting for joint distributions of wave period and height for fixed wave directions (NEMOS 2000). For instance, since the bins do not have to be evenly spaced, one can set up the lower and upper wave period and wave height bins to include relatively extreme or rare events in period and height. For instance, the lower wave period bin could include all wave periods from 0 to 5 sec. The upper wave period bin might include all periods between 17 and 23 sec, or whatever high period limit is contained in the dataset. Similarly for wave heights, bin size can be 2 ft for the smaller waves with an upper bin to include all waves between 20 and 30 ft. Again, the number and increments for the bins should be based on the minimum and maximum values for the entire dataset. The NEMOS reports the distributions in percent and number of occurrences. The program has the option to report the mean values for each bin, so these should be used in building the wave parameter statistics for generating the empirical directional wave spectra. The number of occurrences relative to the total provides the wave probabilities for CADET. A good rule of thumb is to ignore bins that have less than 0.05 percent of the total number of occurrences, as these represent very rare events on both low and high ends of the dataset. As mentioned previously, wave direction can be limited by the land features to include lower and upper directions that are possible. A fixed increment like 22.5 deg is a reasonable value although other values are also acceptable.

One of the main features in CADET is its risk-based predictions of UKC. The wave climatology for each reach is composed of the set of directional wave spectra and their associated probability of occurrence. This probability is converted into the number of days per year that each of the individual wave components contributes to the total wave environment. The total of all wave probabilities should equal 1.0 or 365 days. However, the total can be less than these values since missing values are assumed to represent wave conditions that are either (a) small and not a concern for safe navigation or (b) conditions that are very rare and do not represent more than 0.05 percent of the total number of observations. The small waves, or calm water, could represent a substantial part of the year, i.e. 103 calm water days at Pensacola, Florida.

**CADET Wave Format.** Figure 11 is an example of the wave record in CADET. Waves are listed for each reach and include (a) filename, (b) significant wave height $H_{1/3}$, (c) calculated significant wave height $H_{1/3}$, (d) peak wave period $T_p$, (e) mean wave direction $\theta_m$, (f) wave probability of occurrence, (g) days per year for each wave, and (h) wave file location path. The significant wave height, peak period, and peak direction of each wave record in the wave climatology is then used to generate directional wave spectra. The calculated $H_{1/3}$ is a “check” on the input wave height that is calculated from the zero-moment wave height of the directional spectrum. The wave probability of occurrence is input with the individual directional spectra or can be manually entered after importing the wave file(s). The days/yr field is automatically populated based on these wave probabilities. All of the other parameters are input on the header line of the individual directional wave spectra files. The user can import these files individually or in batch import mode using a text file listing the filenames.

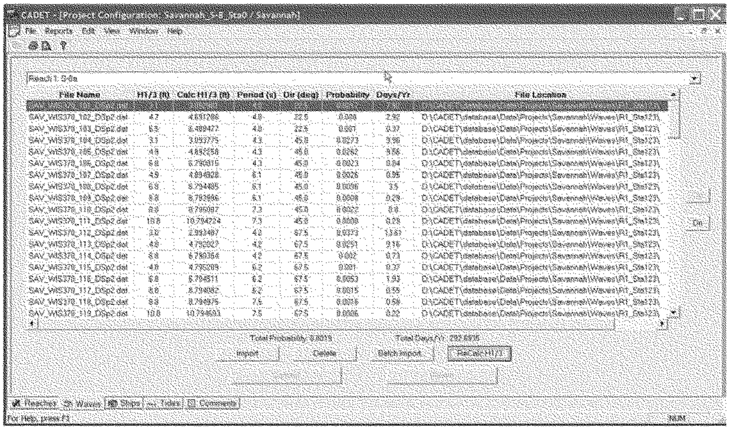



Figure 11. Example CADET wave record.

Figure 12 is an example of a directional spectrum in CADET. Individual spectral ordinates are listed in ft²/Hz-rad as a function of wave frequency and wave direction. CADET allows up to 400 individual wave frequencies in units of Hz to define the directional wave spectrum. It requires a total of 24 wave directions in 15 deg increments from 0 to 345 deg, however.

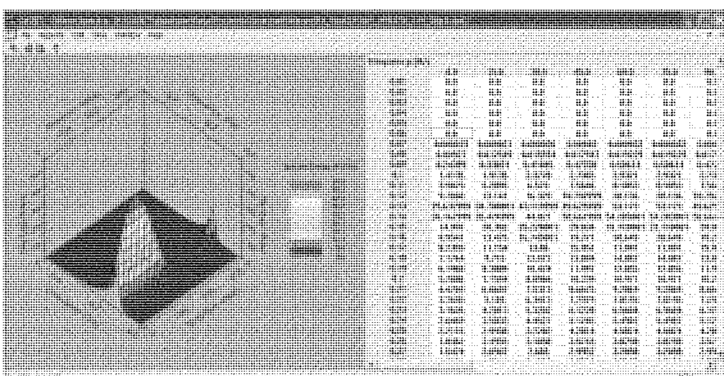


Figure 12. Example CADET directional spectrum.

**Empirical directional wave spectrum.** The directional wave spectrum S(f,θ) is typically created using empirical formulas for the frequency spectrum S(f) and the directional spreading function D(f,θ) given by

$$S(f,\theta) = S(f)D(f,\theta) \tag{6}$$

It must satisfy the constraints that

$$S(f) = \sum_{0}^{2\pi} S(f,\theta)\Delta\theta \quad ; \qquad \sum_{0}^{2\pi} D(f,\theta)\Delta\theta = 1 \tag{7}$$

The TMA (Texel, MARSEN, ARSLOE) is a shallow-water spectral form (Bouws, et al. 1985) for *S(f)* that characterizes waves generated in deepwater which have propagated into shallow water. It is defined as

$$S(f) = \frac{\alpha g^2}{(2\pi)^4 f^5}\Phi(2\pi,h)e^{a}\gamma^{b} \tag{8}$$

where:

$\alpha$ = Phillip's constant (defined below)
$g$ = gravitational acceleration
γ = peak enhancement factor

The functions φ(2πf,h), *a*, and *b* are described below. The function φ(2πf,h) may be approximated as

$$\Phi(2\pi f,h) = \begin{cases} 0.5\omega^2 & \omega \le 1 \\ 1 - 0.5(2-\omega)^2 & \omega > 1 \end{cases} \tag{9}$$

where $\omega = 2\pi f\sqrt{h/g}$. The functions *a* and *b* are given by

$$a = -1.25\left(\frac{f}{f_p}\right)^{-4} \quad ; \quad b = \exp\left[\frac{-1}{2\sigma^2}\left(\frac{f}{f_p}-1\right)^2\right] \tag{10}$$

where $f_p$ = peak spectral frequency and $\sigma$ is given by

$$\sigma = \begin{cases} 0.07 & f \le f_p \\ 0.09 & f > f_p \end{cases} \tag{11}$$

Procedures for estimating $\alpha$ and $\gamma$ are discussed by Hughes (1984), Briggs et al. (1987), Briggs (1988), and U.S. Army Corps of Engineers (USACE 1989). The value for the Phillip's constant $\alpha$ is calculated using an iterative procedure that compares the target wave height to the calculated value for a required tolerance. The $\gamma$ controls the width of the frequency spectrum (small values give broad frequency peaks and large values give narrow peaks). Comparing sea and swell wave components, swell tends to have longer wave periods and correspondingly narrower frequency space spectra. Table 3 provides some guidance in the selection of $\gamma$ based on wave period (Thompson et al. 1996).

The TMA spectral parameters are the same as those in the more widely known JONSWAP (Joint North Sea Wave Program) spectrum, with the addition of $\varphi(2\pi f,h)$. The TMA spectrum reduces to the JONSWAP spectrum in the deepwater limit.

The directional spreading function $D(f,\theta)$ can be approximated using several different empirical formulas. One of the simplest is a $\cos^n\theta$ directional distribution (Smith et al. 2001). It is given by

$$D(f,\theta) = \frac{1}{C}\cos^n\left(\frac{\theta-\theta_m}{2}\right) \tag{12}$$

where:

$C$ = conversion constant to insure that the constraint in Eq. 7 is satisfied

$\theta$ = direction of the spectral component

$\theta_m$ = peak or dominant direction of the spectral component.

The SCORES module requires that $\theta$ be in twenty-four 15-deg increments from 0 to 345 deg. The $n$ is the multiplier that determines the width of the directional spreading. As for frequency spreading, a small $n$ gives broader directional spreading and a large $n$ gives narrower spreading. Guidance as a function of wave period is provided in Table 3.

Table 3. TMA spectral peakedness γ and directional spreading n parameters.

| $T_p$, sec | γ | $n$ |
|---|---|---|
| ≤ 10 | 3.3 | 4 |
| 11 | 4 | 8 |
| 12 | 4 | 10 |
| 13 | 5 | 12 |
| 14 | 5 | 16 |
| 15 | 6 | 18 |
| 16 | 6 | 20 |
| 17 | 7 | 22 |
| 18 | 7 | 26 |
| 19 | 8 | 28 |
| 20 | 8 | 30 |

*Ships*

Multiple ships and loading conditions can be selected for each reach in a project in CADET. Thus, several types of "design" ships can be included in the overall evaluation of UKC and channel accessibility. Since ship squat (i.e., sinkage and trim) is influenced by the channel cross-section, the user can accommodate changes in reach bathymetry by specifying different squat files for different reaches for the same ship (see page 46).

*Tides*

CADET has an optional tide duration prediction program that calculates durations above a threshold level (i.e. project depth) as a function of different water levels. This program can be used if the selected dredge depth from CADET does not allow for enough accessibility for a specific deep draft ship through the year. From the astronomic tide constants for a local port, the increased water level can provide additional accessibility by calculating a tidal window.

To generate the tide window table, two input data files are required. The first input file contains the 37 tidal constituents for orbital computations that are relevant for any port and required to calculate the tide level. The second input file contains the location-specific tidal constituents. The first line in this file contains the formal geographic name of the location. The second line is the name of the tide datum that is used in the tide level calculation. This can be MLLW, as used in the United States, or Mean Low Water Springs (MLWS), as used in Europe, or any other datum. The third line contains three values. The first value is the difference between the water depth at mean sea level (MSL) at the port and the datum. The second value is the number of lines of tide constants that follow the header information. The third value is the difference, in number of hours, between the local standard time and Greenwich Mean Time (GMT) since the tide is calculated based on local time. The final value on this line is a unique four-digit number identifying the tide station for these tide constants. The succeeding lines in the table include three values: the index number for the tidal constituent, the amplitude of the tide constant in ft, and the phase of the tide constant for the specific port location.

These tables are then input to the tide duration prediction program which calculates the tides and the average tide range for 20 years between 1986 and 2006. Using this information, the number of hours the depth of the water in the channel is 1 to 10 ft (in 1 ft increments) above the datum is calculated. The tide duration prediction program then determines the number of days per year the water level is 1 to 10 ft above the user specified tide datum for 1 to 12 hours duration in 1 hr increments. This duration is continuous so that a ship can expect that this time interval is available for transit during the calculated number of days per year.

The output from the tide duration prediction program information is then applied to the channel accessibility plots. If the deep draft ship requires a channel depth that is too deep to afford the cost of dredging, then the use of tide levels can increase the accessibility. For example, suppose there is a deep draft ship that requires 50 ft of water in the entrance channel to safely transit at all times and this channel is 10 miles long. The budget for dredging can only afford to dredge the channel so that the water in the channel is 47 ft above MLLW. That means the ship would need an additional 3 ft to safely transit at all times. If the ship generally would be traveling at a speed of 5 kt in the channel, then it would need the extra 3 ft of water for at least 2 hours to safely transit the channel. The tide prediction program calculates that the tide would be 3 ft higher than MLLW for a period of 2 hours for 356 days per year. If the ship used the daily astronomic predictions, the channel and port would be accessible at some point for almost every day during any given year. Table 4 is an example of the output from the tidal prediction option in CADET.

Table 4. Number of days tide level is predicted to be 1 to 4 ft above MLLW datum for 2 to 4 hours in a specific channel.

| Tidal window (hrs) | Water level above MLLW (ft) | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 2 | 360 | 357 | 356 | 324 |
| 3 | 360 | 357 | 344 | 290 |
| 4 | 360 | 357 | 309 | 235 |

### Analyses modules

Three analysis modules run in both foreground and background modes. As previously discussed, CADET utilizes external programs for computing underway sinkage and trim and ship motions due to waves. These programs are run in the background with all necessary input data files being created as needed from the ship and loading condition information managed by the CADET interface. Output from these programs is also parsed and manipulated as needed, creating the appropriate data files in the analysis of a project.

*Motion transfer analysis module 1*

The first analysis module uses the previously computed motion transfer functions for each selected ship, loading condition, water depth, and the wave spectra data files defined for each project reach. From these input data files, the vertical motion variances (displacement $\sigma_j$ and velocity $\sigma_{Vj}$ according to Eq. 3) are computed for each ship speed, for both inbound and outbound transit directions at the motion control points defined for each ship. There is one motion variance output file created for each ship/loading condition, channel reach, and project depth combination. These motion variance output files are considered to be intermediate data and are not viewable directly within CADET.

*Risk analysis module 2*

The second analysis module performs the risk analysis and generates three output files for each combination of ship/loading condition (one with minimum clearance), channel reach, and water depth. The first output file is a summary file and includes limiting primary and alternative control point and corresponding clearance (includes sinkage and trim, motions allowance, etc.) and risk of touching a flat bottom and a bottom with random variation for each reach, water depth, wave condition, ship heading, and ship speed. The second output file contains the ship motion allowances (according to Eq. 4) at all nine control points for each reach, water depth, wave condition, ship heading, and ship speed combination. The third and final output file is similar to the second output file. It contains the clearance values at all nine control points for each reach, water depth, wave condition, ship heading, and ship speed combination.

*Accessibility analysis module 3*

Finally, the third analysis program determines the accessibility for each channel reach and each ship/loading condition combination. Output files of days of accessibility are generated based on if the risk of grounding is equal or less than $\alpha = 0.01$ (or corresponding value of the risk factor $\alpha$) for each reach and water depth. Accessibility data is provided for primary and alternative control points (grouped separately in report) for each ship loading condition, ship speed, inbound or outbound ship heading, and each channel reach.

**Results module**

Multiple set of analysis results may be logically associated with each project. This allows for different studies to be performed where project parameters are varied. This is useful for determining the sensitivity of the results to the varied parameters or for investigating design alternatives. When viewing the results of a study, CADET allows the user to change the data view between accessibility and risk results. Inbound and/or outbound transit directions may be selected and the view toggled between tabular or graphical presentations. Additionally, the data views may be filtered by the different channel reaches and by ship/loading conditions (or a composite of all ships).

Accessibility results are given in terms of the number of days of accessibility versus the range of project water depths. Risk results are somewhat more complicated in that they can be given in terms of multiple parameters including control points on a ship, ship speed, wave height, water depth, etc. Figure 13 illustrates a typical plot of days of accessibility from CADET.

While the viewing capabilities provided by CADET are useful for the analyst performing a study, they are not necessarily exhaustive. Therefore, CADET is capable of transferring tabular data from any data view to the

Windows clipboard so that it may be pasted into other programs. Of course, data files can always be imported outside of CADET into spreadsheet programs like Excel. Images of all plots and graphical presentations of data may also be copied to the clipboard, allowing the user to paste report quality graphics into Word or PowerPoint documents. CADET can also be used to create printed summary reports or listings of the ship and project data and results.

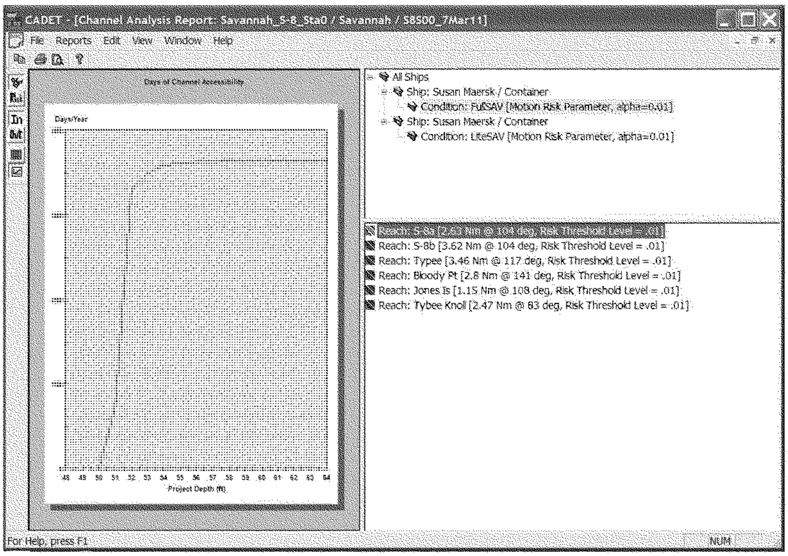



Figure 13. CADET analysis results plots.

## CADET inputs

This section summarizes the ship and project module input parameters used in CADET for this study.

### Ship module parameters

Table 5 summarizes the input parameters that were used in the ship module. These data are based on the best available information for the light- and fully-loaded *Susan Maersk*. Ship data is typically proprietary and not available to the public. Best judgment is used as necessary in these cases.

Table 5. Input and derived parameters for *Susan Maersk* containership, CADET ship module.

| Parameter description | Symbol | Units | Light-loaded | Fully-loaded |
|---|---|---|---|---|
| **General** | | | | |
| Length overall | $L_{OA}$ | ft | 1138.40 | 1138.40 |
| Length between perpendiculars | $L_{PP}$ | ft | 1087.93 | 1087.93 |
| Station spacing | | ft | 54.40 | 54.40 |
| Beam | $B$ | ft | 140.43 | 140.43 |
| Block coefficient | $C_B$ | -- | 0.67 | 0.67 |
| Vertical center of buoyancy (ft above baseline) | $V_{CB}$ | ft | 25.32 | 26.17 |
| Metacentric height | $GM$ | ft | 1.97 | 2.48 |
| **Drafts** | | | | |
| Draft forward | $T_{Fwd}$ | ft | 46.0 | 47.5 |
| Fwd draft station (Usually 0) | | -- | 0 | 0 |
| Draft aft | $T_{Aft}$ | ft | 46.0 | 47.5 |
| Aft draft station (Usually 20) | | -- | 20 | 20 |
| Error in Fwd draft | | ft | 0.1 | 0.1 |
| Error in Aft draft | | ft | 0.1 | 0.1 |
| **Ship Speeds, knots** (Max 8) | | | | |
| Initial | $V_k$ | kt | 6 | 6 |
| Final | $V_k$ | kt | 16 | 16 |
| Increment | $V_k$ | kt | 2 | 2 |
| **Loading** | | | | |
| Roll damping factor, fractional percent | | -- | 0.04 | 0.08 |
| Vertical center of gravity (+ up from waterline) | $V_{CG}$ | ft | 16.8 | 14.7 |
| Longitudinal center of gravity (=$L_{CB}$) | $L_{CG}$ | ft | 563.03 | 563.71 |
| Roll Gyradius, 0.41*$B$ | $k_4$ | ft | 57.60 | 57.60 |
| Pitch Gyradius, 0.25*$L_{PP}$ | $k_6$ | ft | 272.0 | 272.0 |
| **Motion Risk Parameter** (0.01 typical) | $\alpha$ | - | 0.01 | 0.01 |
| **Water Depths** | | | | |
| Initial | $h$ | ft | 48 | 48 |
| Final | $h$ | ft | 64 | 64 |
| Increment | $h$ | ft | 1 | 1 |
| **Wave Frequencies** (max of 30) | | | | |
| Initial | $f_{Init}$ | Hz | 0.01 | 0.01 |
| Final | $f_{Final}$ | Hz | 0.30 | 0.30 |

| Parameter description | Symbol | Units | Light-loaded | Fully-loaded |
|---|---|---|---|---|
| Increment | $f_{inc}$ | Hz | 0.01 | 0.01 |
| **Sinkage and trim (Squat)** | | | | |
| Filename: Squat-BNT_ | | – | 4S16D6.dat | 43H3DH.dat |
| Channel width | *W* | ft | 600 | 600 |
| Outer water depth (-1=uniform depth) | $H_{Out}$ | ft | -1 | -1 |
| Error in underway sinkage | | ft | 0.1 | 0.1 |
| Error in underway trim angle | | deg | 0.01 | 0.01 |
| **Critical Point Locations, Primary Points** (bottom touching offset 0.0) | | | | |
| *Point Bow* | | | | |
| X (Station) | *X* | – | 0 | 0 |
| Y (+ port) | *Y* | ft | 0 | 0 |
| Z (+ up from baseline) | *Z* | ft | 0 | 0 |
| *Point Port Rudder* | | | | |
| X (Station) | *X* | – | 20 | 20 |
| Y (+ port) | *Y* | ft | 0 | 0 |
| Z (+ up from baseline) | *Z* | ft | 0 | 0 |
| *Point Strb Rudder (repeat above since only 1 rudder in center)* | | | | |
| X (Station) | *X* | – | 20 | 20 |
| Y (+ port) | *Y* | ft | 0 | 0 |
| Z (+ up from baseline) | *Z* | ft | 0 | 0 |
| *Point Port Bilge* | | | | |
| X (Station) | *X* | – | 10 | 10 |
| Y (+ port) | *Y* | ft | 69.8 | 70.2 |
| Z (+ up from baseline) | *Z* | ft | 0 | 0 |
| *Point Stbd Bilge* | | | | |
| X (Station) | *X* | – | 10 | 10 |
| Y (+ port) | *Y* | ft | -69.8 | -70.2 |
| Z (+ up from baseline) | *Z* | ft | 0 | 0 |
| **Alternate Points** (User selects up to 4) | | | | |
| *Point Alternate 1 (Center keel)* | | | | |
| X (Station) | *X* | – | 10 | 10 |
| Y (+ port) | *Y* | ft | 0 | 0 |
| Z (+ up from baseline) | *Z* | ft | 0 | 0 |

## Project module parameters

### *Reach input*

The first step in defining the CADET project module is to select channel reaches. Typically, reaches are defined where the channel depth, width, and/or alignment changes. Figure 14 shows the offshore bathymetry for the Savannah Channel. It shows the locations of the different Stations along the Existing channel and the proposed channel S-1. The Existing channel ends at Station 60 (i.e., 60,000 ft) and S-1 continues on to Station 123. Only the portion of S-1 extending to Station 87 is shown on this figure as an earlier proposal had option S-1 ending at Station 87. The alignment of S-1 does not change from Station 87 to Station 123. A new "existing" channel S-1_Sta0 was defined for the entire length that included the original existing channel plus the proposed extensions along S-1.

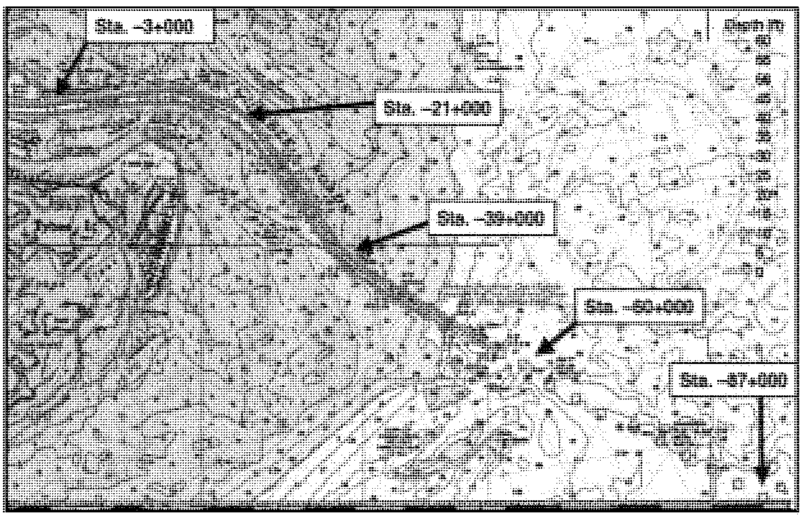



Figure 14. Station numbers for Savannah Outer Channel.

Table 6 lists the channel particulars for these three options and the existing channel. Included are group ID, range number, wave ID, reach ID, beginning and ending stations, length, and alignment angle. Additional parameters required by CADET are also listed. The groups were defined according to the new reaches for the three options to facilitate comparisons among the three options (Figure 3). Group S-1_Sta39, S-3_Sta39, and S-8_Sta39 were defined with three reaches that include the existing Tybee reach.

The second set of groups includes the preferred option S-8 and the S-1_Sta0 channel. There are six reaches in each of these two groups. The purpose of these last two groups was to make sure there were no unforeseen UKC problems when the entire channel is considered in a transit. Of course, many of the reaches are the same in the different groups (i.e., Reach 3 Tybee is the same in all groups; Reach 2 S-1b is the same in S-1_Sta39, S-3_Sta39, and S-1_Sta0; and Reaches 4 to 6 are the same in S-1_Sta0 and S-8_Sta0).

*Wave input*

Calculation of the directional wave spectra from the WIS 20-yr hindcast is described in Chapter 4.

*Ship input*

The light- and fully-loaded *Susan Maersk* ships were used in this study. They were combined with the appropriate ship squat (i.e., sinkage and trim) from the CADET BNT ship squat module. A description of this program is contained in Chapter 3.

*Tide input*

Table 7 is a listing of the 37 tidal constituents for Ft. Pulaski that are representative of the Outer Channel in Savannah. Each constituent also includes the amplitude and phase of the tide constant for Savannah. The tidal datum is an important input parameter in the tide level calculations. In the United States, this is MLLW. The program also needs the value of the difference between the water depth at mean sea level (MSL) and the MLLW datum. This value is equal to 3.82 ft at Savannah. The difference in number of hours between the local standard time and Greenwich Mean Time (GMT) is also required since the tide is calculated based on local time. Local time in Savannah is Eastern Standard Time (EST), which is 5 hours behind GMT. Finally, a unique seven-digit number identifying the Ft. Pulaski tide station for these tide constants is required. Its value is 8670681.

Table 6. Savannah Outer Channel parameters.

| Group ID | Range No. | Wave ID | Reach | Station | | Length | | Angle (deg) |
|---|---|---|---|---|---|---|---|---|
| | | | | Begin | End | (ft) | (NM) | |
| Basic Comparisons of Reach Differences | | | | | | | | |
| S-1_Sta39 | 1 | 100 | S-1a | 82 | 123 | 41,000 | 6.75 | 117 |
| | 2 | 200 | S-1b | 60 | 82 | 22,000 | 3.62 | 117 |
| | 3 | 300 | Tybee | 39 | 60 | 21,000 | 3.46 | 117 |
| S-3_ Sta39 | 1 | 100 | S-3 | 82 | 98 | 16,000 | 2.63 | 90 |
| | 2 | 200 | S-1b | 60 | 82 | 22,000 | 3.62 | 117 |
| | 3 | 300 | Tybee | 39 | 60 | 21,000 | 3.46 | 117 |
| S-8_ Sta39 | 1 | 100 | S-8a | 82 | 98 | 16,000 | 2.63 | 104 |
| | 2 | 200 | S-8b | 60 | 82 | 22,000 | 3.62 | 104 |
| | 3 | 300 | Tybee | 39 | 60 | 21,000 | 3.46 | 117 |
| Comparisons of Entire Channel to Station 0 | | | | | | | | |
| S-1_Sta0 | 1 | 100 | S-1a | 82 | 123 | 41,000 | 6.75 | 117 |
| | 2 | 200 | S-1b | 60 | 82 | 22,000 | 3.62 | 117 |
| | 3 | 300 | Tybee | 39 | 60 | 21,000 | 3.46 | 117 |
| | 4 | 400 | Bloody Pt | 22 | 39 | 17,000 | 2.80 | 141 |
| | 5 | 500 | Jones Is | 15 | 22 | 7,000 | 1.15 | 108 |
| | 6 | 600 | Tybee Knoll Cut | 0 | 15 | 15,000 | 2.47 | 83 |
| S-8_Sta0 | 1 | 100 | S-8a | 82 | 98 | 16,000 | 2.63 | 104 |
| | 2 | 200 | S-8b | 60 | 82 | 22,000 | 3.62 | 104 |
| | 3 | 300 | Tybee | 39 | 60 | 21,000 | 3.46 | 117 |
| | 4 | 400 | Bloody Pt | 22 | 39 | 17,000 | 2.80 | 141 |
| | 5 | 500 | Jones Is | 15 | 22 | 7,000 | 1.15 | 108 |
| | 6 | 600 | Tybee Knoll Cut | 0 | 15 | 15,000 | 2.47 | 83 |

Notes:

1. Existing channel is from Station 0 to 60 for this study.
2. S-1_Sta39 = Tybee + S-1a + S-1b reaches.
3. S-1_Sta0 = Existing + S-1a + S-1b reaches.
4. Angle = channel alignment relative to outbound vessel, clockwise from north, i.e., 297 deg - 180 deg = 117 deg for channel aligned with NW/SE.
5. Channel width = 600 ft.
6. Effective depth variability = 0.1 ft
7. Bottom type = sandy.
8. Depth increment = 1 ft.
9. Overdredge allowance = 2 ft.
10. Dredge variability = 0.85 ft.
11. Wave coefficient of variability = 0.4.
12. Risk level = 0.01.

Table 7. Tidal constants for Ft Pulaski, Savannah, GA.

| Tidal Constituent | Amplitude (ft) | Phase (deg) |
|---|---|---|
| 1 | 3.325 | 232.9 |
| 2 | 0.517 | 255.8 |
| 3 | 0.717 | 220.0 |
| 4 | 0.362 | 125.4 |
| 5 | 0.138 | 318.2 |
| 6 | 0.258 | 136.7 |
| 7 | 0.020 | 345.6 |
| 8 | 0.031 | 172.9 |
| 9 | 0.024 | 109.4 |
| 10 | 0.065 | 314.7 |
| 11 | 0.143 | 212.8 |
| 12 | 0.000 | 0.0 |
| 13 | 0.106 | 270.3 |
| 14 | 0.093 | 209.6 |
| 15 | 0.018 | 132.6 |
| 16 | 0.059 | 218.3 |
| 17 | 0.063 | 93.1 |
| 18 | 0.020 | 176.7 |
| 19 | 0.019 | 150.0 |
| 20 | 0.000 | 0.0 |
| 21 | 0.196 | 51.3 |
| 22 | 0.277 | 175.7 |
| 23 | 0.000 | 0.0 |
| 24 | 0.000 | 0.0 |
| 25 | 0.011 | 137.3 |
| 26 | 0.057 | 131.9 |
| 27 | 0.062 | 240.9 |
| 28 | 0.035 | 135.3 |
| 29 | 0.007 | 147.9 |
| 30 | 0.129 | 125.0 |
| 31 | 0.010 | 327.3 |
| 32 | 0.078 | 294.7 |
| 33 | 0.145 | 224.5 |
| 34 | 0.016 | 222.3 |
| 35 | 0.133 | 255.4 |
| 36 | 0.000 | 0.0 |
| 37 | 0.076 | 339.4 |

# 3 Ship Squat Theory

Ship squat for the light- and fully-loaded *Susan Maersk* containership in the Savannah Outer Channel are compared for PIANC, Ankudinov, and CADET/BNT predictions. The entire Outer channel is modeled as an open or unrestricted channel cross-section in this study as it is assumed that the effect of the trench will be minimal on the predicted squat and the variability is included by using the average of all the squat predictors.

## PIANC squat formulas

PIANC has many empirical formulas for predicting ship squat in entrance channels. Each formula has certain constraints based on the ship and channel conditions for which they were developed. No one formula works best for all channel and ship types. Thus, it is necessary to examine the squat predictions with more than one formula and compare the results based on the type of ship, channel, and formula constraints.

Five of the most "user friendly" and "popular" PIANC squat formulas include those of Barrass, Eryuzlu, Huuska, Römisch, and Yoshimura. Briggs (2006)) programmed these formulas in a FORTRAN program and Briggs et al. (2010a) provided updates. All of these formulas give predictions of bow squat $S_b$, but only the Römisch method explicitly gives predictions for stern squat $S_s$ for all channel types. Barrass gives $S_s$ for unrestricted channels (U), and for canals (C) and restricted (R) channels depending on the value of $C_B$. Of course, for channel design, maximum squat is the most important and location at the bow or stern is not necessarily significant. Even though this report focuses on unrestricted channels, all channel types are included for completeness in the descriptions of the individual PIANC formulas.

### Barrass

Barrass has completed his fourth iteration of ship squat formulas. In this report, his third version is used (Barrass 2004, Barrass 2002). Barrass (2009) published a book summarizing his many squat formulas. The BAW (Uliczka and Kondziella 2006) uses Barrass for squat predictions in German waterways. Stocks et al. (2002) found that the Barrass formulas gave the best results for New and Traditional Lakers in the Lake St. Francis area (unrestricted channel) of the St. Lawrence Seaway study. Barrass's formulas are relatively straight-forward and easy to use. The maximum squat $S_{Max}$ at the bow or stern is determined as

$$S_{Max} = \frac{KC_B V_k^2}{100} \tag{13}$$

where:

$C_B$ = ship's block coefficient
$V_k$ = ship speed in knots.

Barrass's channel coefficient $K$ is based on analysis of over 600 laboratory and prototype measurements for all three channel types (Barrass 2007). It is defined as

$$K = 5.74 S^{0.76} \qquad 1 \le K \le 2 \tag{14}$$

The limits on $K$ are designed so that $K$=1 for U channels and $K$=2 for R channels. The blockage factor $S$ is a measure of the relative cross-sectional area of the ship to that of the channel defined as

$$S = \frac{A_s}{A_c} \tag{15}$$

where:

$A_s$ = ship cross-sectional area
$A_c$ = channel cross-sectional area.

The $A_s$ is defined by

$$A_S = 0.98BT \tag{16}$$

The $A_c$ is a projection of the channel sides up to the water surface given by

$$A_c = \begin{cases} W_{Eff} h & \text{U} \\ Wh + nh^2 & \text{R, C} \end{cases} \tag{17}$$

where:

U = Unrestricted or open channel
R = Restricted channel
C = Canal channel.

Since there is no width for a U channel, Barrass (2004) defined an effective channel width $W_{Eff}$ or width of influence $F_B$ as

$$W_{eff} = F_B = \left[\frac{7.04}{C_B^{0.85}}\right] B \tag{18}$$

Finally, if $S$<0.1 for U channels, the value of $K$ is set to 1.0. Similarly, for R channels, if $S$>0.25, $K$ is set to 2. This insures the limits required above for $K$.

According to Barrass (1995), the value of $C_B$ determines whether $S_{Max}$ is at the bow $S_b$ or stern $S_s$ (requires even keel when static). He notes that full-form ships with $C_B$>0.7 tend to squat by the bow and fine-form ships with $C_B$<0.7 tend to squat by the stern. The $C_B$=0.7 is an "even keel" situation with squat the same at both bow and stern.

For ships in U channels that are at even keel when in a static condition, one can estimate the squat at the other end of the ship (either bow or stern) based on $S_{Max}$. Thus, if $C_B$ indicates the ship will squat by the bow, then this formula will give the squat at the stern, and vice versa.

$$\left[1-40(0.7-C_B)^2\right] S_{Max} = \begin{cases} S_b & C_B \le 0.7 \\ S_S & C_B > 0.7 \end{cases} \tag{19}$$

**Eryuzlu**

The next PIANC squat formula was developed by Eryuzlu et al. (1994) based on laboratory experiments and is considered his second-generation squat formula. Although it has some serious constraints (i.e., $C_B$ >0.8), it is used exclusively by the Canadian Coast Guard (2001). It is defined as

$$S_b = 0.298 \frac{h^2}{T} \left(\frac{V_s}{\sqrt{gT}}\right)^{2.289} \left(\frac{h}{T}\right)^{-2.972} K_b \tag{20}$$

where the factor $K_b$ is a correction factor accounting for channel width $W$ relative to beam $B$ given by

$$K_b = \begin{cases} \dfrac{3.1}{\sqrt{W/B}} & \dfrac{W}{B} < 9.61 \\ 1 & \dfrac{W}{B} \geq 9.61 \end{cases} \tag{21}$$

The Eryuzlu formula is appropriate for U and R, but not C channels. Use the second value of $K_b$=1 for unrestricted channels.

**Huuska/Guliev**

The third PIANC squat formula was developed by Huuska (1976) and Guliev (1971). The Spanish ROM (Puertos del Estado 1999) and the Finnish Maritime Institute (FMA 2005, Sirkiä 2007) use the Huuska/Guliev for all three channel types. It is defined as

$$S_b = C_S \frac{\nabla}{L_{pp}^2} \frac{F_{nh}^2}{\sqrt{1 - F_{nh}^2}} K_s \tag{22}$$

The squat constant $C_S$=2.4 is typically used as an average value in this formula, although Hooft (1974) had originally used $C_S$=1.96, with values from $C_S$=1.9 to 2.03 sometimes used. The ship displacement $\nabla$ given by

$$\nabla = C_B L_{pp} B T \tag{23}$$

The depth Froude Number $F_{nh}$ is defined as

$$F_{nh} = \frac{V_s}{\sqrt{gh}} \tag{24}$$

where:

$V_s$ = ship speed in ft/s
$g$ = gravitational acceleration in ft/s$^2$
$h$ = water depth in ft.

The channel width correction factor $K_s$ is defined as

$$K_s = \begin{cases} 7.45 s_1 + 0.76 & s_1 > 0.03 \\ 1.0 & s_1 \le 0.03 \end{cases} \tag{25}$$

where the corrected blockage factor $s_1$ is given by

$$s_1 = \begin{cases} 0.03 & \text{U} \\ \dfrac{S}{K_1} & \text{R} \\ S & \text{C} \end{cases} \tag{26}$$

Note that $K_s$ goes to 1.0 when $s_1$=0.03 for both ranges of $s_1$ in Eq. 25 above. The correction factor $K_1$ is a function of normalized trench height ratios $h_T/h$ provided by Huuska as a function of $S$ for $0.2 \le h_T/h \le 1.0$. For U channels, $h_T/h$=0 so $K_1$ is not required. Therefore, one can either set $K_s$=1.0 or calculate $s_1$ using $h_T/h$=0.2 and calculate $K_s$. In most cases, the value of $s_1$ equals approximately 0.03, and Huuska's formula is identical to the ICORELS (1980) formula. For C channels, $s_1$=$S$ as $K_1$=1 since $h_T$=$h$.

**Römisch**

Römisch (1989) developed formulas for both bow $S_b$ and stern $S_s$ squat from physical model experiments for all three channel configurations. His empirical formulas are some of the most difficult to use, but seem to give good predictions for newer, larger ships and are given by

$$\begin{aligned} S_b &= C_V C_F K_{\Delta T} T \\ S_s &= C_V K_{\Delta T} T \end{aligned} \tag{27}$$

The factors in this equation are correction factors for ship speed $C_V$, ship shape $C_F$, and squat at critical speed $K\Delta T$ defined as

$$C_V = 8\left(\frac{V}{V_{cr}}\right)^2 \left[\left(\frac{V}{V_{cr}} - 0.5\right)^4 + 0.0625\right] \tag{28}$$

$$C_F = \begin{cases} \left(\dfrac{10 B C_B}{L_{pp}}\right)^2 & \text{Bow} \\ 1.0 & \text{Stern} \end{cases} \tag{29}$$

$$K_{\Delta T} = 0.155\sqrt{h/T} \tag{30}$$

Critical ship speed $V_{cr}$ is a function of channel configuration defined as

$$V_{cr} = \begin{cases} CK_U & \text{U} \\ CK_C & \text{C} \\ CK_R & \text{R} \end{cases} \tag{31}$$

where wave celerity $C$ is a function of the water depth for the particular channel given by

$$C = \begin{cases} \sqrt{gh} & \text{U} \\ \sqrt{gh_m} & \text{C} \\ \sqrt{gh_{mT}} & \text{R} \end{cases} \tag{32}$$

The mean water depth $h_m$ is a function of the projected width at the top of the channel $W_{Top}$ given by

$$h_m = \frac{A_C}{W_{Top}} = \frac{A_C}{W + 2nh} \tag{33}$$

The restricted channel water depth $h_{mT}$ is a combination of both $h$ and $h_m$ defined as

$$h_{mT} = h - \frac{h_T}{h}(h - h_m) \tag{34}$$

where $h_T$ is the trench height measured from the bottom. Finally, the correction factors $K_U$, $K_C$, and $K_R$ are given by

$$K_U = 0.58\left(\frac{hL_{pp}}{BT}\right)^{0.125} \tag{35}$$

$$K_C = \left[2\sin\left(\frac{Arc\sin(1-S)}{3}\right)\right]^{1.5} \tag{36}$$

$$K_R = K_U(1 - h_T/h) + K_C(h_T/h) \tag{37}$$

### Yoshimura

The last squat formula was developed by Yoshimura (Yoshimura 1986, Overseas Coastal Area Development Institute 2002) as part of Japan's Design Standard for Fairways in Japan. It was enhanced by Ohtsu et al. (2006) to include predictions for R and C channels. It is defined as

$$S_b = \left[\left(0.7+\frac{1.5T}{h}\right)\left(\frac{BC_B}{L_{pp}}\right)+\frac{15T}{h}\left(\frac{BC_B}{L_{pp}}\right)^3\right]\frac{V_e^{\;2}}{g} \qquad (38)$$

where the enhanced ship speed term $V_e$ is given by

$$V_e = \begin{cases} V_s & \text{U} \\ \dfrac{V_s}{(1-S)} & \text{R, C} \end{cases} \qquad (39)$$

## Ankudinov squat formula

The Ankudinov squat formulas are much more complicated than the PIANC squat formulas and were originally used in the STS (Briggs 2009). The older versions in the STS tended to overpredict ship squat. However, recent modifications have given more realistic predictions that are comparable with the PIANC predictions (Briggs and Daggett 2009). Ankudinov squat predictions account for the effects of both ship and channel. Initial ship trim has recently been shown by German researchers to be an important consideration in dynamic trim and resulting ship squat. Ankudinov includes mid-point sinkage and initial trim in his predictions.

Ankudinov and Jakobsen (1996) and Ankudinov et al. (1996, 2000) proposed the MARSIM 2000 formula for maximum squat based on a mid-point sinkage $S_m$ and vessel trim $T_r$ in shallow water. The Ankudinov method has undergone considerable revision as new data was collected and compared. The most recent modifications from a study of ship squat in the St. Lawrence Seaway (Stocks, et al. 2002) and emails and telecons in April 2009 (Ankudinov 2009) are contained in the FORTRAN programs.

The Ankudinov prediction is one of the most thorough, but also the most complicated formulas for predicting ship squat. These components include factors to account for the effects of the ship and channel. The restriction on Depth Froude Number $F_{nh}$ is for values less than or equal to 0.6. The maximum ship squat $S_{Max}$ is a function of two main components: the mid-point sinkage $S_m$ and the vessel trim, $T_r$ given by

$$S_{Max} = L_{pp}\left(S_m \mp 0.5T_r\right) \tag{40}$$

The $S_{Max}$ can be at the bow or stern depending on the value of $T_r$. The negative sign in the equation above is used for bow squat $S_b$ and the positive sign for stern squat $S_s$.

**Midpoint sinkage $S_m$**

The $S_m$ is defined as

$$S_m = \left(1 + K_P^S\right) P_{Hu} P_{F_{nh}} P_{+h/T} P_{Ch1} \tag{41}$$

The ship, water depth, and channel parameters in this midpoint sinkage equation are described in the paragraphs below. The Propeller parameter $K_P^S$ is defined as

$$K_P^S = \begin{cases} 0.15 & \text{single propeller} \\ 0.13 & \text{twin propellers} \end{cases} \tag{42}$$

The Ship hull parameter for shallow water $P_{Hu}$ was recently modified by Ankudinov (2009) as

$$P_{Hu} = 1.7C_B\left(\frac{BT}{L_{pp}^2}\right) + 0.004C_B^2 \tag{43}$$

The Ship forward speed parameter $P_{Fnh}$ is given by

$$P_{F_{nh}} = F_{nh}^{(1.8+0.4F_{nh})} \tag{44}$$

which is a numerical approximation to the term " $F_{nh}^2 / \sqrt{1-F_{nh}^2}$ " that is in many of the PIANC empirical squat formulas. The $F_{nh}$ is defined as

$$F_{nh} = \frac{V_s}{\sqrt{gh}} \tag{45}$$

The water depth effects parameter $P_{+h/T}$ is defined as

$$P_{+h/T} = 1.0 + \frac{0.35}{(h/T)^2} \quad (46)$$

The Channel effects parameter $P_{Ch1}$ is given by

$$P_{Ch1} = \begin{cases} 1.0 & \text{U} \\ 1.0 + 10S_h - 1.5(1.0 + S_h)\sqrt{S_h} & \text{R,C} \end{cases} \quad (47)$$

where the canal or restricted configuration is incorporated in the Channel depth factor $S_h$ defined by

$$S_h = C_B \left( \frac{S}{h/T} \right) \left( \frac{h_T}{h} \right) \quad \text{R,C} \quad (48)$$

and the Blockage factor $S$ $(=A_S/A_{Ch})$ is the fraction of the cross-sectional area of the waterway $A_{Ch}$ that is occupied by the Ship's underwater mid-ships cross-section $A_S$.

### Vessel trim $T_r$

The second main component in the MARSIM squat equation is the vessel trim, $T_r$ that was also recently modified by Ankudinov (2009) as

$$T_r = -1.7 P_{Hu} P_{F_{nh}} P_{h/T} K_{Tr} P_{Ch2} \quad (49)$$

In addition to the three parameters already described for the midpoint sinkage equation, the $T_r$ also includes parameter $P_{h/T}$ and coefficient $K_{Tr}$ to quantify the effects of the ship propellers, bulbous bow, stern transom, and initial trim.

The Vessel trim parameter $P_{h/T}$ accounts for the reduction in trim due to the propeller in shallow water and is defined as

$$P_{h/T} = 1 - e^{\left[\frac{2.5(1-h/T)}{F_{nh}}\right]} \quad (50)$$

The trim coefficient $K_{Tr}$ is a function of many factors and is given by

$$K_{Tr} = C_B^{nTr} - \left(0.15K_P^S + K_P^T\right) - \left(K_B^T + K_{Tr}^T + K_{T1}^T\right) \quad (51)$$

The first factor in this equation $C_B^{nTr}$ is the block coefficient $C_B$, raised to the $n_{Tr}$ power. This trim exponent $n_{Tr}$ is defined as

$$n_{Tr} = 2.0 + 0.8\frac{P_{Ch1}}{C_B} \tag{52}$$

The next two factors define the propeller effect on the vessel trim. The first factor $K_P^S$ is the same as the Propeller parameter for the midpoint sinkage and the second factor is the Propeller trim parameter $K_P^T$

$$K_P^T = \begin{cases} 0.15 & \text{single propeller} \\ 0.20 & \text{twin propellers} \end{cases} \tag{53}$$

The last group of three factors define the effects of the bulbous bow $K_b^T$, stern transom $K_{Tr}^T$, and initial trim $K_{T1}^T$ on the vessel trim. The Bulbous bow factor $K_b^T$ is given by

$$K_b^T = \begin{cases} 0.1 & \text{bulbous bow} \\ 0.0 & \text{no bulbous bow} \end{cases} \tag{54}$$

The Stern transom factor $K_{Tr}^T$ is defined by

$$K_{Tr}^T = \begin{cases} 0.1\left[\dfrac{B_{Tr}}{B}\right] = 0.1\left[\dfrac{0.4B}{B}\right] = 0.04 & \text{stern transom} \\ 0.0 & \text{no stern transom} \end{cases} \tag{55}$$

where $B_{Tr}$ is the Stern transom width and is typically 0.4 B, although values as high as 0.7 B have sometimes been used.

The Initial trim effect factor $K_{T1}^T$ is given by

$$K_{T1}^T = \frac{\left(T_{ap} - T_{fp}\right)}{\left(T_{ap} + T_{fp}\right)} \tag{56}$$

where $T_{ap}$ is the static draft at the stern or aft perpendicular and $T_{fp}$ is the static draft at the bow or forward perpendicular.

Finally, the Channel effect trim correction parameter $P_{Ch2}$ is defined as

$$P_{Ch2} = \begin{cases} 1.0 & \text{U} \\ 1.0 - 5S_h & \text{R,C} \end{cases} \quad (57)$$

## CADET sinkage and trim

Underway sinkage and trim may be provided externally by calculations or model test data and imported into CADET. Alternatively, it can be calculated within CADET using the BNT (**B**eck, **N**ewman, and **T**uck) potential flow program by Beck et al. (1975). Although included in CADET, BNT is completely independent and standalone. The user has the option to import squat data from other programs as long as the input format is the same. Since channel geometry can vary from reach to reach, CADET supports the ability to define multiple sets of sinkage and trim data sets for the same ship and loading condition.

The BNT sinkage and trim prediction program is based on early work by Tuck (1966) investigating the dynamics of a slender ship in shallow water at various speeds for an infinitely wide channel and for a finite width channel such as a canal (Tuck 1967). This work was expanded to include a typically dredged channel with a finite-width inner channel of a certain depth and an infinitely-wide outside channel of shallower depth (Beck et al. 1975).

Figure 15 is a schematic of the simplified channel cross-section used in BNT. In addition to the automatically-specified inside channel depth $H$, the user has the option to include the channel width $W$ and outside channel depth $H_{out}$ (i.e., similar to PIANC $h_T$ trench height for restricted channels, but measured from the water surface to the top of the trench). The value of $H_{out}$ remains the same for all $H$ values. For unrestricted channel applications, the user can input "-1" in the $H_{out}$ input space to automatically insure that the outer depths are equivalent to the inner channel depths, regardless of depth increment.

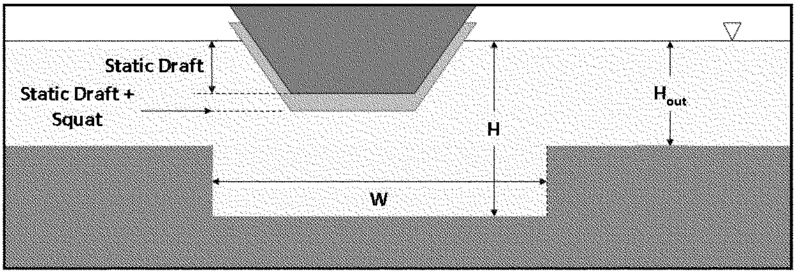



Figure 15. BNT channel geometry variables.

In his early work, Tuck (1966) calculated the dynamic pressure of slender ships in finite-water depth and infinite and finite-water width by modeling the underwater area of the hull. This underwater area was defined by the 21 equally-spaced stations along the ship's length. Therefore, the ship's geometry file, draft, speeds, and water depths are used in the BNT squat calculations. Within this analysis, the fluid is assumed to be inviscid and irrotational and the hull long and slender. Input hull definition is provided in terms of the waterline beam and sectional area at 20 stations along the hull. The dynamic pressure is obtained for each Depth Froude Number $F_{nh}$ by differentiating the velocity potential along the length of the hull. The sinkage and trim predictions are obtained from the dynamic pressure by calculating the vertical force and pitching moment which are translated to vertical sinkage and trim angle. The proper use of this BNT program requires that channel depths be of the same order as the draft of the ship, therefore satisfying the shallow-water approximations assumed in Tuck (1966).

The BNT program produces tabular listings and plots of midship sinkage $S_{Mid}$ and trim $T_R$ as a function of $F_{nh}$. Sinkage is measured in ft, positive for downward movement. Trim in ft is the difference between sinkage at the bow and stern, positive for bow down. The equivalent bow $S_b$ and stern $S_s$ squat are given by

$$\begin{aligned} S_b &= S_{Mid} + 0.5(T_R) \\ S_s &= S_{Mid} - 0.5(T_R) \end{aligned} \tag{58}$$

This is a simplistic representation of the squat at the bow and stern as it assumes they are equally distant from the midpoint of the ship. In CADET the squat is calculated for the actual distances to individual control points.

# 4 Waves

This chapter is divided into two main sections: CADET waves and STS waves. The first section describes the procedure for estimating the directional wave spectra for CADET from the 20-year hindcast dataset. The second section describes the procedure for estimating the wave height, period, and direction combinations for input to the STS simulator.

## CADET waves

### Deepwater hindcast waves

The 20-year hindcast wave data for this study were provided by the Wave Information Study (WIS). Figure 16 shows the location of WIS Station 370 (WIS370) that was selected due to its proximity to the Savannah Channel (Table 8). The WIS hindcast data is provided at 1-hour intervals over the 20-year time period. It includes significant wave height $H_s$, peak period $T_p$, and peak direction $\theta_p$. The $\theta_p$ represents the dominant wave direction for wave energy within the frequency band of peak energy. Wave directions in degrees are directions from which the waves are traveling, the same as meteorological conventions.

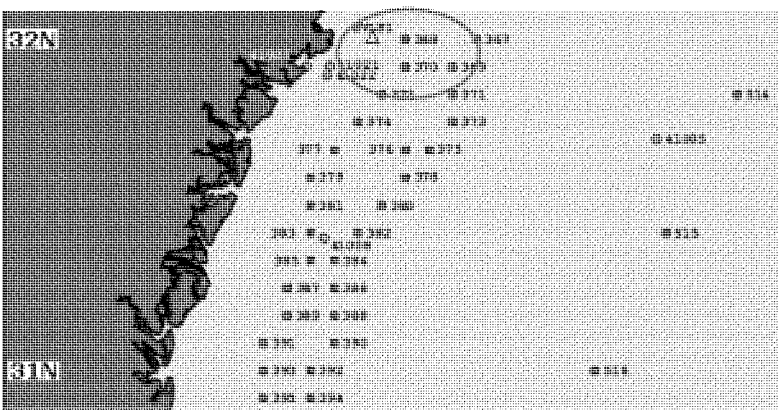



Figure 16. Location of WIS370 hindcast wave station.

Table 8. Wave climate information.

| Source | Years | Depth (ft) | Station 98 distance (nm) | Latitude (deg N) | Longitude (deg W) |
|---|---|---|---|---|---|
| WIS370 | 1980-1999 | 50 | 0.6 | 31.92 | -80.58 |
| WIS33 | 1976-1995 | 50 | 2.0 | 32.00 | -80.50 |
| Station 98 | NA | 50 | NA | 31.95 | -80.61 |

Figure 17 is a percent occurrence histogram of wave direction, period, and height. Direction bands are in 22.5 deg increments from 0 to 360 deg. The numbers on top of the bars are the percentages, and the numbers on the bottom of the bars are the mean values. The most common wave direction, with 22.3 percent of the cases, is between 101.3 and 123.8 deg, with a mean of 112.8 deg. The overall mean wave direction is 130 deg. Both of these wave directions are nearly parallel with the existing and S-1 channel alignments. Wave periods range from 1 to 23 sec, with variable band limits. The most commonly occurring wave period band, with 81.5 percent of the cases, is from 1 to 5 sec, with a mean of 4.2 sec. The overall mean wave period is 5 sec. Significant wave heights range from 0 to 30 ft, with variable band limits. The most common wave height, with 54.4 percent of the cases, is from 2 to 4 ft, with a mean of 2.9 ft. The overall mean wave height is 3.4 ft. The largest significant wave height is 28.8 ft, with corresponding peak period of 14.3 sec and wave direction of 112.5 deg. However, this is a very rare occurrence.

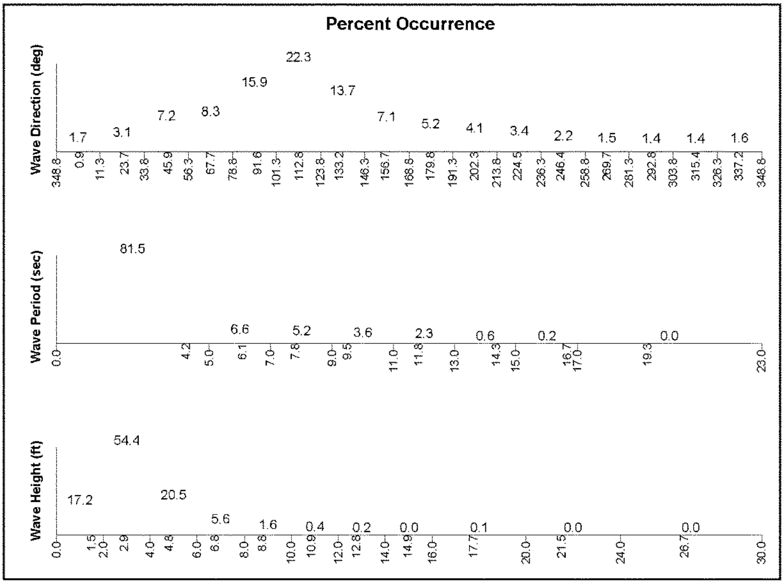
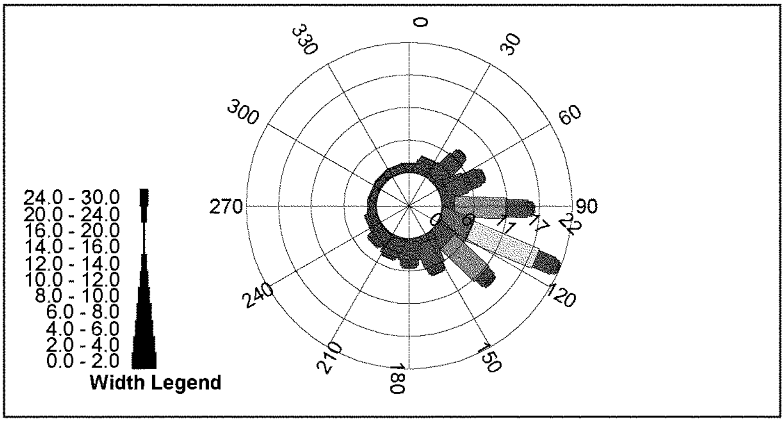
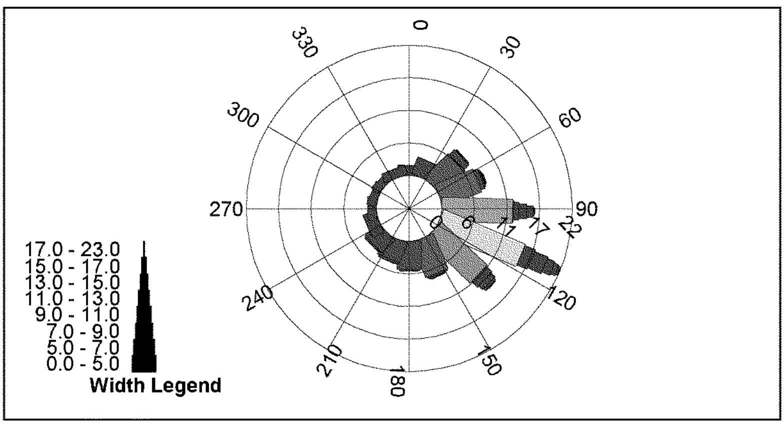



Figure 17. WIS370 percent occurrence histogram of wave direction, period, and height, 1980 to 1999.

Figure 18a is a rose of $H_s$ that illustrates the percentage of waves coming from different directions. Figure 18b is a similar rose for $T_p$. The length of the radial bars indicates the percentage from that particular wave direction. Thicker bars represent smaller $H_s$ or $T_p$ bands. The lowest bands are shown nearest the center of the rose. The radial bars become narrower toward the outer end of each bar, indicating increasing wave heights or periods.




a)




b)

Figure 18. WIS370 wave roses for 1980 to 1999 (a) wave height and (b) peak wave period.

### Joint probability distributions

The next step in the wave processing is to separate the data into joint probability or percent occurrence tables of $T_p$ vs. $H_s$ for a realistic set of direction bands. Because of the angle of the shore, wave directions outside the range of 11.3 to 236.3 deg would not impact the Savannah Channel, so the set of direction bands was reduced. The total number of observations for the entire 20-year hindcast dataset is 175,314. The limited dataset has 90 percent of these observations, or 158,138 observations. Table 9 summarizes the lower, upper, and mid-point direction band limits for the ten 22.5-deg direction bands. The number of observations and the percent of the limited and total dataset are also listed for each band. The $T_p$ vs. $H_s$ percent occurrence tables for each of the ten direction bands are contained in Appendix A. The top table is the percent occurrence in the band, and the bottom table lists the corresponding number of occurrences.

Table 9. Band limits on wave direction.

| Band No. | Direction band limits, deg | | | No. Observations | Percent | |
|---|---|---|---|---|---|---|
| | Lower | Upper | Middle | | Limited | Total |
| 1 | 11.25 | 33.74 | 22.5 | 5,380 | 3.4% | 3.1% |
| 2 | 33.75 | 56.24 | 45.0 | 12,698 | 8.0% | 7.2% |
| 3 | 56.25 | 78.74 | 67.5 | 14,569 | 9.2% | 8.3% |
| 4 | 78.75 | 101.24 | 90.0 | 27,851 | 17.6% | 15.9% |
| 5 | 101.25 | 123.74 | 112.5 | 39,030 | 24.7% | 22.3% |
| 6 | 123.75 | 146.24 | 135.0 | 24,092 | 15.2% | 13.7% |
| 7 | 146.25 | 168.74 | 157.5 | 12,366 | 7.8% | 7.1% |
| 8 | 168.75 | 191.24 | 180.0 | 9,031 | 5.7% | 5.2% |
| 9 | 191.25 | 213.74 | 202.5 | 7,182 | 4.5% | 4.1% |
| 10 | 213.75 | 236.24 | 225.0 | 5,939 | 3.8% | 3.4% |

Notes:
1. Direction bands were 22.5 deg wide.
2. Total number of observations = 175,314.
3. Total number of observations within direction band limits = 158,138 or 90.2 percent of total.
4. Did not include observations if less than 0.05 percent (i.e., 0.0005) of total.
5. Minimum number of occurrences to keep based on total observations = 88 (79 for direction-limited).

From these joint probability distributions of wave period and wave height, wave parameter statistics were gathered for generating empirical directional wave spectra representative of the WIS370 deepwater data. A total of 99 different combinations of $T_p$, $H_s$, and $\theta_p$ were obtained. Wave bins that had less than 0.05 percent (i.e., 0.0005) of the total number of occurrences were eliminated as these represent very rare events on both low and high ends of the dataset. With the elimination of these rare occurrences and including all the very low wave energy days, a total of 72.3 days per year (19.8 percent of a year) are considered "calm" days. During these days, wave-induced vertical ship motions are insignificant and will not impact the available UKC in the Savannah Entrance Channel.

### Directional wave spectra

The directional wave spectra were then generated using a TMA frequency spectrum and a $\text{Cos}^n$ spreading function. Spectral frequencies ranged from 0.01 Hz to 0.50 Hz in 0.01-Hz intervals to cover frequencies corresponding to one half to three times the peak frequency. Because of directional spreading and CADET requirements, the full circle of 360 deg was modeled in 15 deg increments. Spectral wave parameters were selected for each wave based on wave period, a standard approach for CHL studies. For the TMA spectrum, frequency spreading is a function of the $\gamma$ parameter that varied between 3.3 (broad) to 8 (narrow). For the directional $\text{Cos}^n$ spreading function, the "$n$" parameter ranged from 4 (broad) to 30 (narrow). These spectra formed the incident wave input at Station 123 (beginning of Reach 1) in the Savannah Channel.

### Wave transformation

Thompson (2002) modeled the Savannah Channel when it was proposed to extend the existing channel from Station 60 to Station 87. He had run the STWAVE numerical model (Smith et al. 2001) and calculated wave transformation along the channel as a function of distance from the deepwater WIS33. The WIS370 and WIS33 stations are located near to each other (Table 8) in the same water depth so it is assumed that the wave transformation is similar. These transformation factors for wave height were used in this study to reduce the wave height in the empirical directional wave spectra for the six different reaches from the offshore Station 123 to the inshore Station 0. Table 10 lists these wave height reduction factors. It was assumed that the wave period and wave directions would not change significantly across the relatively short distances of the Savannah Channel. Thus, the directional spectra were identical for each reach except for the reduction in wave height. All the other parameters remained unchanged between reaches. Appendix B contains tables of the wave parameters, probabilities, and corresponding days per year for each of the 99 wave conditions in each reach.

Table 10. Wave summary by reach.

| Reach No. | Wave ID | Station No. | Height ratio |
|---|---|---|---|
| 1 | 100 | 123 | 1.00 |
| 2 | 200 | 82 | 0.94 |
| 3 | 300 | 60 | 0.85 |
| 4 | 400 | 39 | 0.56 |
| 5 | 500 | 24 | 0.57 |
| 6 | 600 | 15 | 0.28 |

### Summary

A joint probability distribution of wave height and period was created in ten 22.5-deg direction bands from 11.25 to 236.24 deg. It consisted of 158,138 observations representing 90.2 percent of the deepwater data from the WIS 20-year hindcast buoy WIS370. A total of 99 empirical directional wave spectra were created from this joint probability distribution. Parameters for these directional spectra were based on wave period and height for a TMA frequency spectrum and $Cos^n$ directional spreading function. The spectral wave heights were reduced at each reach along the Savannah Channel according to the previous study results of Thompson (2002).

## STS waves

This section describes how the waves were selected for the STS. It was not possible to simulate the large number of wave cases used in the CADET numerical simulations for the STS runs. The STS required only one representative wave at each station along the channel. The highest 3-5 percent of wave heights were identified since only the higher wave conditions are a concern for navigation. Ships would not be affected by routine smaller waves and would not use the channels during extreme storm events. The 3-5 percent highest waves are believed to give a more realistic view of design wave conditions during ship transits. Thus, the mean $H_s$, mean $T_p$, and mean $\theta_p$ were calculated at every third station along the channel from Station 0 to Station 99 for simulating waves in the STS.

### Wave statistics along channel

Thompson (2002) had calculated wave statistics at every third station (i.e., 3,000 ft distance) along the channel from Station 0 to 87 for the existing and plan options for three water levels (i.e., 0 ft, +3.3 ft, +6.6 ft MLLW). His statistics were based on the highest 3-5 percent waves using transformed STWAVE data from the deepwater WIS33 hindcast station. Thompson found that tide level did not seem to affect wave heights in the Outer Channel seaward of Station 48. He also found that deepening the channel from 44 to 50 ft did not significantly increase the wave heights as they tended to be smaller than in the existing channel due to the deeper depths and increased refraction over longer channel side slopes extending along more of the channel. Therefore, in this study it was decided that it was reasonable to model just the +3.3 ft water level in the deeper water depths of 50 ft.

Figure 19 is a plot of the mean $H_s$ at stations along the channel for the 3-5 percent highest $H_s$ waves from Thompson's STWAVE modeling for h = 50 ft and a tide level of +3.3 ft. Wave heights range from zero at Station 0 to $H_s$ = 6.7 ft at Station 87. The red line on this plot is a least-squares fit (LSF) to the data between Stations 0 to 87 using a second-order polynomial fit. The polynomial coefficients and correlation coefficient ($R^2$ = 0.96) are shown on the plot for reference. This line was used to predict the wave height at locations between Stations 87 and 99. An indication of the relative goodness-of-fit of the LSF to the data is that typical differences between the STWAVE $H_s$ and predicted $H_s$ between Stations 60 to 87 were less than 0.1 ft. Although this line tends to decrease with increasing station, it was felt that this was not realistic and that the wave heights should remain more or less uniform with a value $H_s$ = 6.7 ft that is equal to the wave height at Station 87. Also, this value is in reasonable agreement with the mean $H_s$ = 7.2 ft for the 3-5 percent highest waves at the deepwater WIS33, which is 2 nm from Station 98.

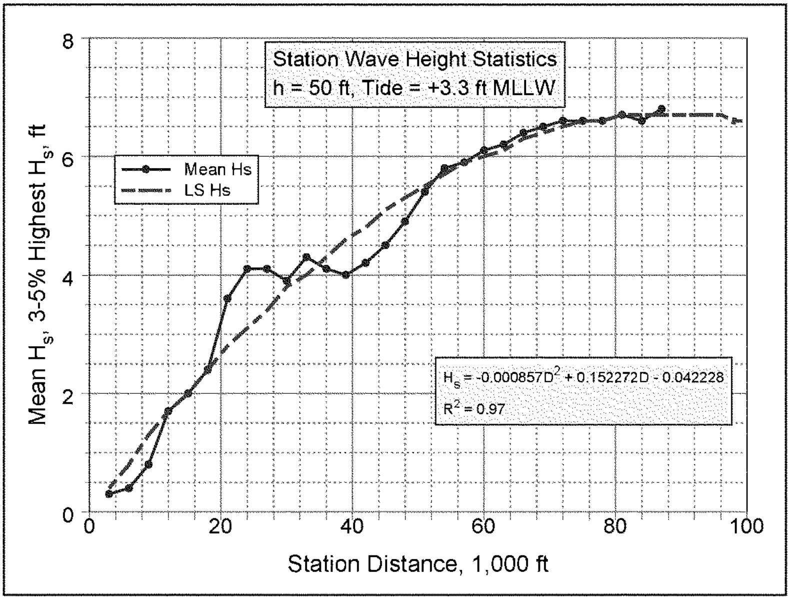



Figure 19. Mean $H_s$ along channel, 3-5 percent highest $H_s$, h=50 ft, tide=+3.3 ft MLLW.

Figure 20 is the corresponding plot for the mean $T_p$ at stations along the channel for the 3-5 percent highest waves from the STWAVE modeling. Values ranged from $T_p$ = 5 sec at Station 3, increased to $T_p$ = 10 sec between Stations 21 to 33, and remained fairly constant at $T_p$ = 9 sec for stations seaward of Station 36. Again, a LSF was obtained with a second order polynomial fit to the data. However, since only wave periods from seaward of Station 87 were required, only the data from Station 39 to 87 was used in the fitted curve since it is fairly constant in this range. The predicted wave periods were $T_p$ = 9 sec from Stations 87 to 99. Again, typical differences between the STWAVE $T_p$ and predicted $T_p$ between Stations 60 to 87 were less than 0.2 sec. The wave period is slightly higher than the overall mean $T_p$ = 8.3 sec for all waves in the 3-5 percent highest wave group at the WIS33 station.

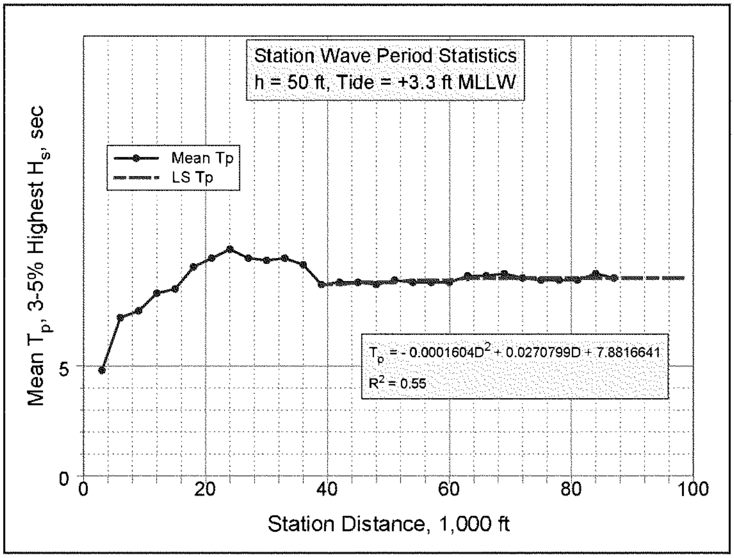



Figure 20. Mean of $T_p$ along channel, 3-5 percent highest $H_s$, h=50 ft, tide=+3.3 ft MLLW.

The corresponding mean $\theta_p$ (i.e., vector averages) for stations along the channel for the 3-5 percent highest waves is shown in Figure 21. Values ranged from 115 to 120 deg, becoming more variable shoreward from Station 30. Refraction produces a narrower wave direction shoreward of this point. Most of the wave directions are aligned with the seaward channel orientation. Thompson (2002) found that the wave directions were not affected by tide level. Again, a LSF to the wave direction data from Station 21 to 87 was used to predict values seaward of Station 87. Values were more or less uniform between $\theta_p$ = 107 to 113 deg. Again, goodness-of-fit is demonstrated by typical differences between STWAVE $\theta_p$ and predicted $\theta_p$ between Stations 60 to 87 being less than 3.5 deg. Finally, this compares favorably with the overall mean $\theta_p$ = 106 deg for the 3-5 percent highest waves at WIS33.

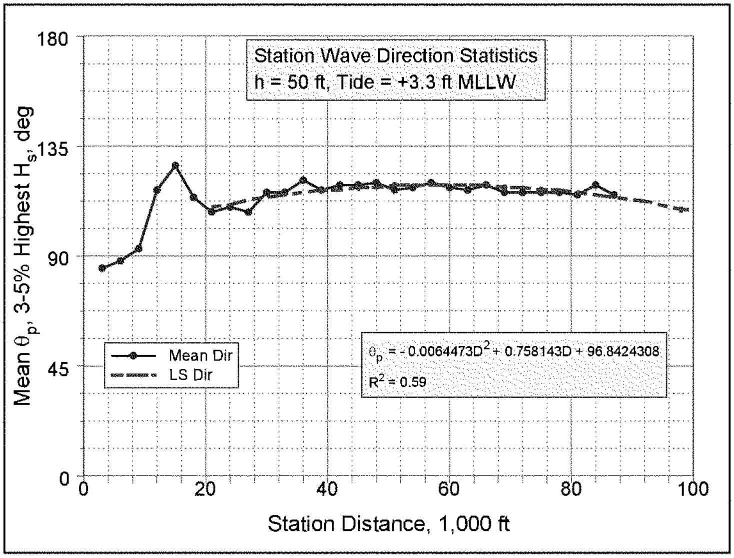



Figure 21. Mean of $\theta_p$ along channel, 3-5 percent highest $H_s$, h=50 ft, tide=+3.3 ft MLLW.

Table 11 is a listing of these wave parameters that were provided to the STS as a function of channel station. The channel configuration or option is also shown for reference. The rows at the bottom are shown in bold font to highlight the extrapolated values seaward of Station 87.

## Summary

The STS requires the wave period, height, and direction combination at stations along the channel to prepare wave cases for each simulation run. Since it is impractical to model multiple wave cases in the STS, the most representative wave cases were selected based on the 3-5 percent highest waves in the 20-year hindcast at deepwater station WIS33. Values from an earlier study using the STWAVE transformation model were provided for Stations 0 to 87 in all channel options including the Existing channel. These data were then extrapolated seaward to Station 99 for the new channel options S-1, S-3, and S-8.

Table 11. Wave parameters for STS, Savannah Outer Channel.

| Station (1000 ft) | Channel option | | | 3-5% Highest values | | |
|---|---|---|---|---|---|---|
| | | | | Mean $H_s$ (ft) | Mean $T_p$ (sec) | Mean $\theta_p$ (deg) |
| 3 | Exist | | | 0.3 | 4.8 | 85 |
| 6 | Exist | | | 0.4 | 7.2 | 88 |
| 9 | Exist | | | 0.8 | 7.5 | 93 |
| 12 | Exist | | | 1.7 | 8.3 | 117 |
| 15 | Exist | | | 2.0 | 8.5 | 127 |
| 18 | Exist | | | 2.4 | 9.5 | 114 |
| 21 | Exist | | | 3.6 | 9.9 | 108 |
| 24 | Exist | | | 4.1 | 10.3 | 110 |
| 27 | Exist | | | 4.1 | 9.9 | 108 |
| 30 | Exist | | | 3.9 | 9.8 | 116 |
| 33 | Exist | | | 4.3 | 9.9 | 116 |
| 36 | Exist | | | 4.1 | 9.6 | 121 |
| 39 | Exist | | | 4.0 | 8.7 | 117 |
| 42 | Exist | | | 4.2 | 8.8 | 119 |
| 45 | Exist | | | 4.5 | 8.8 | 119 |
| 48 | Exist | | | 4.9 | 8.7 | 120 |
| 51 | Exist | | | 5.4 | 8.9 | 117 |
| 54 | Exist | | | 5.8 | 8.8 | 118 |
| 57 | Exist | | | 5.9 | 8.8 | 120 |
| 60 | Exist | | S-8 | 6.1 | 8.8 | 118 |
| 63 | S-1 | | S-8 | 6.2 | 9.1 | 117 |
| 66 | S-1 | | S-8 | 6.4 | 9.1 | 119 |
| 69 | S-1 | | S-8 | 6.5 | 9.2 | 116 |
| 72 | S-1 | | S-8 | 6.6 | 9.0 | 116 |
| 75 | S-1 | | S-8 | 6.6 | 8.9 | 116 |
| 78 | S-1 | | S-8 | 6.6 | 8.9 | 116 |
| 81 | S-1 | S-3 | S-8 | 6.7 | 8.9 | 115 |
| 84 | S-1 | S-3 | S-8 | 6.6 | 9.2 | 119 |
| 87 | S-1 | S-3 | S-8 | 6.8 | 9.0 | 115 |
| 90 | S-1 | S-3 | S-8 | 6.7 | 9.0 | 113 |
| 93 | S-1 | S-3 | S-8 | 6.7 | 9.0 | 112 |
| 96 | S-1 | S-3 | S-8 | 6.7 | 9.0 | 110 |
| 99 | S-1 | S-3 | S-8 | 6.6 | 9.0 | 109 |

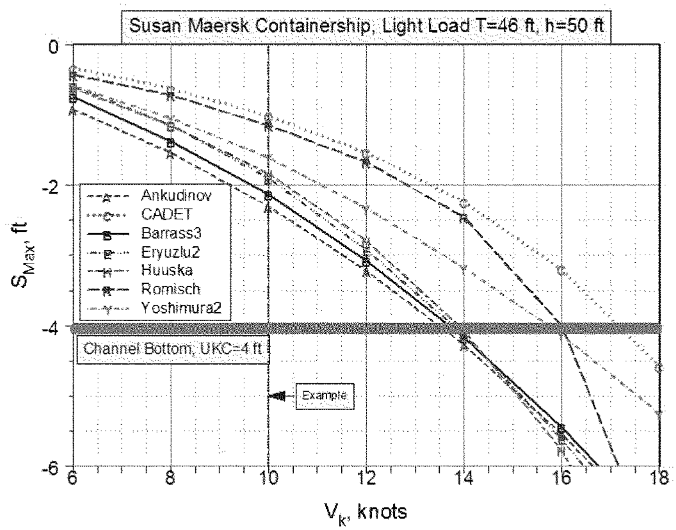
# 5 Ship Squat Results

This chapter compares PIANC, Ankudinov, and CADET predicted ship squat for the *Susan Maersk* for both light- and fully-loaded conditions. Although the CADET predictions are based on the BNT program, they are referred to as “CADET” or “CAD” in this report.

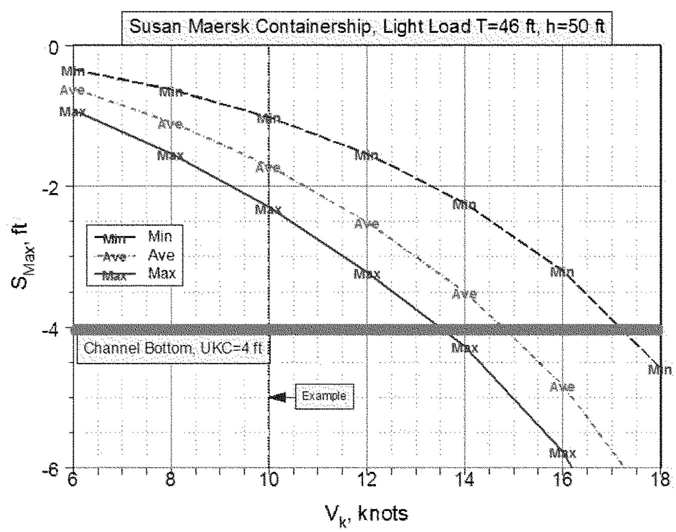
## Light-loaded conditions

Figure 22 shows maximum predicted ship squat as a function of ship speed for the light-loaded ($T$=46 ft) *Susan Maersk* containership in a water depth of $h$=50 ft (+1 ft tide) in the Outer (offshore) Entrance Channel. This maximum squat can occur at the bow or stern of the ship. The top plot (Figure 22a) shows the individual predictions for the Ankudinov, CADET, Barrass, Eryuzlu, Huuska/Guliev, Römisch, and Yoshimura methods. The last five predictors are the PIANC empirical predictions. The bottom plot (Figure 22b) is a summary of these seven predictions showing average, minimum, and maximum values. In general, the “average” squat prediction line is probably a good “design” value. The “maximum” squat prediction is the value that one could feel would not be exceeded. Of course, this does not include any wave-induced vertical motions for heave, pitch, and roll. The solid brown horizontal line represents the bottom of the channel for this particular water depth. Although ship speeds from $V_k$=6 to 18 kt are shown for comparison, a ship speed of $V_k$ =10 kt is the maximum allowed speed because of the whale restrictions. The faster speeds are included mainly to indicate the effects of these speeds on available UKC if these restrictions were not required. Figures 23 and 24 are analogous figures for the two water depths of $h$=52 ft (+3 ft tide) and $h$=54 ft (+5 ft tide), respectively. These depths were selected since they are realistic depths due to tide increases that the ship might encounter during transits. Table 12 lists the squat values that are plotted in these three figures for each water depth and light-loaded combination.

The Ankudinov and CADET predictions are good validation for the PIANC predictions since they confirm the overall values. The CADET predictions tend to be on the “low” side and the Ankudinov on the “high” side of the PIANC predictions.

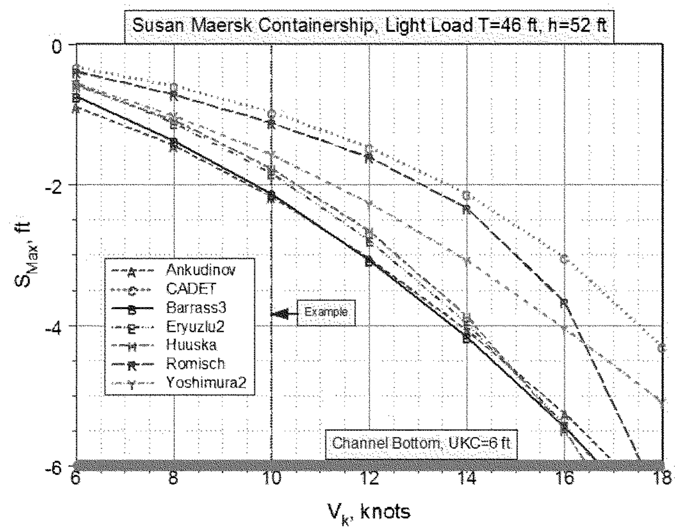



a)

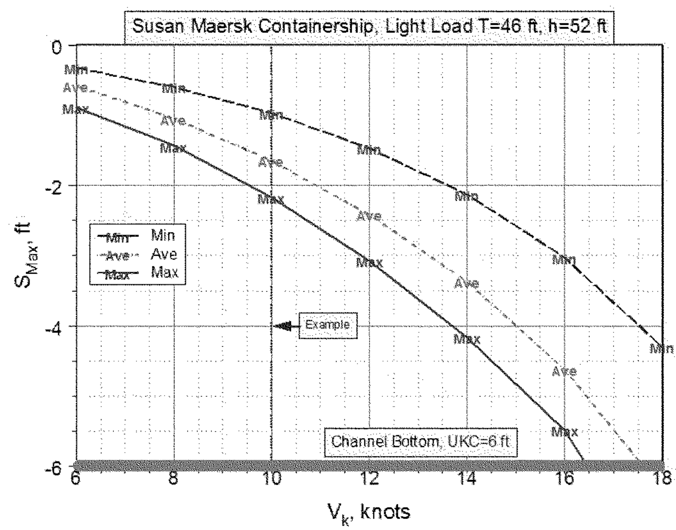



b)

Figure 22. Ship squat for light-loaded $T$=46 ft *Susan Maersk* containership, water depth $h$=50 ft Savannah Channel (a) Ankudinov, CADET, Barrass, Eryuzlu, Huuska, Römisch, and Yoshimura predictions, (b) average, minimum, and maximum squat for all seven predictors.

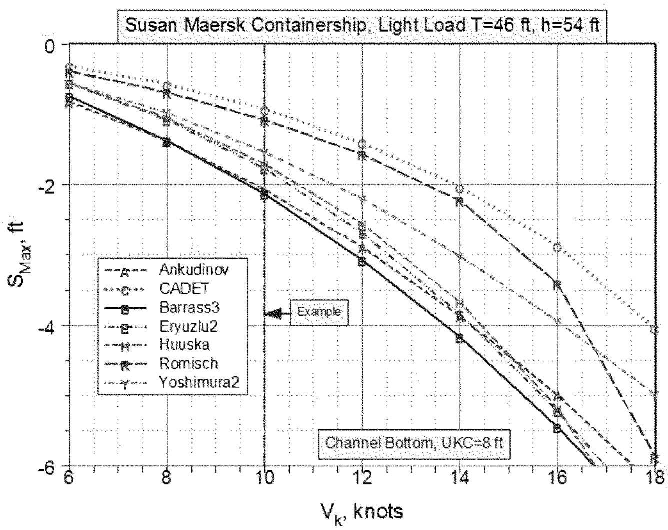



a)

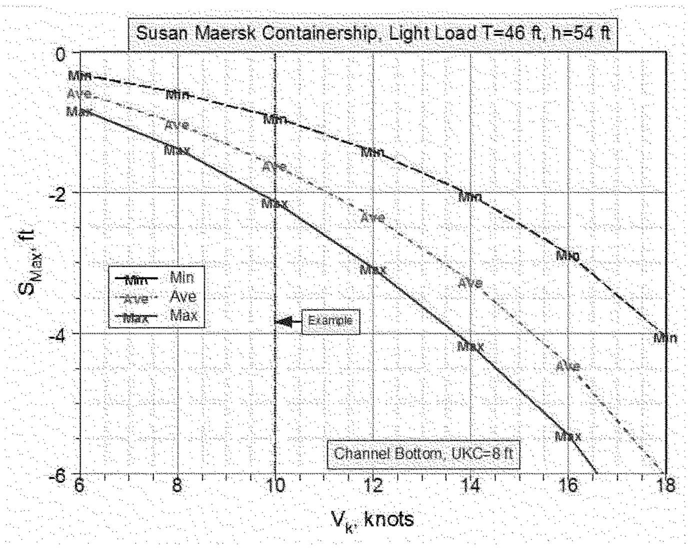



b)

Figure 23. Ship squat for light-loaded *T*=46 ft *Susan Maersk* containership, water depth *h*=52 ft Savannah Channel (a) Ankudinov, CADET, Barrass, Eryuzlu, Huuska, Römisch, and Yoshimura predictions, (b) average, minimum, and maximum squat for all seven predictors.




a)




b)

Figure 24. Ship squat for light-loaded *T*=46 ft *Susan Maersk* containership, water depth *h*=54 ft Savannah Channel (a) Ankudinov, CADET, Barrass, Eryuzlu, Huuska, Römisch, and Yoshimura predictions, (b) average, minimum, and maximum squat for all seven predictors.

Table 12. Ship squat predictions for light-loaded *Susan Maersk* containership.

| Speed (kt) | Ank (ft) | CAD (ft) | B3 (ft) | E2 (ft) | Hus (ft) | Röm (ft) | Yosh (ft) | Ave (ft) | Min (ft) | Max (ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| *h* =50 ft (UKC=4 ft) | | | | | | | | | | |
| 6 | 0.92 | 0.34 | 0.75 | 0.59 | 0.62 | 0.43 | 0.59 | 0.61 | 0.34 | 0.92 |
| 8 | 1.54 | 0.63 | 1.38 | 1.15 | 1.15 | 0.72 | 1.05 | 1.09 | 0.63 | 1.54 |
| 10 | 2.30 | 1.02 | 2.13 | 1.90 | 1.84 | 1.15 | 1.61 | 1.71 | 1.02 | 2.30 |
| 12 | 3.22 | 1.54 | 3.08 | 2.92 | 2.79 | 1.67 | 2.33 | 2.51 | 1.54 | 3.22 |
| 14 | 4.27 | 2.24 | 4.17 | 4.13 | 4.07 | 2.46 | 3.18 | 3.50 | 2.24 | 4.27 |
| 16 | 5.54 | 3.20 | 5.45 | 5.61 | 5.77 | 4.00 | 4.13 | 4.82 | 3.20 | 5.77 |
| 18 | 6.99 | 4.58 | 6.92 | 7.35 | 8.30 | 7.45 | 5.25 | 6.69 | 4.58 | 8.30 |
| *h* =52 ft (UKC=6 ft) | | | | | | | | | | |
| 6 | 0.89 | 0.33 | 0.75 | 0.56 | 0.59 | 0.39 | 0.56 | 0.58 | 0.33 | 0.89 |
| 8 | 1.44 | 0.60 | 1.38 | 1.12 | 1.08 | 0.72 | 1.02 | 1.05 | 0.60 | 1.44 |
| 10 | 2.17 | 0.97 | 2.13 | 1.84 | 1.77 | 1.12 | 1.57 | 1.65 | 0.97 | 2.17 |
| 12 | 3.05 | 1.47 | 3.08 | 2.79 | 2.66 | 1.61 | 2.26 | 2.42 | 1.47 | 3.08 |
| 14 | 4.07 | 2.13 | 4.17 | 3.97 | 3.87 | 2.33 | 3.08 | 3.37 | 2.13 | 4.17 |
| 16 | 5.25 | 3.03 | 5.45 | 5.41 | 5.48 | 3.67 | 4.04 | 4.62 | 3.03 | 5.48 |
| 18 | 6.63 | 4.30 | 6.92 | 7.09 | 7.78 | 6.59 | 5.09 | 6.34 | 4.30 | 7.78 |
| *h* =54 ft (UKC=8 ft) | | | | | | | | | | |
| 6 | 0.82 | 0.32 | 0.75 | 0.56 | 0.56 | 0.39 | 0.56 | 0.57 | 0.32 | 0.82 |
| 8 | 1.38 | 0.58 | 1.38 | 1.08 | 1.05 | 0.69 | 0.98 | 1.02 | 0.58 | 1.38 |
| 10 | 2.07 | 0.93 | 2.13 | 1.77 | 1.71 | 1.08 | 1.54 | 1.61 | 0.93 | 2.13 |
| 12 | 2.89 | 1.41 | 3.08 | 2.69 | 2.56 | 1.57 | 2.20 | 2.34 | 1.41 | 3.08 |
| 14 | 3.87 | 2.03 | 4.17 | 3.84 | 3.67 | 2.23 | 3.02 | 3.26 | 2.03 | 4.17 |
| 16 | 4.99 | 2.87 | 5.45 | 5.22 | 5.18 | 3.41 | 3.94 | 4.44 | 2.87 | 5.45 |
| 18 | 6.30 | 4.05 | 6.92 | 6.82 | 7.32 | 5.87 | 4.99 | 6.04 | 4.05 | 7.32 |

Notes:
Ank = Ankudinov
CAD = CADET
B3 = Barrass version 3
E2 = Eryuzlu version 2
Hus = Huuska/Guliev
Röm = Römisch
Yosh = Yoshimura
Ave, Min, Max = Average, Minimum, or Maximum of all 7 squat predictions
Red = Squat exceeds available UKC, Yellow shade = Ave, Min, Max at $V_k$ =10 kt

In the first scenario of $h$=50 ft ($h/T$=1.09) for the light-loaded ship (Figure 22), there is only 4 ft of UKC available (i.e., 50 – 46 ft). Therefore, without additional water depth from the tides, the ship could be expected to touch the bottom at a speed between $V_k$ =13 to 14 kt. The values in Table 12 have been highlighted in red to indicate possible grounding situations where predicted squat exceeds the available UKC of 4 ft. For the maximum allowed $V_k$ =10 kt due to whaling restrictions, predicted squat (yellow shading) ranges between 1.02 to 2.30 ft, with an average of 1.71 ft. This would leave a clearance ranging from a low of 1.71 to a high of 2.98 ft, with an average of 2.30 ft.

In the second scenario of $h$=52 ft ($h/T$=1.13) with a 2-ft tidal increase (Figure 23), the available UKC is 6 ft. With this water depth, the ship is not in danger of touching bottom (i.e., exceeding the available UKC of 6 ft) due to squat except for the fastest speed of $V_k$ =18 kt. Again, these values are highlighted in red. For the maximum $V_k$ =10 kt, predicted squat ranges between 0.97 to 2.17 ft, with an average of 1.65 ft. This would leave a clearance ranging from a low of 3.84 to a high of 5.03 ft, with an average of 4.35 ft.

Finally, for the last scenario of $h$=54 ft ($h/T$=1.17) with a 4-ft tidal increase (Figure 24), the available UKC is 8 ft. With this water depth, there are no speeds that would cause ship touching due to ship squat only. For the maximum $V_k$ =10 kt, predicted squat (yellow shading) ranges between 0.93 to 2.13 ft, with an average of 1.61 ft. This would leave a clearance ranging from a low of 5.87 to a high of 7.07 ft, with an average of 6.40 ft.

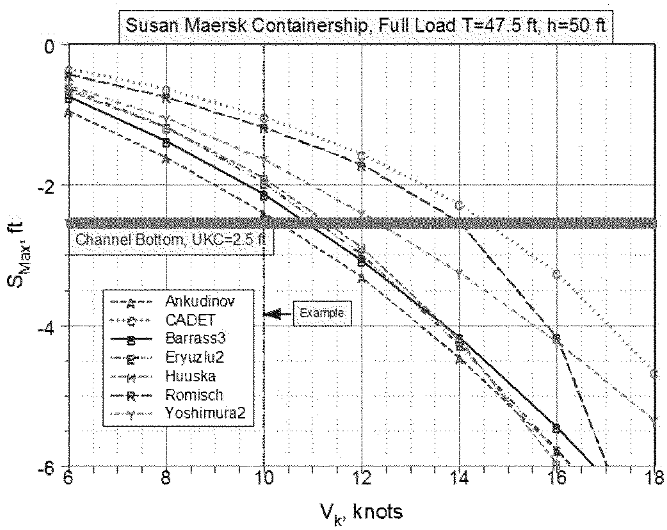
## Fully-loaded conditions

Figures 25-27 are analogous figures for the fully-loaded *Susan Maersk* containership in water depths of $h$=50, 52, and 54 ft (i.e., +1, +3, and +5 ft tide), respectively. Table 13 lists the corresponding squat values for the fully-loaded ship at these three water depths. As before, the grounding situations are highlighted in red and the squat statistics are shaded in yellow for the maximum ship speed of $V_k$ =10 kt.

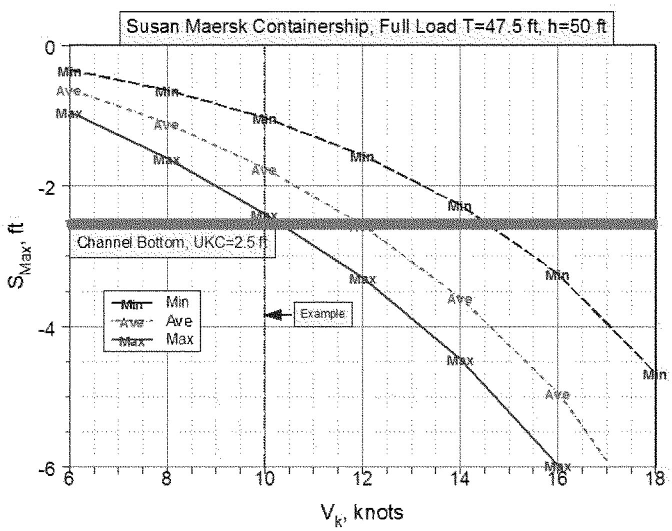
In the first scenario for $h$=50 ft (Figure 25), the available UKC is only 2.5 ft as the fully-loaded ship draws a deeper draft of $T$=47.5 ft ($h/T$=1.05). In this case, one would expect to hit the bottom at a ship speed of approximately $V_k$ =10.5 kt. Table 13 shows that speeds greater than $V_k$ =12 kt are all uniformly highlighted in red as the available UKC is exceeded. For the maximum allowed ship speed of $V_k$ =10 kt, predicted squat (yellow shading) ranges between 1.03 to 2.40 ft, with an average of 1.75 ft. This would leave a clearance ranging from a low of 0.10 to a high of 1.47 ft, with an average of 0.74 ft. Pilots would probably not want to attempt a transit during this low water depth condition with a fully-loaded ship.

In the second scenario of $h$=52 ft ($h/T$=1.09) with 2-ft tidal increase (Figure 26), the available UKC increases to 4.5 ft. One would expect to hit the bottom at a ship speed of approximately $V_k$ =14.5 kt. Table 13 shows that the predicted squat (highlighted in red) would exceed available UKC for speeds greater than $V_k$ =14 kt. For the maximum $V_k$ =10 kt, predicted squat (yellow shading) ranges between 0.99 to 2.26 ft, with an average of 1.70 ft. This would leave a clearance ranging from a low of 2.23 to a high of 3.51 ft, with an average of 2.80 ft.

Finally, in the last scenario of $h$=54 ft ($h/T$=1.14) with 4-ft tidal increase (Figure 27), the available UKC is 6.5 ft. One would expect to hit the bottom at a ship speed greater than $V_k$ =16.5 kt. Table 13 shows that the predicted squat (highlighted in red) would exceed available UKC for speeds greater than $V_k$ =16 kt. For the maximum speed of $V_k$ =10 kt, predicted squat (yellow shading) ranges between 0.95 to 2.17 ft, with an average of 1.64 ft. This would leave a clearance ranging from a low of 4.33 to a high of 5.55 ft, with an average of 4.85 ft.




a)




b)

Figure 25. Ship squat for fully-loaded *T*=47.5 ft *Susan Maersk* containership, water depth *h*=50 ft Savannah Channel (a) Ankudinov, CADET, Barrass, Eryuzlu, Huuska, Römisch, and Yoshimura predictions, (b) average, minimum, and maximum squat for all seven predictors.

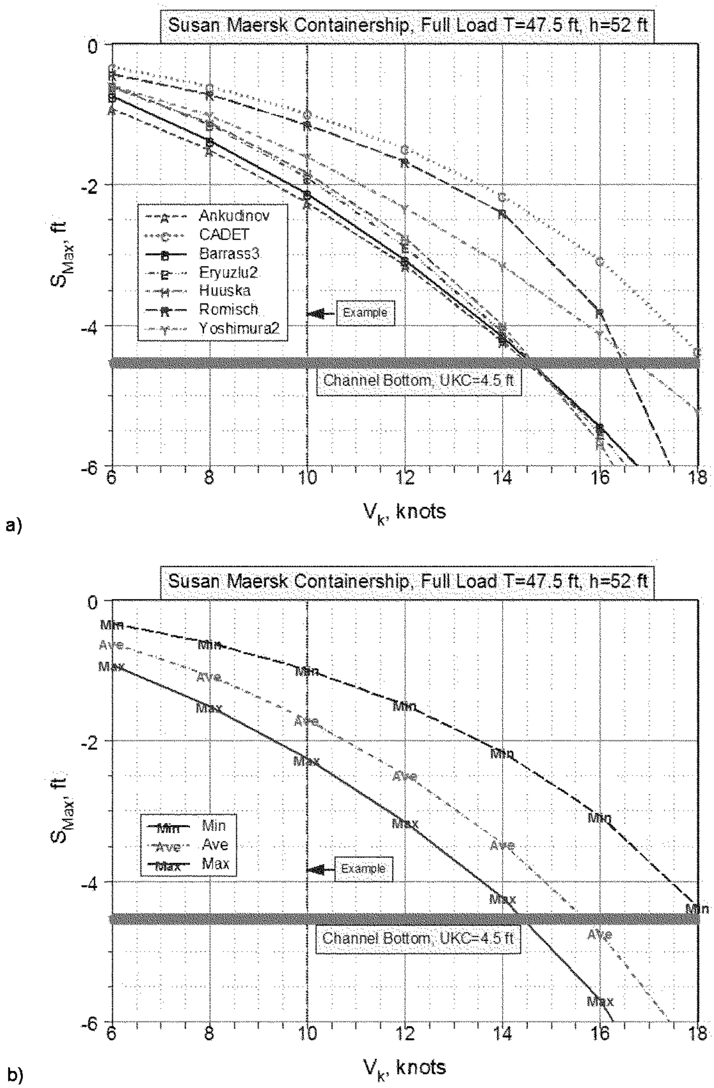
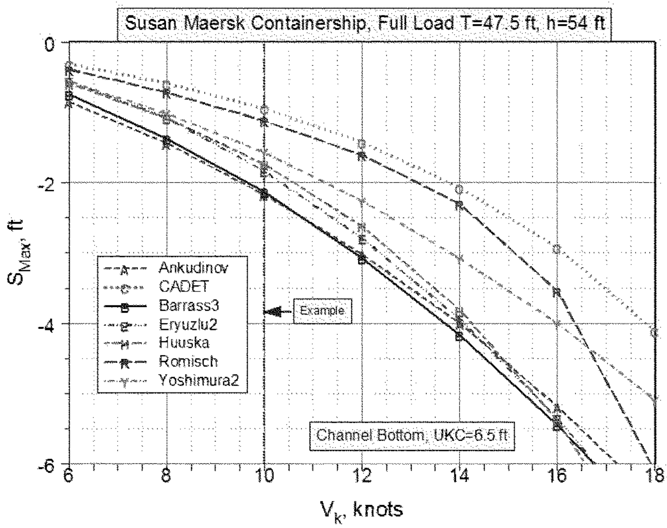
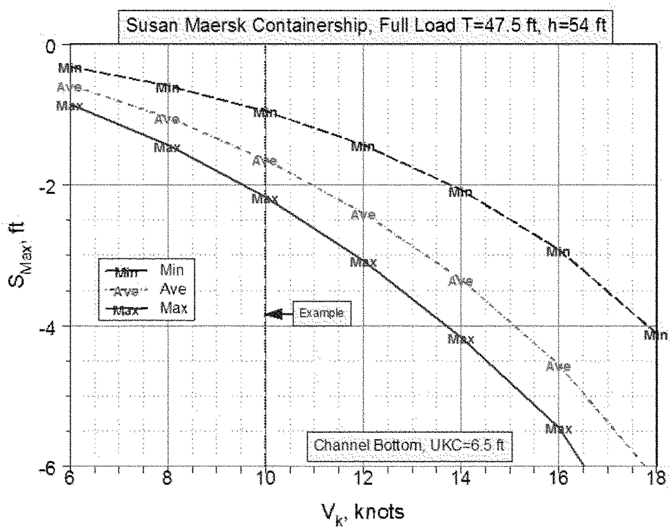



Figure 26. Ship squat for fully-loaded *T*=47.5 ft *Susan Maersk* containership, water depth *h*=52 ft Savannah Channel (a) Ankudinov, CADET, Barrass, Eryuzlu, Huuska, Römisch, and Yoshimura predictions, (b) average, minimum, and maximum squat for all seven predictors.




a)




b)

Figure 27. Ship squat for fully-loaded $T$=47.5 ft *Susan Maersk* containership, water depth $h$=54 ft Savannah Channel (a) Ankudinov, CADET, Barrass, Eryuzlu, Huuska, Römisch, and Yoshimura predictions, (b) average, minimum, and maximum squat for all seven predictors.

Table 13. Ship squat predictions for fully-loaded *Susan Maersk* containership.

| Speed (kt) | Ank (ft) | CAD (ft) | B3 (ft) | E2 (ft) | Hus (ft) | Röm (ft) | Yosh (ft) | Ave (ft) | Min (ft) | Max (ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| *h* =50 ft (UKC=2.5 ft) | | | | | | | | | | |
| 6 | 0.95 | 0.35 | 0.75 | 0.62 | 0.66 | 0.43 | 0.59 | 0.62 | 0.35 | 0.95 |
| 8 | 1.61 | 0.64 | 1.38 | 1.18 | 1.18 | 0.75 | 1.05 | 1.11 | 0.64 | 1.61 |
| 10 | 2.40 | 1.03 | 2.13 | 1.97 | 1.90 | 1.18 | 1.64 | 1.75 | 1.03 | 2.40 |
| 12 | 3.31 | 1.56 | 3.08 | 2.99 | 2.89 | 1.71 | 2.40 | 2.56 | 1.56 | 3.31 |
| 14 | 4.46 | 2.27 | 4.17 | 4.27 | 4.20 | 2.53 | 3.25 | 3.59 | 2.27 | 4.46 |
| 16 | 5.77 | 3.25 | 5.45 | 5.77 | 5.97 | 4.17 | 4.23 | 4.94 | 3.25 | 5.97 |
| 18 | 7.28 | 4.66 | 6.92 | 7.55 | 8.56 | 7.74 | 5.35 | 6.87 | 4.66 | 8.56 |
| *h* =52 ft (UKC=4.5 ft) | | | | | | | | | | |
| 6 | 0.92 | 0.33 | 0.75 | 0.59 | 0.62 | 0.43 | 0.59 | 0.61 | 0.33 | 0.92 |
| 8 | 1.51 | 0.61 | 1.38 | 1.15 | 1.12 | 0.72 | 1.02 | 1.07 | 0.61 | 1.51 |
| 10 | 2.26 | 0.99 | 2.13 | 1.90 | 1.84 | 1.15 | 1.61 | 1.70 | 0.99 | 2.26 |
| 12 | 3.15 | 1.49 | 3.08 | 2.89 | 2.76 | 1.67 | 2.33 | 2.48 | 1.49 | 3.15 |
| 14 | 4.23 | 2.16 | 4.17 | 4.10 | 4.00 | 2.40 | 3.15 | 3.46 | 2.16 | 4.23 |
| 16 | 5.45 | 3.07 | 5.45 | 5.54 | 5.68 | 3.81 | 4.13 | 4.73 | 3.07 | 5.68 |
| 18 | 6.89 | 4.37 | 6.92 | 7.28 | 8.04 | 6.86 | 5.22 | 6.51 | 4.37 | 8.04 |
| *h*=54 ft (UKC=6.5 ft) | | | | | | | | | | |
| 6 | 0.85 | 0.32 | 0.75 | 0.56 | 0.59 | 0.39 | 0.56 | 0.58 | 0.32 | 0.85 |
| 8 | 1.44 | 0.59 | 1.38 | 1.08 | 1.08 | 0.72 | 1.02 | 1.04 | 0.59 | 1.44 |
| 10 | 2.17 | 0.95 | 2.13 | 1.84 | 1.74 | 1.12 | 1.57 | 1.64 | 0.95 | 2.17 |
| 12 | 3.02 | 1.43 | 3.08 | 2.79 | 2.62 | 1.61 | 2.26 | 2.40 | 1.43 | 3.08 |
| 14 | 4.00 | 2.07 | 4.17 | 3.94 | 3.81 | 2.30 | 3.08 | 3.34 | 2.07 | 4.17 |
| 16 | 5.18 | 2.92 | 5.45 | 5.35 | 5.38 | 3.54 | 4.00 | 4.55 | 2.92 | 5.45 |
| 18 | 6.53 | 4.11 | 6.92 | 7.02 | 7.58 | 6.10 | 5.09 | 6.19 | 4.11 | 7.58 |

Notes:
Ank = Ankudinov
CAD = CADET
B3 = Barrass version 3
E2 = Eryuzlu version 2
Hus = Huuska/Guliev
Röm = Römisch
Yosh = Yoshimura
Ave, Min, Max = Average, Minimum, or Maximum of all 7 squat predictions
Red = Squat exceeds available UKC, Yellow shade = Ave, Min, Max at $V_k$ =10 kt

## Summary

Table 14 summarizes the available UKC for all combinations of ship loading, channel depth, and ship speed. The remaining UKC is listed for the average and maximum (or worst case) ship squat predictions. Negative UKC values are highlighted in red and represent a grounded ship. In summary, these represent only the ship squat values and do not include wave-induced vertical ship motions of heave, pitch, and roll. These will add to the required clearance values and will result in smaller available UKC when added to these squat predictions. For the light-loaded *Susan Maersk* at $T$=46 ft at the shallowest water depth of $h$=50 ft (requiring an additional 1 ft of tidal depth to the shallowest depth of $h$=49 ft), pilots should proceed with caution if attempting ship speeds faster than $V_k$ =10 to 12 kt, especially if any significant wave activity is present. There should be sufficient UKC for water depths greater than 50 ft for speeds as high as $V_k$ =14 to 16 kt. For the fully-loaded ship at $T$=47.5 ft at the 50 ft (+1 ft tide) depth, pilots should exercise extreme caution if attempting to move at speeds as high as $V_k$ =10 kt. This speed is probably not even possible unless wave heights and periods are relatively small. For the deeper depths when tides are present, the available UKC should be sufficient up to speeds $V_k$ =12 to 14 kt. Of course, pilots should be vigilant at higher speeds as ship squat can always be reduced by slowing down.

Table 14. UKC summary for *Susan Maersk* containership, Savannah Outer Channel.

| Speed (kt) | *h*=50 ft | | *h*=52 ft | | *h*=54ft | |
|---|---|---|---|---|---|---|
| | Ave (ft) | Max (ft) | Ave (ft) | Max (ft) | Ave (ft) | Max (ft) |
| Light-loaded *Susan Maersk* Containership *T*=46 ft | | | | | | |
| 6 | 3.40 | 3.08 | 5.42 | 5.12 | 7.44 | 7.19 |
| 8 | 2.91 | 2.46 | 4.95 | 4.56 | 6.99 | 6.63 |
| 10 | 2.30 | 1.71 | 4.35 | 3.84 | 6.40 | 5.87 |
| 12 | 1.50 | 0.79 | 3.59 | 2.92 | 5.66 | 4.92 |
| 14 | 0.50 | -0.26 | 2.63 | 1.84 | 4.74 | 3.84 |
| 16 | -0.81 | -1.77 | 1.39 | 0.52 | 3.57 | 2.56 |
| 18 | -2.69 | -4.30 | -0.34 | -1.77 | 1.97 | 0.69 |
| Fully-loaded *Susan Maersk* Containership *T*=47.5 ft | | | | | | |
| 6 | 1.87 | 1.54 | 3.89 | 3.58 | 5.92 | 5.64 |
| 8 | 1.38 | 0.89 | 3.42 | 2.99 | 5.45 | 5.05 |
| 10 | 0.74 | 0.10 | 2.80 | 2.23 | 4.85 | 4.33 |
| 12 | -0.07 | -0.82 | 2.01 | 1.35 | 4.09 | 3.41 |
| 14 | -1.10 | -1.97 | 1.04 | 0.26 | 3.16 | 2.33 |
| 16 | -2.45 | -3.48 | -0.24 | -1.18 | 1.95 | 1.05 |
| 18 | -4.37 | -6.07 | -2.02 | -3.54 | 0.30 | -1.08 |
| Notes:<br>1. Negative (red) values represent grounded ship. | | | | | | |

# 6 Ship Accessibility Results

The CADET numerical model predicts the days/year of accessibility based on the ship parameters, channel configuration, input wave conditions, and risk of grounding. This accessibility is generated for each reach, transit direction, and ship loading condition. Based on these values, the project designer can select the optimum dredge depth which is defined as the shallowest dredge depth with the largest percentage of time the channel could be safely transited each year. Therefore, any notation that "CADET recommends" should be construed as the "author of this report recommends" based on the CADET results.

## Absolute water levels

This section presents results for the light- and fully-loaded *Susan Maersk* for absolute water levels. These water levels represent a combined water depth that includes tides and/or future dredging. For instance, a depth of 52 ft represents either a dredged depth of 52 ft or a depth of 50 ft plus a tide level of +3 ft. The effect of the tides on the actual water depths is discussed later in this chapter.

### Light-loaded conditions

This section discusses the effects of inbound, outbound, and combined transit directions on days of accessibility for the light-loaded *Susan Maersk*. Appendix C contains tables with the days of accessibility for each of the channel option configurations. A comparison between Reach 1 and Reach 6 in the preferred option S-8_Sta0 is also presented to illustrate the range in accessibility between the different reaches.

#### *Inbound transits*

Figure 28a compares accessibility among the three channel options of S-1 (open squares), S-3 (solid triangles), and S-8 (solid line) for the light-loaded *Susan Maersk* at speeds of 6 (blue), 10 (red), and 14 (green) knots. Remember that the Savannah offshore channel is restricted to maximum ship speeds of 10 kt due to the Wright whale. Accessibility is shown for channel depths ranging from 48 to 60 ft. Of course, the maximum proposed project depth will be only 49 ft, so these deeper water depths represent the maximum tidal range up to 7-8 ft, plus some additional depth for future consideration. Ideally, one wants 365 days of accessibility at the shallowest water depth possible. These water levels do not occur continuously as they are only possible for limited time intervals each year according to the tides.

These plots represent the worst case combinations for all three reaches in a group for inbound transits. The left-most curves in these accessibility figures represent the best results since they indicate the most number of days of accessibility for the shallowest channel depth. In general, the slower ship speeds have greater days of accessibility than the faster speeds. In general, all three options would provide the same number of days of accessibility for all three ship speeds. However, there is one small exception for a depth of 49 ft and speed of 14 kts where option S-8 is slightly better than S-3 and S-1.

Figure 28b is the analogous plot for the comparison between the S-1_Sta0 (dashed line) channel and the S-8_Sta0 (solid line) option. Both of these channel options consist of 6 reaches going from the offshore Station 123 to inshore Station 0. Again, there are no significant differences between the S-8 option and the S-1 channel alignment except for the 49 ft depth and 14 kt speed.

*Outbound transits*

Figure 29 for outbound transits is similar to Figure 28 for the inbound transits. The main difference between these two figures is the increase in number of days of accessibility for the outbound transits relative to the inbound direction, especially for the 49 ft depth. Figure 29a indicates that all three options would provide similar days of accessibility for all ship speeds. This is a similar result as shown in Figure 28 for the inbound transits. Thus, it looks like the preferred S-8 option is as good a choice as either S-1 or S-3 options. Figure 29b is the comparison between the S-1_Sta0 (dashed line) channel and the S-8_Sta0 (solid line) option for all six reaches. Again, the S-8_Sta0 option is similar for all three ship speeds and even slightly better at the 49 ft depth and 14 kt speed than the S-1_Sta0 channel alignment.

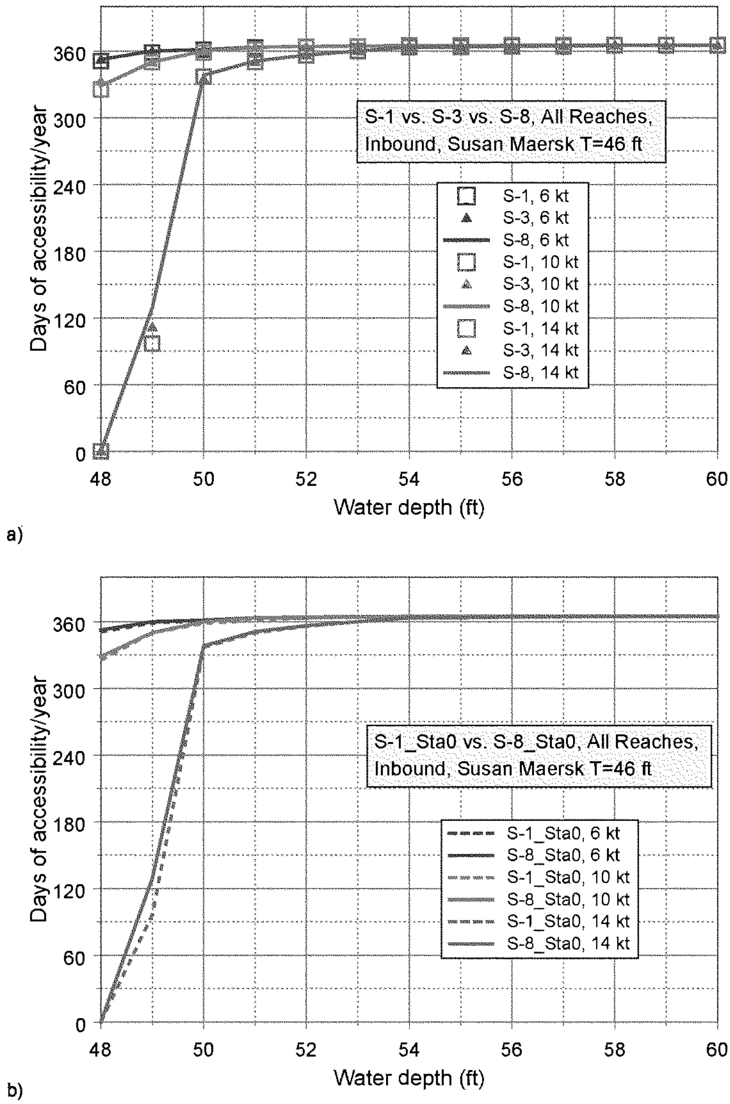
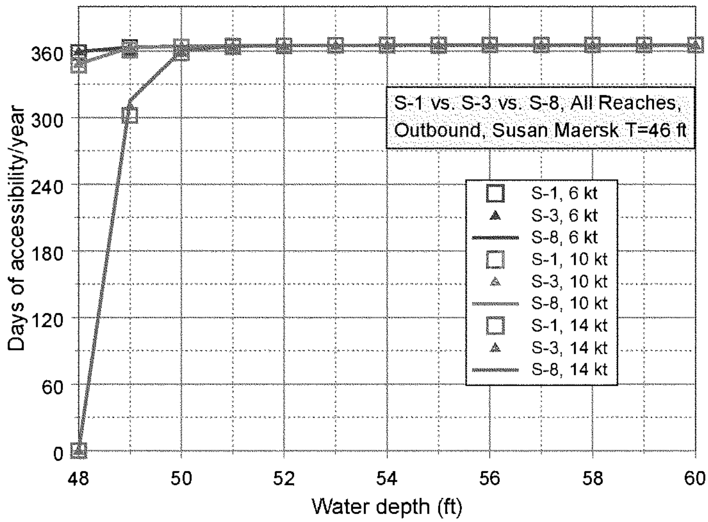
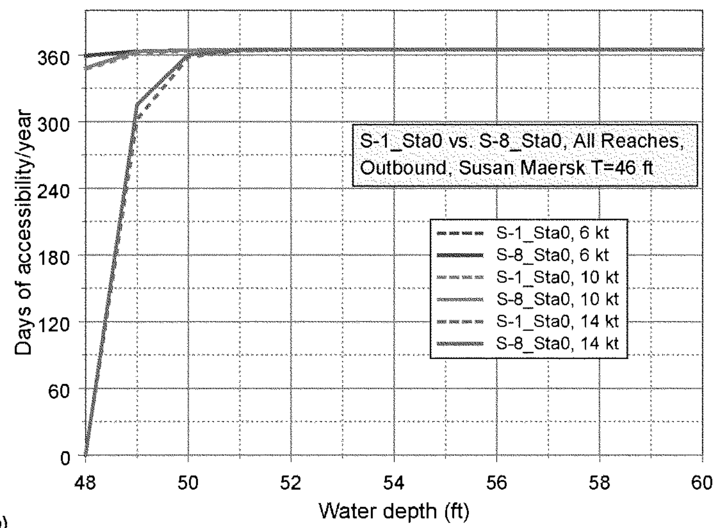



Figure 28. CADET predictions of days of accessibility for inbound light-loaded *Susan Maersk* as a function of channel depth and ship speed for (a) S-1_Sta39 vs. S-3_Sta39 vs. S-8_Sta39 channel groups and (b) S-1_Sta0 vs. S-8_Sta0 group.




a)




b)

Figure 29. CADET predictions of days of accessibility for outbound light-loaded *Susan Maersk* as a function of channel depth and ship speed for (a) S-1_Sta39 vs. S-3_Sta39 vs. S-8_Sta39 channel groups and (b) S-1_Sta0 vs. S-8_Sta0 group.

Figure 30 illustrates the differences between inbound and outbound transits for the S-8_Sta0 group for all reaches. These are the same curves presented in Figures 28 and 29 for S-8_Sta0, but presented on the same figure to facilitate comparison of the differences in days of accessibility. As previously stated, the outbound transits have more days of accessibility than the inbound transits, especially as ship speed increases.

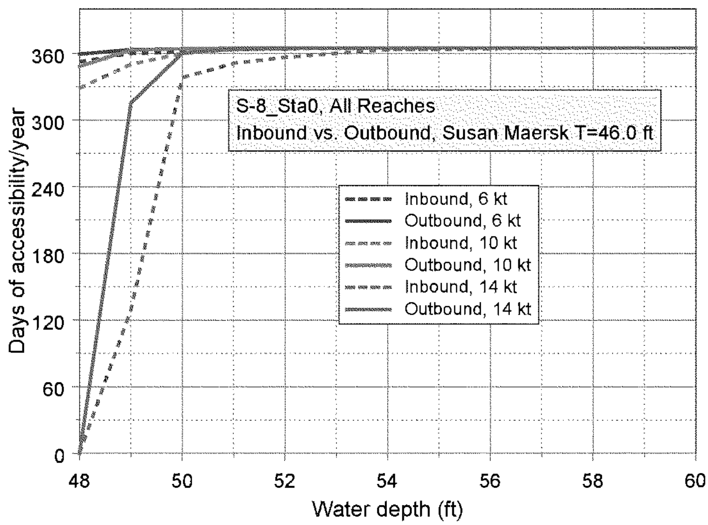



**Figure 30. CADET predictions of days of accessibility for inbound vs. outbound light-loaded *Susan Maersk* as a function of channel depth and ship speed for all six reaches in S-8_Sta0 group.**

*Combined transits*

The combined transit results include the grouping of all results for inbound and outbound transits and all reaches in each channel option. Since the inbound transit presents the worst conditions for vertical ship motions, the combined transit cases are identical to the inbound results. Typically, these results reflect the minimum number of days of accessibility for all reaches and both transit directions.

*Effect of reach*

The effect of channel reach on the days of accessibility for reaches 1 (R1) and 6 (R6) in the S-8_Sta0 group is shown in Figure 31a for inbound and Figure 31b for outbound transits. This figure is similar to the previous figures. Reach 1 has less days of accessibility than Reach 6 for both inbound and outbound transits and all ship speeds. The changes in days of accessibility are more pronounced for the inbound than the outbound transits, especially for the 14 kt speed. Although not shown, days of accessibility increase as reach increases from Reach 1 to Reach 6 since wave heights are reduced for inland reaches. Appendix C contains listings of days of accessibility for all reaches in both inbound and outbound transits.

*Depth selection for light-loaded ship*

In summary for light-loaded ships, days of accessibility increase for slower ship speeds, outbound transits, and interior reaches. As can be seen from the figures, a light-loaded ship has approximately 90 percent or more of each year available for ship transits for depths from 48 to 52 ft. Obviously, shallower depths are less expensive from the dredging and environmental standpoint. An optimum depth would be the shallowest depth that will provide safe transits and the desired days of accessibility. Table 15 lists the days of accessibility for the design ship speed of 10 kt for all three design options and the comparison with the preferred S-8 option and the S-1_Sta 0 channels. Three depths from 49 to 51 ft (i.e., 0, to +2 ft tide) are listed for each case to illustrate the variability in the accessibility as the depth increases. As the slope of the accessibility curve flattens, the benefit of the extra foot of depth decreases relative to the dredging cost. For the light-loaded ship, a depth of 50 ft (+1 ft) will give a gross underkeel clearance of 4 ft with 360 days of accessibility for inbound and 364 days for outbound ships. The S-8 option gives slightly larger inbound days of accessibility than the 358 days for the S-1 alternative.

**Table 15. Days of accessibility for light-loaded ship at 10 kt.**

| | Inbound | | | Outbound | | |
|---|---|---|---|---|---|---|
| Group ID | h=49 ft | h=50 ft | h=51 ft | h=49 ft | h=50 ft | h=51 ft |
| S-1_Sta39 | 350 | 358 | 361 | 361 | 364 | 364 |
| S-3_Sta39 | 350 | 360 | 363 | 362 | 364 | 364 |
| S-8_Sta39 | 350 | 360 | 363 | 363 | 364 | 365 |
| S-1_Sta0 | 350 | 358 | 361 | 361 | 364 | 364 |
| S-8_Sta0 | 350 | 360 | 363 | 363 | 364 | 365 |

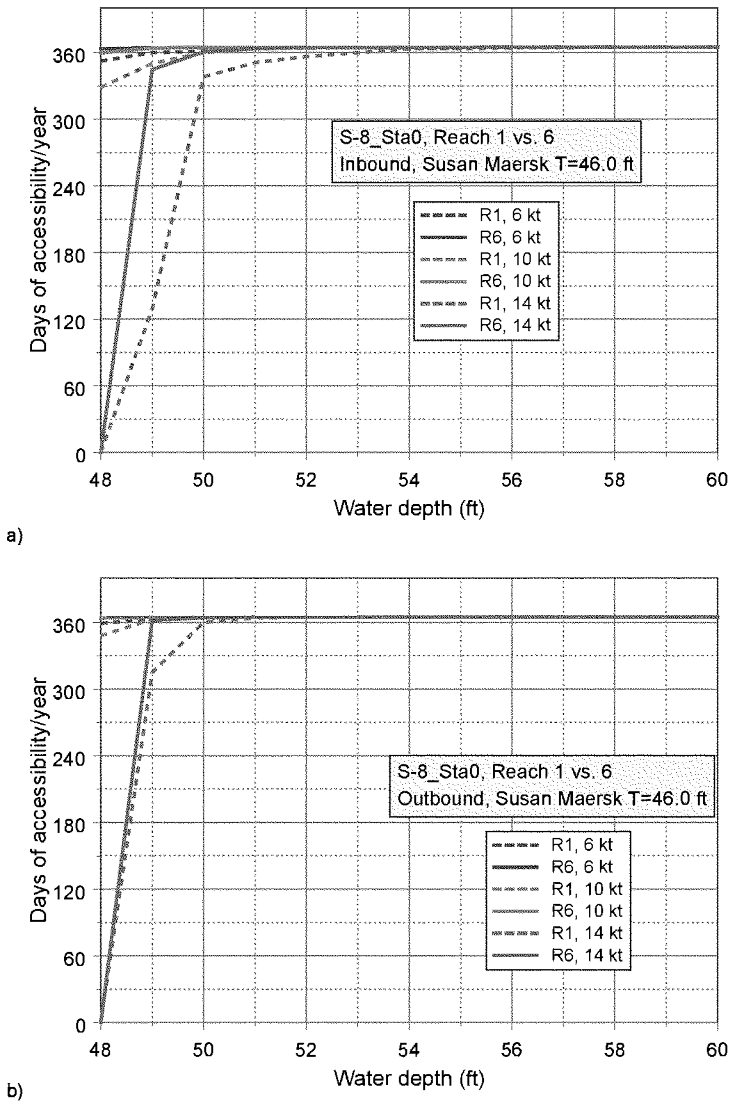



Figure 31. Effect of reaches on CADET predictions of days of accessibility in Reaches 1 (R1) and 6 (R6) in S-8_Sta0 for light-loaded *Susan Maersk* as a function of channel depth and ship speed for (a) inbound and (b) outbound transits.

### Fully-loaded conditions

This section discusses the effects of inbound, outbound, and combined transit directions on days of accessibility for the fully-loaded *Susan Maersk*. Again, Appendix C contains tables with the days of accessibility for each of the channel option configurations. As done for the light-loaded ship, a comparison between Reach 1 and Reach 6 in the preferred option S-8_Sta0 is also presented to illustrate the range in accessibility between the different reaches.

#### *Inbound transits*

Figure 32 shows the analogous plots for the inbound fully-loaded *Susan Maersk*. The trends are similar to Figure 28 for the light-loaded ship. Although the overall days of accessibility are reduced for the same depth due to the deeper draft, the S-8 option shows no significant differences than the other two options S-1 or S-3 (Figure 32a) and the S-1_Sta0 alignment (Figure 32b).

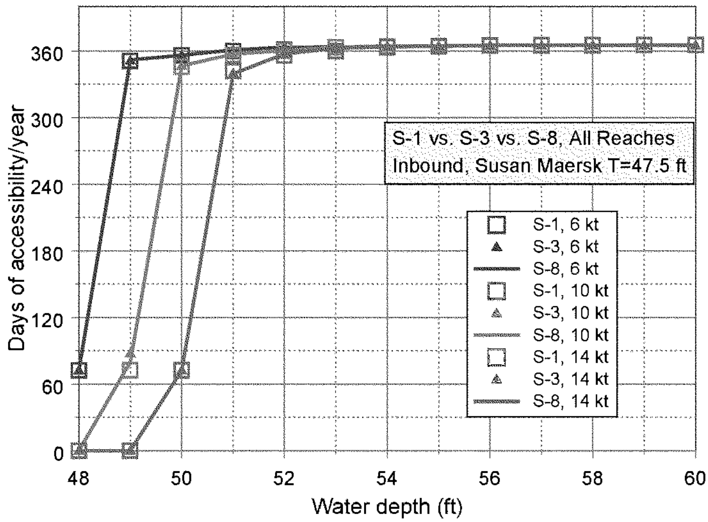
#### *Outbound transits*

Figure 33 shows the plots for the outbound fully-loaded *Susan Maersk*. The trends are similar to the light-loaded ship in Figure 29. At the 49 ft depth and 10 kt speed, the preferred S-8 option is marginally better than the other two options S-1 or S-3 (Figure 33a) and the S-1_Sta0 alignment (Figure 33b).

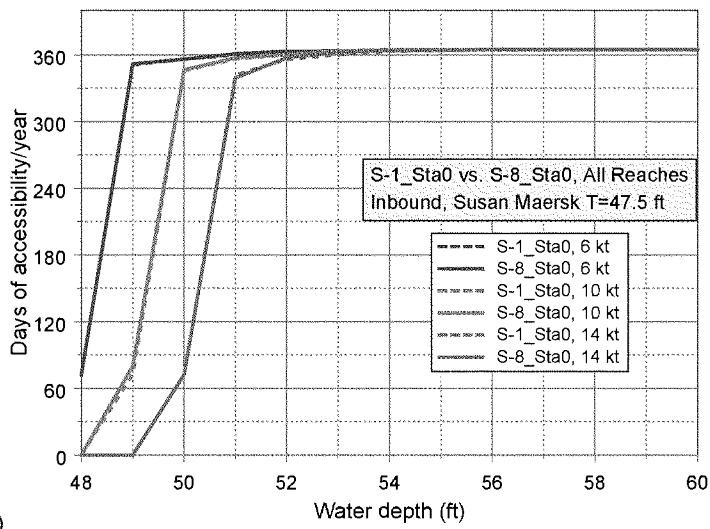
Figure 34 compares the inbound and outbound transits for the fully-loaded *Susan Maersk* for all six reaches in the S-8_Sta0 group. Again, these are the same values shown in Figures 32 and 33, but re-plotted to facilitate comparison of the effect of inbound and outbound transits on the days of accessibility. Outbound transits have slightly more days of accessibility than inbound transits, the same as for the light-loaded ship. For the fully-loaded ship, the largest difference occurs for the 49 ft depth at a 10 kt speed instead of the 14 kt speed for the light-loaded ship.

#### *Combined transits*

Again, the combined transits are not shown since they are equivalent to the inbound transits.

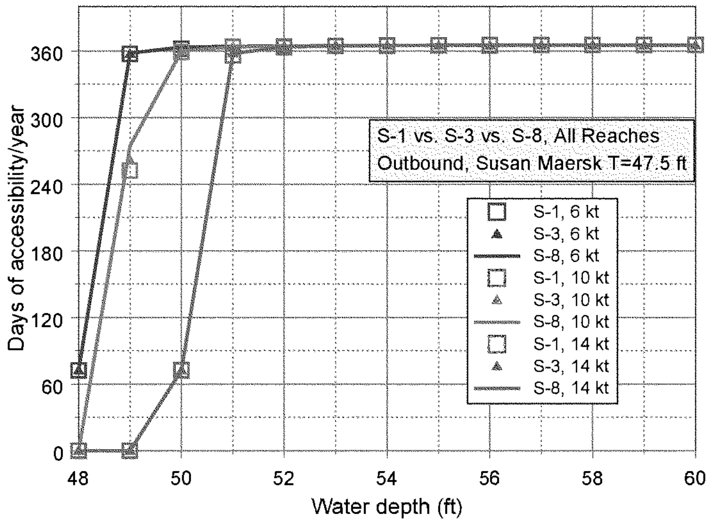



a)

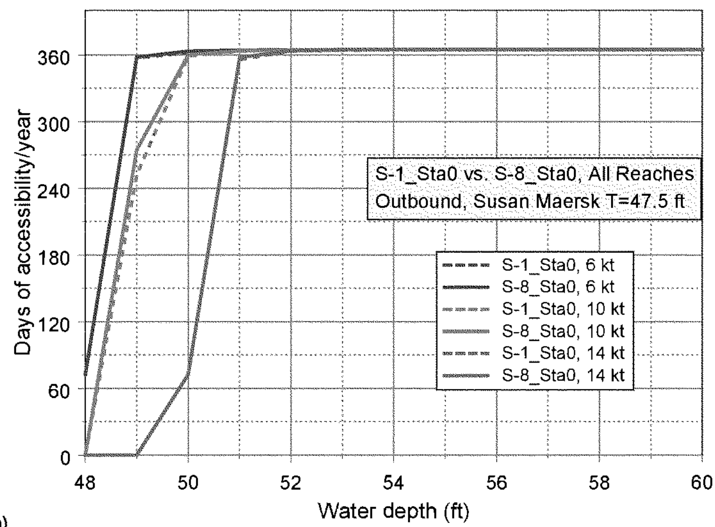



b)

Figure 32. CADET predictions of days of accessibility for inbound fully-loaded *Susan Maersk* as a function of channel depth and ship speed for (a) S-1_Sta39 vs. S-3_Sta39 vs. S-8_Sta39 channel groups and (b) S-1_Sta0 vs. S-8_Sta0 group.




a)




b)

Figure 33. CADET predictions of days of accessibility for outbound fully-loaded *Susan Maersk* as a function of channel depth and ship speed for (a) S-1_Sta39 vs. S-3_Sta39 vs. S-8_Sta39 channel groups and (b) S-1_Sta0 vs. S-8_Sta0 group.

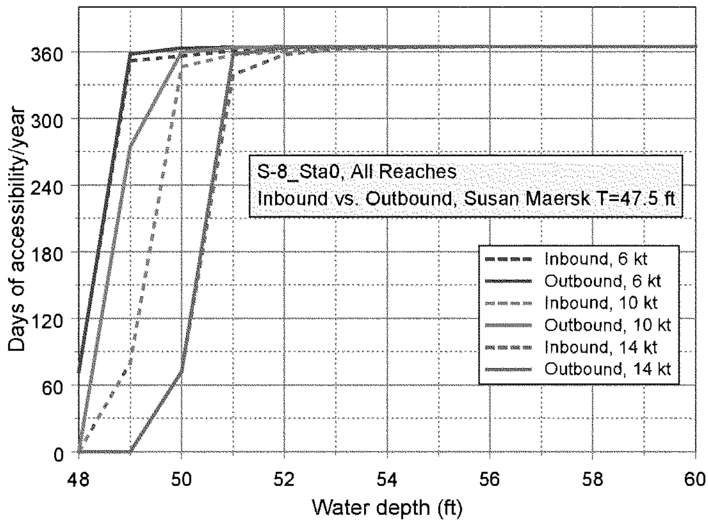



Figure 34. CADET predictions of days of accessibility for inbound vs. outbound fully-loaded *Susan Maersk* as a function of channel depth and ship speed for all six reaches in S-8_Sta0 group.

*Effect of reach*

As shown in Figure 31 for the light-loaded ship, the effect of channel reach on the days of accessibility is shown in Figure 35 for inbound and outbound transits for reaches 1 (R1) and 6 (R6) in the S-8_Sta0 group. The results are similar as for the light-loaded ship as the days of accessibility increase as reach moves farther inland for both inbound and outbound transits and all ship speeds. The largest effect occurred for the 10 kt speed for the fully-loaded ship compared to the 14 kt speed for the light-loaded ship. Appendix C contains listings of days of accessibility for all reaches in both inbound and outbound transits.

*Depth selection for fully-loaded ship*

As before for the light-loaded ship, the days of accessibility increase for slower ship speeds, outbound transits, and interior reaches. As can be seen from the figures, a fully-loaded ship has approximately 90 percent or more of each year available for ship transits for depths from 50 to 54 ft (i.e., +1 to +5 ft tide). Again, Table 16 lists the days of accessibility for the ship speed of 10 kt for all three design options and the comparison with the preferred S-8_Sta0 option and the S-1_Sta0 channels. Three depths from

51 to 53 ft are listed for each case to illustrate the variability in the accessibility as the depth increases. For the fully-loaded ship, a depth of 52 ft (+3 ft) will give a gross underkeel clearance of 4.5 ft with 360 days of accessibility for inbound and 364 days for outbound ships. The S-8 option gives similar days of accessibility as the other two options.

Table 16. Days of accessibility for fully-loaded ship at 10 kt.

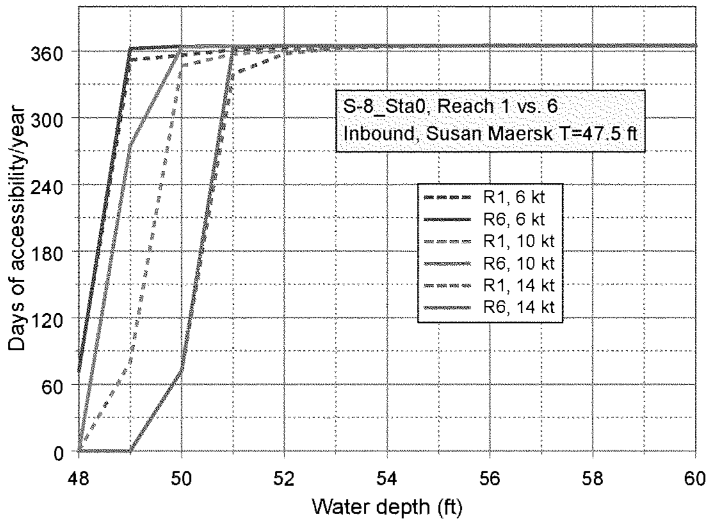
| | Inbound | | | Outbound | | |
|---|---|---|---|---|---|---|
| Group ID | h=51 ft | h=52 ft | h=53 ft | h=51 ft | h=52 ft | h=53 ft |
| S-1_Sta39 | 356 | 360 | 363 | 363 | 364 | 364 |
| S-3_Sta39 | 357 | 360 | 363 | 364 | 364 | 365 |
| S-8_Sta39 | 357 | 360 | 363 | 364 | 364 | 365 |
| S-1_Sta0 | 356 | 360 | 363 | 363 | 364 | 364 |
| S-8_Sta0 | 357 | 360 | 363 | 364 | 364 | 365 |

### Light- versus fully-loaded ship

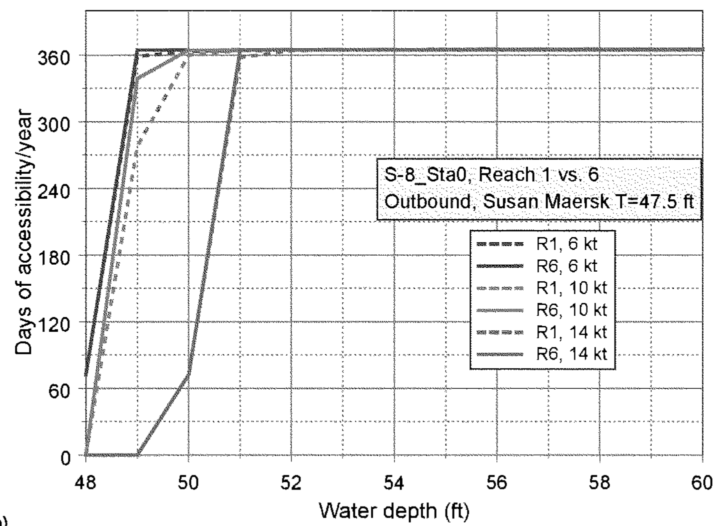
To facilitate comparison between the light- and fully-loaded *Susan Maersk*, Figure 36 shows days of accessibility for inbound (36a) and outbound (36b) transits. These are the same data shown in previous figures, but re-plotted to facilitate comparisons between ship loading conditions. As expected, the light-loaded ship (dashed line) has increased days of accessibility compared to the fully-loaded ship (solid line) for all ship speeds for both inbound and outbound transits. As noted previously, the outbound transits have slightly increased days of accessibility relative to the inbound transits.

#### *Summary for light- and fully-loaded ships*

In summary for both light- and fully-loaded ships, the days of accessibility increase for slower ship speeds, outbound transits, interior reaches, and light-load. The optimum depths are 50 (+1 ft) and 52 ft (+3 ft) for the light- and fully-loaded ships, respectively. The S-8 option is as good or better as the other options relative to days of accessibility.

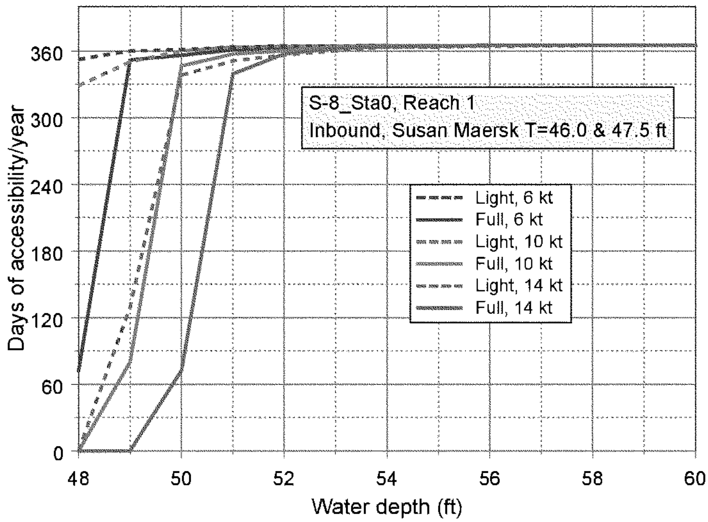



a)

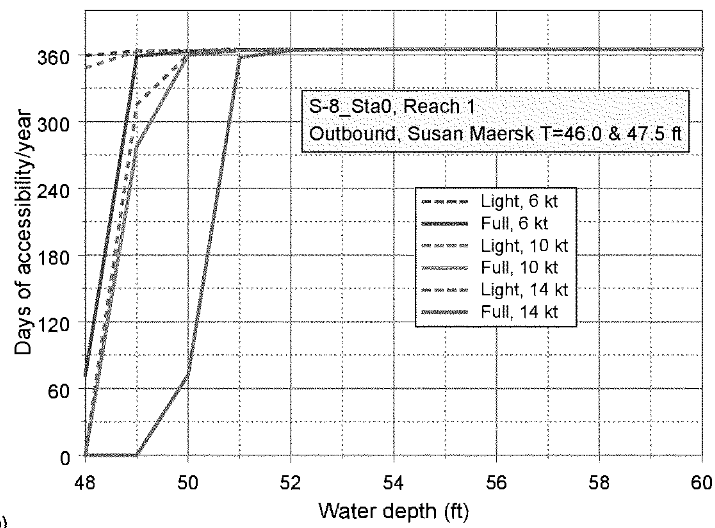



b)

Figure 35. CADET predictions of days of accessibility in Reaches 1 (R1) and 6 (R6) in S-8_Sta0 for fully-loaded *Susan Maersk* as a function of channel depth and ship speed for (a) inbound and (b) outbound transits.




a)




b)

Figure 36. CADET predictions of days of accessibility for Reach 1 in S-8_Sta0 group for light- and fully-loaded *Susan Maersk* as a function of channel depth and ship speed for (a) inbound and (b) outbound transits.

## Effect of tides

The output from the tide duration prediction program can be applied to the channel accessibility plots. As noted in the previous section, the recommended depths for the light- and fully-loaded ships will require the use of the tide to achieve the desired water levels for safe transit. Therefore, these deeper depths can be achieved by taking advantage of the tides during transits. Travel times and effect of tides on the days of accessibility are discussed for the Outer Channel.

*Travel times*

The existing Savannah Outer Channel has a length of 10 nm (60,000 ft, Sta0 to Sta60) and a water depth of 44 ft MLLW. All three options considered in this study would include the Existing channel as the inner reach that ships would transit. The S-1 channel option (S-1_Sta0) would have a total length of 20.2 nm as it daylights at Sta123 (123,000 ft). Channel options S-3 (S-3_Sta0) and S-8 (S-8_Sta0) options would have a length of 16.3 nm as they daylight at Sta99 (99,000 ft). All options would be deepened to 50 ft MLLW. Table 17 lists the minimum travel times for each channel option as a function of ship speed. The numbers in parenthesis are the recommended times that might be considered to insure safe transits in the event of unexpected delays and variability in ship speed. Typically, these are just rounded up so that the reader can substitute a longer time if desired.

Table 17. Travel times in hours for safe transit, Savannah Outer Channel.

| Channel option | Distance | | Ship speed (kt) | | |
|---|---|---|---|---|---|
| | (ft) | (nm) | 6 | 10 | 14 |
| Existing | 60,000 | 9.9 | 1.7 (2) | 1.0 (2) | 0.7 (1) |
| S-1_Sta0 | 123,000 | 20.3 | 3.4 (4) | 2.0 (3) | 1.4 (2) |
| S-3_Sta0 | 98,000 | 16.2 | 2.7 (3) | 1.6 (2) | 1.2 (2) |
| S-8_Sta0 | 98,000 | 16.2 | 2.7 (3) | 1.6 (2) | 1.2 (2) |

*Tidal predictions*

As noted earlier, tide levels for the Savannah channel are based on predictions at Ft Pulaski. At the ocean boundary or outer reaches of the Outer channel, one might expect a reduction to 91 to 94 percent of the full tide level predicted at Ft. Pulaski (David Elliott[1], NOAA). This reduction is due to the changes in geometry and channel configuration at the ocean boundary relative to the inner portions of the channel. At Ft Pulaski, 100 percent of the tide height would be present, decreasing along the length of the Outer channel to 91 percent of this value. For a maximum tidal increase of +8 ft at Ft Pulaski, this reduction in water level is equivalent to a tide of only +7.3 ft at the ocean boundary of the channel. Of course, this water level varies continuously along the channel from the high level at Ft Pulaski. The maximum water level difference is equivalent to 0.72 ft (i.e., 100 – 91 = 9 percent). For a minimum tide increase of +1 ft, the difference between Ft Pulaski and the ocean boundary is only 0.09 ft. Therefore, subtracting 1 ft from the Ft Pulaski predictions would be an overly conservative estimate of the water levels along the entire length of the Savannah Outer channel. Thus, no change was made to the predicted tide levels

Table 18 lists days of higher water levels from the CADET tidal duration prediction module based on the Ft Pulaski tidal data. The top half of the table lists the number of days per year as a function of the duration in hours for water levels of 1 to 8 ft above the MLLW datum of 49 ft. The bottom half of Table 18 lists the corresponding values in percentage relative to 365 days per year. For instance, for a depth of 55 ft and 2 hr duration, 276 days/365 days = 76 percent are available. The durations from 1 to 4 hr have been highlighted since they reflect the minimum durations required for safe transit in the Outer Channel for the range of ship speeds from 6 to 14 kt.

[1] David Elliott, NOAA, telecon with Wilbur Wiggins, SAS, March 2011.

Table 18. Effect of tides on water levels at ocean boundary of Savannah Outer Channel using Ft Pulaski predictions.

| Duration (hr) | Water level for 49 ft datum (ft) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 50 (+1) | 51 (+2) | 52 (+3) | 53 (+4) | 54 (+5) | 55 (+6) | 56 (+7) | 57 (+8) |
| Days of higher water level | | | | | | | | |
| 1 | 365 | 365 | 365 | 365 | 364 | 329 | 132 | 7 |
| 2 | 365 | 365 | 365 | 365 | 358 | 276 | 67 | 0 |
| 3 | 365 | 365 | 365 | 365 | 331 | 160 | 13 | 0 |
| 4 | 365 | 365 | 365 | 365 | 242 | 39 | 0 | 0 |
| 5 | 365 | 365 | 365 | 328 | 93 | 0 | 0 | 0 |
| 6 | 365 | 365 | 365 | 144 | 0 | 0 | 0 | 0 |
| 7 | 365 | 365 | 200 | 1 | 0 | 0 | 0 | 0 |
| 8 | 365 | 280 | 25 | 0 | 0 | 0 | 0 | 0 |
| 9 | 331 | 75 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 188 | 9 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 93 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 64 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Percentage based on 365 days per year | | | | | | | | |
| 1 | 100% | 100% | 100% | 100% | 100% | 90% | 36% | 2% |
| 2 | 100% | 100% | 100% | 100% | 98% | 76% | 18% | 0% |
| 3 | 100% | 100% | 100% | 100% | 91% | 44% | 4% | 0% |
| 4 | 100% | 100% | 100% | 100% | 66% | 11% | 0% | 0% |
| 5 | 100% | 100% | 100% | 90% | 25% | 0% | 0% | 0% |
| 6 | 100% | 100% | 100% | 39% | 0% | 0% | 0% | 0% |
| 7 | 100% | 100% | 55% | 0% | 0% | 0% | 0% | 0% |
| 8 | 100% | 77% | 7% | 0% | 0% | 0% | 0% | 0% |
| 9 | 91% | 21% | 0% | 0% | 0% | 0% | 0% | 0% |
| 10 | 52% | 2% | 0% | 0% | 0% | 0% | 0% | 0% |
| 11 | 25% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 12 | 18% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |

Notes:
1. Days of higher water levels based on subtracting 1 ft from predicted water levels to compensate for reduction of 1 ft in project depth to 49 ft in Outer channel.

*Light-loaded ship example*

Based on CADET results, a minimum water depth of 50 ft (+1 ft tide) is recommended for the light-loaded ship. This had a corresponding 358 days of accessibility for inbound transits (worst case). The days of accessibility were presented in Figure 28b for the existing S-1_Sta0 and preferred S-8_Sta0 option. Since the plan is to dredge the Outer channel to 49 ft, it will be necessary to require the use of 1 ft of tide to accommodate safe transits for light-loaded ships. Of course, the tides will provide additional safety margins.

*Fully-loaded ship example*

For the fully-loaded ship, CADET results showed that 360 days of accessibility were available with a depth of 52 ft. The days of accessibility were presented in Figure 32b for the S-1_Sta0 and preferred option S-8_Sta0. A tide of +3 ft will be required to achieve this 52 ft water level along the entire length of the Outer channel. Looking in the column labeled "52 (+3)" shows that 365 days of additional water depth are available for durations up to 6 hours. Therefore, since the required transit time is between 2 to 3 hr (Table 17) for all channel options, there should be sufficient time to insure a safe transit in the Outer Channel at this water level.

Of course, this assumes that the tide actually occurs at the time the Susan Maersk is planning to transit the channel since the 6 hr duration is only equivalent to 25 percent of each day. The CADET days of accessibility are based on a full 24-hr day. Therefore, there might be some instances where ships will be forced to wait on the tide if their transits do not coincide with these tide levels. These tidal predictions are only a statistical representation of the tides and should only be used as a planning tool for evaluating the suitability and cost benefit of the channel depth.

As another example, consider a faster ship speed of 14 kt. Figure 32b and Appendix Table C10 show that the Susan Maersk would have approximately 362 days of accessibility at this faster speed (same as 10 kt speed) if the water depth was increased by 4 ft due to tides to 53 ft. Checking Table 18 for a depth of "53 (+4)" and a duration of 2 hr, 365 days per year or 100 percent of the time will satisfy this water level. Therefore, since the 362 days of accessibility from Figure 32b is based on having a depth of 53 ft available year round and it is available 100 percent of the year (i.e., 362

≤ 365 days), one would not expect to reduce the number of days of availability for this case. The pilot would still have to make sure that the 2 hr duration for the transit would occur when the tide has raised the water level to 53 ft.

If the number of days at a water level due to the tide were less than the predicted days of accessibility, then one would expect to reduce the number of days of accessibility by the percentage of the tide level. A simplistic estimate would be to reduce the days of accessibility by multiplying this value by the tidal percentage. Of course, this assumes that the tide and waves are in phase which is not likely to occur simultaneously every time in a real world situation. As a design tool, it is probably acceptable to interpret the results in this fashion as it makes the comparisons uniform. During actual transits, pilots would need to take into account the wave and tide conditions expected during the transit, especially if the UKC is small.

For example, for the recommended S-8 option in Reach 1, the light-loaded 46-ft-draft *Susan Maersk* in a depth of 50 ft (+1 ft tide) will have a total of 360 days of accessibility per year during inbound transits at 10 kt (Table 15 or Table C9). At this depth, tide levels are not a problem as the Outer Channel will have 8-hr durations for 365 days per year, more than sufficient to accommodate transit times (Table 18). Increased ship speed can be accommodated with decreasing durations of 7 hr or less as the tide level increases. For instance looking at Appendix Table C9, 338 days per year are predicted for inbound transits at 14 kt at 50 ft depth. A tide level increase of 3 ft to a depth of 52 ft will accommodate inbound transits at 14 kt for 356 days per year. However, Table 18 shows that this water level is only available for 6 hr durations every day of the year at this depth of 52 ft. Durations up to 8 hr are available, but only for 25 days per year. Using the percentage of tide level, this is equivalent to reduced days of accessibility of only 24 days per year (i.e., 356 days * 25 days/yr/365 days/yr).

Similarly, for the recommended S-8 option in Reach 1 for the fully-loaded 47.5-ft-draft *Susan Maersk*, a depth of 52 ft (+3 ft tide) will provide a total of 360 days of accessibility per year during inbound transits at 10 kt (Table 16 or Table C10). At this depth, tide levels are available every day of the year for durations up to 6 hr (Table 18). If necessary, a duration of 8 hr is available for 25 days a year. As before, this is equivalent to a reduced days of accessibility of only 24 days per year for this 8-hr duration. Increased ship speed can be accommodated with decreasing durations of 6 hr or less as the tide level increases above a depth of 52 ft. Appendix Table C10 shows that 357 days per year are predicted for inbound transits at 14 kt at 52 ft depth. A tide level increase of 4 ft to a depth of 53 ft will accommodate inbound transits at 14 kt for 362 days per year. Table 18 indicates that this water level is only available for 4 hr durations every day of the year at this depth of 53 ft. Durations up to 6 hr are available, but only for 144 days per year. Again, using the percentage of tide level fraction, the equivalent reduced days of accessibility for these conditions is 43 days per year (i.e., 362 days/yr * 144 days/yr/365days/yr). Increasing the depth by 5 ft to 54 ft would provide 364 days per year accessibility, but only for a duration of 4 hr for 242 days per year. In this case, the equivalent reduced days of accessibility is only 241 days per year (i.e., 364 days/yr * 242 days/yr/365days/yr).

#### Summary

Based on the economic study, the final proposed project depth for the Outer Channel will be 49 ft. This represents a 1 ft reduction in the original project depth of 50 ft used in this engineering study. The water levels have been adjusted accordingly by incorporating the tidal advantage due to the tides during a year.

Based on the CADET tidal analysis, for the light-loaded ship, the Savannah entrance channel will have an additional water level of 1 ft above the 49 ft proposed project depth (i.e., $h$=50 ft) for durations of 8 hr for 365 days (i.e. 100 percent) of every year. To accommodate the fully-loaded ship, an additional water level of 3 ft above the 49 ft proposed project depth (i.e., $h$=52 ft) will be required. This depth will have durations of 6 hr for 365 days (i.e. 100 percent) of every year, but decreasing to only 25 days per year for 8 hr durations. Water depths of 53 to 57 ft will have continually decreasing durations from 4 hr (365 days per year) to 1 hr (7 days per year). The 6-hr durations should be more than adequate to accommodate safe transits for this draft.

# 7 Wave-induced Ship Motions and UKC

Wave-induced vertical ship motions and net UKC are discussed in this chapter. These ship motions are composed of the combined effects of heave, pitch, and roll on each of the five critical points. The gross UKC is the depth minus the static draft of the ship. The net UKC is obtained by subtracting dynamic squat and these ship motions from the gross UKC.

## Wave-induced vertical ship motions

### Light-loaded conditions

This section discusses the wave-induced vertical ship motions for the light-loaded *Susan Maersk*. Maximum ship displacements, CADET vertical motion allowances, and CADET vertical motion allowance statistics are presented.

#### *Maximum ship displacements*

Table 19 lists the maximum ship displacements that each water depth can safely accommodate without grounding as a function of speed. This value is equivalent to the gross UKC minus the dynamic squat. It is not the predicted ship vertical motion allowances from CADET, but the maximum possible ship displacement at a particular depth and speed. The purpose is to give the reader an indication of the "space" in the water column that is available for these vertical ship motions after everything else has been removed. Therefore, negative values are possible since the squat may be so large that there is literally "no room" for ship motions as the depth is not sufficiently deep. Thus, the average ship squat at each speed and depth is shown in this table for reference. For example, the ship at a speed of 16 kt in the shallow 50 ft (+1 ft tide) depth, will ground due to ship squat (i.e., -0.82 ft) leaving no clearance for vertical ship motions. However, for the design maximum speed of 10 kt, there would be 2.29 ft of clearance available at 50 ft.

Table 19. Maximum ship displacements for light-loaded *Susan Maersk*.

| Speed | Ship squat (ft) | | | Maximum ship displacement (ft) | | |
|---|---|---|---|---|---|---|
| (kt) | h=50 ft | h=52 ft | h=54 ft | h=50 ft | h=52 ft | h=54 ft |
| 6 | 0.61 | 0.58 | 0.57 | 3.39 | 5.42 | 7.43 |
| 8 | 1.09 | 1.05 | 1.02 | 2.91 | 4.95 | 6.98 |
| 10 | 1.71 | 1.65 | 1.61 | 2.29 | 4.35 | 6.39 |
| 12 | 2.51 | 2.42 | 2.34 | 1.49 | 3.58 | 5.66 |
| 14 | 3.50 | 3.37 | 3.26 | 0.50 | 2.63 | 4.74 |
| 16 | 4.82 | 4.62 | 4.44 | -0.82 | 1.38 | 3.56 |
| Notes:<br>1. Gross UKC=4, 6, and 8 ft for h=50, 52, and 54 ft, respectively. | | | | | | |

*CADET vertical motion allowances*

As noted in Chapter 2, CADET outputs the wave-induced vertical motion allowances for each ship loading condition, channel reach, and water depth. These allowances are based on Eq. 4 and are output for each wave condition, transit direction, ship speed, five critical points, and four alternate points. Therefore, the CADET "vertical motion allowances" are equivalent to the generic term "wave-induced vertical ship motions" term.

The FORTRAN program ReadIn_CADET_Allow2 reads in these files and calculates the largest or maximum allowance over all five control points for each wave condition, ship speed, and transit direction. These "maximum values" are the vertical motion allowances that are reported in this report.

Reach 1, located at the offshore end of the channel, has the largest vertical motion allowances since it is exposed to the largest wave heights. Table 20 compares the CADET predictions of vertical motion allowances in Reach 1 for a typical and extreme wave condition for the three channel options S-1, S-3, and S-8. Allowances are listed for both inbound and outbound transits for each ship speed. An example of a typical wave, ID 141, occurs 40.5 days/yr with a wave period of 4.5 s and wave height of 2.8 ft. The extreme wave example, ID 159, occurs only 0.2 days/yr with a wave period of 14.4 s and height of 8.9 ft. Both waves are from 112.5 deg, which is the most frequently occurring wave direction for Savannah.

Table 20. Vertical motion allowances (ft), Reach 1, h=50 ft, light-loaded *Susan Maersk*, inbound and outbound transits.

| Wave ID | Days/yr | Inbound ship speed (kt) | | | | | | Outbound ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| S-1 | | | | | | | | | | | | | |
| 141 | 40.5 | 0.05 | 0.09 | 0.23 | 0.20 | 0.59 | 0.40 | 0.03 | 0.03 | 0.03 | 0.03 | 0.06 | 0.05 |
| 159 | 0.2 | 6.80 | 6.50 | 6.74 | 10.14 | 25.85 | 45.41 | 4.77 | 4.14 | 3.76 | 3.45 | 3.08 | 2.79 |
| S-3 | | | | | | | | | | | | | |
| 141 | 40.5 | 0.05 | 0.08 | 0.21 | 0.18 | 0.55 | 0.37 | 0.03 | 0.03 | 0.03 | 0.04 | 0.09 | 0.07 |
| 159 | 0.2 | 7.60 | 7.26 | 7.34 | 10.60 | 24.05 | 40.16 | 5.65 | 5.00 | 4.66 | 4.38 | 3.98 | 3.69 |
| S-8 | | | | | | | | | | | | | |
| 141 | 40.5 | 0.05 | 0.09 | 0.22 | 0.19 | 0.56 | 0.38 | 0.03 | 0.03 | 0.03 | 0.03 | 0.06 | 0.05 |
| 159 | 0.2 | 6.47 | 6.18 | 6.39 | 9.59 | 24.39 | 42.72 | 4.55 | 3.94 | 3.58 | 3.28 | 2.93 | 2.65 |
| Notes:<br>1. Gross UKC = 4.0 ft for h=50 ft. | | | | | | | | | | | | | |

One should realize that the ship is not going to actually experience motions this large in most cases as the gross UKC is less than the predicted ship motion. For instance the gross UKC is only 4 ft for the 50 ft depth. The CADET program does not cut off the vertical motion prediction based on available UKC. Of course, once the ship is grounded, it cannot experience any greater vertical motion (assuming a hard bottom), so the maximum ship motions are limited to 4 ft at this depth.

One way to understand why these ship motions are so large is that the size of the Susan Maersk leads to significant motions even for relatively small rotations in pitch and roll. Table 21 lists the vertical motions one can expect in pitch at the ends of the ship and roll at the bilge for different angles of rotation.

Also, a wave with $\theta_m$=112.5 direction is almost parallel with the channel that is aligned with an angle of 297 deg (clockwise from North) for inbound transits. The ship experiences starboard, stern quartering seas that are only 4 to 5 deg off the centerline of the ship (nearly following seas). This wave has the potential to produce significant ship motions due to directional spreading, especially roll. Figures 37a and 37b illustrate the roll RAO transfer function at a depth of 50 ft for speeds of 10 and 16 kt, respectively. Notice the shift in the location of the peak frequency between these two RAO's. The 14.4 s wave period for the extreme wave corresponds to a wave frequency of 0.07 Hz (i.e., =1/14.4). The large motion allowance for 16 kt is due to the large RAO in roll at this frequency.

Table 21. Vertical ship motions due to pitch and roll.

| Angle (deg) | Pitch (ft) | Roll (ft) |
|---|---|---|
| 0.1 | 0.9 | 0.1 |
| 0.5 | 4.7 | 0.6 |
| 1.0 | 9.5 | 1.2 |
| 2.0 | 19.0 | 2.5 |
| 5.0 | 47.4 | 6.1 |
| 10.0 | 94.5 | 12.2 |

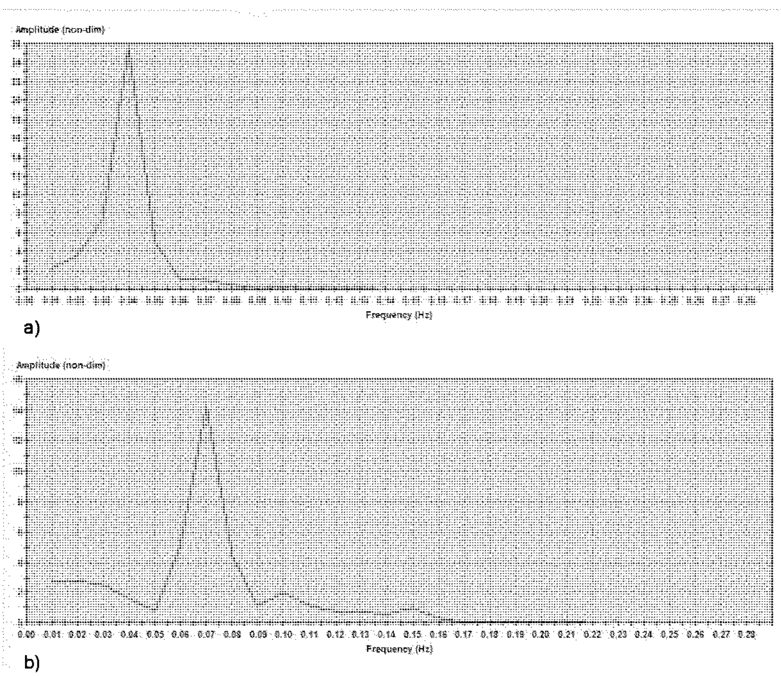



Figure 37. CADET roll RAO transfer functions at an angle of 165 deg relative to the ship (starboard stern quartering) and a depth of 50 ft for light-loaded *Susan Maersk* as a function of wave frequency for (a) 10 kt (b) 16 kt speeds.

The first conclusion is that outbound transits are much less of a problem than inbound transits as their motions are much smaller. Secondly, the motions tend to increase as ship speed increases. The next conclusion is that the extreme wave produces significantly larger vertical motions than the typical wave case. Finally, both waves indicate that the S-8 option is the preferred alternative as it has smaller predicted motions than the existing S-1 or the S-3 option for all speeds, especially for 10 kt.

Appendix D contains the full listings of vertical motion allowances for the light-loaded *Susan Maersk* for inbound and outbound transits for all ship speeds at the recommended minimum depth of 50 ft (+1 ft tide).

*CADET vertical motion allowance statistics*

As mentioned previously, maximum vertical motion allowances were calculated for each wave condition, transit direction, and ship speed. Average and maximum values over all 99 waves were calculated to facilitate comparisons among the different parameters affecting the light-loaded ship transits. These statistics are presented in this section.

Table 22 lists the average and maximum ship motion allowances for each of the three channel options for inbound and outbound transits in Reach 1. The maximum values tend to agree with the values previously discussed for wave ID 159. The average values indicate that the day to day transits will not experience such large vertical motions. Again, note that the motion allowances decrease with change in transit direction from inbound to outbound, increases in depth, and decreases in speed. Also, the S-8 option is as good as or better than the existing S-1 and S-3 option.

Table 22. Vertical motion allowance statistics (ft), Reach 1, light-loaded *Susan Maersk*, inbound and outbound transits.

| Statistic | Depth (ft) | Inbound ship speed (kt) 6 | 8 | 10 | 12 | 14 | 16 | Outbound ship speed (kt) 6 | 8 | 10 | 12 | 14 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S-1 | | | | | | | | | | | | | |
| Ave | 50 | 0.90 | 0.95 | 1.10 | 1.31 | 2.27 | 4.04 | 0.62 | 0.59 | 0.60 | 0.61 | 0.71 | 0.84 |
| Max | | 6.80 | 6.50 | 6.74 | 10.14 | 25.85 | 45.41 | 4.77 | 4.14 | 3.76 | 3.45 | 3.08 | 3.22 |
| Ave | 52 | 0.92 | 0.99 | 1.12 | 1.25 | 1.79 | 3.68 | 0.67 | 0.64 | 0.65 | 0.65 | 0.69 | 0.85 |
| Max | | 6.45 | 5.86 | 6.32 | 8.77 | 15.20 | 42.70 | 5.21 | 4.61 | 4.19 | 3.87 | 3.48 | 3.20 |
| Ave | 54 | 0.95 | 1.03 | 1.14 | 1.20 | 1.58 | 3.31 | 0.71 | 0.68 | 0.69 | 0.68 | 0.71 | 0.88 |
| Max | | 6.07 | 5.59 | 5.97 | 8.00 | 12.94 | 32.90 | 5.48 | 4.92 | 4.52 | 4.20 | 3.80 | 3.53 |
| S-3 | | | | | | | | | | | | | |
| Ave | 50 | 0.85 | 0.89 | 1.03 | 1.22 | 2.13 | 3.79 | 0.58 | 0.56 | 0.57 | 0.58 | 0.69 | 0.82 |
| Max | | 7.60 | 7.26 | 7.34 | 10.60 | 24.05 | 40.16 | 5.65 | 5.00 | 4.66 | 4.38 | 3.98 | 3.69 |
| Ave | 52 | 0.87 | 0.93 | 1.05 | 1.17 | 1.68 | 3.45 | 0.63 | 0.60 | 0.62 | 0.62 | 0.67 | 0.83 |
| Max | | 7.40 | 6.83 | 7.04 | 9.32 | 14.21 | 37.50 | 6.09 | 5.51 | 5.13 | 4.84 | 4.40 | 4.13 |
| Ave | 54 | 0.90 | 0.96 | 1.07 | 1.12 | 1.48 | 3.10 | 0.67 | 0.65 | 0.66 | 0.65 | 0.68 | 0.86 |
| Max | | 7.09 | 6.64 | 6.70 | 8.59 | 12.29 | 29.19 | 6.36 | 5.81 | 5.46 | 5.19 | 4.73 | 4.48 |
| S-8 | | | | | | | | | | | | | |
| Ave | 50 | 0.84 | 0.88 | 1.03 | 1.22 | 2.16 | 3.87 | 0.56 | 0.53 | 0.54 | 0.55 | 0.65 | 0.77 |
| Max | | 6.47 | 6.18 | 6.39 | 9.59 | 24.39 | 42.72 | 4.55 | 3.94 | 3.58 | 3.28 | 2.93 | 2.65 |
| Ave | 52 | 0.85 | 0.92 | 1.04 | 1.17 | 1.70 | 3.53 | 0.61 | 0.58 | 0.59 | 0.58 | 0.63 | 0.77 |
| Max | | 6.14 | 5.57 | 6.00 | 8.30 | 14.35 | 40.18 | 4.96 | 4.39 | 3.99 | 3.68 | 3.30 | 3.04 |
| Ave | 54 | 0.88 | 0.95 | 1.06 | 1.12 | 1.49 | 3.16 | 0.64 | 0.62 | 0.63 | 0.62 | 0.65 | 0.80 |
| Max | | 5.78 | 5.31 | 5.66 | 7.58 | 12.21 | 30.97 | 5.23 | 4.68 | 4.30 | 3.99 | 3.61 | 3.35 |

Notes:
1. Gross UKC=4, 6, and 8 ft for h=50, 52, and 54 ft, respectively.

### Fully-loaded conditions

This section discusses the wave-induced vertical ship motions for the fully-loaded *Susan Maersk*. Again, maximum ship displacements, CADET vertical motion allowances, and CADET vertical motion allowance statistics are presented.

*Maximum ship displacements*

Table 23 lists the maximum ship displacements that each water depth can safely accommodate without grounding as a function of speed for the fully-loaded *Susan Maersk*. As before, this value is equivalent to the gross UKC minus dynamic squat. The average ship squat is again shown for reference. Note that the ship would ground due to squat alone at a 50 ft (+1 ft) depth with a speed of 12 kt or greater. For the design maximum speed of 10 kt at 52 ft (+3 ft) depth, there is 2.80 ft of clearance available.

Table 23. Maximum ship displacements for fully-loaded *Susan Maersk*.

| Speed | Ship squat (ft) | | | Maximum ship displacement (ft) | | |
|---|---|---|---|---|---|---|
| (kt) | h=50 ft | h=52 ft | h=54 ft | h=50 ft | h=52 ft | h=54 ft |
| 6 | 0.62 | 0.61 | 0.58 | 1.88 | 3.89 | 5.92 |
| 8 | 1.11 | 1.07 | 1.04 | 1.39 | 3.43 | 5.46 |
| 10 | 1.75 | 1.70 | 1.64 | 0.75 | 2.80 | 4.86 |
| 12 | 2.56 | 2.48 | 2.40 | -0.06 | 2.02 | 4.10 |
| 14 | 3.59 | 3.46 | 3.34 | -1.09 | 1.04 | 3.16 |
| 16 | 4.94 | 4.73 | 4.55 | -2.44 | -0.23 | 1.95 |
| Notes:<br>1. Gross UKC=2.5, 4.5, and 6.5 ft for h=50, 52, and 54 ft, respectively. | | | | | | |

*CADET ship motion allowances*

Table 24 compares the CADET predictions of vertical motion allowances for the fully-loaded ship in Reach 1 with a depth of 52 ft (+3 ft) for the three channel options S-1, S-3, and S-8. The same typical and extreme waves are used as examples. The gross UKC is only 4.5 ft for the 52 ft depth, so the ship cannot experience vertical motions greater than 4.5 ft before grounding.

Table 24. Vertical motion allowances (ft), Reach 1, h=52 ft, fully-loaded *Susan Maersk*, inbound and outbound transits.

| Wave ID | Days/yr | Inbound ship speed (kt) | | | | | | Outbound ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| S-1 | | | | | | | | | | | | | |
| 141 | 40.5 | 0.05 | 0.10 | 0.24 | 0.18 | 0.27 | 0.45 | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.05 |
| 159 | 0.2 | 6.66 | 6.37 | 5.62 | 5.41 | 9.44 | 18.37 | 4.71 | 4.24 | 3.87 | 3.44 | 3.16 | 2.88 |
| S-3 | | | | | | | | | | | | | |
| 141 | 40.5 | 0.05 | 0.09 | 0.22 | 0.16 | 0.25 | 0.41 | 0.01 | 0.02 | 0.02 | 0.03 | 0.04 | 0.05 |
| 159 | 0.2 | 7.47 | 7.16 | 6.50 | 6.11 | 9.04 | 16.92 | 5.55 | 5.11 | 4.78 | 4.29 | 4.05 | 7.47 |
| S-8 | | | | | | | | | | | | | |
| 141 | 40.5 | 0.05 | 0.10 | 0.22 | 0.17 | 0.25 | 0.42 | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.04 |
| 159 | 0.2 | 6.34 | 6.05 | 5.34 | 5.12 | 8.91 | 17.29 | 4.50 | 4.03 | 3.68 | 3.27 | 3.00 | 2.74 |
| Notes:<br>1. Gross UKC = 4.5 ft for h=52 ft. | | | | | | | | | | | | | |

The same reasoning used before can be used for the fully-loaded ship to explain why the motions are so large for the extreme wave ID 159. The ship still experiences starboard stern quartering that drives the ship to roll and pitch.

Again, the outbound transits have significantly smaller vertical motion allowances than inbound transits. Ship motions do not monotonically decrease as ship speed increases as was the case for the light-loaded ship, but tend to decrease until reaching a ship speed of about 12 kt before increasing again at the highest speeds. Of course, the extreme wave still produces significantly larger vertical motion allowances than the typical wave case. Finally, both waves indicate that the S-8 option is the preferred alternative as it has smaller predicted motion allowances than the existing S-1 or the S-3 option for all speeds, especially for 10 kt.

Finally, Appendix D contains the full listings of the vertical motion allowances for the fully-loaded *Susan Maersk* for inbound and outbound transits for all ship speeds at the recommended minimum depth of 52 ft.

*CADET vertical motion allowance statistics*

Table 25 lists the average and maximum vertical motion allowances for the fully-loaded ship for each of the three channel options and inbound and outbound transits in Reach 1. Again, the maximum values agree with the values previously discussed for wave ID 159. The average values indicate that the day to day transits will not experience such large vertical motions. Also, note that the vertical motion allowances decrease with change in transit direction from inbound to outbound and increases in depth. The speed affects are the same as previously described since they tend to decrease with increases in speed up to 12 kts before increasing again for the faster speeds. Also, the S-8 option is as good as or better than the existing S-1 and S-3 option.

Table 25. Vertical motion allowance statistics (ft), Reach 1, fully-loaded *Susan Maersk*, inbound and outbound transits.

| Statistic | Depth (ft) | Inbound ship speed (kt) | | | | | | Outbound ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| S-1 | | | | | | | | | | | | | |
| Ave | 50 | 0.79 | 0.90 | 1.10 | 1.09 | 1.22 | 2.10 | 0.46 | 0.45 | 0.49 | 0.50 | 0.52 | 0.61 |
| Max | | 6.58 | 6.93 | 6.21 | 6.14 | 11.06 | 19.53 | 4.17 | 3.70 | 3.35 | 2.96 | 2.66 | 2.43 |
| Ave | 52 | 0.87 | 0.97 | 1.12 | 1.07 | 1.16 | 1.94 | 0.56 | 0.54 | 0.57 | 0.56 | 0.57 | 0.65 |
| Max | | 6.66 | 6.37 | 5.62 | 5.41 | 9.44 | 18.37 | 4.71 | 4.24 | 3.87 | 3.44 | 3.16 | 2.88 |
| Ave | 54 | 0.93 | 1.02 | 1.13 | 1.07 | 1.11 | 1.84 | 0.63 | 0.62 | 0.63 | 0.61 | 0.61 | 0.69 |
| Max | | 6.39 | 5.89 | 5.42 | 5.06 | 8.16 | 17.84 | 5.05 | 4.61 | 4.23 | 3.79 | 3.53 | 3.23 |
| S-3 | | | | | | | | | | | | | |
| Ave | 50 | 0.75 | 0.84 | 1.03 | 1.01 | 1.14 | 1.96 | 0.44 | 0.43 | 0.47 | 0.47 | 0.49 | 0.59 |
| Max | | 7.48 | 7.51 | 6.81 | 6.17 | 10.41 | 18.20 | 5.00 | 4.51 | 4.19 | 3.77 | 3.47 | 3.25 |
| Ave | 52 | 0.82 | 0.91 | 1.05 | 1.00 | 1.08 | 1.81 | 0.53 | 0.52 | 0.54 | 0.53 | 0.55 | 0.63 |
| Max | | 7.47 | 7.16 | 6.50 | 6.11 | 9.04 | 16.92 | 5.55 | 5.11 | 4.78 | 4.29 | 4.05 | 3.79 |
| Ave | 54 | 0.88 | 0.95 | 1.05 | 1.00 | 1.03 | 1.71 | 0.60 | 0.59 | 0.60 | 0.58 | 0.59 | 0.67 |
| Max | | 7.30 | 6.88 | 6.43 | 6.12 | 7.89 | 16.20 | 5.87 | 5.49 | 5.15 | 4.66 | 4.44 | 4.16 |
| S-8 | | | | | | | | | | | | | |
| Ave | 50 | 0.73 | 0.84 | 1.03 | 1.01 | 1.15 | 2.00 | 0.42 | 0.41 | 0.44 | 0.45 | 0.47 | 0.56 |
| Max | | 6.26 | 6.59 | 5.89 | 5.80 | 10.43 | 18.39 | 3.98 | 3.52 | 3.18 | 2.81 | 2.53 | 2.31 |
| Ave | 52 | 0.81 | 0.90 | 1.04 | 0.99 | 1.09 | 1.85 | 0.50 | 0.49 | 0.51 | 0.50 | 0.52 | 0.59 |
| Max | | 6.34 | 6.05 | 5.34 | 5.12 | 8.91 | 17.29 | 4.50 | 4.03 | 3.68 | 3.27 | 3.00 | 2.74 |
| Ave | 54 | 0.86 | 0.94 | 1.05 | 0.99 | 1.03 | 1.74 | 0.57 | 0.56 | 0.57 | 0.55 | 0.56 | 0.63 |
| Max | | 6.08 | 5.60 | 5.14 | 4.79 | 7.71 | 16.79 | 4.81 | 4.39 | 4.02 | 3.61 | 3.35 | 3.07 |

## Net UKC

This section presents results for the net UKC for the light- and fully-loaded *Susan Maersk*. The net UKC is obtained by subtracting dynamic squat and CADET vertical motion allowances from the gross UKC (i.e., = depth – draft).

### Light-loaded conditions

This section discusses the net UKC for the light-loaded *Susan Maersk*. Discussions on CADET net UKC predictions, net UKC statistics, and a net UKC summary are presented.

#### *Net UKC predictions*

We will continue to follow the similar pattern of analysis used for the vertical motion allowances in the previous section. Table 26 compares CADET predictions of net UKC in Reach 1 at a depth of 50 ft (+1 ft) for the same typical and extreme wave conditions. The format of this table is the same as before. Negative values indicate groundings due to insufficient water depth. For the typical wave represented by ID 141 and inbound transits, there is sufficient net UKC until the ship attempts speeds greater than 14 kt. Speeds up to 16 kt are possible for outbound transits for this typical wave case. For the extreme wave case (ID 159) for both inbound and outbound transits, there is insufficient net UKC for all speeds. As expected, the net UKC decreases as speed increases.

Appendix E contains the full net UKC listings for the light-loaded *Susan Maersk* for inbound and outbound transits for all ship speeds at the recommended minimum depth of 50 ft (+1 ft).

Table 26. Net UKC (ft), Reach 1, h=50 ft, light-loaded *Susan Maersk*, inbound and outbound transits.

| Wave ID | Days/yr | Inbound ship speed (kt) | | | | | | Outbound ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| S-1 | | | | | | | | | | | | | |
| 141 | 40.5 | 3.33 | 2.80 | 2.02 | 1.24 | -0.18 | -1.34 | 3.35 | 2.86 | 2.22 | 1.41 | 0.35 | -0.99 |
| 159 | 0.2 | -3.42 | -3.61 | -4.49 | -8.70 | -25.44 | -46.35 | -1.39 | -1.25 | -1.51 | -2.01 | -2.67 | -3.73 |
| S-3 | | | | | | | | | | | | | |
| 141 | 40.5 | 3.33 | 2.81 | 2.04 | 1.26 | -0.14 | -1.31 | 3.35 | 2.86 | 2.22 | 1.40 | 0.32 | -1.01 |
| 159 | 0.2 | -4.22 | -4.37 | -5.09 | -9.16 | -23.64 | -41.10 | -2.27 | -2.11 | -2.41 | -2.94 | -3.57 | -4.63 |
| S-8 | | | | | | | | | | | | | |
| 141 | 40.5 | 3.33 | 2.80 | 2.03 | 1.25 | -0.15 | -1.32 | 3.35 | 2.86 | 2.22 | 1.41 | 0.35 | -0.99 |
| 159 | 0.2 | -3.09 | -3.29 | -4.14 | -8.15 | -23.98 | -43.66 | -1.17 | -1.05 | -1.33 | -1.84 | -2.52 | -3.59 |

Notes:
1. Gross UKC = 4.0 ft for h=50 ft.

*Net UKC statistics*

As before for the vertical motion allowances, statistics were calculated to facilitate comparisons. Minimum values are used instead of maximum values since the net UKC is the inverse of the ship motion. A minimum value is the worst case of the net UKC, which is equivalent to the "maximum" vertical motion allowance. Table 27 lists the average and minimum net UKC for each of the three channel options and water depths for inbound and outbound transits in Reach 1. These minimums agree with the values in the previous table for the extreme wave ID 159. Negative values indicate grounding due to insufficient net UKC. As before, note that the net UKC increase with change in transit direction from inbound to outbound, increases in depth, and decreases in speed. Also, the S-8 option is as good as or better than the existing S-1 and S-3 option channel configurations.

Table 27. Net UKC statistics (ft), Reach 1, light-loaded *Susan Maersk*, inbound and outbound transits.

| Statistic | Depth (ft) | Inbound ship speed (kt) | | | | | | Outbound ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| S-1 | | | | | | | | | | | | | |
| Ave | 50 | 2.48 | 1.94 | 1.15 | 0.13 | -1.87 | -4.98 | 2.76 | 2.30 | 1.65 | 0.83 | -0.30 | -1.79 |
| Min | | -3.42 | -3.61 | -4.49 | -8.70 | -25.44 | -46.35 | -1.39 | -1.25 | -1.51 | -2.01 | -2.67 | -4.16 |
| Ave | 52 | 4.47 | 3.94 | 3.18 | 2.27 | 0.75 | -2.41 | 4.73 | 4.29 | 3.66 | 2.87 | 1.85 | 0.42 |
| Min | | -1.06 | -0.93 | -2.02 | -5.25 | -12.66 | -41.43 | 0.18 | 0.32 | 0.11 | -0.35 | -0.94 | -1.93 |
| Ave | 54 | 6.47 | 5.93 | 5.21 | 4.40 | 3.08 | 0.14 | 6.72 | 6.28 | 5.67 | 4.92 | 3.95 | 2.58 |
| Min | | 1.35 | 1.37 | 0.39 | -2.40 | -8.28 | -29.45 | 1.94 | 2.04 | 1.84 | 1.40 | 0.86 | -0.08 |
| S-3 | | | | | | | | | | | | | |
| Ave | 50 | 2.53 | 2.00 | 1.22 | 0.22 | -1.73 | -4.74 | 2.80 | 2.33 | 1.67 | 0.85 | -0.28 | -1.77 |
| Min | | -4.22 | -4.37 | -5.09 | -9.16 | -23.64 | -41.10 | -2.27 | -2.11 | -2.41 | -2.94 | -3.57 | -4.63 |
| Ave | 52 | 4.52 | 4.00 | 3.26 | 2.35 | 0.86 | -2.18 | 4.77 | 4.32 | 3.68 | 2.90 | 1.87 | 0.44 |
| Min | | -2.01 | -1.90 | -2.74 | -5.80 | -11.67 | -36.23 | -0.70 | -0.58 | -0.83 | -1.32 | -1.86 | -2.86 |
| Ave | 54 | 6.52 | 5.99 | 5.29 | 4.48 | 3.18 | 0.35 | 6.76 | 6.31 | 5.69 | 4.95 | 3.98 | 2.60 |
| Min | | 0.33 | 0.32 | -0.34 | -2.99 | -7.63 | -25.74 | 1.06 | 1.15 | 0.90 | 0.41 | -0.07 | -1.03 |
| S-8 | | | | | | | | | | | | | |
| Ave | 50 | 2.54 | 2.01 | 1.22 | 0.22 | -1.75 | -4.82 | 2.82 | 2.35 | 1.71 | 0.89 | -0.24 | -1.71 |
| Min | | -3.09 | -3.29 | -4.14 | -8.15 | -23.98 | -43.66 | -1.17 | -1.05 | -1.33 | -1.84 | -2.52 | -3.59 |
| Ave | 52 | 4.54 | 4.01 | 3.26 | 2.35 | 0.84 | -2.26 | 4.79 | 4.35 | 3.71 | 2.93 | 1.91 | 0.50 |
| Min | | -0.75 | -0.64 | -1.70 | -4.78 | -11.81 | -38.91 | 0.43 | 0.54 | 0.31 | -0.16 | -0.76 | -1.77 |
| Ave | 54 | 6.54 | 6.01 | 5.30 | 4.48 | 3.17 | 0.29 | 6.78 | 6.34 | 5.73 | 4.98 | 4.02 | 2.65 |
| Min | | 1.64 | 1.65 | 0.70 | -1.98 | -7.55 | -27.52 | 2.19 | 2.28 | 2.06 | 1.61 | 1.05 | 0.10 |

Notes:
1. Gross UKC=4, 6, and 8 ft for h=50, 52, and 54 ft, respectively.

### *Net UKC summary*

This section gives a summary of the wave cases with predicted grounding for the light-loaded ship at a depth of 50 ft (+1 ft). This depth was selected for the light-loaded ship since it is the minimum water depth that is recommended based on the accessibility predictions. Only inbound transits at speeds of 10 kt are discussed as they are the main ships of interest. The tables in Appendix E were sorted to identify the waves with predictions of grounding for inbound transits at 10 kt and a depth of 50 ft. Table 28 lists the net UKC for each wave for the three water depths and channel options. Wave parameters are also included for reference. Negative values indicate ship grounding and are highlighted in red.

These twelve waves represent relatively rare occurrences, as all of them only occur for a total of 4.9 days/yr. The average duration is 0.4 days/yr, with a maximum of 1.2 days/yr. The wave periods range from 9.4 to 14.4 s, wave heights from 4.8 to 8.9 ft, and wave directions from 67.5 to 135 deg. These are relatively large wave periods and heights compared to the typical waves at Savannah.

For the existing S-1 option, the worst cases occur for wave IDs 159, 139, and 157. Grounding is avoided for all but these three cases at a depth of 52 ft (+3 ft). A depth of 54 ft (+5 ft) eliminates all of the grounding. For option S-3, wave IDs 159 and 157 are the worst grounding cases. The addition of 2 ft to a depth of 52 ft avoids grounding in all but these two cases and the addition of 4 ft to a 54 ft depth eliminates grounding in ID 157 but not in ID 159. Finally, for option S-8, only wave ID 159 is a major problem as grounding is eliminated for all but this case with the addition of 2 ft to a depth of 52 ft. Another 2 ft of depth to 54 ft eliminates grounding for this case. Thus, S-8 again looks like the preferred channel option.

Table 28. Net UKC summary for light-loaded *Susan Maersk*, inbound transits, 10 kt speed.

| Wave ID | Period (s) | Height (ft) | Angle (deg) | Days/yr | h=50 (ft) | h=52 (ft) | h=54 (ft) |
|---|---|---|---|---|---|---|---|
| S-1 | | | | | | | |
| 121 | 11.8 | 4.8 | 67.5 | 0.2 | -0.88 | 1.02 | 2.96 |
| 135 | 9.5 | 8.9 | 90.0 | 0.3 | -0.40 | 1.52 | 3.44 |
| 137 | 11.8 | 4.8 | 90.0 | 1.2 | -0.45 | 1.56 | 3.56 |
| 138 | 11.8 | 6.7 | 90.0 | 0.4 | -1.52 | 0.48 | 2.45 |
| 139 | 11.8 | 8.9 | 90.0 | 0.2 | -2.76 | -0.78 | 1.17 |
| 140 | 14.3 | 4.8 | 90.0 | 0.2 | -2.15 | 0.01 | 2.23 |
| 153 | 9.4 | 8.9 | 112.5 | 0.4 | -0.33 | 1.59 | 3.54 |
| 155 | 12.0 | 4.8 | 112.5 | 0.8 | -0.24 | 1.88 | 3.93 |
| 156 | 12.0 | 6.7 | 112.5 | 0.4 | -1.23 | 0.92 | 2.97 |
| 157 | 12.0 | 8.9 | 112.5 | 0.3 | -2.37 | -0.19 | 1.86 |
| 159 | 14.4 | 8.9 | 112.5 | 0.2 | -4.49 | -2.02 | 0.39 |
| 173 | 9.4 | 8.6 | 135.0 | 0.3 | -0.25 | 1.68 | 3.63 |
| S-3 | | | | | | | |
| 121 | 11.8 | 4.8 | 67.5 | 0.2 | -0.20 | 1.87 | 3.89 |
| 135 | 9.5 | 8.9 | 90.0 | 0.3 | -0.27 | 1.65 | 3.60 |
| 137 | 11.8 | 4.8 | 90.0 | 1.2 | 0.05 | 2.15 | 4.19 |
| 138 | 11.8 | 6.7 | 90.0 | 0.4 | -0.82 | 1.30 | 3.34 |
| 139 | 11.8 | 8.9 | 90.0 | 0.2 | -1.83 | 0.31 | 2.34 |
| 140 | 14.3 | 4.8 | 90.0 | 0.2 | -0.96 | 1.30 | 3.53 |
| 153 | 9.4 | 8.9 | 112.5 | 0.4 | -0.21 | 1.73 | 3.67 |
| 155 | 12.0 | 4.8 | 112.5 | 0.8 | -0.33 | 1.75 | 3.77 |
| 156 | 12.0 | 6.7 | 112.5 | 0.4 | -1.36 | 0.73 | 2.75 |
| 157 | 12.0 | 8.9 | 112.5 | 0.3 | -2.54 | -0.44 | 1.56 |
| 159 | 14.4 | 8.9 | 112.5 | 0.2 | -5.09 | -2.74 | -0.34 |
| 173 | 9.4 | 8.6 | 135.0 | 0.3 | -0.11 | 1.84 | 3.75 |
| S-8 | | | | | | | |
| 121 | 11.8 | 4.8 | 67.5 | 0.2 | -0.46 | 1.52 | 3.50 |
| 135 | 9.5 | 8.9 | 90.0 | 0.3 | -0.27 | 1.65 | 3.60 |
| 137 | 11.8 | 4.8 | 90.0 | 1.2 | -0.10 | 2.01 | 4.05 |
| 138 | 11.8 | 6.7 | 90.0 | 0.4 | -1.03 | 1.11 | 3.13 |
| 139 | 11.8 | 8.9 | 90.0 | 0.2 | -2.11 | 0.06 | 2.07 |
| 140 | 14.3 | 4.8 | 90.0 | 0.2 | -1.40 | 0.85 | 3.09 |
| 153 | 9.4 | 8.9 | 112.5 | 0.4 | -0.20 | 1.72 | 3.68 |
| 155 | 12.0 | 4.8 | 112.5 | 0.8 | -0.12 | 2.00 | 4.06 |
| 156 | 12.0 | 6.7 | 112.5 | 0.4 | -1.05 | 1.09 | 3.14 |
| 157 | 12.0 | 8.9 | 112.5 | 0.3 | -2.14 | 0.04 | 2.09 |
| 159 | 14.4 | 8.9 | 112.5 | 0.2 | -4.14 | -1.70 | 0.70 |
| 173 | 9.4 | 8.6 | 135.0 | 0.3 | -0.13 | 1.82 | 3.75 |

### Fully-loaded conditions

This section discusses the net UKC for the fully-loaded *Susan Maersk*. Again, CADET Net UKC predictions, statistics, and summary are presented.

*Net UKC predictions*

Table 29 compares CADET predictions of net UKC in Reach 1 at a depth of 52 ft (+3 ft) for the same typical and extreme wave conditions. The format of this table is the same as before. Negative values indicate groundings due to insufficient water depth. For the typical wave represented by ID 141 and inbound and outbound transits, there is sufficient net UKC until the ship attempts speeds greater than 14 kt. For the extreme wave case for inbound and outbound transits, there is insufficient net UKC for all speeds. As expected, the net UKC decreases as speed increases.

Table 29. Net UKC (ft), Reach 1, h=52 ft, fully-loaded *Susan Maersk*, inbound and outbound transits.

| Wave ID | Days/yr | Inbound ship speed (kt) | | | | | | Outbound ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| S-1 | | | | | | | | | | | | | |
| 141 | 40.5 | 3.84 | 3.33 | 2.56 | 1.84 | 0.77 | -0.68 | 3.88 | 3.42 | 2.78 | 2.00 | 1.01 | -0.28 |
| 159 | 0.2 | -2.77 | -2.94 | -2.82 | -3.39 | -8.40 | -18.60 | -0.82 | -0.81 | -1.07 | -1.42 | -2.12 | -3.11 |
| S-3 | | | | | | | | | | | | | |
| 141 | 40.5 | 3.84 | 3.34 | 2.58 | 1.86 | 0.79 | -0.64 | 3.88 | 3.41 | 2.78 | 1.99 | 1.00 | -0.30 |
| 159 | 0.2 | -3.58 | -3.73 | -3.70 | -4.09 | -8.00 | -17.15 | -1.66 | -1.68 | -1.98 | -2.27 | -3.01 | -4.02 |
| S-8 | | | | | | | | | | | | | |
| 141 | 40.5 | 3.84 | 3.33 | 2.58 | 1.85 | 0.79 | -0.65 | 3.88 | 3.42 | 2.78 | 2.00 | 1.01 | -0.27 |
| 159 | 0.2 | -2.45 | -2.62 | -2.54 | -3.10 | -7.87 | -17.52 | -0.61 | -0.60 | -0.88 | -1.25 | -1.96 | -2.97 |
| Notes:<br>1. Gross UKC = 4.5 ft for h=52 ft. | | | | | | | | | | | | | |

Appendix E contains the complete net UKC listings for the fully-loaded *Susan Maersk* for inbound and outbound transits for all ship speeds at the recommended minimum depth of 52 ft (+3 ft).

*Net UKC statistics*

As before for the light-loaded ship, Table 30 lists the average and minimum net UKC statistics for each of the three channel options and water depths for inbound and outbound transits in Reach 1. Again, negative values indicate grounding due to insufficient net UKC. In summary, the net UKC increases with change in transit direction from inbound to outbound, increases in depth, and decreases in speed. Also, the S-8 option is as good as or better than the existing S-1 and S-3 option channel configurations.

Table 30. Net UKC statistics (ft), Reach 1, fully-loaded *Susan Maersk*, inbound and outbound transits.

| Statistic | Depth (ft) | Inbound ship speed (kt) | | | | | | Outbound ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| S-1 | | | | | | | | | | | | | |
| Ave | 50 | 1.09 | 0.49 | -0.35 | -1.15 | -2.31 | -4.55 | 1.42 | 0.93 | 0.26 | -0.56 | 1.09 | 0.49 |
| Min | | -4.70 | -5.54 | -5.46 | -6.20 | -12.15 | -21.97 | -2.29 | -2.31 | -2.60 | -3.02 | -4.70 | -5.54 |
| Ave | 52 | 3.03 | 2.46 | 1.68 | 0.94 | -0.12 | -2.18 | 3.34 | 2.88 | 2.24 | 1.46 | 3.03 | 2.46 |
| Min | | -2.77 | -2.94 | -2.82 | -3.39 | -8.40 | -18.60 | -0.82 | -0.81 | -1.07 | -1.42 | -2.77 | -2.94 |
| Ave | 54 | 4.99 | 4.44 | 3.73 | 3.03 | 2.05 | 0.12 | 5.30 | 4.84 | 4.23 | 3.48 | 4.99 | 4.44 |
| Min | | -0.47 | -0.43 | -0.56 | -0.96 | -5.00 | -15.89 | 0.87 | 0.85 | 0.63 | 0.31 | -0.47 | -0.43 |
| S-3 | | | | | | | | | | | | | |
| Ave | 50 | 1.13 | 0.54 | -0.28 | -1.07 | -2.23 | -4.41 | 1.44 | 0.96 | 0.28 | -0.54 | -1.59 | -3.04 |
| Min | | -5.60 | -6.12 | -6.06 | -6.23 | -11.50 | -20.64 | -3.12 | -3.12 | -3.44 | -3.83 | -4.56 | -5.69 |
| Ave | 52 | 3.07 | 2.52 | 1.76 | 1.02 | -0.04 | -2.05 | 3.37 | 2.91 | 2.26 | 1.49 | 0.49 | -0.86 |
| Min | | -3.58 | -3.73 | -3.70 | -4.09 | -8.00 | -17.15 | -1.66 | -1.68 | -1.98 | -2.27 | -3.01 | -4.02 |
| Ave | 54 | 5.05 | 4.50 | 3.80 | 3.10 | 2.14 | 0.24 | 5.33 | 4.87 | 4.25 | 3.51 | 2.58 | 1.29 |
| Min | | -1.38 | -1.42 | -1.57 | -2.02 | -4.73 | -14.25 | 0.05 | -0.03 | -0.29 | -0.56 | -1.28 | -2.21 |
| S-8 | | | | | | | | | | | | | |
| Ave | 50 | 1.14 | 0.55 | -0.28 | -1.07 | -2.24 | -4.44 | 1.46 | 0.98 | 0.31 | -0.51 | -1.56 | -3.00 |
| Min | | -4.38 | -5.20 | -5.14 | -5.86 | -11.52 | -20.83 | -2.10 | -2.13 | -2.43 | -2.87 | -3.62 | -4.75 |
| Ave | 52 | 3.09 | 2.53 | 1.76 | 1.02 | -0.05 | -2.08 | 3.39 | 2.94 | 2.29 | 1.51 | 0.53 | -0.82 |
| Min | | -2.45 | -2.62 | -2.54 | -3.10 | -7.87 | -17.52 | -0.61 | -0.60 | -0.88 | -1.25 | -1.96 | -2.97 |
| Ave | 54 | 5.06 | 4.51 | 3.81 | 3.11 | 2.13 | 0.21 | 5.35 | 4.90 | 4.28 | 3.54 | 2.61 | 1.33 |
| Min | | -0.16 | -0.14 | -0.28 | -0.69 | -4.55 | -14.84 | 1.11 | 1.07 | 0.84 | 0.49 | -0.19 | -1.12 |

Notes:
1. Gross UKC=4, 6, and 8 ft for h=50, 52, and 54 ft, respectively.

*Net UKC summary*

This section gives a summary of the wave cases with predicted grounding for the fully-loaded ship at a depth of 52 ft (+3 ft). This depth was selected for the fully-loaded ship since it is the minimum water depth that is recommended based on the accessibility predictions. Again, only inbound transits at speeds of 10 kt are discussed as they are the main ships of interest. The tables in Appendix E were sorted to identify the waves with predictions of grounding for inbound transits at 10 kt and a depth of 52 ft. Table 31 lists the net UKC for each wave for the three water depths and channel options. The format of this table is the same as before for the light-loaded ship.

Table 31. Net UKC summary for fully-loaded *Susan Maersk*, inbound transits, 10 kt speed.

| Wave ID | Period (s) | Height (ft) | Angle (deg) | Days/yr | h=50 (ft) | h=52 (ft) | h=54 (ft) |
|---|---|---|---|---|---|---|---|
| S-1 | | | | | | | |
| 121 | 11.8 | 4.8 | 67.5 | 0.2 | -2.20 | -0.34 | 1.60 |
| 138 | 11.8 | 6.7 | 90.0 | 0.4 | -2.95 | -1.00 | 1.02 |
| 139 | 11.8 | 8.9 | 90.0 | 0.2 | -4.16 | -2.25 | -0.25 |
| 140 | 14.3 | 4.8 | 90.0 | 0.2 | -3.46 | -1.32 | 0.73 |
| 156 | 12.0 | 6.7 | 112.5 | 0.4 | -2.77 | -0.72 | 1.42 |
| 157 | 12.0 | 8.9 | 112.5 | 0.3 | -3.93 | -1.88 | 0.29 |
| 159 | 14.4 | 8.9 | 112.5 | 0.2 | -5.46 | -2.82 | -0.56 |
| S-3 | | | | | | | |
| 121 | 11.8 | 4.8 | 67.5 | 0.2 | -1.66 | 0.35 | 2.41 |
| 138 | 11.8 | 6.7 | 90.0 | 0.4 | -2.38 | -0.32 | 1.80 |
| 139 | 11.8 | 8.9 | 90.0 | 0.2 | -3.40 | -1.35 | 0.79 |
| 140 | 14.3 | 4.8 | 90.0 | 0.2 | -2.34 | 0.03 | 2.21 |
| 156 | 12.0 | 6.7 | 112.5 | 0.4 | -2.82 | -0.83 | 1.25 |
| 157 | 12.0 | 8.9 | 112.5 | 0.3 | -4.00 | -2.02 | 0.07 |
| 159 | 14.4 | 8.9 | 112.5 | 0.2 | -6.06 | -3.70 | -1.57 |
| S-8 | | | | | | | |
| 121 | 11.8 | 4.8 | 67.5 | 0.2 | -1.87 | 0.07 | 2.07 |
| 138 | 11.8 | 6.7 | 90.0 | 0.4 | -2.49 | -0.46 | 1.63 |
| 139 | 11.8 | 8.9 | 90.0 | 0.2 | -3.55 | -1.54 | 0.56 |
| 140 | 14.3 | 4.8 | 90.0 | 0.2 | -2.60 | -0.31 | 1.83 |
| 156 | 12.0 | 6.7 | 112.5 | 0.4 | -2.59 | -0.55 | 1.59 |
| 157 | 12.0 | 8.9 | 112.5 | 0.3 | -3.69 | -1.65 | 0.52 |
| 159 | 14.4 | 8.9 | 112.5 | 0.2 | -5.14 | -2.54 | -0.28 |

These seven waves represent relatively rare occurrences with a total of only 2.6 days/yr. The average duration is 0.3 days/yr, with a maximum of 0.8 days/yr. The wave periods range from 11.8 to 14.4 s, wave heights from 4.8 to 8.9 ft, and wave directions from 67.5 to 112.5 deg. Again, these are relatively large wave periods and heights compared to the typical waves at Savannah.

For the existing S-1 case, all seven wave cases indicate grounding at a depth of 52 ft (+3 ft). At a depth of 54 ft (+5 ft)with an additional 2 ft of water level, only wave IDs 159 and 139 still exhibit grounding. For option S-3, only five of the wave cases indicate grounding at a depth of 52 ft, and only wave ID 159 at 54 ft. For option S-8, six of the waves still indicate grounding at a depth of 52 ft, and again only wave ID 159 at a depth of 54 ft. In general, option S-3 appears to have larger net UKC for wave directions less than 112.5 deg, while S-8 is better for directions of 112.5 deg.

# 8 Summary and Conclusions

The Savannah District (SAS) is finalizing the engineering appendix pending the economics study for the "Savannah Harbor Expansion Project: Extension of Entrance Channel." Some shallower offshore shoals were discovered that might influence the safety and efficiency of navigation if the project proceeds as originally proposed. The U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), conducted a vertical ship motion study to evaluate three proposed channel alignments S-1, S-3, and S-8. These alignment changes (doglegs) are proposed to allow ships to reach deeper water in less distance, with reduced dredging costs. The Channel Analysis and Design Evaluation Tool (CADET) was used to predict vertical ship motions due to wave-induced heave, pitch, and roll. PIANC and Ankudinov ship squat were calculated and compared with the CADET squat predictions. The CADET days of accessibility, vertical motion allowances, and net UKC were calculated based on these vertical ship motion components to provide a risk-based method of evaluating different channel depths.

Based on the separate economic study for the Savannah Harbor Expansion Project, a final proposed project depth of 49 ft was selected for the Outer Channel. This represents a 1 ft reduction in the original project depth of 50 ft used in this engineering study. However, since the range and duration of the tides is sufficient to increase water levels to accommodate safe transits for the ship drafts discussed in this study, results are still valid and accurate. Water depths were adjusted for the tides and discussed as necessary in this report.

A joint probability distribution of wave height and period was created in ten 22.5-deg direction bands from 11.25 to 236.24 deg. It consisted of 158,138 observations representing 90.2 percent of the deepwater data from the WIS 20-year hindcast buoy WIS370. A total of 99 empirical directional wave spectra were created from this joint probability distribution. Parameters for these directional spectra were based on wave period and height for a TMA frequency spectrum and $\mathrm{Cos}^n$ directional spreading function. The spectra wave heights were reduced at each reach along the Savannah Channel according to the previous study results of Thompson.

The STS requires the wave period, height, and direction combination at stations along the channel to prepare wave cases for each simulation run. Since it is impractical to model multiple wave cases in the STS, the most representative wave cases were selected based on the 3-5 percent highest waves in the 20-year hindcast at deepwater station WIS33. Values from an earlier study using the STWAVE transformation model were provided for Stations 0 to 87 in all channel options including the Existing channel. These data were then extrapolated seaward to Station 99 for the new channel options S-1, S-3, and S-8.

Ship squat was compared for PIANC, Ankudinov, and CADET/BNT predictions. The five PIANC empirical squat formulas included those of Barrass, Eryuzlu, Huuska, Römisch, and Yoshimura. The Ankudinov formula was originally used in the STS. The CADET squat formula is based on the work of Beck, Newman, and Tuck.

This report summarizes remaining UKC for the average and maximum (or worst case) ship squat predictions. For the light-loaded *Susan Maersk* at $T$=46 ft at the shallowest water depth of $h$=50 ft (+1 ft tide), pilots should proceed with caution if attempting ship speeds faster than $V_k$ =10 to 12 kt, especially if any significant wave activity is present. For water depths greater than 50 ft, there should be sufficient UKC for speeds as high as $V_k$ =14 to 16 kt. For the fully-loaded ship at $T$=47.5 ft at this shallow 50 ft depth(+1 ft tide), pilots should exercise extreme caution if attempting to move at speeds as high as $V_k$ =10 kt. This speed is probably not even possible unless wave heights and periods are relatively small. For the deeper depths when tides are present, the available UKC should be sufficient up to speeds $V_k$ =12 to 14 kt. Of course, pilots should be vigilant at higher speeds as ship squat can always be reduced by slowing down.

In general for both light- and fully-loaded ships, days of accessibility increase for slower ship speeds, outbound transits, interior reaches, and reduced load/lesser draft. The minimum depths are 50 and 52 ft (+3 ft) for the light- and fully-loaded ships, respectively. Based on the CADET analysis of UKC and the corresponding days of accessibility, the S-8 alternative is the best option among the three choices S-1, S-3, and S-8, and much better than the existing channel. The S-8 option will probably have slightly less risk of grounding than S-1 and S-3.

Based on the CADET tidal analysis for the light-loaded ship, the Savannah entrance channel will have an additional water level of 1 ft above the 49 ft proposed project depth (i.e., $h$=50 ft) for durations of 8 hr for 365 days (i.e. 100 percent) of every year. To accommodate the fully-loaded ship, an additional water level of 3 ft above the 49 ft proposed project depth (i.e., $h$=52 ft) will be required. This depth will have durations of 6 hr for 365 days (i.e. 100 percent) of every year, but decreasing to only 25 days per year for 8 hr durations. Water depths of 53 to 57 ft will have continually decreasing durations from 4 hr (365 days per year) to 1 hr (7 days per year).

Thus, for the recommended S-8 option in Reach 1, the light-loaded 46-ft-draft *Susan Maersk* in a depth of 50 ft (+1 ft tide) will have a total of 360 days of accessibility per year during inbound transits at 10 kt. At this depth, tide levels are not a problem as the Outer Channel will have 8-hr durations for 365 days per year, more than sufficient to accommodate transit times. Increased ship speed can be accommodated with decreasing durations of 7 hr or less as the tide level increases. For instance, 338 days per year are predicted for inbound transits at 14 kt at 50 ft depth. A tide level increase of 3 ft to a depth of 52 ft will accommodate inbound transits at 14 kt for 356 days per year. However, this water level is only available for 6 hr durations every day of the year at this depth of 52 ft. Durations up to 8 hr are available, but only for 25 days per year. Using the percentage of tide level fraction, this is equivalent to a reduced days of accessibility of only 24 days per year (i.e., 356 days * 25 days/yr/365 days/yr).

Similarly, for the recommended S-8 option in Reach 1 for the fully-loaded 47.5-ft-draft *Susan Maersk*, a depth of 52 ft will provide a total of 360 days of accessibility per year during inbound transits at 10 kt. At this depth, tide levels are available every day of the year for durations up to 6 hr. If necessary, a duration of 8 hr is available for 25 days a year. As before, this is equivalent to a reduced days of accessibility of only 24 days per year for this 8-hr duration. Increased ship speed can be accommodated with decreasing durations of 6 hr or less as the tide level increases above a depth of 52 ft. For instance, 357 days per year are predicted for inbound transits at 14 kt at 52 ft depth. A tide level increase of 4 ft to a depth of 53 ft will accommodate inbound transits at 14 kt for 362 days per year. This water level is only available for 4 hr durations every day of the year at this depth of 53 ft. Durations up to 6 hr are available, but only for 144 days per year. The equivalent reduced days of accessibility for these conditions is 43 days per year (i.e., 362 days/yr * 144 days/yr/365days/yr). Increasing the depth by 5 ft to 54 ft would provide 364 days per year accessibility, but only for a durations of 4 hr for 242 days per year to 3 hr for 331 days per year. In this case, the equivalent reduced days of accessibility is only 241 days per year (i.e., 364 days/yr * 242 days/yr/365days/yr).

Wave-induced vertical ship motions are composed of the combined effects of heave, pitch, and roll at the five critical points on the bottom of the ship. CADET calculates these vertical motion allowances for each ship loading condition, channel reach, and water depth. The allowances are based on Eq. 4 and are output for each wave condition, transit direction, ship speed, and critical and alternative points. The FORTRAN program ReadIn_CADET_Allow2 reads in these files and calculates the largest allowance over all five critical points for each wave condition, ship speed, and transit direction. These "maximum" values are used for comparisons in this report.

Reach 1, located at the offshore end of the channel, has the largest vertical motion allowances since it is exposed to the largest wave heights. Comparisons were made of inbound and outbound, light- and fully-loaded ship motions in Reach 1 for a typical and extreme wave condition and average and maximum values for all 99 waves, for the three channel options S-1, S-3, and S-8. In general, outbound transits are much less of a problem than inbound transits as their motion allowances are much smaller. For the light-loaded ship, the motion allowances tend to increase as ship speed increases. The motion allowances for the fully-loaded ship, however, tended to decrease until reaching a ship speed of about 12 kt before increasing again at the highest speeds. The extreme ID 159 wave produces significantly larger vertical motion allowances than the typical wave case. This is due to the fact that with a wave period of 14.4 s, height of 8.9 ft, and direction of 112.5 deg, it produces starboard, stern quartering waves that drive the ship in pitch and roll. This wave is relatively rare as it only occurs 0.2 days/yr. These comparisons indicated that the S-8 option is the preferred alternative as it has smaller predicted motions than the existing S-1 or the S-3 option for all speeds, especially for 10 kt.

The net UKC is obtained by subtracting draft, squat, and ship vertical motion allowances from the water depth (i.e., net UKC = gross UKC – squat – ship vertical motion allowance). In general for the light- and fully-loaded *Susan Maersk*, net UKC increases with change in transit direction from inbound to outbound, increases in water depth, and decreases in speed. The S-8 option is as good as or better than the existing S-1 and S-3 option channel configurations.

For the light-loaded inbound ship at a speed of 10 kt, only twelve of the 99 waves indicated grounding conditions at the recommended depth of 50 ft (+1 ft) based on the accessibility results. These 12 waves represent relatively rare occurrences, as all of them only occur for a total of 4.9 days/yr. The average duration for each wave is 0.4 days/yr, with a maximum of 1.2 days/yr. The wave periods range from 9.4 to 14.4 s, wave heights from 4.8 to 8.9 ft, and wave directions from 67.5 to 135 deg. These are relatively large wave periods and heights compared to the typical waves at Savannah, but pilots should be particularly aware of possible grounding conditions when they occur.

For the fully-loaded inbound ship at a speed of 10 kt, only seven waves indicated possible grounding conditions at the recommended depth of 52 ft (+3 ft) from the accessibility results. These seven waves also represent relatively rare occurrences with a total of only 2.6 days/yr. The average duration is 0.3 days/yr, with a maximum of 0.8 days/yr. The wave periods range from 11.8 to 14.4 s, wave heights from 4.8 to 8.9 ft, and wave directions from 67.5 to 112.5 deg. Again, these are relatively large wave periods and heights compared to the typical waves at Savannah. In general, option S-3 appears to have larger net UKC for wave directions less than 112.5 deg, while S-8 is better for directions of 112.5 deg.

The wave-induced vertical motion allowances and corresponding net UKC support and confirm the days of accessibility results for the minimum water depths required for safe transits in both inbound and outbound directions. In summary, a depth of 50 ft (+1 ft) is the minimum acceptable depth for safe transits at 10 kt for the light-loaded, 46-ft-draft *Susan Maersk* in the Savannah Outer Channel. A minimum depth of 52 ft (+3 ft) is required for safe transits at 10 kt for the fully-loaded, 47.5-ft-draft *Susan Maersk*. Faster ship speeds up to 14 kt are possible if higher tide levels are used, but the available durations are reduced such that a transit may not be possible every day of the year.

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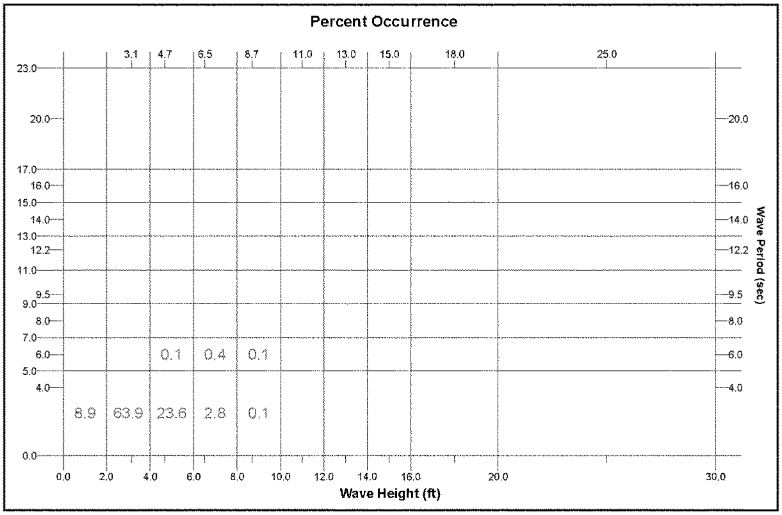
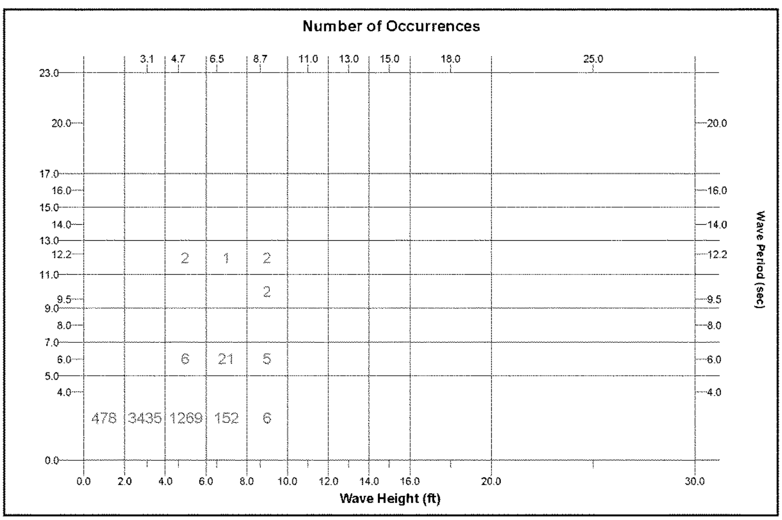
# Appendix A: $T_p$ vs. $H_s$ Percent Occurrence Tables for Each Direction Band

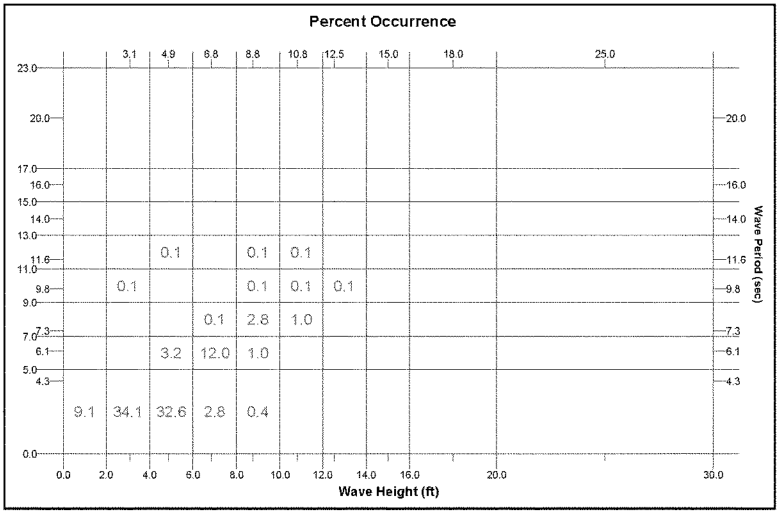



a)

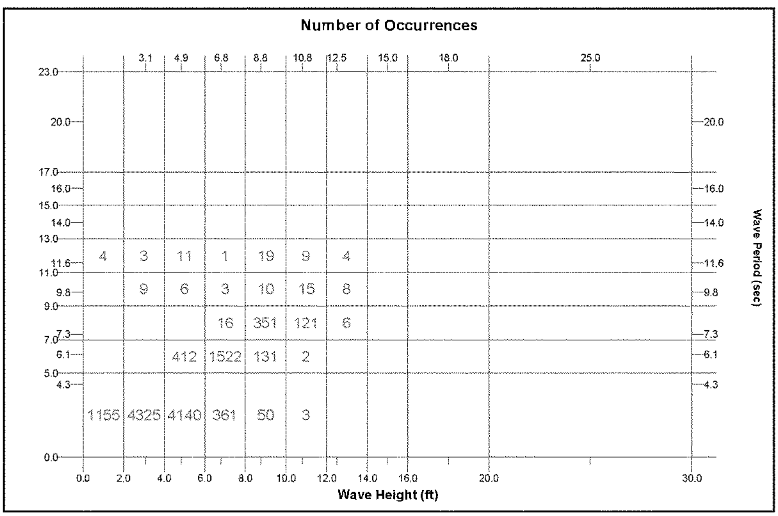



b)

Figure A1. WIS370 $T_p$ vs. $H_s$ percent occurrence table for direction band centered at $\theta_p$ =22.5 deg (a) percent and (b) number of observations.

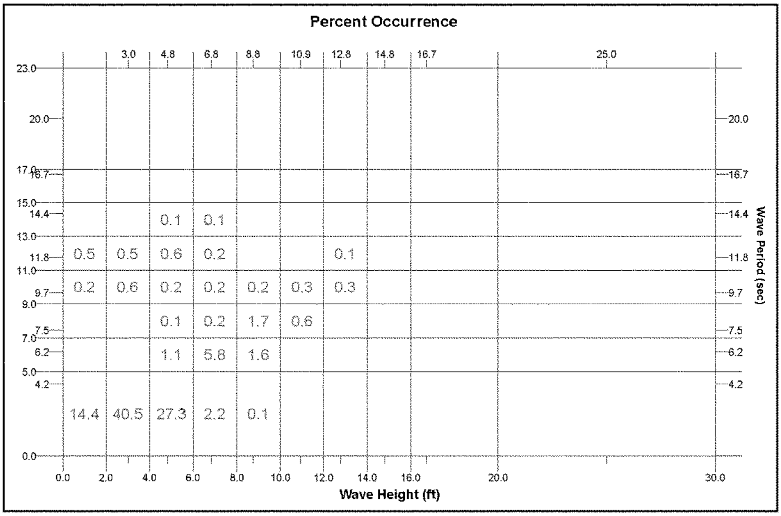



a)

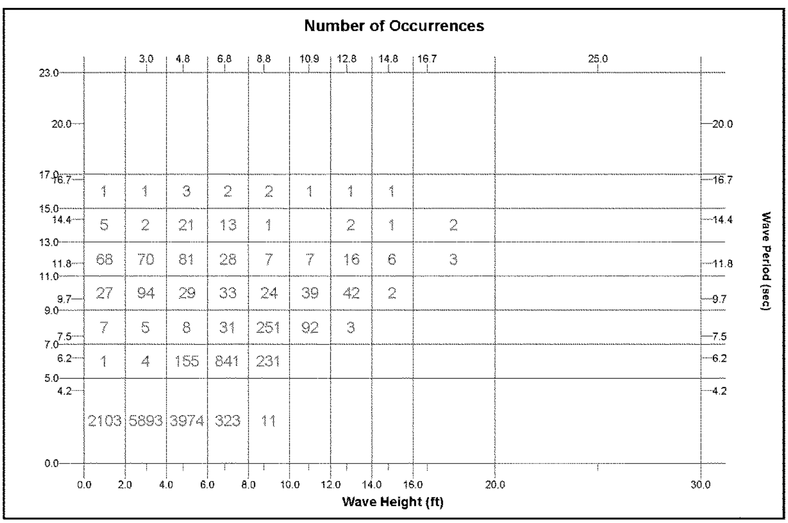



b)

Figure A2. WIS370 $T_p$ vs. $H_s$ percent occurrence table for direction band centered at $\theta_p$ =45 deg (a) percent and (b) number of observations.

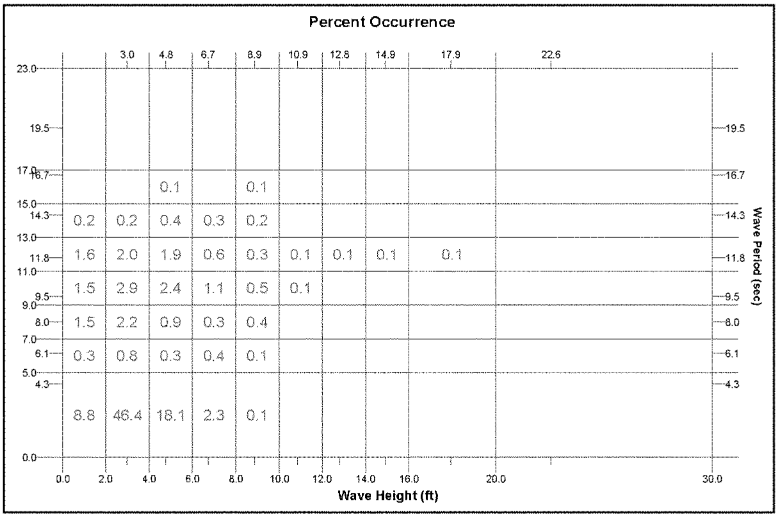



a)

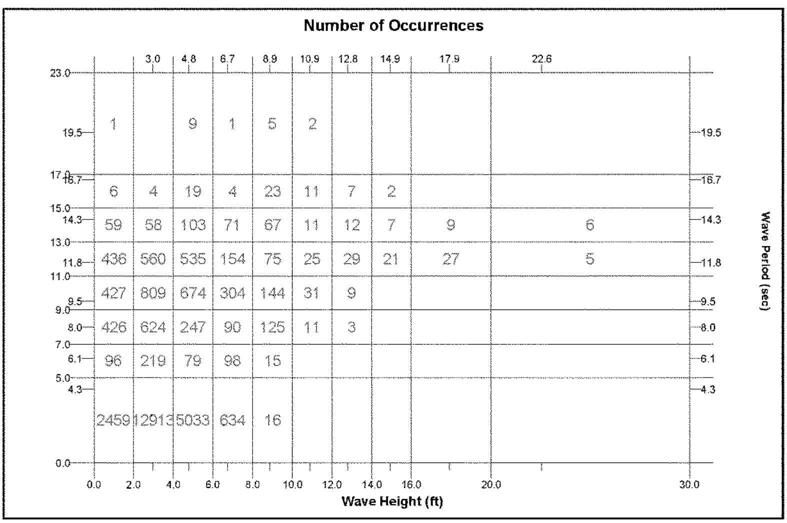



b)

Figure A3. WIS370 $T_p$ vs. $H_s$ percent occurrence table for direction band centered at $\theta_p$ =67.5 deg (a) percent and (b) number of observations.




a)




b)

Figure A4. WIS370 $T_p$ vs. $H_s$ percent occurrence table for direction band centered at $\theta_p$ =90 deg (a) percent and (b) number of observations.

**Percent Occurrence**

| Wave Period (sec) \ Wave Height (ft) | 0.0–2.0 | 2.0–4.0 (2.8) | 4.0–6.0 (4.8) | 6.0–8.0 (6.7) | 8.0–10.0 (8.9) | 10.0–12.0 (10.8) | 12.0–14.0 (12.8) | 14.0–16.0 (15.0) | 16.0–20.0 (17.8) | 20.0–30.0 (25.0) |
|---|---|---|---|---|---|---|---|---|---|---|
| 17.0–23.0 (19.2) | 0.1 | | | | | | | | | |
| 15.0–17.0 (16.7) | 0.1 | | | 0.2 | 0.1 | 0.1 | 0.1 | | | |
| 13.0–15.0 (14.4) | 0.2 | 0.3 | 0.1 | 0.2 | 0.2 | 0.1 | | 0.1 | 0.1 | |
| 11.0–13.0 (12.0) | 1.0 | 0.9 | 0.9 | 0.4 | 0.3 | 0.2 | 0.1 | | | |
| 9.0–11.0 (9.4) | 2.3 | 1.9 | 1.2 | 0.5 | 0.4 | 0.1 | | | | |
| 7.0–9.0 (7.8) | 6.3 | 3.3 | 0.8 | 0.6 | 0.1 | | | | | |
| 5.0–7.0 (6.1) | 4.1 | 3.3 | 0.7 | 0.4 | | | | | | |
| 0.0–5.0 (4.5) | 11.5 | 45.0 | 10.5 | 1.0 | | | | | | |

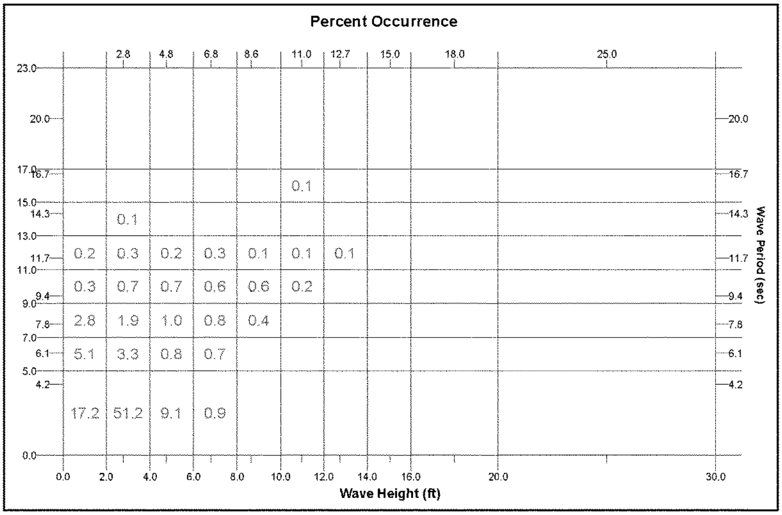
a)

**Number of Occurrences**

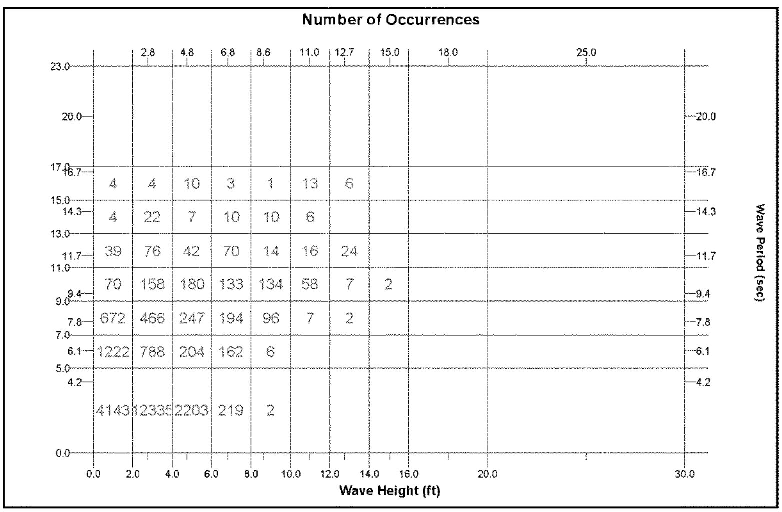
| Wave Period (sec) \ Wave Height (ft) | 0.0–2.0 | 2.0–4.0 (2.8) | 4.0–6.0 (4.8) | 6.0–8.0 (6.7) | 8.0–10.0 (8.9) | 10.0–12.0 (10.8) | 12.0–14.0 (12.8) | 14.0–16.0 (15.0) | 16.0–20.0 (17.8) | 20.0–30.0 (25.0) |
|---|---|---|---|---|---|---|---|---|---|---|
| 17.0–23.0 (19.2) | 20 | 5 | 12 | 4 | 1 | | | | | |
| 15.0–17.0 (16.7) | 49 | 15 | 19 | 74 | 31 | 31 | 20 | 11 | 8 | 1 |
| 13.0–15.0 (14.4) | 69 | 115 | 52 | 73 | 75 | 24 | 16 | 21 | 28 | 12 |
| 11.0–13.0 (12.0) | 385 | 357 | 366 | 174 | 120 | 65 | 26 | 5 | 5 | |
| 9.0–11.0 (9.4) | 910 | 725 | 479 | 202 | 167 | 57 | 11 | | | |
| 7.0–9.0 (7.8) | 2451 | 1298 | 311 | 220 | 53 | 6 | 1 | | | |
| 5.0–7.0 (6.1) | 1593 | 1294 | 259 | 153 | 8 | 1 | | | | |
| 0.0–5.0 (4.5) | 4492 | 17551 | 4087 | 409 | 2 | | | | | |

b)

Figure A5. WIS370 $T_p$ vs. $H_s$ percent occurrence table for direction band centered at $\theta_p$ =112.5 deg (a) percent and (b) number of observations.

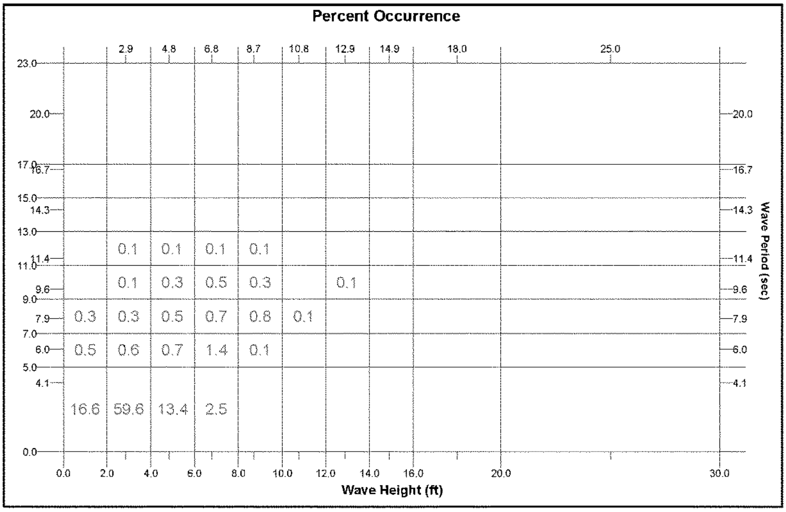



a)

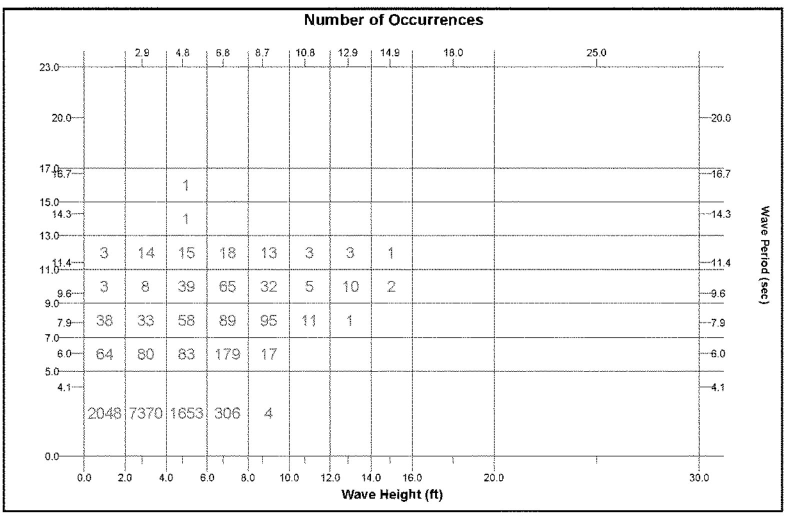



b)

Figure A6. WIS370 $T_p$ vs. $H_s$ percent occurrence table for direction band centered at $\theta_p$ =135 deg (a) percent and (b) number of observations.

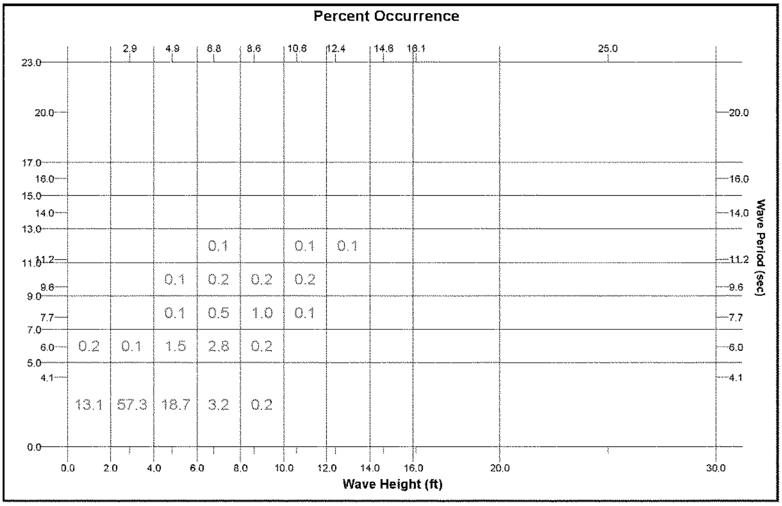



a)

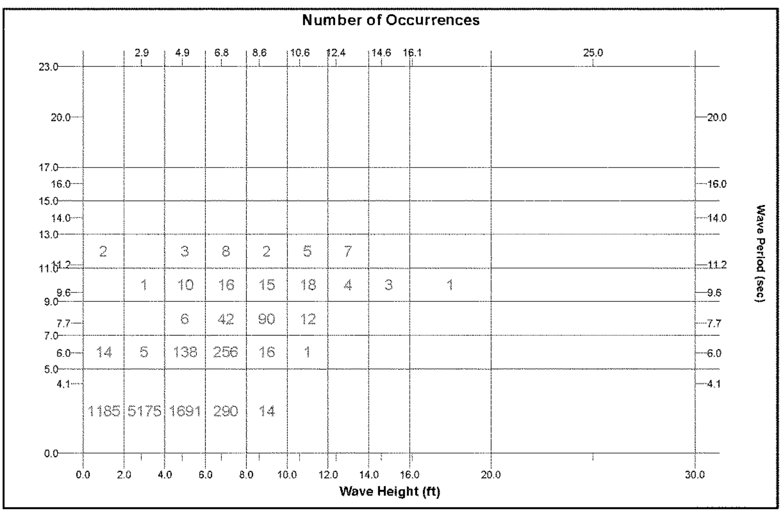



b)

Figure A7. WIS370 $T_p$ vs. $H_s$ percent occurrence table for direction band centered at $\theta_p$ =157.5 deg (a) percent and (b) number of observations.

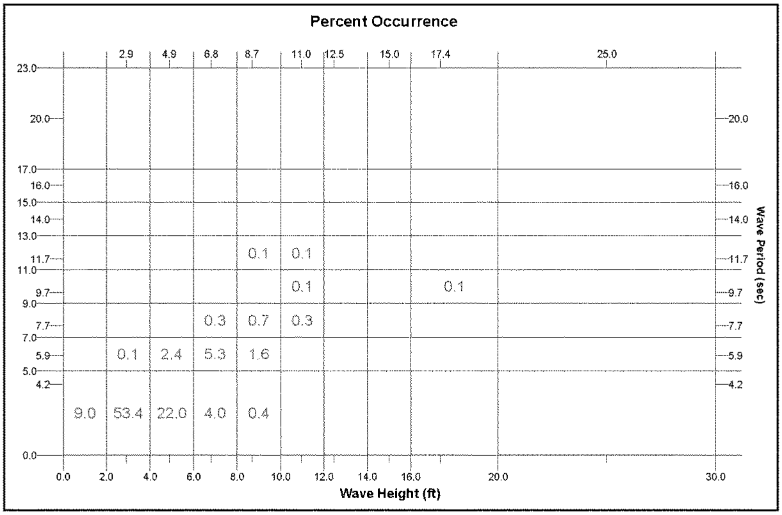



a)

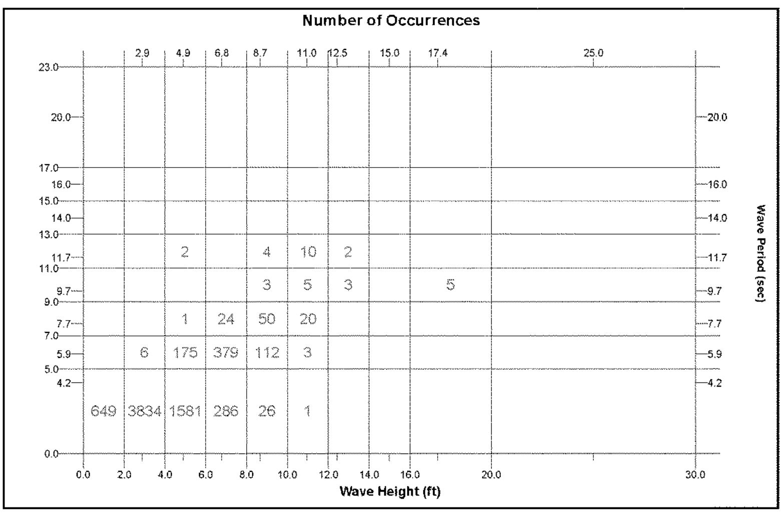



b)

Figure A8. WIS370 $T_p$ vs. $H_s$ percent occurrence table for direction band centered at $\theta_p$ =180 deg (a) percent and (b) number of observations.

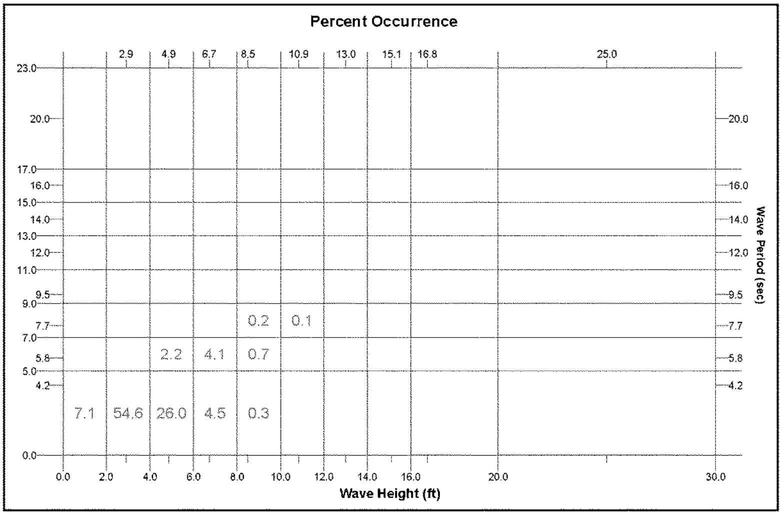



a)

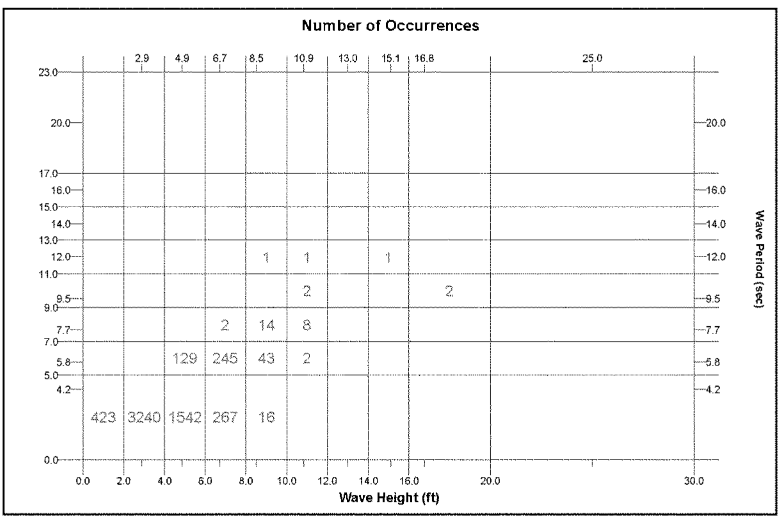



b)

Figure A9. WIS370 $T_p$ vs. $H_s$ percent occurrence table for direction band centered at $\theta_p$ =202.5 deg (a) percent and (b) number of observations.




a)




b)

Figure A10. WIS370 $T_p$ vs. $H_s$ percent occurrence table for direction band centered at $\theta_p$ =225 deg (a) percent and (b) number of observations.

# Appendix B: Wave Climatology in the Savannah Channel Reaches

Table B1. Wave climatology in Savannah Outer Channel, Reach 1, Station 123

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 101 | 3.1 | 4 | 22.5 | 0.012248 | 3.3 | 4 | 0.0217 | 7.9 |
| 102 | 4.7 | 4 | 22.5 | 0.028177 | 3.3 | 4 | 0.0080 | 2.9 |
| 103 | 6.5 | 4 | 22.5 | 0.053917 | 3.3 | 4 | 0.0010 | 0.4 |
| 104 | 3.1 | 4.3 | 45 | 0.009179 | 3.3 | 4 | 0.0273 | 10.0 |
| 105 | 4.9 | 4.3 | 45 | 0.022952 | 3.3 | 4 | 0.0262 | 9.6 |
| 106 | 6.8 | 4.3 | 45 | 0.044223 | 3.3 | 4 | 0.0023 | 0.8 |
| 107 | 4.9 | 6.1 | 45 | 0.006696 | 3.3 | 4 | 0.0026 | 0.9 |
| 108 | 6.8 | 6.1 | 45 | 0.012901 | 3.3 | 4 | 0.0096 | 3.5 |
| 109 | 8.8 | 6.1 | 45 | 0.021612 | 3.3 | 4 | 0.0008 | 0.3 |
| 110 | 8.8 | 7.3 | 45 | 0.012701 | 3.3 | 4 | 0.0022 | 0.8 |
| 111 | 10.8 | 7.3 | 45 | 0.019132 | 3.3 | 4 | 0.0008 | 0.3 |
| 112 | 3 | 4.2 | 67.5 | 0.009432 | 3.3 | 4 | 0.0373 | 13.6 |
| 113 | 4.8 | 4.2 | 67.5 | 0.02417 | 3.3 | 4 | 0.0251 | 9.2 |
| 114 | 6.8 | 4.2 | 67.5 | 0.048531 | 3.3 | 4 | 0.0020 | 0.7 |
| 115 | 4.8 | 6.2 | 67.5 | 0.006104 | 3.3 | 4 | 0.0010 | 0.4 |
| 116 | 6.8 | 6.2 | 67.5 | 0.012255 | 3.3 | 4 | 0.0053 | 1.9 |
| 117 | 8.8 | 6.2 | 67.5 | 0.02053 | 3.3 | 4 | 0.0015 | 0.5 |
| 118 | 8.8 | 7.5 | 67.5 | 0.011765 | 3.3 | 4 | 0.0016 | 0.6 |
| 119 | 10.8 | 7.5 | 67.5 | 0.017723 | 3.3 | 4 | 0.0006 | 0.2 |
| 120 | 3 | 9.7 | 67.5 | 0.000709 | 3.3 | 4 | 0.0006 | 0.2 |
| 121 | 4.8 | 11.8 | 67.5 | 0.001089 | 4 | 10 | 0.0005 | 0.2 |
| 122 | 3 | 4.3 | 90 | 0.008595 | 3.3 | 4 | 0.0817 | 29.8 |
| 123 | 4.8 | 4.3 | 90 | 0.022025 | 3.3 | 4 | 0.0318 | 11.6 |
| 124 | 6.7 | 4.3 | 90 | 0.042931 | 3.3 | 4 | 0.0040 | 1.5 |
| 125 | 3 | 6.1 | 90 | 0.002508 | 3.3 | 4 | 0.0014 | 0.5 |
| 126 | 4.8 | 6.1 | 90 | 0.006425 | 3.3 | 4 | 0.0005 | 0.2 |
| 127 | 6.7 | 6.1 | 90 | 0.012525 | 3.3 | 4 | 0.0006 | 0.2 |
| 128 | 3 | 8 | 90 | 0.001151 | 3.3 | 4 | 0.0039 | 1.4 |
| 129 | 4.8 | 8 | 90 | 0.002949 | 3.3 | 4 | 0.0016 | 0.6 |
| 130 | 6.7 | 8 | 90 | 0.005747 | 3.3 | 4 | 0.0006 | 0.2 |
| 131 | 8.9 | 8 | 90 | 0.010142 | 3.3 | 4 | 0.0008 | 0.3 |
| 132 | 3 | 9.5 | 90 | 0.000749 | 3.3 | 4 | 0.0051 | 1.9 |
| 133 | 4.8 | 9.5 | 90 | 0.001917 | 3.3 | 4 | 0.0043 | 1.6 |
| 134 | 6.7 | 9.5 | 90 | 0.003736 | 3.3 | 4 | 0.0019 | 0.7 |
| 135 | 8.9 | 9.5 | 90 | 0.006595 | 3.3 | 4 | 0.0009 | 0.3 |
| 136 | 3 | 11.8 | 90 | 0.000425 | 4 | 10 | 0.0035 | 1.3 |
| 137 | 4.8 | 11.8 | 90 | 0.001089 | 4 | 10 | 0.0034 | 1.2 |
| 138 | 6.7 | 11.8 | 90 | 0.002123 | 4 | 10 | 0.0010 | 0.4 |
| 139 | 8.9 | 11.8 | 90 | 0.003746 | 4 | 10 | 0.0005 | 0.2 |

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 140 | 4.8 | 14.3 | 90 | 0.00063 | 5 | 16 | 0.0007 | 0.3 |
| 141 | 2.8 | 4.5 | 112.5 | 0.006282 | 3.3 | 4 | 0.1110 | 40.5 |
| 142 | 4.8 | 4.5 | 112.5 | 0.018485 | 3.3 | 4 | 0.0258 | 9.4 |
| 143 | 6.7 | 4.5 | 112.5 | 0.03603 | 3.3 | 4 | 0.0026 | 0.9 |
| 144 | 2.8 | 6.1 | 112.5 | 0.002185 | 3.3 | 4 | 0.0082 | 3.0 |
| 145 | 4.8 | 6.1 | 112.5 | 0.006425 | 3.3 | 4 | 0.0016 | 0.6 |
| 146 | 6.7 | 6.1 | 112.5 | 0.012525 | 3.3 | 4 | 0.0010 | 0.4 |
| 147 | 2.8 | 7.8 | 112.5 | 0.001072 | 3.3 | 4 | 0.0082 | 3.0 |
| 148 | 4.8 | 7.8 | 112.5 | 0.003153 | 3.3 | 4 | 0.0020 | 0.7 |
| 149 | 6.7 | 7.8 | 112.5 | 0.006147 | 3.3 | 4 | 0.0014 | 0.5 |
| 150 | 2.8 | 9.4 | 112.5 | 0.00067 | 3.3 | 4 | 0.0046 | 1.7 |
| 151 | 4.8 | 9.4 | 112.5 | 0.001968 | 3.3 | 4 | 0.0030 | 1.1 |
| 152 | 6.7 | 9.4 | 112.5 | 0.003836 | 3.3 | 4 | 0.0013 | 0.5 |
| 153 | 8.9 | 9.4 | 112.5 | 0.006769 | 3.3 | 4 | 0.0011 | 0.4 |
| 154 | 2.8 | 12 | 112.5 | 0.000355 | 4 | 10 | 0.0023 | 0.8 |
| 155 | 4.8 | 12 | 112.5 | 0.001043 | 4 | 10 | 0.0023 | 0.8 |
| 156 | 6.7 | 12 | 112.5 | 0.002033 | 4 | 10 | 0.0011 | 0.4 |
| 157 | 8.9 | 12 | 112.5 | 0.003587 | 4 | 10 | 0.0008 | 0.3 |
| 158 | 2.8 | 14.4 | 112.5 | 0.000212 | 5 | 16 | 0.0007 | 0.3 |
| 159 | 8.9 | 14.4 | 112.5 | 0.002135 | 5 | 16 | 0.0005 | 0.2 |
| 160 | 2.8 | 4.2 | 135 | 0.008215 | 3.3 | 4 | 0.0780 | 28.5 |
| 161 | 4.8 | 4.2 | 135 | 0.02417 | 3.3 | 4 | 0.0139 | 5.1 |
| 162 | 6.8 | 4.2 | 135 | 0.048531 | 3.3 | 4 | 0.0014 | 0.5 |
| 163 | 2.8 | 6.1 | 135 | 0.002185 | 3.3 | 4 | 0.0050 | 1.8 |
| 164 | 4.8 | 6.1 | 135 | 0.006425 | 3.3 | 4 | 0.0013 | 0.5 |
| 165 | 6.8 | 6.1 | 135 | 0.012901 | 3.3 | 4 | 0.0010 | 0.4 |
| 166 | 2.8 | 7.8 | 135 | 0.001072 | 3.3 | 4 | 0.0029 | 1.1 |
| 167 | 4.8 | 7.8 | 135 | 0.003153 | 3.3 | 4 | 0.0016 | 0.6 |
| 168 | 6.8 | 7.8 | 135 | 0.006332 | 3.3 | 4 | 0.0012 | 0.4 |
| 169 | 8.6 | 7.8 | 135 | 0.01013 | 3.3 | 4 | 0.0006 | 0.2 |
| 170 | 2.8 | 9.4 | 135 | 0.00067 | 3.3 | 4 | 0.0010 | 0.4 |
| 171 | 4.8 | 9.4 | 135 | 0.001968 | 3.3 | 4 | 0.0011 | 0.4 |
| 172 | 6.8 | 9.4 | 135 | 0.003951 | 3.3 | 4 | 0.0008 | 0.3 |
| 173 | 8.6 | 9.4 | 135 | 0.006321 | 3.3 | 4 | 0.0008 | 0.3 |
| 174 | 2.8 | 11.7 | 135 | 0.000378 | 4 | 10 | 0.0005 | 0.2 |
| 175 | 2.9 | 4.1 | 157.5 | 0.009699 | 3.3 | 4 | 0.0466 | 17.0 |
| 176 | 4.8 | 4.1 | 157.5 | 0.026598 | 3.3 | 4 | 0.0105 | 3.8 |
| 177 | 6.8 | 4.1 | 157.5 | 0.053406 | 3.3 | 4 | 0.0019 | 0.7 |
| 178 | 2.9 | 6 | 157.5 | 0.002472 | 3.3 | 4 | 0.0005 | 0.2 |
| 179 | 4.8 | 6 | 157.5 | 0.006777 | 3.3 | 4 | 0.0005 | 0.2 |

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 180 | 6.8 | 6 | 157.5 | 0.013607 | 3.3 | 4 | 0.0011 | 0.4 |
| 181 | 6.8 | 7.9 | 157.5 | 0.006123 | 3.3 | 4 | 0.0006 | 0.2 |
| 182 | 8.7 | 7.9 | 157.5 | 0.010026 | 3.3 | 4 | 0.0006 | 0.2 |
| 183 | 2.9 | 4.1 | 180 | 0.009699 | 3.3 | 4 | 0.0327 | 11.9 |
| 184 | 4.9 | 4.1 | 180 | 0.027719 | 3.3 | 4 | 0.0107 | 3.9 |
| 185 | 6.8 | 4.1 | 180 | 0.053406 | 3.3 | 4 | 0.0018 | 0.7 |
| 186 | 4.9 | 6 | 180 | 0.007063 | 3.3 | 4 | 0.0009 | 0.3 |
| 187 | 6.8 | 6 | 180 | 0.013607 | 3.3 | 4 | 0.0016 | 0.6 |
| 188 | 8.6 | 6 | 180 | 0.02177 | 3.3 | 4 | 0.0006 | 0.2 |
| 189 | 2.9 | 4.2 | 202.5 | 0.008813 | 3.3 | 4 | 0.0242 | 8.8 |
| 190 | 4.9 | 4.2 | 202.5 | 0.025188 | 3.3 | 4 | 0.0100 | 3.7 |
| 191 | 6.8 | 4.2 | 202.5 | 0.048531 | 3.3 | 4 | 0.0018 | 0.7 |
| 192 | 4.9 | 5.9 | 202.5 | 0.007451 | 3.3 | 4 | 0.0011 | 0.4 |
| 193 | 6.8 | 5.9 | 202.5 | 0.014357 | 3.3 | 4 | 0.0024 | 0.9 |
| 194 | 8.7 | 5.9 | 202.5 | 0.023506 | 3.3 | 4 | 0.0007 | 0.3 |
| 195 | 2.9 | 4.2 | 225 | 0.008813 | 3.3 | 4 | 0.0205 | 7.5 |
| 196 | 4.9 | 4.2 | 225 | 0.025188 | 3.3 | 4 | 0.0098 | 3.6 |
| 197 | 6.7 | 4.2 | 225 | 0.047113 | 3.3 | 4 | 0.0017 | 0.6 |
| 198 | 4.9 | 5.8 | 225 | 0.00787 | 3.3 | 4 | 0.0008 | 0.3 |
| 199 | 6.7 | 5.8 | 225 | 0.014719 | 3.3 | 4 | 0.0015 | 0.5 |
| | | | | | | | | |
| | | | | | | | Total Days: | 292.7 |
| | | | | | | | Calm Days: | 72.3 |

Table B2. Wave climatology in Savannah Outer Channel, Reach 2, Station 82

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 201 | 2.9 | 4 | 22.5 | 0.010716 | 3.3 | 4 | 0.0217 | 7.9 |
| 202 | 4.4 | 4 | 22.5 | 0.024693 | 3.3 | 4 | 0.0080 | 2.9 |
| 203 | 6.1 | 4 | 22.5 | 0.047482 | 3.3 | 4 | 0.0010 | 0.4 |
| 204 | 2.9 | 4.3 | 45 | 0.008031 | 3.3 | 4 | 0.0273 | 10.0 |
| 205 | 4.6 | 4.3 | 45 | 0.020225 | 3.3 | 4 | 0.0262 | 9.6 |
| 206 | 6.4 | 4.3 | 45 | 0.039170 | 3.3 | 4 | 0.0023 | 0.8 |
| 207 | 4.6 | 6.1 | 45 | 0.005900 | 3.3 | 4 | 0.0026 | 0.9 |
| 208 | 6.4 | 6.1 | 45 | 0.011427 | 3.3 | 4 | 0.0096 | 3.5 |
| 209 | 8.3 | 6.1 | 45 | 0.019224 | 3.3 | 4 | 0.0008 | 0.3 |
| 210 | 8.3 | 7.3 | 45 | 0.011297 | 3.3 | 4 | 0.0022 | 0.8 |
| 211 | 10.2 | 7.3 | 45 | 0.017065 | 3.3 | 4 | 0.0008 | 0.3 |
| 212 | 2.8 | 4.2 | 67.5 | 0.008215 | 3.3 | 4 | 0.0373 | 13.6 |
| 213 | 4.5 | 4.2 | 67.5 | 0.021241 | 3.3 | 4 | 0.0251 | 9.2 |
| 214 | 6.4 | 4.2 | 67.5 | 0.042987 | 3.3 | 4 | 0.0020 | 0.7 |
| 215 | 4.5 | 6.2 | 67.5 | 0.005364 | 3.3 | 4 | 0.0010 | 0.4 |
| 216 | 6.4 | 6.2 | 67.5 | 0.010855 | 3.3 | 4 | 0.0053 | 1.9 |
| 217 | 8.3 | 6.2 | 67.5 | 0.018262 | 3.3 | 4 | 0.0015 | 0.5 |
| 218 | 8.3 | 7.5 | 67.5 | 0.010466 | 3.3 | 4 | 0.0016 | 0.6 |
| 219 | 10.2 | 7.5 | 67.5 | 0.015808 | 3.3 | 4 | 0.0006 | 0.2 |
| 220 | 2.8 | 9.7 | 67.5 | 0.000617 | 3.3 | 4 | 0.0006 | 0.2 |
| 221 | 4.5 | 11.8 | 67.5 | 0.000957 | 4 | 10 | 0.0005 | 0.2 |
| 222 | 2.8 | 4.3 | 90 | 0.007486 | 3.3 | 4 | 0.0817 | 29.8 |
| 223 | 4.5 | 4.3 | 90 | 0.019356 | 3.3 | 4 | 0.0318 | 11.6 |
| 224 | 6.3 | 4.3 | 90 | 0.037955 | 3.3 | 4 | 0.0040 | 1.5 |
| 225 | 2.8 | 6.1 | 90 | 0.002185 | 3.3 | 4 | 0.0014 | 0.5 |
| 226 | 4.5 | 6.1 | 90 | 0.005646 | 3.3 | 4 | 0.0005 | 0.2 |
| 227 | 6.3 | 6.1 | 90 | 0.011073 | 3.3 | 4 | 0.0006 | 0.2 |
| 228 | 2.8 | 8 | 90 | 0.001002 | 3.3 | 4 | 0.0039 | 1.4 |
| 229 | 4.5 | 8 | 90 | 0.002591 | 3.3 | 4 | 0.0016 | 0.6 |
| 230 | 6.3 | 8 | 90 | 0.005080 | 3.3 | 4 | 0.0006 | 0.2 |
| 231 | 8.4 | 8 | 90 | 0.009035 | 3.3 | 4 | 0.0008 | 0.3 |
| 232 | 2.8 | 9.5 | 90 | 0.000652 | 3.3 | 4 | 0.0051 | 1.9 |
| 233 | 4.5 | 9.5 | 90 | 0.001685 | 3.3 | 4 | 0.0043 | 1.6 |
| 234 | 6.3 | 9.5 | 90 | 0.003303 | 3.3 | 4 | 0.0019 | 0.7 |
| 235 | 8.4 | 9.5 | 90 | 0.005874 | 3.3 | 4 | 0.0009 | 0.3 |
| 236 | 2.8 | 11.8 | 90 | 0.000370 | 4 | 10 | 0.0035 | 1.3 |
| 237 | 4.5 | 11.8 | 90 | 0.000957 | 4 | 10 | 0.0034 | 1.2 |
| 238 | 6.3 | 11.8 | 90 | 0.001877 | 4 | 10 | 0.0010 | 0.4 |
| 239 | 8.4 | 11.8 | 90 | 0.003337 | 4 | 10 | 0.0005 | 0.2 |

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 240 | 4.5 | 14.3 | 90 | 0.000553 | 5 | 16 | 0.0007 | 0.3 |
| 241 | 2.6 | 4.5 | 112.5 | 0.005416 | 3.3 | 4 | 0.1110 | 40.5 |
| 242 | 4.5 | 4.5 | 112.5 | 0.016244 | 3.3 | 4 | 0.0258 | 9.4 |
| 243 | 6.3 | 4.5 | 112.5 | 0.031854 | 3.3 | 4 | 0.0026 | 0.9 |
| 244 | 2.6 | 6.1 | 112.5 | 0.001882 | 3.3 | 4 | 0.0082 | 3.0 |
| 245 | 4.5 | 6.1 | 112.5 | 0.005646 | 3.3 | 4 | 0.0016 | 0.6 |
| 246 | 6.3 | 6.1 | 112.5 | 0.011073 | 3.3 | 4 | 0.0010 | 0.4 |
| 247 | 2.6 | 7.8 | 112.5 | 0.000924 | 3.3 | 4 | 0.0082 | 3.0 |
| 248 | 4.5 | 7.8 | 112.5 | 0.002772 | 3.3 | 4 | 0.0020 | 0.7 |
| 249 | 6.3 | 7.8 | 112.5 | 0.005434 | 3.3 | 4 | 0.0014 | 0.5 |
| 250 | 2.6 | 9.4 | 112.5 | 0.000577 | 3.3 | 4 | 0.0046 | 1.7 |
| 251 | 4.5 | 9.4 | 112.5 | 0.001730 | 3.3 | 4 | 0.0030 | 1.1 |
| 252 | 6.3 | 9.4 | 112.5 | 0.003391 | 3.3 | 4 | 0.0013 | 0.5 |
| 253 | 8.4 | 9.4 | 112.5 | 0.006030 | 3.3 | 4 | 0.0011 | 0.4 |
| 254 | 2.6 | 12 | 112.5 | 0.000306 | 4 | 10 | 0.0023 | 0.8 |
| 255 | 4.5 | 12 | 112.5 | 0.000917 | 4 | 10 | 0.0023 | 0.8 |
| 256 | 6.3 | 12 | 112.5 | 0.001797 | 4 | 10 | 0.0011 | 0.4 |
| 257 | 8.4 | 12 | 112.5 | 0.003195 | 4 | 10 | 0.0008 | 0.3 |
| 258 | 2.6 | 14.4 | 112.5 | 0.000182 | 5 | 16 | 0.0007 | 0.3 |
| 259 | 8.4 | 14.4 | 112.5 | 0.001902 | 5 | 16 | 0.0005 | 0.2 |
| 260 | 2.6 | 4.2 | 135 | 0.007081 | 3.3 | 4 | 0.0780 | 28.5 |
| 261 | 4.5 | 4.2 | 135 | 0.021241 | 3.3 | 4 | 0.0139 | 5.1 |
| 262 | 6.4 | 4.2 | 135 | 0.042987 | 3.3 | 4 | 0.0014 | 0.5 |
| 263 | 2.6 | 6.1 | 135 | 0.001882 | 3.3 | 4 | 0.0050 | 1.8 |
| 264 | 4.5 | 6.1 | 135 | 0.005646 | 3.3 | 4 | 0.0013 | 0.5 |
| 265 | 6.4 | 6.1 | 135 | 0.011427 | 3.3 | 4 | 0.0010 | 0.4 |
| 266 | 2.6 | 7.8 | 135 | 0.000924 | 3.3 | 4 | 0.0029 | 1.1 |
| 267 | 4.5 | 7.8 | 135 | 0.002772 | 3.3 | 4 | 0.0016 | 0.6 |
| 268 | 6.4 | 7.8 | 135 | 0.005608 | 3.3 | 4 | 0.0012 | 0.4 |
| 269 | 8.1 | 7.8 | 135 | 0.008986 | 3.3 | 4 | 0.0006 | 0.2 |
| 270 | 2.6 | 9.4 | 135 | 0.000577 | 3.3 | 4 | 0.0010 | 0.4 |
| 271 | 4.5 | 9.4 | 135 | 0.001730 | 3.3 | 4 | 0.0011 | 0.4 |
| 272 | 6.4 | 9.4 | 135 | 0.003500 | 3.3 | 4 | 0.0008 | 0.3 |
| 273 | 8.1 | 9.4 | 135 | 0.005607 | 3.3 | 4 | 0.0008 | 0.3 |
| 274 | 2.6 | 11.7 | 135 | 0.000325 | 4 | 10 | 0.0005 | 0.2 |
| 275 | 2.7 | 4.1 | 157.5 | 0.008405 | 3.3 | 4 | 0.0466 | 17.0 |
| 276 | 4.5 | 4.1 | 157.5 | 0.023374 | 3.3 | 4 | 0.0105 | 3.8 |
| 277 | 6.4 | 4.1 | 157.5 | 0.047305 | 3.3 | 4 | 0.0019 | 0.7 |
| 278 | 2.7 | 6 | 157.5 | 0.002141 | 3.3 | 4 | 0.0005 | 0.2 |
| 279 | 4.5 | 6 | 157.5 | 0.005956 | 3.3 | 4 | 0.0005 | 0.2 |

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 280 | 6.4 | 6 | 157.5 | 0.012053 | 3.3 | 4 | 0.0011 | 0.4 |
| 281 | 6.4 | 7.9 | 157.5 | 0.005424 | 3.3 | 4 | 0.0006 | 0.2 |
| 282 | 8.2 | 7.9 | 157.5 | 0.008906 | 3.3 | 4 | 0.0006 | 0.2 |
| 283 | 2.7 | 4.1 | 180 | 0.008405 | 3.3 | 4 | 0.0327 | 11.9 |
| 284 | 4.6 | 4.1 | 180 | 0.024426 | 3.3 | 4 | 0.0107 | 3.9 |
| 285 | 6.4 | 4.1 | 180 | 0.047305 | 3.3 | 4 | 0.0018 | 0.7 |
| 286 | 4.6 | 6 | 180 | 0.006224 | 3.3 | 4 | 0.0009 | 0.3 |
| 287 | 6.4 | 6 | 180 | 0.012053 | 3.3 | 4 | 0.0016 | 0.6 |
| 288 | 8.1 | 6 | 180 | 0.019312 | 3.3 | 4 | 0.0006 | 0.2 |
| 289 | 2.7 | 4.2 | 202.5 | 0.007638 | 3.3 | 4 | 0.0242 | 8.8 |
| 290 | 4.6 | 4.2 | 202.5 | 0.022196 | 3.3 | 4 | 0.0100 | 3.7 |
| 291 | 6.4 | 4.2 | 202.5 | 0.042987 | 3.3 | 4 | 0.0018 | 0.7 |
| 292 | 4.6 | 5.9 | 202.5 | 0.006566 | 3.3 | 4 | 0.0011 | 0.4 |
| 293 | 6.4 | 5.9 | 202.5 | 0.012717 | 3.3 | 4 | 0.0024 | 0.9 |
| 294 | 8.2 | 5.9 | 202.5 | 0.020881 | 3.3 | 4 | 0.0007 | 0.3 |
| 295 | 2.7 | 4.2 | 225 | 0.007638 | 3.3 | 4 | 0.0205 | 7.5 |
| 296 | 4.6 | 4.2 | 225 | 0.022196 | 3.3 | 4 | 0.0098 | 3.6 |
| 297 | 6.3 | 4.2 | 225 | 0.041652 | 3.3 | 4 | 0.0017 | 0.6 |
| 298 | 4.6 | 5.8 | 225 | 0.006935 | 3.3 | 4 | 0.0008 | 0.3 |
| 299 | 6.3 | 5.8 | 225 | 0.013014 | 3.3 | 4 | 0.0015 | 0.5 |
| | | | | | | | | |
| | | | | | | | Total Days: | 292.7 |
| | | | | | | | Calm Days: | 72.3 |

Table B3. Wave climatology in Savannah Outer Channel, Reach 3, Station 60

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 301 | 2.6 | 4 | 22.5 | 0.008611 | 3.3 | 4 | 0.0217 | 7.9 |
| 302 | 4 | 4 | 22.5 | 0.020403 | 3.3 | 4 | 0.0080 | 2.9 |
| 303 | 5.5 | 4 | 22.5 | 0.038595 | 3.3 | 4 | 0.0010 | 0.4 |
| 304 | 2.6 | 4.3 | 45 | 0.006453 | 3.3 | 4 | 0.0273 | 10.0 |
| 305 | 4.2 | 4.3 | 45 | 0.016858 | 3.3 | 4 | 0.0262 | 9.6 |
| 306 | 5.8 | 4.3 | 45 | 0.032166 | 3.3 | 4 | 0.0023 | 0.8 |
| 307 | 4.2 | 6.1 | 45 | 0.004918 | 3.3 | 4 | 0.0026 | 0.9 |
| 308 | 5.8 | 6.1 | 45 | 0.009384 | 3.3 | 4 | 0.0096 | 3.5 |
| 309 | 7.5 | 6.1 | 45 | 0.015695 | 3.3 | 4 | 0.0008 | 0.3 |
| 310 | 7.5 | 7.3 | 45 | 0.009223 | 3.3 | 4 | 0.0022 | 0.8 |
| 311 | 9.2 | 7.3 | 45 | 0.013881 | 3.3 | 4 | 0.0008 | 0.3 |
| 312 | 2.6 | 4.2 | 67.5 | 0.007081 | 3.3 | 4 | 0.0373 | 13.6 |
| 313 | 4.1 | 4.2 | 67.5 | 0.017630 | 3.3 | 4 | 0.0251 | 9.2 |
| 314 | 5.8 | 4.2 | 67.5 | 0.035300 | 3.3 | 4 | 0.0020 | 0.7 |
| 315 | 4.1 | 6.2 | 67.5 | 0.004452 | 3.3 | 4 | 0.0010 | 0.4 |
| 316 | 5.8 | 6.2 | 67.5 | 0.008915 | 3.3 | 4 | 0.0053 | 1.9 |
| 317 | 7.5 | 6.2 | 67.5 | 0.014910 | 3.3 | 4 | 0.0015 | 0.5 |
| 318 | 7.5 | 7.5 | 67.5 | 0.008544 | 3.3 | 4 | 0.0016 | 0.6 |
| 319 | 9.2 | 7.5 | 67.5 | 0.012860 | 3.3 | 4 | 0.0006 | 0.2 |
| 320 | 2.6 | 9.7 | 67.5 | 0.000532 | 3.3 | 4 | 0.0006 | 0.2 |
| 321 | 4.1 | 11.8 | 67.5 | 0.000794 | 4 | 10 | 0.0005 | 0.2 |
| 322 | 2.6 | 4.3 | 90 | 0.006453 | 3.3 | 4 | 0.0817 | 29.8 |
| 323 | 4.1 | 4.3 | 90 | 0.016064 | 3.3 | 4 | 0.0318 | 11.6 |
| 324 | 5.7 | 4.3 | 90 | 0.031066 | 3.3 | 4 | 0.0040 | 1.5 |
| 325 | 2.6 | 6.1 | 90 | 0.001882 | 3.3 | 4 | 0.0014 | 0.5 |
| 326 | 4.1 | 6.1 | 90 | 0.004687 | 3.3 | 4 | 0.0005 | 0.2 |
| 327 | 5.7 | 6.1 | 90 | 0.009063 | 3.3 | 4 | 0.0006 | 0.2 |
| 328 | 2.6 | 8 | 90 | 0.000864 | 3.3 | 4 | 0.0039 | 1.4 |
| 329 | 4.1 | 8 | 90 | 0.002151 | 3.3 | 4 | 0.0016 | 0.6 |
| 330 | 5.7 | 8 | 90 | 0.004159 | 3.3 | 4 | 0.0006 | 0.2 |
| 331 | 7.6 | 8 | 90 | 0.007395 | 3.3 | 4 | 0.0008 | 0.3 |
| 332 | 2.6 | 9.5 | 90 | 0.000562 | 3.3 | 4 | 0.0051 | 1.9 |
| 333 | 4.1 | 9.5 | 90 | 0.001398 | 3.3 | 4 | 0.0043 | 1.6 |
| 334 | 5.7 | 9.5 | 90 | 0.002704 | 3.3 | 4 | 0.0019 | 0.7 |
| 335 | 7.6 | 9.5 | 90 | 0.004808 | 3.3 | 4 | 0.0009 | 0.3 |
| 336 | 2.6 | 11.8 | 90 | 0.000320 | 4 | 10 | 0.0035 | 1.3 |
| 337 | 4.1 | 11.8 | 90 | 0.000794 | 4 | 10 | 0.0034 | 1.2 |
| 338 | 5.7 | 11.8 | 90 | 0.001537 | 4 | 10 | 0.0010 | 0.4 |
| 339 | 7.6 | 11.8 | 90 | 0.002732 | 4 | 10 | 0.0005 | 0.2 |

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 340 | 4.1 | 14.3 | 90 | 0.000459 | 5 | 16 | 0.0007 | 0.3 |
| 341 | 2.4 | 4.5 | 112.5 | 0.004613 | 3.3 | 4 | 0.1110 | 40.5 |
| 342 | 4.1 | 4.5 | 112.5 | 0.013483 | 3.3 | 4 | 0.0258 | 9.4 |
| 343 | 5.7 | 4.5 | 112.5 | 0.026072 | 3.3 | 4 | 0.0026 | 0.9 |
| 344 | 2.4 | 6.1 | 112.5 | 0.001604 | 3.3 | 4 | 0.0082 | 3.0 |
| 345 | 4.1 | 6.1 | 112.5 | 0.004687 | 3.3 | 4 | 0.0016 | 0.6 |
| 346 | 5.7 | 6.1 | 112.5 | 0.009063 | 3.3 | 4 | 0.0010 | 0.4 |
| 347 | 2.4 | 7.8 | 112.5 | 0.000788 | 3.3 | 4 | 0.0082 | 3.0 |
| 348 | 4.1 | 7.8 | 112.5 | 0.002301 | 3.3 | 4 | 0.0020 | 0.7 |
| 349 | 5.7 | 7.8 | 112.5 | 0.004448 | 3.3 | 4 | 0.0014 | 0.5 |
| 350 | 2.4 | 9.4 | 112.5 | 0.000491 | 3.3 | 4 | 0.0046 | 1.7 |
| 351 | 4.1 | 9.4 | 112.5 | 0.001435 | 3.3 | 4 | 0.0030 | 1.1 |
| 352 | 5.7 | 9.4 | 112.5 | 0.002775 | 3.3 | 4 | 0.0013 | 0.5 |
| 353 | 7.6 | 9.4 | 112.5 | 0.004936 | 3.3 | 4 | 0.0011 | 0.4 |
| 354 | 2.4 | 12 | 112.5 | 0.000260 | 4 | 10 | 0.0023 | 0.8 |
| 355 | 4.1 | 12 | 112.5 | 0.000761 | 4 | 10 | 0.0023 | 0.8 |
| 356 | 5.7 | 12 | 112.5 | 0.001470 | 4 | 10 | 0.0011 | 0.4 |
| 357 | 7.6 | 12 | 112.5 | 0.002615 | 4 | 10 | 0.0008 | 0.3 |
| 358 | 2.4 | 14.4 | 112.5 | 0.000156 | 5 | 16 | 0.0007 | 0.3 |
| 359 | 7.6 | 14.4 | 112.5 | 0.001557 | 5 | 16 | 0.0005 | 0.2 |
| 360 | 2.4 | 4.2 | 135 | 0.006033 | 3.3 | 4 | 0.0780 | 28.5 |
| 361 | 4.1 | 4.2 | 135 | 0.017630 | 3.3 | 4 | 0.0139 | 5.1 |
| 362 | 5.8 | 4.2 | 135 | 0.035300 | 3.3 | 4 | 0.0014 | 0.5 |
| 363 | 2.4 | 6.1 | 135 | 0.001604 | 3.3 | 4 | 0.0050 | 1.8 |
| 364 | 4.1 | 6.1 | 135 | 0.004687 | 3.3 | 4 | 0.0013 | 0.5 |
| 365 | 5.8 | 6.1 | 135 | 0.009384 | 3.3 | 4 | 0.0010 | 0.4 |
| 366 | 2.4 | 7.8 | 135 | 0.000788 | 3.3 | 4 | 0.0029 | 1.1 |
| 367 | 4.1 | 7.8 | 135 | 0.002301 | 3.3 | 4 | 0.0016 | 0.6 |
| 368 | 5.8 | 7.8 | 135 | 0.004605 | 3.3 | 4 | 0.0012 | 0.4 |
| 369 | 7.3 | 7.8 | 135 | 0.007297 | 3.3 | 4 | 0.0006 | 0.2 |
| 370 | 2.4 | 9.4 | 135 | 0.000491 | 3.3 | 4 | 0.0010 | 0.4 |
| 371 | 4.1 | 9.4 | 135 | 0.001435 | 3.3 | 4 | 0.0011 | 0.4 |
| 372 | 5.8 | 9.4 | 135 | 0.002874 | 3.3 | 4 | 0.0008 | 0.3 |
| 373 | 7.3 | 9.4 | 135 | 0.004553 | 3.3 | 4 | 0.0008 | 0.3 |
| 374 | 2.4 | 11.7 | 135 | 0.000277 | 4 | 10 | 0.0005 | 0.2 |
| 375 | 2.5 | 4.1 | 157.5 | 0.007204 | 3.3 | 4 | 0.0466 | 17.0 |
| 376 | 4.1 | 4.1 | 157.5 | 0.019400 | 3.3 | 4 | 0.0105 | 3.8 |
| 377 | 5.8 | 4.1 | 157.5 | 0.038845 | 3.3 | 4 | 0.0019 | 0.7 |
| 378 | 2.5 | 6 | 157.5 | 0.001836 | 3.3 | 4 | 0.0005 | 0.2 |
| 379 | 4.1 | 6 | 157.5 | 0.004943 | 3.3 | 4 | 0.0005 | 0.2 |

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 380 | 5.8 | 6 | 157.5 | 0.009898 | 3.3 | 4 | 0.0011 | 0.4 |
| 381 | 5.8 | 7.9 | 157.5 | 0.004454 | 3.3 | 4 | 0.0006 | 0.2 |
| 382 | 7.4 | 7.9 | 157.5 | 0.007252 | 3.3 | 4 | 0.0006 | 0.2 |
| 383 | 2.5 | 4.1 | 180 | 0.007204 | 3.3 | 4 | 0.0327 | 11.9 |
| 384 | 4.2 | 4.1 | 180 | 0.020359 | 3.3 | 4 | 0.0107 | 3.9 |
| 385 | 5.8 | 4.1 | 180 | 0.038845 | 3.3 | 4 | 0.0018 | 0.7 |
| 386 | 4.2 | 6 | 180 | 0.005188 | 3.3 | 4 | 0.0009 | 0.3 |
| 387 | 5.8 | 6 | 180 | 0.009898 | 3.3 | 4 | 0.0016 | 0.6 |
| 388 | 7.3 | 6 | 180 | 0.015683 | 3.3 | 4 | 0.0006 | 0.2 |
| 389 | 2.5 | 4.2 | 202.5 | 0.006547 | 3.3 | 4 | 0.0242 | 8.8 |
| 390 | 4.2 | 4.2 | 202.5 | 0.018501 | 3.3 | 4 | 0.0100 | 3.7 |
| 391 | 5.8 | 4.2 | 202.5 | 0.035300 | 3.3 | 4 | 0.0018 | 0.7 |
| 392 | 4.2 | 5.9 | 202.5 | 0.005473 | 3.3 | 4 | 0.0011 | 0.4 |
| 393 | 5.8 | 5.9 | 202.5 | 0.010442 | 3.3 | 4 | 0.0024 | 0.9 |
| 394 | 7.4 | 5.9 | 202.5 | 0.017003 | 3.3 | 4 | 0.0007 | 0.3 |
| 395 | 2.5 | 4.2 | 225 | 0.006547 | 3.3 | 4 | 0.0205 | 7.5 |
| 396 | 4.2 | 4.2 | 225 | 0.018501 | 3.3 | 4 | 0.0098 | 3.6 |
| 397 | 5.7 | 4.2 | 225 | 0.034092 | 3.3 | 4 | 0.0017 | 0.6 |
| 398 | 4.2 | 5.8 | 225 | 0.005781 | 3.3 | 4 | 0.0008 | 0.3 |
| 399 | 5.7 | 5.8 | 225 | 0.010651 | 3.3 | 4 | 0.0015 | 0.5 |
| | | | | | | | | |
| | | | | | | | Total Days: | 292.7 |
| | | | | | | | Calm Days: | 72.3 |

Table B4. Wave climatology in Savannah Outer Channel, Reach 4, Station 39

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 401 | 1.7 | 4 | 22.5 | 0.003676 | 3.3 | 4 | 0.0217 | 7.9 |
| 402 | 2.6 | 4 | 22.5 | 0.008611 | 3.3 | 4 | 0.0080 | 2.9 |
| 403 | 3.6 | 4 | 22.5 | 0.016523 | 3.3 | 4 | 0.0010 | 0.4 |
| 404 | 1.7 | 4.3 | 45 | 0.002754 | 3.3 | 4 | 0.0273 | 10.0 |
| 405 | 2.7 | 4.3 | 45 | 0.006960 | 3.3 | 4 | 0.0262 | 9.6 |
| 406 | 3.8 | 4.3 | 45 | 0.013798 | 3.3 | 4 | 0.0023 | 0.8 |
| 407 | 2.7 | 6.1 | 45 | 0.002031 | 3.3 | 4 | 0.0026 | 0.9 |
| 408 | 3.8 | 6.1 | 45 | 0.004025 | 3.3 | 4 | 0.0096 | 3.5 |
| 409 | 4.9 | 6.1 | 45 | 0.006696 | 3.3 | 4 | 0.0008 | 0.3 |
| 410 | 4.9 | 7.3 | 45 | 0.003935 | 3.3 | 4 | 0.0022 | 0.8 |
| 411 | 6 | 7.3 | 45 | 0.005902 | 3.3 | 4 | 0.0008 | 0.3 |
| 412 | 1.7 | 4.2 | 67.5 | 0.003023 | 3.3 | 4 | 0.0373 | 13.6 |
| 413 | 2.7 | 4.2 | 67.5 | 0.007638 | 3.3 | 4 | 0.0251 | 9.2 |
| 414 | 3.8 | 4.2 | 67.5 | 0.015142 | 3.3 | 4 | 0.0020 | 0.7 |
| 415 | 2.7 | 6.2 | 67.5 | 0.001929 | 3.3 | 4 | 0.0010 | 0.4 |
| 416 | 3.8 | 6.2 | 67.5 | 0.003824 | 3.3 | 4 | 0.0053 | 1.9 |
| 417 | 4.9 | 6.2 | 67.5 | 0.006361 | 3.3 | 4 | 0.0015 | 0.5 |
| 418 | 4.9 | 7.5 | 67.5 | 0.003645 | 3.3 | 4 | 0.0016 | 0.6 |
| 419 | 6 | 7.5 | 67.5 | 0.005467 | 3.3 | 4 | 0.0006 | 0.2 |
| 420 | 1.7 | 9.7 | 67.5 | 0.000228 | 3.3 | 4 | 0.0006 | 0.2 |
| 421 | 2.7 | 11.8 | 67.5 | 0.000344 | 4 | 10 | 0.0005 | 0.2 |
| 422 | 1.7 | 4.3 | 90 | 0.002754 | 3.3 | 4 | 0.0817 | 29.8 |
| 423 | 2.7 | 4.3 | 90 | 0.006960 | 3.3 | 4 | 0.0318 | 11.6 |
| 424 | 3.7 | 4.3 | 90 | 0.013081 | 3.3 | 4 | 0.0040 | 1.5 |
| 425 | 1.7 | 6.1 | 90 | 0.000804 | 3.3 | 4 | 0.0014 | 0.5 |
| 426 | 2.7 | 6.1 | 90 | 0.002031 | 3.3 | 4 | 0.0005 | 0.2 |
| 427 | 3.7 | 6.1 | 90 | 0.003816 | 3.3 | 4 | 0.0006 | 0.2 |
| 428 | 1.7 | 8 | 90 | 0.000369 | 3.3 | 4 | 0.0039 | 1.4 |
| 429 | 2.7 | 8 | 90 | 0.000932 | 3.3 | 4 | 0.0016 | 0.6 |
| 430 | 3.7 | 8 | 90 | 0.001752 | 3.3 | 4 | 0.0006 | 0.2 |
| 431 | 4.9 | 8 | 90 | 0.003073 | 3.3 | 4 | 0.0008 | 0.3 |
| 432 | 1.7 | 9.5 | 90 | 0.000240 | 3.3 | 4 | 0.0051 | 1.9 |
| 433 | 2.7 | 9.5 | 90 | 0.000606 | 3.3 | 4 | 0.0043 | 1.6 |
| 434 | 3.7 | 9.5 | 90 | 0.001138 | 3.3 | 4 | 0.0019 | 0.7 |
| 435 | 4.9 | 9.5 | 90 | 0.001998 | 3.3 | 4 | 0.0009 | 0.3 |
| 436 | 1.7 | 11.8 | 90 | 0.000137 | 4 | 10 | 0.0035 | 1.3 |
| 437 | 2.7 | 11.8 | 90 | 0.000344 | 4 | 10 | 0.0034 | 1.2 |
| 438 | 3.7 | 11.8 | 90 | 0.000647 | 4 | 10 | 0.0010 | 0.4 |
| 439 | 4.9 | 11.8 | 90 | 0.001135 | 4 | 10 | 0.0005 | 0.2 |

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 440 | 2.7 | 14.3 | 90 | 0.000199 | 5 | 16 | 0.0007 | 0.3 |
| 441 | 1.6 | 4.5 | 112.5 | 0.002048 | 3.3 | 4 | 0.1110 | 40.5 |
| 442 | 2.7 | 4.5 | 112.5 | 0.005841 | 3.3 | 4 | 0.0258 | 9.4 |
| 443 | 3.7 | 4.5 | 112.5 | 0.010978 | 3.3 | 4 | 0.0026 | 0.9 |
| 444 | 1.6 | 6.1 | 112.5 | 0.000712 | 3.3 | 4 | 0.0082 | 3.0 |
| 445 | 2.7 | 6.1 | 112.5 | 0.002031 | 3.3 | 4 | 0.0016 | 0.6 |
| 446 | 3.7 | 6.1 | 112.5 | 0.003816 | 3.3 | 4 | 0.0010 | 0.4 |
| 447 | 1.6 | 7.8 | 112.5 | 0.000349 | 3.3 | 4 | 0.0082 | 3.0 |
| 448 | 2.7 | 7.8 | 112.5 | 0.000997 | 3.3 | 4 | 0.0020 | 0.7 |
| 449 | 3.7 | 7.8 | 112.5 | 0.001873 | 3.3 | 4 | 0.0014 | 0.5 |
| 450 | 1.6 | 9.4 | 112.5 | 0.000219 | 3.3 | 4 | 0.0046 | 1.7 |
| 451 | 2.7 | 9.4 | 112.5 | 0.000622 | 3.3 | 4 | 0.0030 | 1.1 |
| 452 | 3.7 | 9.4 | 112.5 | 0.001169 | 3.3 | 4 | 0.0013 | 0.5 |
| 453 | 4.9 | 9.4 | 112.5 | 0.002051 | 3.3 | 4 | 0.0011 | 0.4 |
| 454 | 1.6 | 12 | 112.5 | 0.000116 | 4 | 10 | 0.0023 | 0.8 |
| 455 | 2.7 | 12 | 112.5 | 0.000330 | 4 | 10 | 0.0023 | 0.8 |
| 456 | 3.7 | 12 | 112.5 | 0.000620 | 4 | 10 | 0.0011 | 0.4 |
| 457 | 4.9 | 12 | 112.5 | 0.001086 | 4 | 10 | 0.0008 | 0.3 |
| 458 | 1.6 | 14.4 | 112.5 | 0.000069 | 5 | 16 | 0.0007 | 0.3 |
| 459 | 4.9 | 14.4 | 112.5 | 0.000648 | 5 | 16 | 0.0005 | 0.2 |
| 460 | 1.6 | 4.2 | 135 | 0.002677 | 3.3 | 4 | 0.0780 | 28.5 |
| 461 | 2.7 | 4.2 | 135 | 0.007638 | 3.3 | 4 | 0.0139 | 5.1 |
| 462 | 3.8 | 4.2 | 135 | 0.015142 | 3.3 | 4 | 0.0014 | 0.5 |
| 463 | 1.6 | 6.1 | 135 | 0.000712 | 3.3 | 4 | 0.0050 | 1.8 |
| 464 | 2.7 | 6.1 | 135 | 0.002031 | 3.3 | 4 | 0.0013 | 0.5 |
| 465 | 3.8 | 6.1 | 135 | 0.004025 | 3.3 | 4 | 0.0010 | 0.4 |
| 466 | 1.6 | 7.8 | 135 | 0.000349 | 3.3 | 4 | 0.0029 | 1.1 |
| 467 | 2.7 | 7.8 | 135 | 0.000997 | 3.3 | 4 | 0.0016 | 0.6 |
| 468 | 3.8 | 7.8 | 135 | 0.001976 | 3.3 | 4 | 0.0012 | 0.4 |
| 469 | 4.8 | 7.8 | 135 | 0.003153 | 3.3 | 4 | 0.0006 | 0.2 |
| 470 | 1.6 | 9.4 | 135 | 0.000219 | 3.3 | 4 | 0.0010 | 0.4 |
| 471 | 2.7 | 9.4 | 135 | 0.000622 | 3.3 | 4 | 0.0011 | 0.4 |
| 472 | 3.8 | 9.4 | 135 | 0.001233 | 3.3 | 4 | 0.0008 | 0.3 |
| 473 | 4.8 | 9.4 | 135 | 0.001968 | 3.3 | 4 | 0.0008 | 0.3 |
| 474 | 1.6 | 11.7 | 135 | 0.000123 | 4 | 10 | 0.0005 | 0.2 |
| 475 | 1.6 | 4.1 | 157.5 | 0.002946 | 3.3 | 4 | 0.0466 | 17.0 |
| 476 | 2.7 | 4.1 | 157.5 | 0.008405 | 3.3 | 4 | 0.0105 | 3.8 |
| 477 | 3.8 | 4.1 | 157.5 | 0.016663 | 3.3 | 4 | 0.0019 | 0.7 |
| 478 | 1.6 | 6 | 157.5 | 0.000751 | 3.3 | 4 | 0.0005 | 0.2 |
| 479 | 2.7 | 6 | 157.5 | 0.002141 | 3.3 | 4 | 0.0005 | 0.2 |

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 480 | 3.8 | 6 | 157.5 | 0.004246 | 3.3 | 4 | 0.0011 | 0.4 |
| 481 | 3.8 | 7.9 | 157.5 | 0.001911 | 3.3 | 4 | 0.0006 | 0.2 |
| 482 | 4.8 | 7.9 | 157.5 | 0.003050 | 3.3 | 4 | 0.0006 | 0.2 |
| 483 | 1.6 | 4.1 | 180 | 0.002946 | 3.3 | 4 | 0.0327 | 11.9 |
| 484 | 2.7 | 4.1 | 180 | 0.008405 | 3.3 | 4 | 0.0107 | 3.9 |
| 485 | 3.8 | 4.1 | 180 | 0.016663 | 3.3 | 4 | 0.0018 | 0.7 |
| 486 | 2.7 | 6 | 180 | 0.002141 | 3.3 | 4 | 0.0009 | 0.3 |
| 487 | 3.8 | 6 | 180 | 0.004246 | 3.3 | 4 | 0.0016 | 0.6 |
| 488 | 4.8 | 6 | 180 | 0.006777 | 3.3 | 4 | 0.0006 | 0.2 |
| 489 | 1.6 | 4.2 | 202.5 | 0.002677 | 3.3 | 4 | 0.0242 | 8.8 |
| 490 | 2.7 | 4.2 | 202.5 | 0.007638 | 3.3 | 4 | 0.0100 | 3.7 |
| 491 | 3.8 | 4.2 | 202.5 | 0.015142 | 3.3 | 4 | 0.0018 | 0.7 |
| 492 | 2.7 | 5.9 | 202.5 | 0.002260 | 3.3 | 4 | 0.0011 | 0.4 |
| 493 | 3.8 | 5.9 | 202.5 | 0.004480 | 3.3 | 4 | 0.0024 | 0.9 |
| 494 | 4.8 | 5.9 | 202.5 | 0.007150 | 3.3 | 4 | 0.0007 | 0.3 |
| 495 | 1.6 | 4.2 | 225 | 0.002677 | 3.3 | 4 | 0.0205 | 7.5 |
| 496 | 2.7 | 4.2 | 225 | 0.007638 | 3.3 | 4 | 0.0098 | 3.6 |
| 497 | 3.7 | 4.2 | 225 | 0.014355 | 3.3 | 4 | 0.0017 | 0.6 |
| 498 | 2.7 | 5.8 | 225 | 0.002386 | 3.3 | 4 | 0.0008 | 0.3 |
| 499 | 3.7 | 5.8 | 225 | 0.004485 | 3.3 | 4 | 0.0015 | 0.5 |
| | | | | | | | | |
| | | | | | | | Total Days: | 292.7 |
| | | | | | | | Calm Days: | 72.3 |

Table B5. Wave climatology in Savannah Outer Channel, Reach 5, Station 24

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 501 | 1.8 | 4 | 22.5 | 0.004122 | 3.3 | 4 | 0.0217 | 7.9 |
| 502 | 2.7 | 4 | 22.5 | 0.009287 | 3.3 | 4 | 0.0080 | 2.9 |
| 503 | 3.7 | 4 | 22.5 | 0.017454 | 3.3 | 4 | 0.0010 | 0.4 |
| 504 | 1.8 | 4.3 | 45 | 0.003089 | 3.3 | 4 | 0.0273 | 10.0 |
| 505 | 2.8 | 4.3 | 45 | 0.007486 | 3.3 | 4 | 0.0262 | 9.6 |
| 506 | 3.9 | 4.3 | 45 | 0.014534 | 3.3 | 4 | 0.0023 | 0.8 |
| 507 | 2.8 | 6.1 | 45 | 0.002185 | 3.3 | 4 | 0.0026 | 0.9 |
| 508 | 3.9 | 6.1 | 45 | 0.004241 | 3.3 | 4 | 0.0096 | 3.5 |
| 509 | 5 | 6.1 | 45 | 0.006972 | 3.3 | 4 | 0.0008 | 0.3 |
| 510 | 5 | 7.3 | 45 | 0.004097 | 3.3 | 4 | 0.0022 | 0.8 |
| 511 | 6.2 | 7.3 | 45 | 0.006302 | 3.3 | 4 | 0.0008 | 0.3 |
| 512 | 1.7 | 4.2 | 67.5 | 0.003023 | 3.3 | 4 | 0.0373 | 13.6 |
| 513 | 2.7 | 4.2 | 67.5 | 0.007638 | 3.3 | 4 | 0.0251 | 9.2 |
| 514 | 3.9 | 4.2 | 67.5 | 0.015950 | 3.3 | 4 | 0.0020 | 0.7 |
| 515 | 2.7 | 6.2 | 67.5 | 0.001929 | 3.3 | 4 | 0.0010 | 0.4 |
| 516 | 3.9 | 6.2 | 67.5 | 0.004028 | 3.3 | 4 | 0.0053 | 1.9 |
| 517 | 5 | 6.2 | 67.5 | 0.006623 | 3.3 | 4 | 0.0015 | 0.5 |
| 518 | 5 | 7.5 | 67.5 | 0.003795 | 3.3 | 4 | 0.0016 | 0.6 |
| 519 | 6.2 | 7.5 | 67.5 | 0.005838 | 3.3 | 4 | 0.0006 | 0.2 |
| 520 | 1.7 | 9.7 | 67.5 | 0.000228 | 3.3 | 4 | 0.0006 | 0.2 |
| 521 | 2.7 | 11.8 | 67.5 | 0.000344 | 4 | 10 | 0.0005 | 0.2 |
| 522 | 1.7 | 4.3 | 90 | 0.002754 | 3.3 | 4 | 0.0817 | 29.8 |
| 523 | 2.7 | 4.3 | 90 | 0.006960 | 3.3 | 4 | 0.0318 | 11.6 |
| 524 | 3.8 | 4.3 | 90 | 0.013798 | 3.3 | 4 | 0.0040 | 1.5 |
| 525 | 1.7 | 6.1 | 90 | 0.000804 | 3.3 | 4 | 0.0014 | 0.5 |
| 526 | 2.7 | 6.1 | 90 | 0.002031 | 3.3 | 4 | 0.0005 | 0.2 |
| 527 | 3.8 | 6.1 | 90 | 0.004025 | 3.3 | 4 | 0.0006 | 0.2 |
| 528 | 1.7 | 8 | 90 | 0.000369 | 3.3 | 4 | 0.0039 | 1.4 |
| 529 | 2.7 | 8 | 90 | 0.000932 | 3.3 | 4 | 0.0016 | 0.6 |
| 530 | 3.8 | 8 | 90 | 0.001847 | 3.3 | 4 | 0.0006 | 0.2 |
| 531 | 5.1 | 8 | 90 | 0.003329 | 3.3 | 4 | 0.0008 | 0.3 |
| 532 | 1.7 | 9.5 | 90 | 0.000240 | 3.3 | 4 | 0.0051 | 1.9 |
| 533 | 2.7 | 9.5 | 90 | 0.000606 | 3.3 | 4 | 0.0043 | 1.6 |
| 534 | 3.8 | 9.5 | 90 | 0.001201 | 3.3 | 4 | 0.0019 | 0.7 |
| 535 | 5.1 | 9.5 | 90 | 0.002164 | 3.3 | 4 | 0.0009 | 0.3 |
| 536 | 1.7 | 11.8 | 90 | 0.000137 | 4 | 10 | 0.0035 | 1.3 |
| 537 | 2.7 | 11.8 | 90 | 0.000344 | 4 | 10 | 0.0034 | 1.2 |
| 538 | 3.8 | 11.8 | 90 | 0.000683 | 4 | 10 | 0.0010 | 0.4 |
| 539 | 5.1 | 11.8 | 90 | 0.001229 | 4 | 10 | 0.0005 | 0.2 |

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 540 | 2.7 | 14.3 | 90 | 0.000199 | 5 | 16 | 0.0007 | 0.3 |
| 541 | 1.6 | 4.5 | 112.5 | 0.002048 | 3.3 | 4 | 0.1110 | 40.5 |
| 542 | 2.7 | 4.5 | 112.5 | 0.005841 | 3.3 | 4 | 0.0258 | 9.4 |
| 543 | 3.8 | 4.5 | 112.5 | 0.011580 | 3.3 | 4 | 0.0026 | 0.9 |
| 544 | 1.6 | 6.1 | 112.5 | 0.000712 | 3.3 | 4 | 0.0082 | 3.0 |
| 545 | 2.7 | 6.1 | 112.5 | 0.002031 | 3.3 | 4 | 0.0016 | 0.6 |
| 546 | 3.8 | 6.1 | 112.5 | 0.004025 | 3.3 | 4 | 0.0010 | 0.4 |
| 547 | 1.6 | 7.8 | 112.5 | 0.000349 | 3.3 | 4 | 0.0082 | 3.0 |
| 548 | 2.7 | 7.8 | 112.5 | 0.000997 | 3.3 | 4 | 0.0020 | 0.7 |
| 549 | 3.8 | 7.8 | 112.5 | 0.001976 | 3.3 | 4 | 0.0014 | 0.5 |
| 550 | 1.6 | 9.4 | 112.5 | 0.000219 | 3.3 | 4 | 0.0046 | 1.7 |
| 551 | 2.7 | 9.4 | 112.5 | 0.000622 | 3.3 | 4 | 0.0030 | 1.1 |
| 552 | 3.8 | 9.4 | 112.5 | 0.001233 | 3.3 | 4 | 0.0013 | 0.5 |
| 553 | 5.1 | 9.4 | 112.5 | 0.002222 | 3.3 | 4 | 0.0011 | 0.4 |
| 554 | 1.6 | 12 | 112.5 | 0.000116 | 4 | 10 | 0.0023 | 0.8 |
| 555 | 2.7 | 12 | 112.5 | 0.000330 | 4 | 10 | 0.0023 | 0.8 |
| 556 | 3.8 | 12 | 112.5 | 0.000653 | 4 | 10 | 0.0011 | 0.4 |
| 557 | 5.1 | 12 | 112.5 | 0.001177 | 4 | 10 | 0.0008 | 0.3 |
| 558 | 1.6 | 14.4 | 112.5 | 0.000069 | 5 | 16 | 0.0007 | 0.3 |
| 559 | 5.1 | 14.4 | 112.5 | 0.000701 | 5 | 16 | 0.0005 | 0.2 |
| 560 | 1.6 | 4.2 | 135 | 0.002677 | 3.3 | 4 | 0.0780 | 28.5 |
| 561 | 2.7 | 4.2 | 135 | 0.007638 | 3.3 | 4 | 0.0139 | 5.1 |
| 562 | 3.9 | 4.2 | 135 | 0.015950 | 3.3 | 4 | 0.0014 | 0.5 |
| 563 | 1.6 | 6.1 | 135 | 0.000712 | 3.3 | 4 | 0.0050 | 1.8 |
| 564 | 2.7 | 6.1 | 135 | 0.002031 | 3.3 | 4 | 0.0013 | 0.5 |
| 565 | 3.9 | 6.1 | 135 | 0.004241 | 3.3 | 4 | 0.0010 | 0.4 |
| 566 | 1.6 | 7.8 | 135 | 0.000349 | 3.3 | 4 | 0.0029 | 1.1 |
| 567 | 2.7 | 7.8 | 135 | 0.000997 | 3.3 | 4 | 0.0016 | 0.6 |
| 568 | 3.9 | 7.8 | 135 | 0.002081 | 3.3 | 4 | 0.0012 | 0.4 |
| 569 | 4.9 | 7.8 | 135 | 0.003286 | 3.3 | 4 | 0.0006 | 0.2 |
| 570 | 1.6 | 9.4 | 135 | 0.000219 | 3.3 | 4 | 0.0010 | 0.4 |
| 571 | 2.7 | 9.4 | 135 | 0.000622 | 3.3 | 4 | 0.0011 | 0.4 |
| 572 | 3.9 | 9.4 | 135 | 0.001299 | 3.3 | 4 | 0.0008 | 0.3 |
| 573 | 4.9 | 9.4 | 135 | 0.002051 | 3.3 | 4 | 0.0008 | 0.3 |
| 574 | 1.6 | 11.7 | 135 | 0.000123 | 4 | 10 | 0.0005 | 0.2 |
| 575 | 1.7 | 4.1 | 157.5 | 0.003326 | 3.3 | 4 | 0.0466 | 17.0 |
| 576 | 2.7 | 4.1 | 157.5 | 0.008405 | 3.3 | 4 | 0.0105 | 3.8 |
| 577 | 3.9 | 4.1 | 157.5 | 0.017553 | 3.3 | 4 | 0.0019 | 0.7 |
| 578 | 1.7 | 6 | 157.5 | 0.000848 | 3.3 | 4 | 0.0005 | 0.2 |
| 579 | 2.7 | 6 | 157.5 | 0.002141 | 3.3 | 4 | 0.0005 | 0.2 |

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 580 | 3.9 | 6 | 157.5 | 0.004472 | 3.3 | 4 | 0.0011 | 0.4 |
| 581 | 3.9 | 7.9 | 157.5 | 0.002013 | 3.3 | 4 | 0.0006 | 0.2 |
| 582 | 5 | 7.9 | 157.5 | 0.003310 | 3.3 | 4 | 0.0006 | 0.2 |
| 583 | 1.7 | 4.1 | 180 | 0.003326 | 3.3 | 4 | 0.0327 | 11.9 |
| 584 | 2.8 | 4.1 | 180 | 0.009041 | 3.3 | 4 | 0.0107 | 3.9 |
| 585 | 3.9 | 4.1 | 180 | 0.017553 | 3.3 | 4 | 0.0018 | 0.7 |
| 586 | 2.8 | 6 | 180 | 0.002303 | 3.3 | 4 | 0.0009 | 0.3 |
| 587 | 3.9 | 6 | 180 | 0.004472 | 3.3 | 4 | 0.0016 | 0.6 |
| 588 | 4.9 | 6 | 180 | 0.007063 | 3.3 | 4 | 0.0006 | 0.2 |
| 589 | 1.7 | 4.2 | 202.5 | 0.003023 | 3.3 | 4 | 0.0242 | 8.8 |
| 590 | 2.8 | 4.2 | 202.5 | 0.008215 | 3.3 | 4 | 0.0100 | 3.7 |
| 591 | 3.9 | 4.2 | 202.5 | 0.015950 | 3.3 | 4 | 0.0018 | 0.7 |
| 592 | 2.8 | 5.9 | 202.5 | 0.002430 | 3.3 | 4 | 0.0011 | 0.4 |
| 593 | 3.9 | 5.9 | 202.5 | 0.004719 | 3.3 | 4 | 0.0024 | 0.9 |
| 594 | 5 | 5.9 | 202.5 | 0.007759 | 3.3 | 4 | 0.0007 | 0.3 |
| 595 | 1.7 | 4.2 | 225 | 0.003023 | 3.3 | 4 | 0.0205 | 7.5 |
| 596 | 2.8 | 4.2 | 225 | 0.008215 | 3.3 | 4 | 0.0098 | 3.6 |
| 597 | 3.8 | 4.2 | 225 | 0.015142 | 3.3 | 4 | 0.0017 | 0.6 |
| 598 | 2.8 | 5.8 | 225 | 0.002567 | 3.3 | 4 | 0.0008 | 0.3 |
| 599 | 3.8 | 5.8 | 225 | 0.004731 | 3.3 | 4 | 0.0015 | 0.5 |
| | | | | | | | | |
| | | | | | | | Total Days: | 292.7 |
| | | | | | | | Calm Days: | 72.3 |

Table B6. Wave climatology in Savannah Outer Channel, Reach 6, Station 15

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 601 | 0.9 | 4 | 22.5 | 0.001026 | 3.3 | 4 | 0.0217 | 7.9 |
| 602 | 1.3 | 4 | 22.5 | 0.002147 | 3.3 | 4 | 0.0080 | 2.9 |
| 603 | 1.8 | 4 | 22.5 | 0.004122 | 3.3 | 4 | 0.0010 | 0.4 |
| 604 | 0.9 | 4.3 | 45 | 0.000769 | 3.3 | 4 | 0.0273 | 10.0 |
| 605 | 1.4 | 4.3 | 45 | 0.001866 | 3.3 | 4 | 0.0262 | 9.6 |
| 606 | 1.9 | 4.3 | 45 | 0.003443 | 3.3 | 4 | 0.0023 | 0.8 |
| 607 | 1.4 | 6.1 | 45 | 0.000545 | 3.3 | 4 | 0.0026 | 0.9 |
| 608 | 1.9 | 6.1 | 45 | 0.001005 | 3.3 | 4 | 0.0096 | 3.5 |
| 609 | 2.5 | 6.1 | 45 | 0.001741 | 3.3 | 4 | 0.0008 | 0.3 |
| 610 | 2.5 | 7.3 | 45 | 0.001023 | 3.3 | 4 | 0.0022 | 0.8 |
| 611 | 3 | 7.3 | 45 | 0.001474 | 3.3 | 4 | 0.0008 | 0.3 |
| 612 | 0.8 | 4.2 | 67.5 | 0.000667 | 3.3 | 4 | 0.0373 | 13.6 |
| 613 | 1.3 | 4.2 | 67.5 | 0.001765 | 3.3 | 4 | 0.0251 | 9.2 |
| 614 | 1.9 | 4.2 | 67.5 | 0.003778 | 3.3 | 4 | 0.0020 | 0.7 |
| 615 | 1.3 | 6.2 | 67.5 | 0.000446 | 3.3 | 4 | 0.0010 | 0.4 |
| 616 | 1.9 | 6.2 | 67.5 | 0.000954 | 3.3 | 4 | 0.0053 | 1.9 |
| 617 | 2.5 | 6.2 | 67.5 | 0.001654 | 3.3 | 4 | 0.0015 | 0.5 |
| 618 | 2.5 | 7.5 | 67.5 | 0.000948 | 3.3 | 4 | 0.0016 | 0.6 |
| 619 | 3 | 7.5 | 67.5 | 0.001365 | 3.3 | 4 | 0.0006 | 0.2 |
| 620 | 0.8 | 9.7 | 67.5 | 0.000050 | 3.3 | 4 | 0.0006 | 0.2 |
| 621 | 1.3 | 11.8 | 67.5 | 0.000080 | 4 | 10 | 0.0005 | 0.2 |
| 622 | 0.8 | 4.3 | 90 | 0.000607 | 3.3 | 4 | 0.0817 | 29.8 |
| 623 | 1.3 | 4.3 | 90 | 0.001608 | 3.3 | 4 | 0.0318 | 11.6 |
| 624 | 1.9 | 4.3 | 90 | 0.003443 | 3.3 | 4 | 0.0040 | 1.5 |
| 625 | 0.8 | 6.1 | 90 | 0.000178 | 3.3 | 4 | 0.0014 | 0.5 |
| 626 | 1.3 | 6.1 | 90 | 0.000470 | 3.3 | 4 | 0.0005 | 0.2 |
| 627 | 1.9 | 6.1 | 90 | 0.001005 | 3.3 | 4 | 0.0006 | 0.2 |
| 628 | 0.8 | 8 | 90 | 0.000082 | 3.3 | 4 | 0.0039 | 1.4 |
| 629 | 1.3 | 8 | 90 | 0.000216 | 3.3 | 4 | 0.0016 | 0.6 |
| 630 | 1.9 | 8 | 90 | 0.000461 | 3.3 | 4 | 0.0006 | 0.2 |
| 631 | 2.5 | 8 | 90 | 0.000799 | 3.3 | 4 | 0.0008 | 0.3 |
| 632 | 0.8 | 9.5 | 90 | 0.000054 | 3.3 | 4 | 0.0051 | 1.9 |
| 633 | 1.3 | 9.5 | 90 | 0.000141 | 3.3 | 4 | 0.0043 | 1.6 |
| 634 | 1.9 | 9.5 | 90 | 0.000300 | 3.3 | 4 | 0.0019 | 0.7 |
| 635 | 2.5 | 9.5 | 90 | 0.000520 | 3.3 | 4 | 0.0009 | 0.3 |
| 636 | 0.8 | 11.8 | 90 | 0.000030 | 4 | 10 | 0.0035 | 1.3 |
| 637 | 1.3 | 11.8 | 90 | 0.000080 | 4 | 10 | 0.0034 | 1.2 |
| 638 | 1.9 | 11.8 | 90 | 0.000171 | 4 | 10 | 0.0010 | 0.4 |
| 639 | 2.5 | 11.8 | 90 | 0.000295 | 4 | 10 | 0.0005 | 0.2 |

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 640 | 60.47 | 14.3 | 90 | 0.100005 | 5 | 16 | 0.0007 | 0.3 |
| 641 | 0.8 | 4.5 | 112.5 | 0.000509 | 3.3 | 4 | 0.1110 | 40.5 |
| 642 | 1.3 | 4.5 | 112.5 | 0.001350 | 3.3 | 4 | 0.0258 | 9.4 |
| 643 | 1.9 | 4.5 | 112.5 | 0.002889 | 3.3 | 4 | 0.0026 | 0.9 |
| 644 | 0.8 | 6.1 | 112.5 | 0.000178 | 3.3 | 4 | 0.0082 | 3.0 |
| 645 | 1.3 | 6.1 | 112.5 | 0.000470 | 3.3 | 4 | 0.0016 | 0.6 |
| 646 | 1.9 | 6.1 | 112.5 | 0.001005 | 3.3 | 4 | 0.0010 | 0.4 |
| 647 | 0.8 | 7.8 | 112.5 | 0.000087 | 3.3 | 4 | 0.0082 | 3.0 |
| 648 | 1.3 | 7.8 | 112.5 | 0.000231 | 3.3 | 4 | 0.0020 | 0.7 |
| 649 | 1.9 | 7.8 | 112.5 | 0.000494 | 3.3 | 4 | 0.0014 | 0.5 |
| 650 | 0.8 | 9.4 | 112.5 | 0.000055 | 3.3 | 4 | 0.0046 | 1.7 |
| 651 | 1.3 | 9.4 | 112.5 | 0.000144 | 3.3 | 4 | 0.0030 | 1.1 |
| 652 | 1.9 | 9.4 | 112.5 | 0.000308 | 3.3 | 4 | 0.0013 | 0.5 |
| 653 | 2.5 | 9.4 | 112.5 | 0.000533 | 3.3 | 4 | 0.0011 | 0.4 |
| 654 | 0.8 | 12 | 112.5 | 0.000029 | 4 | 10 | 0.0023 | 0.8 |
| 655 | 1.3 | 12 | 112.5 | 0.000076 | 4 | 10 | 0.0023 | 0.8 |
| 656 | 1.9 | 12 | 112.5 | 0.000164 | 4 | 10 | 0.0011 | 0.4 |
| 657 | 2.5 | 12 | 112.5 | 0.000283 | 4 | 10 | 0.0008 | 0.3 |
| 658 | 0.8 | 14.4 | 112.5 | 0.000017 | 5 | 16 | 0.0007 | 0.3 |
| 659 | 2.5 | 14.4 | 112.5 | 0.000168 | 5 | 16 | 0.0005 | 0.2 |
| 660 | 0.8 | 4.2 | 135 | 0.000667 | 3.3 | 4 | 0.0780 | 28.5 |
| 661 | 1.3 | 4.2 | 135 | 0.001765 | 3.3 | 4 | 0.0139 | 5.1 |
| 662 | 1.9 | 4.2 | 135 | 0.003778 | 3.3 | 4 | 0.0014 | 0.5 |
| 663 | 0.8 | 6.1 | 135 | 0.000178 | 3.3 | 4 | 0.0050 | 1.8 |
| 664 | 1.3 | 6.1 | 135 | 0.000470 | 3.3 | 4 | 0.0013 | 0.5 |
| 665 | 1.9 | 6.1 | 135 | 0.001005 | 3.3 | 4 | 0.0010 | 0.4 |
| 666 | 0.8 | 7.8 | 135 | 0.000087 | 3.3 | 4 | 0.0029 | 1.1 |
| 667 | 1.3 | 7.8 | 135 | 0.000231 | 3.3 | 4 | 0.0016 | 0.6 |
| 668 | 1.9 | 7.8 | 135 | 0.000494 | 3.3 | 4 | 0.0012 | 0.4 |
| 669 | 2.4 | 7.8 | 135 | 0.000788 | 3.3 | 4 | 0.0006 | 0.2 |
| 670 | 0.8 | 9.4 | 135 | 0.000055 | 3.3 | 4 | 0.0010 | 0.4 |
| 671 | 1.3 | 9.4 | 135 | 0.000144 | 3.3 | 4 | 0.0011 | 0.4 |
| 672 | 1.9 | 9.4 | 135 | 0.000308 | 3.3 | 4 | 0.0008 | 0.3 |
| 673 | 2.4 | 9.4 | 135 | 0.000491 | 3.3 | 4 | 0.0008 | 0.3 |
| 674 | 45.52 | 11.7 | 135 | 0.100002 | 4 | 10 | 0.0005 | 0.2 |
| 675 | 0.8 | 4.1 | 157.5 | 0.000734 | 3.3 | 4 | 0.0466 | 17.0 |
| 676 | 1.3 | 4.1 | 157.5 | 0.001943 | 3.3 | 4 | 0.0105 | 3.8 |
| 677 | 1.9 | 4.1 | 157.5 | 0.004157 | 3.3 | 4 | 0.0019 | 0.7 |
| 678 | 0.8 | 6 | 157.5 | 0.000187 | 3.3 | 4 | 0.0005 | 0.2 |
| 679 | 1.3 | 6 | 157.5 | 0.000496 | 3.3 | 4 | 0.0005 | 0.2 |

| ID | $H_s$ (ft) | $T_p$ (sec) | Direction (deg) | α | γ | n | Probability | Days/yr |
|---|---|---|---|---|---|---|---|---|
| 680 | 1.9 | 6 | 157.5 | 0.001060 | 3.3 | 4 | 0.0011 | 0.4 |
| 681 | 1.9 | 7.9 | 157.5 | 0.000477 | 3.3 | 4 | 0.0006 | 0.2 |
| 682 | 2.4 | 7.9 | 157.5 | 0.000762 | 3.3 | 4 | 0.0006 | 0.2 |
| 683 | 0.8 | 4.1 | 180 | 0.000734 | 3.3 | 4 | 0.0327 | 11.9 |
| 684 | 1.4 | 4.1 | 180 | 0.002254 | 3.3 | 4 | 0.0107 | 3.9 |
| 685 | 1.9 | 4.1 | 180 | 0.004157 | 3.3 | 4 | 0.0018 | 0.7 |
| 686 | 1.4 | 6 | 180 | 0.000575 | 3.3 | 4 | 0.0009 | 0.3 |
| 687 | 1.9 | 6 | 180 | 0.001060 | 3.3 | 4 | 0.0016 | 0.6 |
| 688 | 2.4 | 6 | 180 | 0.001692 | 3.3 | 4 | 0.0006 | 0.2 |
| 689 | 0.8 | 4.2 | 202.5 | 0.000667 | 3.3 | 4 | 0.0242 | 8.8 |
| 690 | 1.4 | 4.2 | 202.5 | 0.002048 | 3.3 | 4 | 0.0100 | 3.7 |
| 691 | 1.9 | 4.2 | 202.5 | 0.003778 | 3.3 | 4 | 0.0018 | 0.7 |
| 692 | 1.4 | 5.9 | 202.5 | 0.000606 | 3.3 | 4 | 0.0011 | 0.4 |
| 693 | 1.9 | 5.9 | 202.5 | 0.001118 | 3.3 | 4 | 0.0024 | 0.9 |
| 694 | 2.4 | 5.9 | 202.5 | 0.001785 | 3.3 | 4 | 0.0007 | 0.3 |
| 695 | 0.8 | 4.2 | 225 | 0.000667 | 3.3 | 4 | 0.0205 | 7.5 |
| 696 | 1.4 | 4.2 | 225 | 0.002048 | 3.3 | 4 | 0.0098 | 3.6 |
| 697 | 1.9 | 4.2 | 225 | 0.003778 | 3.3 | 4 | 0.0017 | 0.6 |
| 698 | 1.4 | 5.8 | 225 | 0.000640 | 3.3 | 4 | 0.0008 | 0.3 |
| 699 | 1.9 | 5.8 | 225 | 0.001180 | 3.3 | 4 | 0.0015 | 0.5 |
| | | | | | | | | |
| | | | | | | | Total Days: | 292.7 |
| | | | | | | | Calm Days: | 72.3 |

# Appendix C: Days of Accessibility for Light- and Fully-loaded *Susan Maersk* for Savannah Channels: S-1_Sta39, S-3_Sta39, S-8_Sta39, S-1_Sta0, and S-8_Sta 0

Table C1. Days of accessibility for Savannah S-1_Sta39 Channel, Reaches R1 to R3, light-loaded *Susan Maersk*, inbound and outbound transits.

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| Reach R1: S-1a | | | | | | | | | | | | |
| 48 | 351 | 348 | 325 | 72 | 0 | 0 | 359 | 355 | 347 | 78 | 0 | 0 |
| 49 | 359 | 357 | 350 | 339 | 97 | 0 | 363 | 362 | 361 | 355 | 302 | 0 |
| 50 | 361 | 360 | 358 | 351 | 337 | 303 | 364 | 364 | 364 | 363 | 358 | 334 |
| 51 | 363 | 363 | 361 | 358 | 350 | 325 | 364 | 364 | 364 | 364 | 364 | 352 |
| 52 | 363 | 363 | 363 | 361 | 356 | 334 | 364 | 364 | 364 | 364 | 364 | 362 |
| 53 | 364 | 364 | 364 | 363 | 360 | 347 | 365 | 365 | 365 | 365 | 365 | 364 |
| 54 | 364 | 364 | 365 | 364 | 363 | 350 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 364 | 363 | 355 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 359 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R2: S-1b | | | | | | | | | | | | |
| 48 | 354 | 349 | 333 | 72 | 0 | 0 | 359 | 356 | 349 | 78 | 0 | 0 |
| 49 | 360 | 357 | 350 | 343 | 111 | 0 | 363 | 363 | 362 | 356 | 310 | 0 |
| 50 | 361 | 360 | 360 | 356 | 340 | 306 | 364 | 364 | 364 | 364 | 358 | 335 |
| 51 | 363 | 363 | 363 | 360 | 351 | 325 | 364 | 364 | 364 | 364 | 364 | 356 |
| 52 | 364 | 364 | 364 | 363 | 358 | 339 | 365 | 365 | 365 | 365 | 364 | 363 |
| 53 | 364 | 364 | 364 | 364 | 360 | 348 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 364 | 363 | 354 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 363 | 357 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R3: Tybee | | | | | | | | | | | | |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 48 | 355 | 349 | 338 | 72 | 0 | 0 | 361 | 359 | 352 | 78 | 0 | 0 |
| 49 | 360 | 360 | 356 | 348 | 142 | 0 | 364 | 364 | 363 | 359 | 316 | 0 |
| 50 | 363 | 362 | 360 | 356 | 344 | 306 | 364 | 364 | 364 | 364 | 360 | 335 |
| 51 | 363 | 363 | 363 | 360 | 355 | 326 | 365 | 365 | 365 | 364 | 364 | 358 |
| 52 | 364 | 364 | 364 | 363 | 360 | 341 | 365 | 365 | 365 | 365 | 365 | 364 |
| 53 | 365 | 365 | 365 | 364 | 361 | 350 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 365 | 363 | 355 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| All 3 Reaches | | | | | | | | | | | | |
| 48 | 351 | 348 | 325 | 72 | 0 | 0 | 359 | 355 | 347 | 78 | 0 | 0 |
| 49 | 359 | 357 | 350 | 339 | 97 | 0 | 363 | 362 | 361 | 355 | 302 | 0 |
| 50 | 361 | 360 | 358 | 351 | 337 | 303 | 364 | 364 | 364 | 363 | 358 | 334 |
| 51 | 363 | 363 | 361 | 358 | 350 | 325 | 364 | 364 | 364 | 364 | 364 | 352 |
| 52 | 363 | 363 | 363 | 361 | 356 | 334 | 364 | 364 | 364 | 364 | 364 | 362 |
| 53 | 364 | 364 | 364 | 363 | 360 | 347 | 365 | 365 | 365 | 365 | 365 | 364 |
| 54 | 364 | 364 | 365 | 364 | 363 | 350 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 364 | 363 | 355 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 359 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |

Notes:
1. Depths 62 to 64 ft not included as all have 365 days per year accessibility.

Table C2. Days of accessibility for Savannah S-1_Sta39 Channel, Reaches 1 to 3, fully-loaded *Susan Maersk*, inbound and outbound transits.

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| Reach R1: S-1a | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 351 | 342 | 72 | 0 | 0 | 0 | 357 | 350 | 252 | 0 | 0 | 0 |
| 50 | 356 | 352 | 346 | 326 | 72 | 0 | 362 | 361 | 359 | 349 | 72 | 0 |
| 51 | 360 | 358 | 356 | 349 | 342 | 80 | 364 | 364 | 363 | 362 | 356 | 88 |
| 52 | 361 | 360 | 360 | 359 | 356 | 329 | 364 | 364 | 364 | 364 | 363 | 354 |
| 53 | 363 | 363 | 363 | 361 | 360 | 347 | 364 | 364 | 364 | 364 | 364 | 364 |
| 54 | 364 | 364 | 364 | 364 | 363 | 355 | 365 | 365 | 365 | 365 | 364 | 364 |
| 55 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R2: S-1b | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 352 | 342 | 88 | 0 | 0 | 0 | 358 | 353 | 261 | 0 | 0 | 0 |
| 50 | 357 | 356 | 346 | 330 | 72 | 0 | 362 | 362 | 359 | 352 | 72 | 0 |
| 51 | 361 | 360 | 357 | 352 | 342 | 88 | 364 | 364 | 364 | 362 | 358 | 73 |
| 52 | 363 | 362 | 360 | 360 | 358 | 331 | 364 | 364 | 364 | 364 | 364 | 358 |
| 53 | 363 | 363 | 363 | 363 | 361 | 351 | 365 | 365 | 365 | 364 | 364 | 364 |
| 54 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 364 |
| 55 | 364 | 365 | 365 | 365 | 364 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R3: Tybee | | | | | | | | | | | | |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 352 | 343 | 88 | 0 | 0 | 0 | 358 | 353 | 274 | 0 | 0 | 0 |
| 50 | 359 | 356 | 349 | 333 | 72 | 0 | 363 | 362 | 362 | 353 | 72 | 0 |
| 51 | 361 | 360 | 358 | 356 | 347 | 80 | 364 | 364 | 364 | 364 | 360 | 100 |
| 52 | 363 | 363 | 363 | 361 | 360 | 334 | 364 | 364 | 364 | 364 | 364 | 358 |
| 53 | 364 | 364 | 364 | 363 | 363 | 354 | 365 | 365 | 365 | 365 | 364 | 364 |
| 54 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| All 3 Reaches | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 351 | 342 | 72 | 0 | 0 | 0 | 357 | 350 | 252 | 0 | 0 | 0 |
| 50 | 356 | 352 | 346 | 326 | 72 | 0 | 362 | 361 | 359 | 349 | 72 | 0 |
| 51 | 360 | 358 | 356 | 349 | 342 | 80 | 364 | 364 | 363 | 362 | 356 | 73 |
| 52 | 361 | 360 | 360 | 359 | 356 | 329 | 364 | 364 | 364 | 364 | 363 | 354 |
| 53 | 363 | 363 | 363 | 361 | 360 | 347 | 364 | 364 | 364 | 364 | 364 | 364 |
| 54 | 364 | 364 | 364 | 364 | 363 | 355 | 365 | 365 | 365 | 365 | 364 | 364 |
| 55 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |

Notes:
1. Depths 62 to 64 ft not included as all have 365 days per year accessibility.

Table C3. Days of accessibility for Savannah S-3_Sta39 Channel, Reaches 1 to 3, light-loaded *Susan Maersk*, inbound and outbound transits.

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| Reach R1: S-3 | | | | | | | | | | | | |
| 48 | 352 | 349 | 333 | 72 | 0 | 0 | 359 | 357 | 348 | 76 | 0 | 0 |
| 49 | 360 | 358 | 350 | 340 | 134 | 0 | 363 | 364 | 362 | 358 | 312 | 0 |
| 50 | 362 | 360 | 360 | 354 | 335 | 304 | 364 | 365 | 364 | 363 | 359 | 333 |
| 51 | 363 | 363 | 363 | 360 | 350 | 326 | 365 | 365 | 365 | 365 | 364 | 356 |
| 52 | 364 | 364 | 364 | 363 | 356 | 336 | 365 | 365 | 365 | 365 | 365 | 363 |
| 53 | 364 | 364 | 364 | 364 | 360 | 348 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 364 | 363 | 351 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 364 | 355 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R2: S-1b | | | | | | | | | | | | |
| 48 | 354 | 349 | 333 | 72 | 0 | 0 | 359 | 356 | 349 | 78 | 0 | 0 |
| 49 | 360 | 357 | 350 | 343 | 111 | 0 | 363 | 363 | 362 | 356 | 310 | 0 |
| 50 | 361 | 360 | 360 | 356 | 340 | 306 | 364 | 364 | 364 | 364 | 358 | 335 |
| 51 | 363 | 363 | 363 | 360 | 351 | 325 | 364 | 364 | 364 | 364 | 364 | 356 |
| 52 | 364 | 364 | 364 | 363 | 358 | 339 | 365 | 365 | 365 | 365 | 364 | 363 |
| 53 | 364 | 364 | 364 | 364 | 360 | 348 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 364 | 363 | 354 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 363 | 357 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R3: Tybee | | | | | | | | | | | | |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 48 | 355 | 349 | 338 | 72 | 0 | 0 | 361 | 359 | 352 | 78 | 0 | 0 |
| 49 | 360 | 360 | 356 | 348 | 142 | 0 | 364 | 364 | 363 | 359 | 316 | 0 |
| 50 | 363 | 362 | 360 | 356 | 344 | 306 | 364 | 364 | 364 | 364 | 360 | 335 |
| 51 | 363 | 363 | 363 | 360 | 355 | 326 | 365 | 365 | 365 | 364 | 364 | 358 |
| 52 | 364 | 364 | 364 | 363 | 360 | 341 | 365 | 365 | 365 | 365 | 365 | 364 |
| 53 | 365 | 365 | 365 | 364 | 361 | 350 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 365 | 363 | 355 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| All 3 Reaches | | | | | | | | | | | | |
| 48 | 352 | 349 | 333 | 72 | 0 | 0 | 359 | 356 | 348 | 76 | 0 | 0 |
| 49 | 360 | 357 | 350 | 340 | 111 | 0 | 363 | 363 | 362 | 356 | 310 | 0 |
| 50 | 361 | 360 | 360 | 354 | 335 | 304 | 364 | 364 | 364 | 363 | 358 | 333 |
| 51 | 363 | 363 | 363 | 360 | 350 | 325 | 364 | 364 | 364 | 364 | 364 | 356 |
| 52 | 364 | 364 | 364 | 363 | 356 | 336 | 365 | 365 | 365 | 365 | 364 | 363 |
| 53 | 364 | 364 | 364 | 364 | 360 | 348 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 364 | 363 | 351 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 363 | 355 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |

Notes:

1. Depths 62 to 64 ft not included as all have 365 days per year accessibility.

Table C4. Days of accessibility for Savannah S-3 Channel, Reaches 1 to 3, fully-loaded *Susan Maersk*, inbound and outbound transits.

| Depth | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (ft) | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| Reach R1: S-3 | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 351 | 342 | 92 | 0 | 0 | 0 | 357 | 352 | 271 | 0 | 0 | 0 |
| 50 | 356 | 353 | 347 | 331 | 72 | 0 | 362 | 362 | 361 | 349 | 72 | 0 |
| 51 | 360 | 360 | 357 | 350 | 340 | 85 | 364 | 364 | 364 | 363 | 358 | 88 |
| 52 | 362 | 362 | 361 | 360 | 357 | 332 | 365 | 365 | 365 | 365 | 364 | 357 |
| 53 | 364 | 364 | 364 | 364 | 362 | 349 | 365 | 365 | 365 | 365 | 365 | 364 |
| 54 | 364 | 364 | 364 | 364 | 364 | 359 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 364 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R2: S-1b | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 352 | 342 | 88 | 0 | 0 | 0 | 358 | 353 | 261 | 0 | 0 | 0 |
| 50 | 357 | 356 | 346 | 330 | 72 | 0 | 362 | 362 | 359 | 352 | 72 | 0 |
| 51 | 361 | 360 | 357 | 352 | 342 | 88 | 364 | 364 | 364 | 362 | 358 | 73 |
| 52 | 363 | 362 | 360 | 360 | 358 | 331 | 364 | 364 | 364 | 364 | 364 | 358 |
| 53 | 363 | 363 | 363 | 363 | 361 | 351 | 365 | 365 | 365 | 364 | 364 | 364 |
| 54 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 364 |
| 55 | 364 | 365 | 365 | 365 | 364 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R3: Tybee | | | | | | | | | | | | |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 352 | 343 | 88 | 0 | 0 | 0 | 358 | 353 | 274 | 0 | 0 | 0 |
| 50 | 359 | 356 | 349 | 333 | 72 | 0 | 363 | 362 | 362 | 353 | 72 | 0 |
| 51 | 361 | 360 | 358 | 356 | 347 | 80 | 364 | 364 | 364 | 364 | 360 | 100 |
| 52 | 363 | 363 | 363 | 361 | 360 | 334 | 364 | 364 | 364 | 364 | 364 | 358 |
| 53 | 364 | 364 | 364 | 363 | 363 | 354 | 365 | 365 | 365 | 365 | 364 | 364 |
| 54 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| All 3 Reaches | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 351 | 342 | 88 | 0 | 0 | 0 | 357 | 352 | 261 | 0 | 0 | 0 |
| 50 | 356 | 353 | 346 | 330 | 72 | 0 | 362 | 362 | 359 | 349 | 72 | 0 |
| 51 | 360 | 360 | 357 | 350 | 340 | 80 | 364 | 364 | 364 | 362 | 358 | 73 |
| 52 | 362 | 362 | 360 | 360 | 357 | 331 | 364 | 364 | 364 | 364 | 364 | 357 |
| 53 | 363 | 363 | 363 | 363 | 361 | 349 | 365 | 365 | 365 | 364 | 364 | 364 |
| 54 | 364 | 364 | 364 | 364 | 364 | 359 | 365 | 365 | 365 | 365 | 365 | 364 |
| 55 | 364 | 365 | 365 | 365 | 364 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |

Notes:

1. Depths 62 to 64 ft not included as all have 365 days per year accessibility.

Table C5. Days of accessibility for Savannah S-8_Sta39 Channel, Reaches 1 to 3, light-loaded *Susan Maersk*, inbound and outbound transits.

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| Reach R1: S-8a | | | | | | | | | | | | |
| 48 | 352 | 349 | 328 | 72 | 0 | 0 | 359 | 356 | 348 | 78 | 0 | 0 |
| 49 | 360 | 358 | 350 | 341 | 129 | 0 | 363 | 363 | 363 | 357 | 315 | 0 |
| 50 | 361 | 360 | 360 | 354 | 338 | 304 | 364 | 364 | 364 | 364 | 360 | 336 |
| 51 | 363 | 363 | 363 | 360 | 351 | 325 | 365 | 365 | 365 | 365 | 364 | 357 |
| 52 | 364 | 364 | 364 | 363 | 356 | 335 | 365 | 365 | 365 | 365 | 365 | 364 |
| 53 | 364 | 364 | 364 | 363 | 360 | 348 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 364 | 363 | 354 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 363 | 356 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R2: S-8b | | | | | | | | | | | | |
| 48 | 354 | 349 | 332 | 72 | 0 | 0 | 360 | 357 | 349 | 78 | 0 | 0 |
| 49 | 360 | 358 | 350 | 344 | 129 | 0 | 363 | 363 | 363 | 357 | 315 | 0 |
| 50 | 362 | 360 | 360 | 356 | 338 | 304 | 364 | 364 | 364 | 364 | 360 | 336 |
| 51 | 363 | 363 | 363 | 360 | 351 | 325 | 365 | 365 | 365 | 365 | 364 | 358 |
| 52 | 364 | 364 | 364 | 363 | 358 | 335 | 365 | 365 | 365 | 365 | 365 | 364 |
| 53 | 364 | 364 | 364 | 364 | 360 | 348 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 364 | 363 | 354 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 364 | 356 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R3: Tybee | | | | | | | | | | | | |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 48 | 355 | 349 | 338 | 72 | 0 | 0 | 361 | 359 | 352 | 78 | 0 | 0 |
| 49 | 360 | 360 | 356 | 348 | 142 | 0 | 364 | 364 | 363 | 359 | 316 | 0 |
| 50 | 363 | 362 | 360 | 356 | 344 | 306 | 364 | 364 | 364 | 364 | 360 | 335 |
| 51 | 363 | 363 | 363 | 360 | 355 | 326 | 365 | 365 | 365 | 364 | 364 | 358 |
| 52 | 364 | 364 | 364 | 363 | 360 | 341 | 365 | 365 | 365 | 365 | 365 | 364 |
| 53 | 365 | 365 | 365 | 364 | 361 | 350 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 365 | 363 | 355 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| All 3 Reaches | | | | | | | | | | | | |
| 48 | 352 | 349 | 328 | 72 | 0 | 0 | 359 | 356 | 348 | 78 | 0 | 0 |
| 49 | 360 | 358 | 350 | 341 | 129 | 0 | 363 | 363 | 363 | 357 | 315 | 0 |
| 50 | 361 | 360 | 360 | 354 | 338 | 304 | 364 | 364 | 364 | 364 | 360 | 335 |
| 51 | 363 | 363 | 363 | 360 | 351 | 325 | 365 | 365 | 365 | 364 | 364 | 357 |
| 52 | 364 | 364 | 364 | 363 | 356 | 335 | 365 | 365 | 365 | 365 | 365 | 364 |
| 53 | 364 | 364 | 364 | 363 | 360 | 348 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 364 | 363 | 354 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 363 | 356 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |

Notes:

1. Depths 62 to 64 ft not included as all have 365 days per year accessibility.

Table C6. Days of accessibility for Savannah S-8_Sta39 Channel, Reaches 1 to 3, fully-loaded *Susan Maersk*, inbound and outbound transits.

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| Reach R1: S-8a | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 352 | 342 | 80 | 0 | 0 | 0 | 359 | 353 | 278 | 0 | 0 | 0 |
| 50 | 356 | 353 | 346 | 331 | 72 | 0 | 363 | 363 | 360 | 350 | 72 | 0 |
| 51 | 361 | 360 | 357 | 349 | 339 | 72 | 364 | 364 | 364 | 363 | 358 | 116 |
| 52 | 363 | 363 | 360 | 360 | 357 | 331 | 365 | 365 | 365 | 364 | 364 | 358 |
| 53 | 363 | 363 | 363 | 363 | 362 | 348 | 365 | 365 | 365 | 365 | 365 | 364 |
| 54 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 364 | 364 | 365 | 364 | 364 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R2: S-8b | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 352 | 342 | 80 | 0 | 0 | 0 | 359 | 353 | 278 | 0 | 0 | 0 |
| 50 | 357 | 354 | 347 | 331 | 72 | 0 | 363 | 363 | 360 | 353 | 72 | 0 |
| 51 | 361 | 360 | 358 | 352 | 343 | 72 | 364 | 364 | 364 | 363 | 358 | 104 |
| 52 | 363 | 363 | 361 | 360 | 358 | 331 | 365 | 365 | 365 | 365 | 364 | 359 |
| 53 | 363 | 363 | 364 | 363 | 363 | 349 | 365 | 365 | 365 | 365 | 365 | 364 |
| 54 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 364 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R3: Tybee | | | | | | | | | | | | |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 352 | 343 | 88 | 0 | 0 | 0 | 358 | 353 | 274 | 0 | 0 | 0 |
| 50 | 359 | 356 | 349 | 333 | 72 | 0 | 363 | 362 | 362 | 353 | 72 | 0 |
| 51 | 361 | 360 | 358 | 356 | 347 | 80 | 364 | 364 | 364 | 364 | 360 | 100 |
| 52 | 363 | 363 | 363 | 361 | 360 | 334 | 364 | 364 | 364 | 364 | 364 | 358 |
| 53 | 364 | 364 | 364 | 363 | 363 | 354 | 365 | 365 | 365 | 365 | 364 | 364 |
| 54 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| All 3 Reaches | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 352 | 342 | 80 | 0 | 0 | 0 | 358 | 353 | 274 | 0 | 0 | 0 |
| 50 | 356 | 353 | 346 | 331 | 72 | 0 | 363 | 362 | 360 | 350 | 72 | 0 |
| 51 | 361 | 360 | 357 | 349 | 339 | 72 | 364 | 364 | 364 | 363 | 358 | 100 |
| 52 | 363 | 363 | 360 | 360 | 357 | 331 | 364 | 364 | 364 | 364 | 364 | 358 |
| 53 | 363 | 363 | 363 | 363 | 362 | 348 | 365 | 365 | 365 | 365 | 364 | 364 |
| 54 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 364 | 364 | 365 | 364 | 364 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |

Notes:

1. Depths 62 to 64 ft not included as all have 365 days per year accessibility.

Table C7. Days of accessibility for Savannah S-1_Sta0 Channel, Reaches 1 to 6, light-loaded *Susan Maersk*, inbound and outbound transits.

| Depth | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (ft) | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| Reach R1: S-1a | | | | | | | | | | | | |
| 48 | 351 | 348 | 325 | 72 | 0 | 0 | 359 | 355 | 347 | 78 | 0 | 0 |
| 49 | 359 | 357 | 350 | 339 | 97 | 0 | 363 | 362 | 361 | 355 | 302 | 0 |
| 50 | 361 | 360 | 358 | 351 | 337 | 303 | 364 | 364 | 364 | 363 | 358 | 334 |
| 51 | 363 | 363 | 361 | 358 | 350 | 325 | 364 | 364 | 364 | 364 | 364 | 352 |
| 52 | 363 | 363 | 363 | 361 | 356 | 334 | 364 | 364 | 364 | 364 | 364 | 362 |
| 53 | 364 | 364 | 364 | 363 | 360 | 347 | 365 | 365 | 365 | 365 | 365 | 364 |
| 54 | 364 | 364 | 365 | 364 | 363 | 350 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 364 | 363 | 355 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 359 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R2: S-1b | | | | | | | | | | | | |
| 48 | 354 | 349 | 333 | 72 | 0 | 0 | 359 | 356 | 349 | 78 | 0 | 0 |
| 49 | 360 | 357 | 350 | 343 | 111 | 0 | 363 | 363 | 362 | 356 | 310 | 0 |
| 50 | 361 | 360 | 360 | 356 | 340 | 306 | 364 | 364 | 364 | 364 | 358 | 335 |
| 51 | 363 | 363 | 363 | 360 | 351 | 325 | 364 | 364 | 364 | 364 | 364 | 356 |
| 52 | 364 | 364 | 364 | 363 | 358 | 339 | 365 | 365 | 365 | 365 | 364 | 363 |
| 53 | 364 | 364 | 364 | 364 | 360 | 348 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 364 | 363 | 354 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 363 | 357 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R3: Tybee | | | | | | | | | | | | |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 48 | 355 | 349 | 338 | 72 | 0 | 0 | 361 | 359 | 352 | 78 | 0 | 0 |
| 49 | 360 | 360 | 356 | 348 | 142 | 0 | 364 | 364 | 363 | 359 | 316 | 0 |
| 50 | 363 | 362 | 360 | 356 | 344 | 306 | 364 | 364 | 364 | 364 | 360 | 335 |
| 51 | 363 | 363 | 363 | 360 | 355 | 326 | 365 | 365 | 365 | 364 | 364 | 358 |
| 52 | 364 | 364 | 364 | 363 | 360 | 341 | 365 | 365 | 365 | 365 | 365 | 364 |
| 53 | 365 | 365 | 365 | 364 | 361 | 350 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 365 | 363 | 355 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R4: Bloody Pt. | | | | | | | | | | | | |
| 48 | 360 | 356 | 349 | 72 | 0 | 0 | 363 | 362 | 356 | 75 | 0 | 0 |
| 49 | 363 | 362 | 360 | 355 | 246 | 0 | 364 | 364 | 364 | 362 | 340 | 0 |
| 50 | 364 | 364 | 363 | 360 | 352 | 318 | 365 | 365 | 364 | 364 | 364 | 343 |
| 51 | 364 | 364 | 364 | 363 | 360 | 345 | 365 | 365 | 365 | 365 | 364 | 362 |
| 52 | 365 | 365 | 365 | 364 | 363 | 353 | 365 | 365 | 365 | 365 | 365 | 364 |
| 53 | 365 | 365 | 365 | 365 | 364 | 359 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 365 | 365 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R5: Jones Island | | | | | | | | | | | | |
| 48 | 360 | 358 | 349 | 72 | 0 | 0 | 364 | 364 | 362 | 77 | 0 | 0 |
| 49 | 363 | 363 | 362 | 355 | 274 | 0 | 365 | 365 | 365 | 364 | 350 | 0 |
| 50 | 364 | 364 | 364 | 363 | 354 | 319 | 365 | 365 | 365 | 365 | 365 | 348 |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 51 | 365 | 365 | 365 | 364 | 360 | 341 | 365 | 365 | 365 | 365 | 365 | 365 |
| 52 | 365 | 365 | 365 | 365 | 363 | 354 | 365 | 365 | 365 | 365 | 365 | 365 |
| 53 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 365 | 365 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R6: Tybee Knoll Cut | | | | | | | | | | | | |
| 48 | 364 | 363 | 360 | 72 | 0 | 0 | 364 | 364 | 364 | 74 | 0 | 0 |
| 49 | 364 | 364 | 364 | 363 | 345 | 0 | 365 | 365 | 365 | 364 | 362 | 0 |
| 50 | 365 | 365 | 364 | 364 | 361 | 335 | 365 | 365 | 365 | 365 | 364 | 361 |
| 51 | 365 | 365 | 365 | 364 | 364 | 355 | 365 | 365 | 365 | 365 | 365 | 365 |
| 52 | 365 | 365 | 365 | 365 | 364 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 53 | 365 | 365 | 365 | 365 | 364 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| All 6 Reaches | | | | | | | | | | | | |
| 48 | 351 | 348 | 325 | 72 | 0 | 0 | 359 | 355 | 347 | 74 | 0 | 0 |
| 49 | 359 | 357 | 350 | 339 | 97 | 0 | 363 | 362 | 361 | 355 | 302 | 0 |
| 50 | 361 | 360 | 358 | 351 | 337 | 303 | 364 | 364 | 364 | 363 | 358 | 334 |
| 51 | 363 | 363 | 361 | 358 | 350 | 325 | 364 | 364 | 364 | 364 | 364 | 352 |
| 52 | 363 | 363 | 363 | 361 | 356 | 334 | 364 | 364 | 364 | 364 | 364 | 362 |
| 53 | 364 | 364 | 364 | 363 | 360 | 347 | 365 | 365 | 365 | 365 | 365 | 364 |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 54 | 364 | 364 | 365 | 364 | 363 | 350 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 364 | 363 | 355 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 359 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| Notes: 1. Depths 62 to 64 ft not included as all have 365 days per year accessibility. | | | | | | | | | | | | |

Table C8. Days of accessibility for Savannah S-1_Sta0 Channel, Reaches 1 to 6, fully-loaded *Susan Maersk*, inbound and outbound transits.

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| Reach R1: S-1a | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 351 | 342 | 72 | 0 | 0 | 0 | 357 | 350 | 252 | 0 | 0 | 0 |
| 50 | 356 | 352 | 346 | 326 | 72 | 0 | 362 | 361 | 359 | 349 | 72 | 0 |
| 51 | 360 | 358 | 356 | 349 | 342 | 80 | 364 | 364 | 363 | 362 | 356 | 88 |
| 52 | 361 | 360 | 360 | 359 | 356 | 329 | 364 | 364 | 364 | 364 | 363 | 354 |
| 53 | 363 | 363 | 363 | 361 | 360 | 347 | 364 | 364 | 364 | 364 | 364 | 364 |
| 54 | 364 | 364 | 364 | 364 | 363 | 355 | 365 | 365 | 365 | 365 | 364 | 364 |
| 55 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R2: S-1b | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 352 | 342 | 88 | 0 | 0 | 0 | 358 | 353 | 261 | 0 | 0 | 0 |
| 50 | 357 | 356 | 346 | 330 | 72 | 0 | 362 | 362 | 359 | 352 | 72 | 0 |
| 51 | 361 | 360 | 357 | 352 | 342 | 88 | 364 | 364 | 364 | 362 | 358 | 73 |
| 52 | 363 | 362 | 360 | 360 | 358 | 331 | 364 | 364 | 364 | 364 | 364 | 358 |
| 53 | 363 | 363 | 363 | 363 | 361 | 351 | 365 | 365 | 365 | 364 | 364 | 364 |
| 54 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 364 |
| 55 | 364 | 365 | 365 | 365 | 364 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R3: Tybee | | | | | | | | | | | | |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 352 | 343 | 88 | 0 | 0 | 0 | 358 | 353 | 274 | 0 | 0 | 0 |
| 50 | 359 | 356 | 349 | 333 | 72 | 0 | 363 | 362 | 362 | 353 | 72 | 0 |
| 51 | 361 | 360 | 358 | 356 | 347 | 80 | 364 | 364 | 364 | 364 | 360 | 100 |
| 52 | 363 | 363 | 363 | 361 | 360 | 334 | 364 | 364 | 364 | 364 | 364 | 358 |
| 53 | 364 | 364 | 364 | 363 | 363 | 354 | 365 | 365 | 365 | 365 | 364 | 364 |
| 54 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R4: Bloody Pt. | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 356 | 351 | 123 | 0 | 0 | 0 | 361 | 358 | 307 | 0 | 0 | 0 |
| 50 | 361 | 360 | 356 | 349 | 72 | 0 | 364 | 364 | 362 | 357 | 72 | 0 |
| 51 | 363 | 363 | 363 | 360 | 356 | 73 | 364 | 364 | 364 | 364 | 362 | 87 |
| 52 | 364 | 364 | 364 | 364 | 363 | 349 | 365 | 365 | 365 | 365 | 364 | 362 |
| 53 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 364 |
| 54 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R5: Jones Island | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 357 | 351 | 136 | 0 | 0 | 0 | 363 | 360 | 319 | 0 | 0 | 0 |
| 50 | 363 | 360 | 358 | 348 | 72 | 0 | 365 | 365 | 364 | 363 | 72 | 0 |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 51 | 364 | 364 | 363 | 362 | 358 | 132 | 365 | 365 | 365 | 365 | 364 | 73 |
| 52 | 365 | 365 | 364 | 364 | 363 | 350 | 365 | 365 | 365 | 365 | 365 | 365 |
| 53 | 365 | 365 | 365 | 365 | 365 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R6: Tybee Knoll Cut | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 362 | 360 | 275 | 0 | 0 | 0 | 364 | 364 | 339 | 0 | 0 | 0 |
| 50 | 364 | 364 | 364 | 361 | 72 | 0 | 364 | 364 | 364 | 364 | 72 | 0 |
| 51 | 364 | 364 | 364 | 364 | 363 | 94 | 365 | 365 | 365 | 365 | 364 | 77 |
| 52 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 364 |
| 53 | 365 | 365 | 365 | 365 | 364 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| All 6 Reaches | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 351 | 342 | 72 | 0 | 0 | 0 | 357 | 350 | 252 | 0 | 0 | 0 |
| 50 | 356 | 352 | 346 | 326 | 72 | 0 | 362 | 361 | 359 | 349 | 72 | 0 |
| 51 | 360 | 358 | 356 | 349 | 342 | 73 | 364 | 364 | 363 | 362 | 356 | 73 |
| 52 | 361 | 360 | 360 | 359 | 356 | 329 | 364 | 364 | 364 | 364 | 363 | 354 |
| 53 | 363 | 363 | 363 | 361 | 360 | 347 | 364 | 364 | 364 | 364 | 364 | 364 |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 54 | 364 | 364 | 364 | 364 | 363 | 355 | 365 | 365 | 365 | 365 | 364 | 364 |
| 55 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |

Notes:

1. Depths 62 to 64 ft not included as all have 365 days per year accessibility.

Table C9. Days of accessibility for Savannah S-8_Sta 0 Channel, Reaches 1 to 6, light-loaded *Susan Maersk*, inbound and outbound transits.

| Depth | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (ft) | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| Reach R1: S-8a | | | | | | | | | | | | |
| 48 | 352 | 349 | 328 | 72 | 0 | 0 | 359 | 356 | 348 | 78 | 0 | 0 |
| 49 | 360 | 358 | 350 | 341 | 129 | 0 | 363 | 363 | 363 | 357 | 315 | 0 |
| 50 | 361 | 360 | 360 | 354 | 338 | 304 | 364 | 364 | 364 | 364 | 360 | 336 |
| 51 | 363 | 363 | 363 | 360 | 351 | 325 | 365 | 365 | 365 | 365 | 364 | 357 |
| 52 | 364 | 364 | 364 | 363 | 356 | 335 | 365 | 365 | 365 | 365 | 365 | 364 |
| 53 | 364 | 364 | 364 | 363 | 360 | 348 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 364 | 363 | 354 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 363 | 356 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R2: S-8b | | | | | | | | | | | | |
| 48 | 354 | 349 | 332 | 72 | 0 | 0 | 360 | 357 | 349 | 78 | 0 | 0 |
| 49 | 360 | 358 | 350 | 344 | 129 | 0 | 363 | 363 | 363 | 357 | 315 | 0 |
| 50 | 362 | 360 | 360 | 356 | 338 | 304 | 364 | 364 | 364 | 364 | 360 | 336 |
| 51 | 363 | 363 | 363 | 360 | 351 | 325 | 365 | 365 | 365 | 365 | 364 | 358 |
| 52 | 364 | 364 | 364 | 363 | 358 | 335 | 365 | 365 | 365 | 365 | 365 | 364 |
| 53 | 364 | 364 | 364 | 364 | 360 | 348 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 364 | 363 | 354 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 364 | 356 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R3: Tybee | | | | | | | | | | | | |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 48 | 355 | 349 | 338 | 72 | 0 | 0 | 361 | 359 | 352 | 78 | 0 | 0 |
| 49 | 360 | 360 | 356 | 348 | 142 | 0 | 364 | 364 | 363 | 359 | 316 | 0 |
| 50 | 363 | 362 | 360 | 356 | 344 | 306 | 364 | 364 | 364 | 364 | 360 | 335 |
| 51 | 363 | 363 | 363 | 360 | 355 | 326 | 365 | 365 | 365 | 364 | 364 | 358 |
| 52 | 364 | 364 | 364 | 363 | 360 | 341 | 365 | 365 | 365 | 365 | 365 | 364 |
| 53 | 365 | 365 | 365 | 364 | 361 | 350 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 365 | 363 | 355 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R4: Bloody Pt. | | | | | | | | | | | | |
| 48 | 360 | 356 | 349 | 72 | 0 | 0 | 363 | 362 | 356 | 75 | 0 | 0 |
| 49 | 363 | 362 | 360 | 355 | 246 | 0 | 364 | 364 | 364 | 362 | 340 | 0 |
| 50 | 364 | 364 | 363 | 360 | 352 | 318 | 365 | 365 | 364 | 364 | 364 | 343 |
| 51 | 364 | 364 | 364 | 363 | 360 | 345 | 365 | 365 | 365 | 365 | 364 | 362 |
| 52 | 365 | 365 | 365 | 364 | 363 | 353 | 365 | 365 | 365 | 365 | 365 | 364 |
| 53 | 365 | 365 | 365 | 365 | 364 | 359 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 365 | 365 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R5: Jones Island | | | | | | | | | | | | |
| 48 | 360 | 358 | 349 | 72 | 0 | 0 | 364 | 364 | 362 | 77 | 0 | 0 |
| 49 | 363 | 363 | 362 | 355 | 274 | 0 | 365 | 365 | 365 | 364 | 350 | 0 |
| 50 | 364 | 364 | 364 | 363 | 354 | 319 | 365 | 365 | 365 | 365 | 365 | 348 |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 51 | 365 | 365 | 365 | 364 | 360 | 341 | 365 | 365 | 365 | 365 | 365 | 365 |
| 52 | 365 | 365 | 365 | 365 | 363 | 354 | 365 | 365 | 365 | 365 | 365 | 365 |
| 53 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 365 | 365 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R6: Tybee Knoll Cut | | | | | | | | | | | | |
| 48 | 364 | 363 | 360 | 72 | 0 | 0 | 364 | 364 | 364 | 74 | 0 | 0 |
| 49 | 364 | 364 | 364 | 363 | 345 | 0 | 365 | 365 | 365 | 364 | 362 | 0 |
| 50 | 365 | 365 | 364 | 364 | 361 | 335 | 365 | 365 | 365 | 365 | 364 | 361 |
| 51 | 365 | 365 | 365 | 364 | 364 | 355 | 365 | 365 | 365 | 365 | 365 | 365 |
| 52 | 365 | 365 | 365 | 365 | 364 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 53 | 365 | 365 | 365 | 365 | 364 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| All 6 Reaches | | | | | | | | | | | | |
| 48 | 352 | 349 | 328 | 72 | 0 | 0 | 359 | 356 | 348 | 74 | 0 | 0 |
| 49 | 360 | 358 | 350 | 341 | 129 | 0 | 363 | 363 | 363 | 357 | 315 | 0 |
| 50 | 361 | 360 | 360 | 354 | 338 | 304 | 364 | 364 | 364 | 364 | 360 | 335 |
| 51 | 363 | 363 | 363 | 360 | 351 | 325 | 365 | 365 | 365 | 364 | 364 | 357 |
| 52 | 364 | 364 | 364 | 363 | 356 | 335 | 365 | 365 | 365 | 365 | 365 | 364 |
| 53 | 364 | 364 | 364 | 363 | 360 | 348 | 365 | 365 | 365 | 365 | 365 | 365 |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 54 | 365 | 365 | 365 | 364 | 363 | 354 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 363 | 356 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |

Notes:

1. Depths 62 to 64 ft not included as all have 365 days per year accessibility.

Table C10. Days of accessibility for Savannah S-8_Sta 0 Channel, Reaches 1 to 6, fully-loaded *Susan Maersk*, inbound and outbound transits.

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| Reach R1: S-8a | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 352 | 342 | 80 | 0 | 0 | 0 | 359 | 353 | 278 | 0 | 0 | 0 |
| 50 | 356 | 353 | 346 | 331 | 72 | 0 | 363 | 363 | 360 | 350 | 72 | 0 |
| 51 | 361 | 360 | 357 | 349 | 339 | 72 | 364 | 364 | 364 | 363 | 358 | 116 |
| 52 | 363 | 363 | 360 | 360 | 357 | 331 | 365 | 365 | 365 | 364 | 364 | 358 |
| 53 | 363 | 363 | 363 | 363 | 362 | 348 | 365 | 365 | 365 | 365 | 365 | 364 |
| 54 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 364 | 364 | 365 | 364 | 364 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R2: S-8b | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 352 | 342 | 80 | 0 | 0 | 0 | 359 | 353 | 278 | 0 | 0 | 0 |
| 50 | 357 | 354 | 347 | 331 | 72 | 0 | 363 | 363 | 360 | 353 | 72 | 0 |
| 51 | 361 | 360 | 358 | 352 | 343 | 72 | 364 | 364 | 364 | 363 | 358 | 104 |
| 52 | 363 | 363 | 361 | 360 | 358 | 331 | 365 | 365 | 365 | 365 | 364 | 359 |
| 53 | 363 | 363 | 364 | 363 | 363 | 349 | 365 | 365 | 365 | 365 | 365 | 364 |
| 54 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 364 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R3: Tybee | | | | | | | | | | | | |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 352 | 343 | 88 | 0 | 0 | 0 | 358 | 353 | 274 | 0 | 0 | 0 |
| 50 | 359 | 356 | 349 | 333 | 72 | 0 | 363 | 362 | 362 | 353 | 72 | 0 |
| 51 | 361 | 360 | 358 | 356 | 347 | 80 | 364 | 364 | 364 | 364 | 360 | 100 |
| 52 | 363 | 363 | 363 | 361 | 360 | 334 | 364 | 364 | 364 | 364 | 364 | 358 |
| 53 | 364 | 364 | 364 | 363 | 363 | 354 | 365 | 365 | 365 | 365 | 364 | 364 |
| 54 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 362 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R4: Bloody Pt. | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 356 | 351 | 123 | 0 | 0 | 0 | 361 | 358 | 307 | 0 | 0 | 0 |
| 50 | 361 | 360 | 356 | 349 | 72 | 0 | 364 | 364 | 362 | 357 | 72 | 0 |
| 51 | 363 | 363 | 363 | 360 | 356 | 73 | 364 | 364 | 364 | 364 | 362 | 87 |
| 52 | 364 | 364 | 364 | 364 | 363 | 349 | 365 | 365 | 365 | 365 | 364 | 362 |
| 53 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 364 |
| 54 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R5: Jones Island | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 357 | 351 | 136 | 0 | 0 | 0 | 363 | 360 | 319 | 0 | 0 | 0 |
| 50 | 363 | 360 | 358 | 348 | 72 | 0 | 365 | 365 | 364 | 363 | 72 | 0 |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 51 | 364 | 364 | 363 | 362 | 358 | 132 | 365 | 365 | 365 | 365 | 364 | 73 |
| 52 | 365 | 365 | 364 | 364 | 363 | 350 | 365 | 365 | 365 | 365 | 365 | 365 |
| 53 | 365 | 365 | 365 | 365 | 365 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| Reach R6: Tybee Knoll Cut | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 362 | 360 | 275 | 0 | 0 | 0 | 364 | 364 | 339 | 0 | 0 | 0 |
| 50 | 364 | 364 | 364 | 361 | 72 | 0 | 364 | 364 | 364 | 364 | 72 | 0 |
| 51 | 364 | 364 | 364 | 364 | 363 | 94 | 365 | 365 | 365 | 365 | 364 | 77 |
| 52 | 365 | 365 | 365 | 365 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 364 |
| 53 | 365 | 365 | 365 | 365 | 364 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 54 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| All 6 Reaches | | | | | | | | | | | | |
| 48 | 72 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 |
| 49 | 352 | 342 | 80 | 0 | 0 | 0 | 358 | 353 | 274 | 0 | 0 | 0 |
| 50 | 356 | 353 | 346 | 331 | 72 | 0 | 363 | 362 | 360 | 350 | 72 | 0 |
| 51 | 361 | 360 | 357 | 349 | 339 | 72 | 364 | 364 | 364 | 363 | 358 | 73 |
| 52 | 363 | 363 | 360 | 360 | 357 | 331 | 364 | 364 | 364 | 364 | 364 | 358 |
| 53 | 363 | 363 | 363 | 363 | 362 | 348 | 365 | 365 | 365 | 365 | 364 | 364 |

| Depth (ft) | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 54 | 364 | 364 | 364 | 364 | 364 | 360 | 365 | 365 | 365 | 365 | 365 | 365 |
| 55 | 364 | 364 | 365 | 364 | 364 | 361 | 365 | 365 | 365 | 365 | 365 | 365 |
| 56 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 57 | 365 | 365 | 365 | 365 | 365 | 363 | 365 | 365 | 365 | 365 | 365 | 365 |
| 58 | 365 | 365 | 365 | 365 | 365 | 364 | 365 | 365 | 365 | 365 | 365 | 365 |
| 59 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 60 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |
| 61 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 | 365 |

Notes:

1. Depths 62 to 64 ft not included as all have 365 days per year accessibility.

# Appendix D: Wave-induced Vertical Motion Allowances for Light- (T=46 ft, h=50 ft) and Fully-loaded (T=47.5 ft, h=52 ft) *Susan Maersk* for Reach 1 in Savannah Channels S-1_Sta0, S-3_Sta39, and S-8_Sta 0

Table D1. Wave-induced vertical motion allowances (ft), Reach 1, h=50 ft, S-1 Channel, light-loaded *Susan Maersk*, inbound and outbound transits.

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 1 | 7.9 | 0.03 | 0.03 | 0.07 | 0.06 | 0.19 | 0.13 | 0.03 | 0.03 | 0.08 | 0.08 | 0.23 | 0.16 |
| 2 | 2.9 | 0.04 | 0.05 | 0.10 | 0.10 | 0.29 | 0.20 | 0.05 | 0.05 | 0.12 | 0.12 | 0.35 | 0.24 |
| 3 | 0.4 | 0.06 | 0.06 | 0.14 | 0.14 | 0.41 | 0.28 | 0.06 | 0.07 | 0.17 | 0.16 | 0.49 | 0.33 |
| 4 | 10.0 | 0.05 | 0.05 | 0.13 | 0.12 | 0.36 | 0.25 | 0.04 | 0.04 | 0.08 | 0.08 | 0.25 | 0.18 |
| 5 | 9.6 | 0.07 | 0.08 | 0.20 | 0.19 | 0.57 | 0.40 | 0.07 | 0.07 | 0.13 | 0.13 | 0.40 | 0.29 |
| 6 | 0.8 | 0.10 | 0.12 | 0.28 | 0.27 | 0.79 | 0.56 | 0.09 | 0.10 | 0.18 | 0.19 | 0.55 | 0.40 |
| 7 | 0.9 | 0.31 | 0.34 | 0.48 | 0.52 | 0.78 | 1.52 | 0.29 | 0.30 | 0.33 | 0.38 | 0.58 | 1.04 |
| 8 | 3.5 | 0.43 | 0.47 | 0.66 | 0.73 | 1.09 | 2.11 | 0.40 | 0.42 | 0.46 | 0.53 | 0.81 | 1.44 |
| 9 | 0.3 | 0.56 | 0.61 | 0.86 | 0.94 | 1.41 | 2.74 | 0.52 | 0.54 | 0.59 | 0.68 | 1.04 | 1.87 |
| 10 | 0.8 | 0.98 | 1.06 | 1.20 | 1.42 | 1.93 | 3.82 | 0.90 | 0.95 | 1.04 | 1.18 | 1.51 | 2.63 |
| 11 | 0.3 | 1.20 | 1.31 | 1.48 | 1.74 | 2.36 | 4.69 | 1.10 | 1.17 | 1.28 | 1.45 | 1.86 | 3.22 |
| 12 | 13.6 | 0.04 | 0.05 | 0.14 | 0.12 | 0.36 | 0.26 | 0.03 | 0.03 | 0.04 | 0.05 | 0.15 | 0.11 |
| 13 | 9.2 | 0.06 | 0.09 | 0.22 | 0.20 | 0.58 | 0.41 | 0.05 | 0.05 | 0.07 | 0.08 | 0.23 | 0.17 |
| 14 | 0.7 | 0.09 | 0.12 | 0.31 | 0.28 | 0.83 | 0.58 | 0.07 | 0.07 | 0.10 | 0.11 | 0.33 | 0.24 |
| 15 | 0.4 | 0.33 | 0.36 | 0.58 | 0.61 | 0.90 | 1.91 | 0.26 | 0.27 | 0.28 | 0.31 | 0.43 | 0.71 |
| 16 | 1.9 | 0.46 | 0.51 | 0.82 | 0.87 | 1.28 | 2.70 | 0.37 | 0.38 | 0.40 | 0.44 | 0.61 | 1.00 |
| 17 | 0.5 | 0.60 | 0.67 | 1.06 | 1.13 | 1.66 | 3.50 | 0.48 | 0.49 | 0.52 | 0.57 | 0.79 | 1.30 |
| 18 | 0.6 | 1.10 | 1.22 | 1.49 | 1.70 | 2.31 | 4.72 | 0.89 | 0.92 | 0.98 | 1.08 | 1.29 | 1.89 |
| 19 | 0.2 | 1.35 | 1.50 | 1.83 | 2.08 | 2.84 | 5.80 | 1.10 | 1.13 | 1.21 | 1.32 | 1.58 | 2.31 |
| 20 | 0.2 | 0.81 | 0.86 | 0.92 | 1.09 | 1.44 | 2.64 | 0.63 | 0.63 | 0.66 | 0.71 | 0.82 | 1.13 |
| 21 | 0.2 | 3.18 | 3.13 | 3.13 | 3.31 | 5.02 | 8.22 | 2.39 | 2.28 | 2.21 | 2.20 | 2.11 | 2.06 |
| 22 | 29.8 | 0.05 | 0.07 | 0.18 | 0.16 | 0.46 | 0.32 | 0.03 | 0.03 | 0.03 | 0.03 | 0.10 | 0.07 |
| 23 | 11.6 | 0.07 | 0.11 | 0.28 | 0.25 | 0.74 | 0.51 | 0.05 | 0.05 | 0.05 | 0.06 | 0.16 | 0.12 |
| 24 | 1.5 | 0.10 | 0.16 | 0.40 | 0.35 | 1.03 | 0.72 | 0.07 | 0.07 | 0.07 | 0.08 | 0.22 | 0.16 |
| 25 | 0.5 | 0.20 | 0.23 | 0.40 | 0.42 | 0.61 | 1.27 | 0.14 | 0.13 | 0.14 | 0.14 | 0.18 | 0.25 |
| 26 | 0.2 | 0.31 | 0.37 | 0.63 | 0.67 | 0.98 | 2.03 | 0.22 | 0.21 | 0.22 | 0.23 | 0.29 | 0.40 |
| 27 | 0.2 | 0.44 | 0.51 | 0.88 | 0.94 | 1.37 | 2.84 | 0.31 | 0.30 | 0.31 | 0.32 | 0.40 | 0.57 |
| 28 | 1.4 | 0.46 | 0.51 | 0.62 | 0.73 | 0.96 | 1.93 | 0.33 | 0.33 | 0.34 | 0.36 | 0.40 | 0.49 |
| 29 | 0.6 | 0.73 | 0.82 | 1.00 | 1.16 | 1.54 | 3.09 | 0.52 | 0.52 | 0.54 | 0.58 | 0.64 | 0.78 |
| 30 | 0.2 | 1.02 | 1.15 | 1.39 | 1.62 | 2.15 | 4.32 | 0.73 | 0.73 | 0.76 | 0.80 | 0.89 | 1.09 |
| 31 | 0.3 | 1.35 | 1.52 | 1.85 | 2.16 | 2.86 | 5.73 | 0.97 | 0.97 | 1.01 | 1.07 | 1.18 | 1.45 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 32 | 1.9 | 0.74 | 0.83 | 0.89 | 1.07 | 1.44 | 2.76 | 0.50 | 0.49 | 0.50 | 0.53 | 0.58 | 0.71 |
| 33 | 1.6 | 1.19 | 1.32 | 1.43 | 1.71 | 2.30 | 4.42 | 0.80 | 0.78 | 0.80 | 0.85 | 0.93 | 1.14 |
| 34 | 0.7 | 1.66 | 1.85 | 2.00 | 2.38 | 3.21 | 6.17 | 1.12 | 1.09 | 1.12 | 1.19 | 1.30 | 1.59 |
| 35 | 0.3 | 2.21 | 2.45 | 2.65 | 3.17 | 4.26 | 8.20 | 1.48 | 1.45 | 1.49 | 1.58 | 1.73 | 2.12 |
| 36 | 1.3 | 1.73 | 1.70 | 1.69 | 2.01 | 3.51 | 6.18 | 1.10 | 1.02 | 0.96 | 0.93 | 0.88 | 0.85 |
| 37 | 1.2 | 2.77 | 2.71 | 2.70 | 3.22 | 5.61 | 9.89 | 1.76 | 1.63 | 1.54 | 1.49 | 1.42 | 1.36 |
| 38 | 0.4 | 3.87 | 3.79 | 3.77 | 4.49 | 7.84 | 13.80 | 2.46 | 2.28 | 2.15 | 2.08 | 1.98 | 1.90 |
| 39 | 0.2 | 5.14 | 5.03 | 5.01 | 5.97 | 10.41 | 18.34 | 3.26 | 3.02 | 2.85 | 2.77 | 2.63 | 2.53 |
| 40 | 0.3 | 4.73 | 4.52 | 4.40 | 6.21 | 13.32 | 21.57 | 3.58 | 3.20 | 3.02 | 2.88 | 2.64 | 2.47 |
| 41 | 40.5 | 0.05 | 0.09 | 0.23 | 0.20 | 0.59 | 0.40 | 0.03 | 0.03 | 0.03 | 0.03 | 0.06 | 0.05 |
| 42 | 9.4 | 0.09 | 0.15 | 0.39 | 0.34 | 1.02 | 0.69 | 0.05 | 0.05 | 0.05 | 0.05 | 0.10 | 0.08 |
| 43 | 0.9 | 0.13 | 0.22 | 0.55 | 0.48 | 1.42 | 0.97 | 0.08 | 0.07 | 0.07 | 0.08 | 0.14 | 0.12 |
| 44 | 3.0 | 0.18 | 0.22 | 0.39 | 0.41 | 0.60 | 1.25 | 0.12 | 0.11 | 0.11 | 0.11 | 0.12 | 0.14 |
| 45 | 0.6 | 0.31 | 0.38 | 0.67 | 0.70 | 1.02 | 2.14 | 0.20 | 0.19 | 0.19 | 0.19 | 0.20 | 0.24 |
| 46 | 0.4 | 0.43 | 0.54 | 0.93 | 0.98 | 1.42 | 2.99 | 0.28 | 0.26 | 0.26 | 0.26 | 0.28 | 0.34 |
| 47 | 3.0 | 0.39 | 0.45 | 0.58 | 0.64 | 0.87 | 1.84 | 0.26 | 0.25 | 0.25 | 0.26 | 0.27 | 0.30 |
| 48 | 0.7 | 0.67 | 0.77 | 1.00 | 1.10 | 1.50 | 3.15 | 0.45 | 0.43 | 0.44 | 0.45 | 0.47 | 0.51 |
| 49 | 0.5 | 0.94 | 1.07 | 1.39 | 1.53 | 2.09 | 4.40 | 0.62 | 0.61 | 0.61 | 0.62 | 0.65 | 0.71 |
| 50 | 1.7 | 0.67 | 0.76 | 0.81 | 0.97 | 1.32 | 2.61 | 0.40 | 0.39 | 0.39 | 0.40 | 0.41 | 0.45 |
| 51 | 1.1 | 1.14 | 1.29 | 1.39 | 1.66 | 2.26 | 4.48 | 0.69 | 0.67 | 0.67 | 0.68 | 0.71 | 0.77 |
| 52 | 0.5 | 1.59 | 1.81 | 1.94 | 2.32 | 3.16 | 6.26 | 0.97 | 0.93 | 0.93 | 0.95 | 0.99 | 1.08 |
| 53 | 0.4 | 2.12 | 2.40 | 2.58 | 3.08 | 4.20 | 8.31 | 1.28 | 1.24 | 1.24 | 1.26 | 1.31 | 1.43 |
| 54 | 0.8 | 1.53 | 1.47 | 1.45 | 1.79 | 3.66 | 6.74 | 0.86 | 0.76 | 0.69 | 0.65 | 0.60 | 0.57 |
| 55 | 0.8 | 2.62 | 2.52 | 2.49 | 3.08 | 6.27 | 11.55 | 1.47 | 1.31 | 1.19 | 1.12 | 1.04 | 0.97 |
| 56 | 0.4 | 3.66 | 3.52 | 3.48 | 4.30 | 8.76 | 16.13 | 2.05 | 1.83 | 1.66 | 1.56 | 1.45 | 1.36 |
| 57 | 0.3 | 4.87 | 4.68 | 4.62 | 5.71 | 11.63 | 21.43 | 2.72 | 2.43 | 2.21 | 2.07 | 1.92 | 1.80 |
| 58 | 0.3 | 2.14 | 2.05 | 2.12 | 3.19 | 8.14 | 14.30 | 1.50 | 1.30 | 1.18 | 1.09 | 0.97 | 0.88 |
| 59 | 0.2 | 6.80 | 6.50 | 6.74 | 10.14 | 25.85 | 45.41 | 4.77 | 4.14 | 3.76 | 3.45 | 3.08 | 2.79 |
| 60 | 28.5 | 0.04 | 0.06 | 0.15 | 0.14 | 0.39 | 0.27 | 0.02 | 0.02 | 0.02 | 0.02 | 0.05 | 0.04 |
| 61 | 5.1 | 0.06 | 0.10 | 0.26 | 0.23 | 0.68 | 0.47 | 0.04 | 0.04 | 0.04 | 0.04 | 0.09 | 0.07 |
| 62 | 0.5 | 0.09 | 0.15 | 0.37 | 0.33 | 0.96 | 0.66 | 0.05 | 0.05 | 0.05 | 0.06 | 0.12 | 0.10 |
| 63 | 1.8 | 0.18 | 0.22 | 0.39 | 0.41 | 0.59 | 1.24 | 0.12 | 0.11 | 0.11 | 0.11 | 0.13 | 0.16 |
| 64 | 0.5 | 0.31 | 0.38 | 0.66 | 0.70 | 1.01 | 2.12 | 0.20 | 0.20 | 0.19 | 0.20 | 0.22 | 0.28 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 65 | 0.4 | 0.44 | 0.54 | 0.94 | 0.99 | 1.43 | 3.00 | 0.29 | 0.28 | 0.27 | 0.28 | 0.32 | 0.39 |
| 66 | 1.1 | 0.39 | 0.45 | 0.58 | 0.64 | 0.87 | 1.82 | 0.26 | 0.26 | 0.26 | 0.27 | 0.29 | 0.33 |
| 67 | 0.6 | 0.67 | 0.76 | 0.99 | 1.10 | 1.49 | 3.12 | 0.45 | 0.45 | 0.45 | 0.46 | 0.49 | 0.56 |
| 68 | 0.4 | 0.95 | 1.08 | 1.40 | 1.55 | 2.12 | 4.42 | 0.64 | 0.63 | 0.64 | 0.66 | 0.70 | 0.79 |
| 69 | 0.2 | 1.21 | 1.37 | 1.77 | 1.96 | 2.68 | 5.59 | 0.81 | 0.80 | 0.81 | 0.83 | 0.89 | 1.00 |
| 70 | 0.4 | 0.67 | 0.75 | 0.81 | 0.97 | 1.32 | 2.59 | 0.41 | 0.40 | 0.41 | 0.42 | 0.44 | 0.50 |
| 71 | 0.4 | 1.14 | 1.29 | 1.39 | 1.67 | 2.26 | 4.45 | 0.71 | 0.69 | 0.69 | 0.72 | 0.76 | 0.85 |
| 72 | 0.3 | 1.62 | 1.83 | 1.97 | 2.36 | 3.20 | 6.30 | 1.00 | 0.97 | 0.98 | 1.02 | 1.07 | 1.21 |
| 73 | 0.3 | 2.04 | 2.32 | 2.50 | 2.99 | 4.05 | 7.97 | 1.27 | 1.23 | 1.24 | 1.29 | 1.35 | 1.53 |
| 74 | 0.2 | 1.42 | 1.39 | 1.41 | 1.71 | 3.23 | 5.88 | 0.81 | 0.73 | 0.67 | 0.64 | 0.60 | 0.57 |
| 75 | 17.0 | 0.03 | 0.05 | 0.13 | 0.12 | 0.34 | 0.23 | 0.02 | 0.02 | 0.03 | 0.03 | 0.09 | 0.07 |
| 76 | 3.8 | 0.06 | 0.08 | 0.22 | 0.19 | 0.56 | 0.38 | 0.04 | 0.04 | 0.04 | 0.05 | 0.15 | 0.11 |
| 77 | 0.7 | 0.08 | 0.12 | 0.31 | 0.27 | 0.80 | 0.54 | 0.05 | 0.06 | 0.06 | 0.07 | 0.21 | 0.15 |
| 78 | 0.2 | 0.18 | 0.21 | 0.36 | 0.39 | 0.57 | 1.13 | 0.13 | 0.13 | 0.14 | 0.14 | 0.19 | 0.28 |
| 79 | 0.2 | 0.30 | 0.34 | 0.60 | 0.64 | 0.95 | 1.87 | 0.22 | 0.22 | 0.22 | 0.24 | 0.32 | 0.47 |
| 80 | 0.4 | 0.42 | 0.49 | 0.85 | 0.91 | 1.34 | 2.64 | 0.31 | 0.31 | 0.32 | 0.34 | 0.45 | 0.67 |
| 81 | 0.2 | 1.00 | 1.12 | 1.35 | 1.58 | 2.10 | 4.19 | 0.75 | 0.76 | 0.79 | 0.85 | 0.96 | 1.24 |
| 82 | 0.2 | 1.28 | 1.44 | 1.73 | 2.02 | 2.69 | 5.36 | 0.96 | 0.97 | 1.01 | 1.09 | 1.23 | 1.58 |
| 83 | 11.9 | 0.03 | 0.04 | 0.11 | 0.10 | 0.30 | 0.21 | 0.03 | 0.03 | 0.04 | 0.05 | 0.14 | 0.10 |
| 84 | 3.9 | 0.06 | 0.07 | 0.19 | 0.17 | 0.50 | 0.35 | 0.05 | 0.05 | 0.07 | 0.08 | 0.24 | 0.17 |
| 85 | 0.7 | 0.08 | 0.10 | 0.26 | 0.24 | 0.70 | 0.48 | 0.06 | 0.07 | 0.10 | 0.11 | 0.34 | 0.24 |
| 86 | 0.3 | 0.30 | 0.33 | 0.53 | 0.58 | 0.86 | 1.66 | 0.25 | 0.26 | 0.28 | 0.32 | 0.47 | 0.77 |
| 87 | 0.6 | 0.42 | 0.46 | 0.74 | 0.80 | 1.19 | 2.30 | 0.35 | 0.36 | 0.39 | 0.44 | 0.65 | 1.07 |
| 88 | 0.2 | 0.53 | 0.58 | 0.93 | 1.01 | 1.51 | 2.91 | 0.45 | 0.46 | 0.49 | 0.55 | 0.82 | 1.35 |
| 89 | 8.8 | 0.04 | 0.04 | 0.10 | 0.09 | 0.27 | 0.19 | 0.04 | 0.04 | 0.08 | 0.08 | 0.23 | 0.16 |
| 90 | 3.7 | 0.06 | 0.07 | 0.16 | 0.16 | 0.46 | 0.33 | 0.06 | 0.06 | 0.13 | 0.13 | 0.39 | 0.28 |
| 91 | 0.7 | 0.09 | 0.09 | 0.23 | 0.22 | 0.64 | 0.46 | 0.08 | 0.09 | 0.18 | 0.18 | 0.54 | 0.39 |
| 92 | 0.4 | 0.28 | 0.30 | 0.42 | 0.47 | 0.72 | 1.28 | 0.27 | 0.28 | 0.35 | 0.40 | 0.61 | 1.06 |
| 93 | 0.9 | 0.39 | 0.42 | 0.58 | 0.65 | 0.99 | 1.77 | 0.37 | 0.39 | 0.48 | 0.55 | 0.85 | 1.47 |
| 94 | 0.3 | 0.50 | 0.53 | 0.74 | 0.83 | 1.27 | 2.27 | 0.48 | 0.50 | 0.61 | 0.71 | 1.09 | 1.88 |
| 95 | 7.5 | 0.03 | 0.04 | 0.07 | 0.07 | 0.21 | 0.15 | 0.04 | 0.04 | 0.11 | 0.10 | 0.29 | 0.21 |
| 96 | 3.6 | 0.06 | 0.06 | 0.12 | 0.12 | 0.35 | 0.25 | 0.06 | 0.07 | 0.18 | 0.17 | 0.50 | 0.35 |
| 97 | 0.6 | 0.08 | 0.08 | 0.16 | 0.16 | 0.48 | 0.34 | 0.09 | 0.10 | 0.25 | 0.23 | 0.68 | 0.48 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 98 | 0.3 | 0.25 | 0.26 | 0.30 | 0.35 | 0.56 | 0.92 | 0.27 | 0.29 | 0.44 | 0.50 | 0.77 | 1.32 |
| 99 | 0.5 | 0.34 | 0.35 | 0.41 | 0.48 | 0.76 | 1.25 | 0.37 | 0.40 | 0.61 | 0.68 | 1.05 | 1.81 |

Table D2. Wave-induced vertical motion allowances, Reach 1, h=50 ft, S-3 Channel, light-loaded *Susan Maersk*, inbound and outbound transits.

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 1 | 7.9 | 0.03 | 0.04 | 0.09 | 0.08 | 0.25 | 0.17 | 0.03 | 0.03 | 0.05 | 0.05 | 0.15 | 0.10 |
| 2 | 2.9 | 0.04 | 0.06 | 0.14 | 0.13 | 0.38 | 0.26 | 0.04 | 0.04 | 0.07 | 0.07 | 0.22 | 0.16 |
| 3 | 0.4 | 0.06 | 0.08 | 0.19 | 0.18 | 0.53 | 0.36 | 0.05 | 0.06 | 0.10 | 0.10 | 0.31 | 0.22 |
| 4 | 10.0 | 0.05 | 0.06 | 0.16 | 0.14 | 0.42 | 0.29 | 0.03 | 0.03 | 0.04 | 0.05 | 0.14 | 0.10 |
| 5 | 9.6 | 0.07 | 0.10 | 0.25 | 0.23 | 0.67 | 0.47 | 0.05 | 0.05 | 0.06 | 0.07 | 0.22 | 0.16 |
| 6 | 0.8 | 0.10 | 0.14 | 0.35 | 0.32 | 0.93 | 0.65 | 0.07 | 0.07 | 0.09 | 0.10 | 0.30 | 0.22 |
| 7 | 0.9 | 0.31 | 0.34 | 0.57 | 0.61 | 0.89 | 1.82 | 0.23 | 0.24 | 0.25 | 0.27 | 0.36 | 0.56 |
| 8 | 3.5 | 0.43 | 0.47 | 0.79 | 0.85 | 1.24 | 2.53 | 0.33 | 0.33 | 0.34 | 0.37 | 0.50 | 0.78 |
| 9 | 0.3 | 0.55 | 0.61 | 1.03 | 1.10 | 1.61 | 3.27 | 0.42 | 0.42 | 0.44 | 0.48 | 0.65 | 1.01 |
| 10 | 0.8 | 0.95 | 1.06 | 1.39 | 1.49 | 2.11 | 4.57 | 0.74 | 0.75 | 0.79 | 0.85 | 1.01 | 1.46 |
| 11 | 0.3 | 1.17 | 1.30 | 1.71 | 1.83 | 2.59 | 5.60 | 0.91 | 0.92 | 0.97 | 1.05 | 1.24 | 1.79 |
| 12 | 13.6 | 0.04 | 0.06 | 0.15 | 0.14 | 0.39 | 0.27 | 0.02 | 0.02 | 0.02 | 0.03 | 0.06 | 0.05 |
| 13 | 9.2 | 0.06 | 0.10 | 0.25 | 0.22 | 0.63 | 0.43 | 0.04 | 0.04 | 0.04 | 0.04 | 0.10 | 0.08 |
| 14 | 0.7 | 0.09 | 0.14 | 0.35 | 0.31 | 0.89 | 0.61 | 0.05 | 0.05 | 0.05 | 0.06 | 0.15 | 0.11 |
| 15 | 0.4 | 0.31 | 0.37 | 0.63 | 0.66 | 0.96 | 2.08 | 0.21 | 0.20 | 0.21 | 0.21 | 0.25 | 0.33 |
| 16 | 1.9 | 0.44 | 0.53 | 0.89 | 0.94 | 1.35 | 2.95 | 0.30 | 0.29 | 0.29 | 0.30 | 0.35 | 0.47 |
| 17 | 0.5 | 0.57 | 0.68 | 1.16 | 1.21 | 1.75 | 3.81 | 0.39 | 0.37 | 0.38 | 0.39 | 0.45 | 0.61 |
| 18 | 0.6 | 1.04 | 1.18 | 1.59 | 1.69 | 2.37 | 5.12 | 0.72 | 0.72 | 0.73 | 0.75 | 0.82 | 0.99 |
| 19 | 0.2 | 1.28 | 1.45 | 1.95 | 2.07 | 2.91 | 6.28 | 0.89 | 0.88 | 0.89 | 0.93 | 1.01 | 1.21 |
| 20 | 0.2 | 0.77 | 0.84 | 0.89 | 1.06 | 1.46 | 2.82 | 0.50 | 0.49 | 0.49 | 0.49 | 0.53 | 0.62 |
| 21 | 0.2 | 2.51 | 2.45 | 2.45 | 2.96 | 5.40 | 9.66 | 1.51 | 1.38 | 1.28 | 1.23 | 1.16 | 1.11 |
| 22 | 29.8 | 0.04 | 0.07 | 0.18 | 0.16 | 0.46 | 0.32 | 0.02 | 0.02 | 0.02 | 0.02 | 0.04 | 0.04 |
| 23 | 11.6 | 0.07 | 0.11 | 0.29 | 0.25 | 0.73 | 0.50 | 0.04 | 0.04 | 0.04 | 0.04 | 0.07 | 0.06 |
| 24 | 1.5 | 0.10 | 0.16 | 0.40 | 0.35 | 1.02 | 0.70 | 0.05 | 0.05 | 0.05 | 0.05 | 0.09 | 0.08 |
| 25 | 0.5 | 0.19 | 0.23 | 0.40 | 0.42 | 0.61 | 1.27 | 0.12 | 0.11 | 0.11 | 0.11 | 0.12 | 0.13 |
| 26 | 0.2 | 0.30 | 0.37 | 0.64 | 0.67 | 0.97 | 2.03 | 0.19 | 0.18 | 0.17 | 0.17 | 0.19 | 0.21 |
| 27 | 0.2 | 0.41 | 0.51 | 0.89 | 0.93 | 1.35 | 2.83 | 0.26 | 0.25 | 0.24 | 0.24 | 0.26 | 0.30 |
| 28 | 1.4 | 0.43 | 0.49 | 0.62 | 0.69 | 0.93 | 1.92 | 0.28 | 0.28 | 0.28 | 0.28 | 0.29 | 0.31 |
| 29 | 0.6 | 0.69 | 0.78 | 0.99 | 1.11 | 1.49 | 3.06 | 0.45 | 0.44 | 0.44 | 0.45 | 0.47 | 0.50 |
| 30 | 0.2 | 0.96 | 1.10 | 1.38 | 1.55 | 2.08 | 4.28 | 0.63 | 0.62 | 0.62 | 0.63 | 0.65 | 0.70 |
| 31 | 0.3 | 1.27 | 1.45 | 1.83 | 2.06 | 2.77 | 5.68 | 0.84 | 0.82 | 0.82 | 0.84 | 0.87 | 0.93 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 32 | 1.9 | 0.71 | 0.80 | 0.85 | 1.00 | 1.38 | 2.72 | 0.43 | 0.41 | 0.41 | 0.41 | 0.41 | 0.45 |
| 33 | 1.6 | 1.13 | 1.27 | 1.36 | 1.60 | 2.20 | 4.36 | 0.69 | 0.66 | 0.65 | 0.65 | 0.66 | 0.71 |
| 34 | 0.7 | 1.58 | 1.78 | 1.90 | 2.24 | 3.08 | 6.08 | 0.96 | 0.92 | 0.91 | 0.91 | 0.93 | 1.00 |
| 35 | 0.3 | 2.10 | 2.36 | 2.52 | 2.97 | 4.09 | 8.08 | 1.28 | 1.22 | 1.21 | 1.21 | 1.23 | 1.32 |
| 36 | 1.3 | 1.44 | 1.39 | 1.37 | 1.66 | 3.40 | 6.28 | 0.79 | 0.70 | 0.63 | 0.59 | 0.55 | 0.51 |
| 37 | 1.2 | 2.31 | 2.23 | 2.20 | 2.66 | 5.44 | 10.05 | 1.26 | 1.12 | 1.01 | 0.95 | 0.87 | 0.82 |
| 38 | 0.4 | 3.22 | 3.11 | 3.07 | 3.71 | 7.59 | 14.03 | 1.76 | 1.56 | 1.42 | 1.32 | 1.22 | 1.14 |
| 39 | 0.2 | 4.28 | 4.13 | 4.08 | 4.93 | 10.08 | 18.64 | 2.34 | 2.07 | 1.88 | 1.75 | 1.62 | 1.52 |
| 40 | 0.3 | 3.38 | 3.23 | 3.21 | 4.88 | 13.03 | 23.01 | 2.32 | 2.00 | 1.80 | 1.64 | 1.46 | 1.32 |
| 41 | 40.5 | 0.05 | 0.08 | 0.21 | 0.18 | 0.55 | 0.37 | 0.03 | 0.03 | 0.03 | 0.04 | 0.09 | 0.07 |
| 42 | 9.4 | 0.09 | 0.14 | 0.36 | 0.32 | 0.94 | 0.64 | 0.06 | 0.06 | 0.06 | 0.06 | 0.15 | 0.12 |
| 43 | 0.9 | 0.12 | 0.20 | 0.50 | 0.44 | 1.31 | 0.89 | 0.08 | 0.08 | 0.08 | 0.09 | 0.22 | 0.16 |
| 44 | 3.0 | 0.17 | 0.21 | 0.36 | 0.38 | 0.55 | 1.15 | 0.12 | 0.11 | 0.11 | 0.12 | 0.14 | 0.19 |
| 45 | 0.6 | 0.30 | 0.36 | 0.62 | 0.65 | 0.95 | 1.96 | 0.20 | 0.19 | 0.20 | 0.20 | 0.24 | 0.32 |
| 46 | 0.4 | 0.42 | 0.50 | 0.86 | 0.91 | 1.32 | 2.74 | 0.28 | 0.27 | 0.27 | 0.28 | 0.33 | 0.44 |
| 47 | 3.0 | 0.38 | 0.43 | 0.54 | 0.61 | 0.82 | 1.69 | 0.26 | 0.26 | 0.26 | 0.27 | 0.30 | 0.35 |
| 48 | 0.7 | 0.65 | 0.73 | 0.93 | 1.04 | 1.40 | 2.90 | 0.45 | 0.44 | 0.45 | 0.47 | 0.51 | 0.60 |
| 49 | 0.5 | 0.90 | 1.02 | 1.30 | 1.45 | 1.96 | 4.04 | 0.63 | 0.62 | 0.63 | 0.66 | 0.71 | 0.84 |
| 50 | 1.7 | 0.63 | 0.71 | 0.77 | 0.92 | 1.24 | 2.41 | 0.41 | 0.40 | 0.41 | 0.43 | 0.46 | 0.54 |
| 51 | 1.1 | 1.09 | 1.23 | 1.33 | 1.58 | 2.13 | 4.14 | 0.70 | 0.69 | 0.70 | 0.73 | 0.78 | 0.92 |
| 52 | 0.5 | 1.52 | 1.71 | 1.85 | 2.21 | 2.97 | 5.78 | 0.97 | 0.96 | 0.98 | 1.02 | 1.09 | 1.28 |
| 53 | 0.4 | 2.02 | 2.27 | 2.46 | 2.94 | 3.95 | 7.67 | 1.29 | 1.27 | 1.30 | 1.36 | 1.45 | 1.71 |
| 54 | 0.8 | 1.57 | 1.52 | 1.51 | 1.83 | 3.40 | 6.11 | 0.95 | 0.87 | 0.81 | 0.77 | 0.73 | 0.69 |
| 55 | 0.8 | 2.70 | 2.61 | 2.58 | 3.13 | 5.83 | 10.47 | 1.64 | 1.49 | 1.39 | 1.33 | 1.25 | 1.19 |
| 56 | 0.4 | 3.76 | 3.64 | 3.61 | 4.37 | 8.14 | 14.62 | 2.29 | 2.08 | 1.94 | 1.85 | 1.74 | 1.66 |
| 57 | 0.3 | 5.00 | 4.83 | 4.79 | 5.81 | 10.82 | 19.42 | 3.04 | 2.77 | 2.57 | 2.46 | 2.32 | 2.21 |
| 58 | 0.3 | 2.39 | 2.28 | 2.31 | 3.34 | 7.57 | 12.64 | 1.78 | 1.57 | 1.47 | 1.38 | 1.25 | 1.16 |
| 59 | 0.2 | 7.60 | 7.26 | 7.34 | 10.60 | 24.05 | 40.16 | 5.65 | 5.00 | 4.66 | 4.38 | 3.98 | 3.69 |
| 60 | 28.5 | 0.04 | 0.05 | 0.13 | 0.12 | 0.34 | 0.23 | 0.03 | 0.03 | 0.03 | 0.04 | 0.11 | 0.08 |
| 61 | 5.1 | 0.06 | 0.09 | 0.22 | 0.20 | 0.58 | 0.40 | 0.04 | 0.05 | 0.05 | 0.06 | 0.19 | 0.14 |
| 62 | 0.5 | 0.09 | 0.12 | 0.31 | 0.28 | 0.82 | 0.57 | 0.06 | 0.07 | 0.08 | 0.09 | 0.27 | 0.20 |
| 63 | 1.8 | 0.17 | 0.19 | 0.33 | 0.35 | 0.51 | 1.04 | 0.13 | 0.13 | 0.14 | 0.15 | 0.21 | 0.32 |
| 64 | 0.5 | 0.30 | 0.33 | 0.56 | 0.60 | 0.88 | 1.78 | 0.23 | 0.23 | 0.24 | 0.26 | 0.35 | 0.55 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 65 | 0.4 | 0.43 | 0.47 | 0.79 | 0.85 | 1.24 | 2.53 | 0.33 | 0.33 | 0.34 | 0.37 | 0.50 | 0.78 |
| 66 | 1.1 | 0.38 | 0.42 | 0.50 | 0.59 | 0.78 | 1.55 | 0.30 | 0.30 | 0.32 | 0.35 | 0.40 | 0.54 |
| 67 | 0.6 | 0.65 | 0.73 | 0.86 | 1.01 | 1.34 | 2.65 | 0.51 | 0.52 | 0.55 | 0.59 | 0.68 | 0.93 |
| 68 | 0.4 | 0.92 | 1.03 | 1.22 | 1.43 | 1.90 | 3.76 | 0.72 | 0.73 | 0.77 | 0.84 | 0.97 | 1.31 |
| 69 | 0.2 | 1.17 | 1.30 | 1.55 | 1.81 | 2.40 | 4.75 | 0.91 | 0.93 | 0.98 | 1.06 | 1.23 | 1.66 |
| 70 | 0.4 | 0.63 | 0.70 | 0.77 | 0.91 | 1.19 | 2.22 | 0.47 | 0.47 | 0.50 | 0.54 | 0.61 | 0.81 |
| 71 | 0.4 | 1.08 | 1.20 | 1.31 | 1.56 | 2.04 | 3.81 | 0.80 | 0.81 | 0.86 | 0.93 | 1.05 | 1.39 |
| 72 | 0.3 | 1.53 | 1.70 | 1.86 | 2.21 | 2.89 | 5.40 | 1.13 | 1.15 | 1.21 | 1.32 | 1.49 | 1.97 |
| 73 | 0.3 | 1.94 | 2.15 | 2.36 | 2.79 | 3.66 | 6.83 | 1.43 | 1.45 | 1.53 | 1.67 | 1.88 | 2.49 |
| 74 | 0.2 | 1.64 | 1.61 | 1.62 | 1.79 | 2.80 | 4.67 | 1.16 | 1.10 | 1.06 | 1.05 | 1.00 | 0.97 |
| 75 | 17.0 | 0.03 | 0.04 | 0.10 | 0.09 | 0.26 | 0.18 | 0.03 | 0.03 | 0.05 | 0.05 | 0.15 | 0.11 |
| 76 | 3.8 | 0.05 | 0.07 | 0.16 | 0.15 | 0.44 | 0.30 | 0.05 | 0.05 | 0.08 | 0.09 | 0.26 | 0.18 |
| 77 | 0.7 | 0.07 | 0.09 | 0.23 | 0.21 | 0.62 | 0.43 | 0.06 | 0.07 | 0.12 | 0.12 | 0.36 | 0.26 |
| 78 | 0.2 | 0.17 | 0.19 | 0.28 | 0.31 | 0.46 | 0.87 | 0.15 | 0.16 | 0.17 | 0.19 | 0.29 | 0.49 |
| 79 | 0.2 | 0.28 | 0.31 | 0.46 | 0.51 | 0.76 | 1.44 | 0.25 | 0.26 | 0.28 | 0.32 | 0.48 | 0.82 |
| 80 | 0.4 | 0.40 | 0.44 | 0.66 | 0.72 | 1.07 | 2.04 | 0.35 | 0.36 | 0.39 | 0.45 | 0.68 | 1.15 |
| 81 | 0.2 | 0.95 | 1.04 | 1.17 | 1.40 | 1.79 | 3.28 | 0.84 | 0.88 | 0.95 | 1.08 | 1.29 | 1.96 |
| 82 | 0.2 | 1.22 | 1.33 | 1.50 | 1.79 | 2.29 | 4.20 | 1.08 | 1.13 | 1.22 | 1.38 | 1.66 | 2.51 |
| 83 | 11.9 | 0.03 | 0.03 | 0.07 | 0.07 | 0.21 | 0.15 | 0.03 | 0.03 | 0.07 | 0.07 | 0.21 | 0.15 |
| 84 | 3.9 | 0.05 | 0.06 | 0.12 | 0.12 | 0.36 | 0.25 | 0.05 | 0.06 | 0.12 | 0.12 | 0.36 | 0.25 |
| 85 | 0.7 | 0.07 | 0.08 | 0.17 | 0.17 | 0.49 | 0.35 | 0.07 | 0.08 | 0.17 | 0.17 | 0.49 | 0.35 |
| 86 | 0.3 | 0.28 | 0.29 | 0.37 | 0.42 | 0.64 | 1.16 | 0.28 | 0.29 | 0.37 | 0.42 | 0.64 | 1.16 |
| 87 | 0.6 | 0.38 | 0.41 | 0.52 | 0.58 | 0.88 | 1.60 | 0.38 | 0.41 | 0.52 | 0.58 | 0.88 | 1.60 |
| 88 | 0.2 | 0.48 | 0.52 | 0.66 | 0.74 | 1.12 | 2.03 | 0.48 | 0.52 | 0.66 | 0.74 | 1.12 | 2.03 |
| 89 | 8.8 | 0.03 | 0.03 | 0.06 | 0.06 | 0.17 | 0.13 | 0.04 | 0.04 | 0.11 | 0.10 | 0.30 | 0.21 |
| 90 | 3.7 | 0.05 | 0.06 | 0.09 | 0.10 | 0.29 | 0.21 | 0.06 | 0.08 | 0.19 | 0.17 | 0.50 | 0.35 |
| 91 | 0.7 | 0.07 | 0.08 | 0.13 | 0.14 | 0.41 | 0.30 | 0.09 | 0.10 | 0.26 | 0.24 | 0.70 | 0.49 |
| 92 | 0.4 | 0.24 | 0.25 | 0.27 | 0.31 | 0.48 | 0.80 | 0.27 | 0.30 | 0.46 | 0.51 | 0.77 | 1.40 |
| 93 | 0.9 | 0.33 | 0.35 | 0.37 | 0.43 | 0.67 | 1.11 | 0.38 | 0.41 | 0.64 | 0.71 | 1.07 | 1.94 |
| 94 | 0.3 | 0.43 | 0.44 | 0.48 | 0.55 | 0.86 | 1.42 | 0.49 | 0.53 | 0.83 | 0.91 | 1.37 | 2.48 |
| 95 | 7.5 | 0.03 | 0.03 | 0.03 | 0.04 | 0.11 | 0.08 | 0.04 | 0.05 | 0.13 | 0.12 | 0.35 | 0.24 |
| 96 | 3.6 | 0.05 | 0.05 | 0.05 | 0.07 | 0.19 | 0.14 | 0.06 | 0.09 | 0.23 | 0.20 | 0.59 | 0.41 |
| 97 | 0.6 | 0.06 | 0.06 | 0.08 | 0.09 | 0.26 | 0.19 | 0.09 | 0.12 | 0.31 | 0.28 | 0.80 | 0.56 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 98 | 0.3 | 0.20 | 0.20 | 0.21 | 0.23 | 0.33 | 0.50 | 0.26 | 0.30 | 0.54 | 0.58 | 0.89 | 1.57 |
| 99 | 0.5 | 0.28 | 0.28 | 0.29 | 0.31 | 0.46 | 0.69 | 0.36 | 0.40 | 0.74 | 0.80 | 1.21 | 2.15 |

Table D3. Wave-induced vertical motion allowances, Reach 1, h=50 ft, S-8 Channel, light-loaded *Susan Maersk*, inbound and outbound transits.

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 1 | 7.9 | 0.03 | 0.03 | 0.08 | 0.07 | 0.22 | 0.15 | 0.03 | 0.03 | 0.06 | 0.06 | 0.18 | 0.13 |
| 2 | 2.9 | 0.04 | 0.05 | 0.12 | 0.11 | 0.33 | 0.23 | 0.04 | 0.04 | 0.09 | 0.09 | 0.28 | 0.19 |
| 3 | 0.4 | 0.06 | 0.07 | 0.16 | 0.15 | 0.46 | 0.31 | 0.06 | 0.06 | 0.13 | 0.13 | 0.39 | 0.27 |
| 4 | 10.0 | 0.04 | 0.06 | 0.14 | 0.13 | 0.38 | 0.27 | 0.04 | 0.04 | 0.06 | 0.06 | 0.19 | 0.14 |
| 5 | 9.6 | 0.07 | 0.09 | 0.23 | 0.21 | 0.61 | 0.43 | 0.06 | 0.06 | 0.09 | 0.10 | 0.29 | 0.21 |
| 6 | 0.8 | 0.10 | 0.13 | 0.31 | 0.29 | 0.84 | 0.59 | 0.08 | 0.08 | 0.13 | 0.14 | 0.41 | 0.30 |
| 7 | 0.9 | 0.30 | 0.33 | 0.52 | 0.56 | 0.82 | 1.65 | 0.26 | 0.26 | 0.28 | 0.31 | 0.45 | 0.76 |
| 8 | 3.5 | 0.42 | 0.46 | 0.72 | 0.77 | 1.14 | 2.28 | 0.35 | 0.36 | 0.39 | 0.44 | 0.63 | 1.06 |
| 9 | 0.3 | 0.55 | 0.60 | 0.93 | 1.00 | 1.48 | 2.96 | 0.46 | 0.47 | 0.51 | 0.57 | 0.81 | 1.37 |
| 10 | 0.8 | 0.95 | 1.05 | 1.28 | 1.43 | 1.98 | 4.13 | 0.80 | 0.83 | 0.89 | 0.99 | 1.22 | 1.94 |
| 11 | 0.3 | 1.16 | 1.28 | 1.57 | 1.76 | 2.43 | 5.06 | 0.99 | 1.02 | 1.10 | 1.22 | 1.50 | 2.38 |
| 12 | 13.6 | 0.04 | 0.06 | 0.14 | 0.13 | 0.37 | 0.26 | 0.03 | 0.03 | 0.03 | 0.03 | 0.10 | 0.07 |
| 13 | 9.2 | 0.06 | 0.09 | 0.23 | 0.21 | 0.60 | 0.41 | 0.04 | 0.04 | 0.05 | 0.05 | 0.16 | 0.12 |
| 14 | 0.7 | 0.09 | 0.13 | 0.33 | 0.29 | 0.85 | 0.59 | 0.06 | 0.06 | 0.06 | 0.08 | 0.22 | 0.17 |
| 15 | 0.4 | 0.31 | 0.36 | 0.60 | 0.63 | 0.92 | 1.96 | 0.23 | 0.23 | 0.24 | 0.25 | 0.32 | 0.48 |
| 16 | 1.9 | 0.44 | 0.50 | 0.84 | 0.89 | 1.30 | 2.78 | 0.32 | 0.32 | 0.33 | 0.35 | 0.46 | 0.68 |
| 17 | 0.5 | 0.58 | 0.65 | 1.09 | 1.15 | 1.68 | 3.60 | 0.42 | 0.42 | 0.43 | 0.46 | 0.59 | 0.88 |
| 18 | 0.6 | 1.05 | 1.18 | 1.52 | 1.66 | 2.30 | 4.85 | 0.78 | 0.79 | 0.83 | 0.88 | 1.01 | 1.34 |
| 19 | 0.2 | 1.29 | 1.45 | 1.87 | 2.04 | 2.82 | 5.95 | 0.96 | 0.97 | 1.01 | 1.08 | 1.24 | 1.64 |
| 20 | 0.2 | 0.77 | 0.84 | 0.89 | 1.06 | 1.43 | 2.69 | 0.55 | 0.54 | 0.55 | 0.58 | 0.64 | 0.82 |
| 21 | 0.2 | 2.78 | 2.73 | 2.71 | 3.11 | 5.16 | 8.87 | 1.87 | 1.75 | 1.67 | 1.63 | 1.55 | 1.50 |
| 22 | 29.8 | 0.04 | 0.07 | 0.18 | 0.16 | 0.45 | 0.31 | 0.03 | 0.03 | 0.03 | 0.03 | 0.06 | 0.05 |
| 23 | 11.6 | 0.07 | 0.11 | 0.28 | 0.25 | 0.73 | 0.50 | 0.04 | 0.04 | 0.04 | 0.04 | 0.09 | 0.07 |
| 24 | 1.5 | 0.10 | 0.16 | 0.40 | 0.35 | 1.01 | 0.70 | 0.06 | 0.06 | 0.06 | 0.06 | 0.13 | 0.10 |
| 25 | 0.5 | 0.19 | 0.23 | 0.39 | 0.41 | 0.60 | 1.25 | 0.12 | 0.12 | 0.12 | 0.12 | 0.13 | 0.17 |
| 26 | 0.2 | 0.30 | 0.36 | 0.63 | 0.66 | 0.96 | 2.00 | 0.20 | 0.19 | 0.19 | 0.19 | 0.21 | 0.26 |
| 27 | 0.2 | 0.42 | 0.51 | 0.88 | 0.92 | 1.34 | 2.79 | 0.27 | 0.26 | 0.26 | 0.26 | 0.30 | 0.37 |
| 28 | 1.4 | 0.43 | 0.49 | 0.61 | 0.70 | 0.93 | 1.89 | 0.29 | 0.29 | 0.29 | 0.30 | 0.32 | 0.36 |
| 29 | 0.6 | 0.69 | 0.78 | 0.98 | 1.11 | 1.49 | 3.03 | 0.47 | 0.46 | 0.46 | 0.48 | 0.51 | 0.57 |
| 30 | 0.2 | 0.96 | 1.09 | 1.36 | 1.56 | 2.08 | 4.23 | 0.65 | 0.64 | 0.65 | 0.67 | 0.71 | 0.80 |
| 31 | 0.3 | 1.28 | 1.45 | 1.81 | 2.07 | 2.76 | 5.62 | 0.87 | 0.85 | 0.86 | 0.89 | 0.94 | 1.06 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 32 | 1.9 | 0.71 | 0.79 | 0.85 | 1.01 | 1.38 | 2.70 | 0.44 | 0.43 | 0.43 | 0.44 | 0.46 | 0.52 |
| 33 | 1.6 | 1.14 | 1.27 | 1.36 | 1.62 | 2.21 | 4.32 | 0.71 | 0.68 | 0.68 | 0.70 | 0.73 | 0.83 |
| 34 | 0.7 | 1.58 | 1.77 | 1.89 | 2.26 | 3.08 | 6.03 | 0.99 | 0.95 | 0.95 | 0.97 | 1.03 | 1.16 |
| 35 | 0.3 | 2.11 | 2.36 | 2.52 | 3.01 | 4.10 | 8.01 | 1.31 | 1.27 | 1.27 | 1.30 | 1.36 | 1.54 |
| 36 | 1.3 | 1.50 | 1.46 | 1.47 | 1.79 | 3.41 | 6.19 | 0.86 | 0.78 | 0.71 | 0.67 | 0.63 | 0.60 |
| 37 | 1.2 | 2.40 | 2.33 | 2.35 | 2.86 | 5.45 | 9.90 | 1.38 | 1.24 | 1.14 | 1.08 | 1.01 | 0.96 |
| 38 | 0.4 | 3.36 | 3.26 | 3.28 | 4.00 | 7.61 | 13.83 | 1.92 | 1.73 | 1.59 | 1.51 | 1.41 | 1.34 |
| 39 | 0.2 | 4.46 | 4.32 | 4.36 | 5.31 | 10.11 | 18.37 | 2.56 | 2.30 | 2.12 | 2.00 | 1.87 | 1.77 |
| 40 | 0.3 | 3.70 | 3.53 | 3.65 | 5.30 | 12.98 | 22.38 | 2.64 | 2.31 | 2.12 | 1.96 | 1.77 | 1.62 |
| 41 | 40.5 | 0.05 | 0.09 | 0.22 | 0.19 | 0.56 | 0.38 | 0.03 | 0.03 | 0.03 | 0.03 | 0.06 | 0.05 |
| 42 | 9.4 | 0.09 | 0.15 | 0.37 | 0.32 | 0.96 | 0.65 | 0.05 | 0.05 | 0.05 | 0.05 | 0.10 | 0.08 |
| 43 | 0.9 | 0.12 | 0.21 | 0.52 | 0.45 | 1.34 | 0.91 | 0.07 | 0.07 | 0.07 | 0.07 | 0.13 | 0.11 |
| 44 | 3.0 | 0.17 | 0.21 | 0.37 | 0.39 | 0.56 | 1.18 | 0.11 | 0.11 | 0.10 | 0.10 | 0.11 | 0.13 |
| 45 | 0.6 | 0.30 | 0.37 | 0.63 | 0.67 | 0.97 | 2.02 | 0.19 | 0.18 | 0.18 | 0.18 | 0.19 | 0.23 |
| 46 | 0.4 | 0.41 | 0.51 | 0.89 | 0.93 | 1.35 | 2.82 | 0.27 | 0.25 | 0.25 | 0.25 | 0.27 | 0.32 |
| 47 | 3.0 | 0.37 | 0.43 | 0.55 | 0.61 | 0.83 | 1.73 | 0.25 | 0.24 | 0.24 | 0.25 | 0.26 | 0.28 |
| 48 | 0.7 | 0.64 | 0.73 | 0.95 | 1.04 | 1.42 | 2.97 | 0.43 | 0.41 | 0.42 | 0.42 | 0.44 | 0.48 |
| 49 | 0.5 | 0.89 | 1.02 | 1.32 | 1.45 | 1.98 | 4.15 | 0.59 | 0.58 | 0.58 | 0.59 | 0.62 | 0.68 |
| 50 | 1.7 | 0.63 | 0.72 | 0.77 | 0.92 | 1.25 | 2.47 | 0.38 | 0.37 | 0.37 | 0.38 | 0.39 | 0.43 |
| 51 | 1.1 | 1.09 | 1.23 | 1.32 | 1.58 | 2.14 | 4.23 | 0.66 | 0.64 | 0.64 | 0.65 | 0.67 | 0.73 |
| 52 | 0.5 | 1.52 | 1.72 | 1.85 | 2.20 | 2.99 | 5.90 | 0.92 | 0.89 | 0.89 | 0.91 | 0.94 | 1.02 |
| 53 | 0.4 | 2.02 | 2.29 | 2.45 | 2.92 | 3.98 | 7.84 | 1.22 | 1.18 | 1.18 | 1.20 | 1.25 | 1.36 |
| 54 | 0.8 | 1.46 | 1.40 | 1.38 | 1.70 | 3.46 | 6.35 | 0.82 | 0.73 | 0.66 | 0.62 | 0.57 | 0.54 |
| 55 | 0.8 | 2.50 | 2.40 | 2.37 | 2.91 | 5.92 | 10.88 | 1.40 | 1.25 | 1.13 | 1.06 | 0.98 | 0.92 |
| 56 | 0.4 | 3.49 | 3.35 | 3.30 | 4.07 | 8.27 | 15.19 | 1.95 | 1.74 | 1.58 | 1.48 | 1.37 | 1.29 |
| 57 | 0.3 | 4.64 | 4.45 | 4.39 | 5.41 | 10.99 | 20.18 | 2.60 | 2.31 | 2.10 | 1.97 | 1.83 | 1.71 |
| 58 | 0.3 | 2.04 | 1.95 | 2.01 | 3.02 | 7.68 | 13.45 | 1.43 | 1.24 | 1.13 | 1.03 | 0.92 | 0.84 |
| 59 | 0.2 | 6.47 | 6.18 | 6.39 | 9.59 | 24.39 | 42.72 | 4.55 | 3.94 | 3.58 | 3.28 | 2.93 | 2.65 |
| 60 | 28.5 | 0.04 | 0.06 | 0.14 | 0.12 | 0.36 | 0.25 | 0.02 | 0.02 | 0.02 | 0.03 | 0.08 | 0.06 |
| 61 | 5.1 | 0.06 | 0.09 | 0.24 | 0.21 | 0.61 | 0.43 | 0.04 | 0.04 | 0.04 | 0.05 | 0.13 | 0.10 |
| 62 | 0.5 | 0.09 | 0.13 | 0.34 | 0.30 | 0.87 | 0.60 | 0.06 | 0.06 | 0.06 | 0.07 | 0.18 | 0.14 |
| 63 | 1.8 | 0.17 | 0.20 | 0.35 | 0.37 | 0.54 | 1.12 | 0.12 | 0.12 | 0.12 | 0.13 | 0.16 | 0.22 |
| 64 | 0.5 | 0.30 | 0.35 | 0.60 | 0.64 | 0.93 | 1.92 | 0.21 | 0.21 | 0.21 | 0.22 | 0.27 | 0.38 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 65 | 0.4 | 0.42 | 0.50 | 0.85 | 0.90 | 1.31 | 2.72 | 0.30 | 0.29 | 0.30 | 0.31 | 0.39 | 0.54 |
| 66 | 1.1 | 0.38 | 0.43 | 0.53 | 0.60 | 0.81 | 1.65 | 0.27 | 0.27 | 0.28 | 0.30 | 0.33 | 0.41 |
| 67 | 0.6 | 0.65 | 0.73 | 0.91 | 1.03 | 1.39 | 2.83 | 0.47 | 0.47 | 0.48 | 0.51 | 0.56 | 0.70 |
| 68 | 0.4 | 0.92 | 1.03 | 1.29 | 1.46 | 1.97 | 4.01 | 0.66 | 0.66 | 0.68 | 0.72 | 0.80 | 0.99 |
| 69 | 0.2 | 1.16 | 1.31 | 1.63 | 1.85 | 2.49 | 5.08 | 0.84 | 0.83 | 0.86 | 0.91 | 1.01 | 1.25 |
| 70 | 0.4 | 0.63 | 0.71 | 0.77 | 0.92 | 1.23 | 2.36 | 0.42 | 0.42 | 0.44 | 0.46 | 0.50 | 0.62 |
| 71 | 0.4 | 1.09 | 1.22 | 1.33 | 1.58 | 2.11 | 4.05 | 0.73 | 0.72 | 0.75 | 0.79 | 0.86 | 1.06 |
| 72 | 0.3 | 1.54 | 1.73 | 1.88 | 2.24 | 2.99 | 5.74 | 1.03 | 1.02 | 1.06 | 1.12 | 1.22 | 1.50 |
| 73 | 0.3 | 1.95 | 2.18 | 2.38 | 2.84 | 3.78 | 7.26 | 1.30 | 1.30 | 1.34 | 1.42 | 1.55 | 1.89 |
| 74 | 0.2 | 1.49 | 1.46 | 1.45 | 1.73 | 2.98 | 5.21 | 0.94 | 0.87 | 0.82 | 0.80 | 0.76 | 0.73 |
| 75 | 17.0 | 0.03 | 0.04 | 0.11 | 0.10 | 0.30 | 0.20 | 0.02 | 0.03 | 0.04 | 0.04 | 0.12 | 0.09 |
| 76 | 3.8 | 0.05 | 0.07 | 0.19 | 0.17 | 0.49 | 0.34 | 0.04 | 0.04 | 0.06 | 0.07 | 0.19 | 0.14 |
| 77 | 0.7 | 0.08 | 0.10 | 0.26 | 0.24 | 0.69 | 0.48 | 0.06 | 0.06 | 0.08 | 0.09 | 0.28 | 0.20 |
| 78 | 0.2 | 0.17 | 0.19 | 0.32 | 0.34 | 0.50 | 0.98 | 0.14 | 0.14 | 0.15 | 0.16 | 0.23 | 0.37 |
| 79 | 0.2 | 0.29 | 0.31 | 0.52 | 0.56 | 0.83 | 1.62 | 0.23 | 0.23 | 0.25 | 0.27 | 0.39 | 0.62 |
| 80 | 0.4 | 0.40 | 0.45 | 0.74 | 0.80 | 1.18 | 2.29 | 0.32 | 0.33 | 0.35 | 0.38 | 0.55 | 0.88 |
| 81 | 0.2 | 0.96 | 1.06 | 1.21 | 1.46 | 1.91 | 3.65 | 0.78 | 0.80 | 0.86 | 0.94 | 1.10 | 1.54 |
| 82 | 0.2 | 1.23 | 1.36 | 1.55 | 1.87 | 2.44 | 4.68 | 1.00 | 1.03 | 1.09 | 1.21 | 1.41 | 1.97 |
| 83 | 11.9 | 0.03 | 0.04 | 0.09 | 0.08 | 0.25 | 0.17 | 0.03 | 0.03 | 0.06 | 0.06 | 0.17 | 0.12 |
| 84 | 3.9 | 0.05 | 0.06 | 0.15 | 0.14 | 0.42 | 0.29 | 0.05 | 0.05 | 0.10 | 0.10 | 0.29 | 0.21 |
| 85 | 0.7 | 0.07 | 0.09 | 0.21 | 0.20 | 0.58 | 0.40 | 0.07 | 0.07 | 0.13 | 0.14 | 0.41 | 0.29 |
| 86 | 0.3 | 0.29 | 0.31 | 0.44 | 0.49 | 0.73 | 1.37 | 0.26 | 0.27 | 0.30 | 0.35 | 0.54 | 0.94 |
| 87 | 0.6 | 0.40 | 0.43 | 0.61 | 0.68 | 1.01 | 1.90 | 0.36 | 0.38 | 0.42 | 0.49 | 0.75 | 1.30 |
| 88 | 0.2 | 0.50 | 0.54 | 0.78 | 0.86 | 1.28 | 2.40 | 0.46 | 0.48 | 0.53 | 0.62 | 0.95 | 1.65 |
| 89 | 8.8 | 0.03 | 0.04 | 0.07 | 0.07 | 0.22 | 0.16 | 0.04 | 0.04 | 0.09 | 0.09 | 0.26 | 0.18 |
| 90 | 3.7 | 0.06 | 0.06 | 0.12 | 0.12 | 0.37 | 0.26 | 0.06 | 0.06 | 0.16 | 0.15 | 0.44 | 0.31 |
| 91 | 0.7 | 0.08 | 0.08 | 0.17 | 0.17 | 0.51 | 0.36 | 0.08 | 0.09 | 0.22 | 0.21 | 0.61 | 0.43 |
| 92 | 0.4 | 0.26 | 0.27 | 0.33 | 0.38 | 0.58 | 1.00 | 0.27 | 0.29 | 0.40 | 0.45 | 0.68 | 1.21 |
| 93 | 0.9 | 0.36 | 0.38 | 0.46 | 0.52 | 0.81 | 1.39 | 0.37 | 0.40 | 0.55 | 0.62 | 0.94 | 1.67 |
| 94 | 0.3 | 0.46 | 0.48 | 0.58 | 0.67 | 1.03 | 1.78 | 0.48 | 0.51 | 0.71 | 0.79 | 1.21 | 2.14 |
| 95 | 7.5 | 0.03 | 0.03 | 0.05 | 0.05 | 0.15 | 0.11 | 0.04 | 0.05 | 0.12 | 0.11 | 0.32 | 0.22 |
| 96 | 3.6 | 0.05 | 0.05 | 0.08 | 0.09 | 0.26 | 0.19 | 0.06 | 0.08 | 0.20 | 0.18 | 0.53 | 0.38 |
| 97 | 0.6 | 0.07 | 0.07 | 0.11 | 0.12 | 0.35 | 0.26 | 0.09 | 0.11 | 0.27 | 0.25 | 0.73 | 0.51 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 98 | 0.3 | 0.22 | 0.23 | 0.24 | 0.27 | 0.43 | 0.68 | 0.26 | 0.29 | 0.49 | 0.53 | 0.81 | 1.42 |
| 99 | 0.5 | 0.30 | 0.31 | 0.33 | 0.37 | 0.59 | 0.92 | 0.36 | 0.39 | 0.67 | 0.73 | 1.11 | 1.95 |

Table D4. Wave-induced vertical motion allowances, Reach 1, h=52 ft, S-1 Channel, fully-loaded *Susan Maersk*, inbound and outbound transits.

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 1 | 7.9 | 0.02 | 0.03 | 0.07 | 0.06 | 0.09 | 0.15 | 0.02 | 0.04 | 0.08 | 0.07 | 0.10 | 0.18 |
| 2 | 2.9 | 0.02 | 0.04 | 0.10 | 0.08 | 0.13 | 0.23 | 0.03 | 0.05 | 0.13 | 0.10 | 0.16 | 0.27 |
| 3 | 0.4 | 0.03 | 0.06 | 0.14 | 0.12 | 0.18 | 0.31 | 0.04 | 0.08 | 0.18 | 0.14 | 0.22 | 0.37 |
| 4 | 10.0 | 0.03 | 0.06 | 0.13 | 0.11 | 0.16 | 0.28 | 0.02 | 0.04 | 0.08 | 0.07 | 0.11 | 0.19 |
| 5 | 9.6 | 0.05 | 0.09 | 0.21 | 0.17 | 0.26 | 0.44 | 0.04 | 0.06 | 0.13 | 0.12 | 0.17 | 0.31 |
| 6 | 0.8 | 0.07 | 0.13 | 0.29 | 0.23 | 0.36 | 0.61 | 0.05 | 0.08 | 0.18 | 0.16 | 0.24 | 0.43 |
| 7 | 0.9 | 0.23 | 0.31 | 0.50 | 0.51 | 0.58 | 0.96 | 0.18 | 0.23 | 0.34 | 0.36 | 0.42 | 0.67 |
| 8 | 3.5 | 0.32 | 0.43 | 0.70 | 0.71 | 0.80 | 1.33 | 0.25 | 0.32 | 0.48 | 0.51 | 0.58 | 0.93 |
| 9 | 0.3 | 0.41 | 0.56 | 0.90 | 0.92 | 1.03 | 1.72 | 0.33 | 0.41 | 0.62 | 0.66 | 0.75 | 1.20 |
| 10 | 0.8 | 0.77 | 0.96 | 1.27 | 1.28 | 1.26 | 1.89 | 0.66 | 0.75 | 0.94 | 0.98 | 0.95 | 1.35 |
| 11 | 0.3 | 0.94 | 1.17 | 1.56 | 1.57 | 1.55 | 2.32 | 0.80 | 0.93 | 1.15 | 1.20 | 1.16 | 1.66 |
| 12 | 13.6 | 0.03 | 0.06 | 0.14 | 0.11 | 0.17 | 0.28 | 0.01 | 0.02 | 0.04 | 0.04 | 0.06 | 0.11 |
| 13 | 9.2 | 0.05 | 0.10 | 0.23 | 0.17 | 0.27 | 0.45 | 0.02 | 0.03 | 0.07 | 0.07 | 0.10 | 0.18 |
| 14 | 0.7 | 0.07 | 0.14 | 0.32 | 0.25 | 0.38 | 0.64 | 0.03 | 0.05 | 0.10 | 0.10 | 0.14 | 0.26 |
| 15 | 0.4 | 0.27 | 0.37 | 0.61 | 0.61 | 0.67 | 1.13 | 0.16 | 0.18 | 0.24 | 0.27 | 0.30 | 0.45 |
| 16 | 1.9 | 0.38 | 0.53 | 0.86 | 0.86 | 0.95 | 1.59 | 0.23 | 0.26 | 0.34 | 0.38 | 0.42 | 0.64 |
| 17 | 0.5 | 0.50 | 0.69 | 1.12 | 1.12 | 1.23 | 2.06 | 0.29 | 0.33 | 0.44 | 0.49 | 0.55 | 0.83 |
| 18 | 0.6 | 0.92 | 1.18 | 1.57 | 1.55 | 1.50 | 2.26 | 0.63 | 0.67 | 0.77 | 0.82 | 0.82 | 0.99 |
| 19 | 0.2 | 1.13 | 1.45 | 1.93 | 1.91 | 1.84 | 2.77 | 0.77 | 0.83 | 0.95 | 1.01 | 1.00 | 1.21 |
| 20 | 0.2 | 0.85 | 0.91 | 0.95 | 0.94 | 0.89 | 1.17 | 0.67 | 0.67 | 0.67 | 0.69 | 0.69 | 0.68 |
| 21 | 0.2 | 3.23 | 3.23 | 3.14 | 3.13 | 3.08 | 3.73 | 2.46 | 2.37 | 2.25 | 2.22 | 2.18 | 2.10 |
| 22 | 29.8 | 0.04 | 0.08 | 0.18 | 0.14 | 0.21 | 0.36 | 0.01 | 0.01 | 0.03 | 0.03 | 0.04 | 0.08 |
| 23 | 11.6 | 0.07 | 0.12 | 0.29 | 0.22 | 0.34 | 0.57 | 0.02 | 0.02 | 0.04 | 0.05 | 0.07 | 0.12 |
| 24 | 1.5 | 0.09 | 0.17 | 0.41 | 0.31 | 0.48 | 0.80 | 0.03 | 0.03 | 0.06 | 0.06 | 0.09 | 0.17 |
| 25 | 0.5 | 0.17 | 0.25 | 0.42 | 0.41 | 0.46 | 0.78 | 0.08 | 0.08 | 0.10 | 0.11 | 0.12 | 0.17 |
| 26 | 0.2 | 0.28 | 0.40 | 0.67 | 0.66 | 0.73 | 1.25 | 0.13 | 0.13 | 0.15 | 0.17 | 0.19 | 0.27 |
| 27 | 0.2 | 0.39 | 0.56 | 0.94 | 0.92 | 1.02 | 1.74 | 0.17 | 0.18 | 0.21 | 0.24 | 0.26 | 0.38 |
| 28 | 1.4 | 0.41 | 0.52 | 0.65 | 0.64 | 0.59 | 0.89 | 0.24 | 0.24 | 0.25 | 0.27 | 0.27 | 0.27 |
| 29 | 0.6 | 0.65 | 0.84 | 1.05 | 1.02 | 0.95 | 1.43 | 0.39 | 0.39 | 0.40 | 0.42 | 0.43 | 0.43 |
| 30 | 0.2 | 0.91 | 1.17 | 1.46 | 1.43 | 1.32 | 2.00 | 0.54 | 0.54 | 0.56 | 0.59 | 0.60 | 0.61 |
| 31 | 0.3 | 1.21 | 1.55 | 1.94 | 1.89 | 1.76 | 2.65 | 0.72 | 0.72 | 0.75 | 0.79 | 0.80 | 0.80 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 32 | 1.9 | 0.78 | 0.87 | 0.92 | 0.89 | 0.83 | 1.23 | 0.53 | 0.52 | 0.51 | 0.52 | 0.52 | 0.52 |
| 33 | 1.6 | 1.26 | 1.39 | 1.48 | 1.43 | 1.33 | 1.96 | 0.84 | 0.82 | 0.82 | 0.84 | 0.83 | 0.83 |
| 34 | 0.7 | 1.75 | 1.94 | 2.06 | 2.00 | 1.86 | 2.74 | 1.18 | 1.15 | 1.14 | 1.17 | 1.16 | 1.15 |
| 35 | 0.3 | 2.33 | 2.58 | 2.74 | 2.65 | 2.47 | 3.64 | 1.57 | 1.53 | 1.52 | 1.55 | 1.55 | 1.53 |
| 36 | 1.3 | 1.76 | 1.75 | 1.70 | 1.65 | 1.60 | 2.66 | 1.13 | 1.06 | 0.99 | 0.95 | 0.92 | 0.88 |
| 37 | 1.2 | 2.81 | 2.80 | 2.72 | 2.65 | 2.56 | 4.26 | 1.81 | 1.70 | 1.58 | 1.52 | 1.46 | 1.40 |
| 38 | 0.4 | 3.93 | 3.91 | 3.80 | 3.70 | 3.57 | 5.95 | 2.53 | 2.37 | 2.21 | 2.12 | 2.05 | 1.96 |
| 39 | 0.2 | 5.22 | 5.20 | 5.05 | 4.91 | 4.75 | 7.91 | 3.36 | 3.15 | 2.93 | 2.81 | 2.72 | 2.60 |
| 40 | 0.3 | 4.66 | 4.48 | 4.12 | 3.92 | 5.06 | 9.29 | 3.52 | 3.27 | 3.09 | 2.80 | 2.68 | 2.53 |
| 41 | 40.5 | 0.05 | 0.10 | 0.24 | 0.18 | 0.27 | 0.45 | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.05 |
| 42 | 9.4 | 0.09 | 0.17 | 0.40 | 0.30 | 0.46 | 0.77 | 0.02 | 0.02 | 0.03 | 0.03 | 0.05 | 0.08 |
| 43 | 0.9 | 0.13 | 0.24 | 0.56 | 0.42 | 0.64 | 1.07 | 0.03 | 0.03 | 0.04 | 0.05 | 0.06 | 0.11 |
| 44 | 3.0 | 0.17 | 0.24 | 0.41 | 0.40 | 0.44 | 0.76 | 0.07 | 0.06 | 0.07 | 0.07 | 0.08 | 0.09 |
| 45 | 0.6 | 0.29 | 0.42 | 0.71 | 0.69 | 0.76 | 1.31 | 0.11 | 0.11 | 0.12 | 0.13 | 0.13 | 0.16 |
| 46 | 0.4 | 0.40 | 0.58 | 0.99 | 0.97 | 1.06 | 1.83 | 0.16 | 0.16 | 0.16 | 0.17 | 0.19 | 0.22 |
| 47 | 3.0 | 0.36 | 0.47 | 0.61 | 0.59 | 0.56 | 0.85 | 0.19 | 0.18 | 0.18 | 0.19 | 0.19 | 0.19 |
| 48 | 0.7 | 0.61 | 0.81 | 1.05 | 1.02 | 0.96 | 1.45 | 0.32 | 0.31 | 0.31 | 0.32 | 0.33 | 0.33 |
| 49 | 0.5 | 0.85 | 1.13 | 1.47 | 1.42 | 1.34 | 2.03 | 0.45 | 0.43 | 0.43 | 0.45 | 0.46 | 0.46 |
| 50 | 1.7 | 0.70 | 0.79 | 0.85 | 0.82 | 0.75 | 1.16 | 0.43 | 0.41 | 0.40 | 0.40 | 0.40 | 0.40 |
| 51 | 1.1 | 1.20 | 1.36 | 1.46 | 1.40 | 1.28 | 1.98 | 0.73 | 0.70 | 0.68 | 0.69 | 0.69 | 0.68 |
| 52 | 0.5 | 1.68 | 1.90 | 2.04 | 1.95 | 1.79 | 2.77 | 1.02 | 0.97 | 0.95 | 0.96 | 0.96 | 0.95 |
| 53 | 0.4 | 2.23 | 2.53 | 2.71 | 2.59 | 2.38 | 3.68 | 1.35 | 1.29 | 1.26 | 1.28 | 1.27 | 1.26 |
| 54 | 0.8 | 1.55 | 1.52 | 1.47 | 1.37 | 1.45 | 2.81 | 0.88 | 0.80 | 0.72 | 0.66 | 0.63 | 0.59 |
| 55 | 0.8 | 2.65 | 2.60 | 2.52 | 2.35 | 2.49 | 4.81 | 1.51 | 1.37 | 1.24 | 1.14 | 1.07 | 1.01 |
| 56 | 0.4 | 3.70 | 3.63 | 3.52 | 3.28 | 3.48 | 6.72 | 2.11 | 1.91 | 1.73 | 1.59 | 1.50 | 1.41 |
| 57 | 0.3 | 4.92 | 4.83 | 4.68 | 4.36 | 4.63 | 8.93 | 2.80 | 2.53 | 2.30 | 2.11 | 1.99 | 1.87 |
| 58 | 0.3 | 2.10 | 2.01 | 1.77 | 1.70 | 2.97 | 5.78 | 1.48 | 1.33 | 1.22 | 1.08 | 1.00 | 0.91 |
| 59 | 0.2 | 6.66 | 6.37 | 5.62 | 5.41 | 9.44 | 18.37 | 4.71 | 4.24 | 3.87 | 3.44 | 3.16 | 2.88 |
| 60 | 28.5 | 0.03 | 0.07 | 0.16 | 0.12 | 0.19 | 0.31 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.04 |
| 61 | 5.1 | 0.06 | 0.11 | 0.27 | 0.20 | 0.32 | 0.52 | 0.01 | 0.02 | 0.02 | 0.03 | 0.04 | 0.07 |
| 62 | 0.5 | 0.08 | 0.16 | 0.39 | 0.29 | 0.45 | 0.74 | 0.02 | 0.02 | 0.03 | 0.04 | 0.05 | 0.10 |
| 63 | 1.8 | 0.17 | 0.24 | 0.41 | 0.40 | 0.44 | 0.76 | 0.07 | 0.07 | 0.07 | 0.08 | 0.08 | 0.11 |
| 64 | 0.5 | 0.28 | 0.41 | 0.70 | 0.69 | 0.75 | 1.30 | 0.11 | 0.12 | 0.12 | 0.14 | 0.14 | 0.19 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 65 | 0.4 | 0.40 | 0.59 | 1.00 | 0.97 | 1.07 | 1.84 | 0.16 | 0.16 | 0.18 | 0.19 | 0.20 | 0.26 |
| 66 | 1.1 | 0.36 | 0.47 | 0.61 | 0.59 | 0.55 | 0.84 | 0.19 | 0.18 | 0.19 | 0.19 | 0.20 | 0.20 |
| 67 | 0.6 | 0.61 | 0.80 | 1.04 | 1.01 | 0.95 | 1.44 | 0.33 | 0.32 | 0.32 | 0.33 | 0.34 | 0.35 |
| 68 | 0.4 | 0.86 | 1.14 | 1.48 | 1.43 | 1.35 | 2.04 | 0.46 | 0.45 | 0.45 | 0.47 | 0.48 | 0.49 |
| 69 | 0.2 | 1.09 | 1.44 | 1.87 | 1.81 | 1.71 | 2.59 | 0.58 | 0.57 | 0.57 | 0.60 | 0.61 | 0.62 |
| 70 | 0.4 | 0.70 | 0.79 | 0.85 | 0.82 | 0.75 | 1.15 | 0.43 | 0.42 | 0.41 | 0.42 | 0.41 | 0.41 |
| 71 | 0.4 | 1.20 | 1.36 | 1.46 | 1.40 | 1.29 | 1.98 | 0.75 | 0.72 | 0.70 | 0.71 | 0.71 | 0.71 |
| 72 | 0.3 | 1.71 | 1.93 | 2.06 | 1.98 | 1.82 | 2.80 | 1.06 | 1.02 | 0.99 | 1.01 | 1.01 | 1.00 |
| 73 | 0.3 | 2.16 | 2.43 | 2.61 | 2.51 | 2.30 | 3.54 | 1.34 | 1.28 | 1.26 | 1.28 | 1.27 | 1.27 |
| 74 | 0.2 | 1.45 | 1.44 | 1.39 | 1.33 | 1.35 | 2.47 | 0.83 | 0.76 | 0.70 | 0.65 | 0.62 | 0.59 |
| 75 | 17.0 | 0.03 | 0.06 | 0.13 | 0.10 | 0.16 | 0.26 | 0.01 | 0.01 | 0.02 | 0.03 | 0.04 | 0.07 |
| 76 | 3.8 | 0.05 | 0.09 | 0.22 | 0.17 | 0.26 | 0.43 | 0.02 | 0.02 | 0.04 | 0.04 | 0.06 | 0.12 |
| 77 | 0.7 | 0.07 | 0.13 | 0.31 | 0.24 | 0.37 | 0.62 | 0.02 | 0.03 | 0.06 | 0.06 | 0.09 | 0.16 |
| 78 | 0.2 | 0.15 | 0.22 | 0.38 | 0.38 | 0.43 | 0.73 | 0.07 | 0.08 | 0.10 | 0.11 | 0.13 | 0.20 |
| 79 | 0.2 | 0.26 | 0.37 | 0.64 | 0.63 | 0.70 | 1.21 | 0.12 | 0.13 | 0.17 | 0.19 | 0.21 | 0.33 |
| 80 | 0.4 | 0.36 | 0.53 | 0.90 | 0.89 | 1.00 | 1.71 | 0.17 | 0.19 | 0.24 | 0.27 | 0.30 | 0.46 |
| 81 | 0.2 | 0.88 | 1.12 | 1.42 | 1.39 | 1.30 | 1.95 | 0.55 | 0.56 | 0.59 | 0.63 | 0.63 | 0.63 |
| 82 | 0.2 | 1.12 | 1.44 | 1.82 | 1.78 | 1.66 | 2.49 | 0.70 | 0.71 | 0.76 | 0.80 | 0.81 | 0.81 |
| 83 | 11.9 | 0.03 | 0.05 | 0.11 | 0.09 | 0.14 | 0.23 | 0.01 | 0.02 | 0.04 | 0.04 | 0.06 | 0.11 |
| 84 | 3.9 | 0.04 | 0.08 | 0.19 | 0.15 | 0.23 | 0.39 | 0.02 | 0.04 | 0.08 | 0.07 | 0.11 | 0.19 |
| 85 | 0.7 | 0.06 | 0.11 | 0.27 | 0.21 | 0.32 | 0.54 | 0.03 | 0.05 | 0.10 | 0.10 | 0.15 | 0.26 |
| 86 | 0.3 | 0.24 | 0.33 | 0.56 | 0.56 | 0.64 | 1.08 | 0.15 | 0.18 | 0.26 | 0.28 | 0.33 | 0.53 |
| 87 | 0.6 | 0.33 | 0.46 | 0.78 | 0.78 | 0.89 | 1.50 | 0.21 | 0.25 | 0.36 | 0.39 | 0.46 | 0.73 |
| 88 | 0.2 | 0.42 | 0.59 | 0.99 | 0.98 | 1.12 | 1.90 | 0.26 | 0.31 | 0.45 | 0.50 | 0.58 | 0.92 |
| 89 | 8.8 | 0.02 | 0.04 | 0.10 | 0.08 | 0.12 | 0.21 | 0.02 | 0.04 | 0.08 | 0.07 | 0.10 | 0.18 |
| 90 | 3.7 | 0.04 | 0.07 | 0.17 | 0.14 | 0.21 | 0.36 | 0.03 | 0.06 | 0.13 | 0.11 | 0.17 | 0.30 |
| 91 | 0.7 | 0.06 | 0.10 | 0.23 | 0.19 | 0.29 | 0.50 | 0.05 | 0.08 | 0.19 | 0.16 | 0.24 | 0.42 |
| 92 | 0.4 | 0.19 | 0.26 | 0.44 | 0.45 | 0.53 | 0.88 | 0.17 | 0.22 | 0.36 | 0.38 | 0.45 | 0.74 |
| 93 | 0.9 | 0.27 | 0.37 | 0.61 | 0.62 | 0.73 | 1.23 | 0.24 | 0.31 | 0.50 | 0.52 | 0.62 | 1.03 |
| 94 | 0.3 | 0.34 | 0.47 | 0.78 | 0.79 | 0.93 | 1.57 | 0.30 | 0.40 | 0.64 | 0.67 | 0.79 | 1.31 |
| 95 | 7.5 | 0.02 | 0.03 | 0.07 | 0.06 | 0.09 | 0.16 | 0.03 | 0.05 | 0.11 | 0.09 | 0.14 | 0.23 |
| 96 | 3.6 | 0.03 | 0.05 | 0.12 | 0.10 | 0.16 | 0.27 | 0.04 | 0.08 | 0.18 | 0.15 | 0.23 | 0.39 |
| 97 | 0.6 | 0.04 | 0.07 | 0.16 | 0.14 | 0.21 | 0.37 | 0.06 | 0.11 | 0.25 | 0.20 | 0.31 | 0.53 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 98 | 0.3 | 0.15 | 0.19 | 0.31 | 0.33 | 0.40 | 0.67 | 0.19 | 0.27 | 0.47 | 0.47 | 0.56 | 0.95 |
| 99 | 0.5 | 0.20 | 0.27 | 0.43 | 0.45 | 0.55 | 0.91 | 0.26 | 0.37 | 0.64 | 0.64 | 0.77 | 1.30 |

Table D5. Wave-induced vertical motion allowances, Reach 1, h=52 ft, S-3 Channel, fully-loaded *Susan Maersk*, inbound and outbound transits.

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 1 | 7.9 | 0.02 | 0.04 | 0.10 | 0.07 | 0.12 | 0.19 | 0.01 | 0.02 | 0.05 | 0.04 | 0.06 | 0.11 |
| 2 | 2.9 | 0.03 | 0.06 | 0.14 | 0.11 | 0.18 | 0.29 | 0.02 | 0.03 | 0.07 | 0.06 | 0.10 | 0.17 |
| 3 | 0.4 | 0.05 | 0.08 | 0.20 | 0.15 | 0.24 | 0.41 | 0.03 | 0.05 | 0.10 | 0.09 | 0.14 | 0.24 |
| 4 | 10.0 | 0.04 | 0.07 | 0.17 | 0.13 | 0.19 | 0.32 | 0.01 | 0.02 | 0.04 | 0.04 | 0.06 | 0.11 |
| 5 | 9.6 | 0.06 | 0.11 | 0.26 | 0.20 | 0.31 | 0.51 | 0.02 | 0.03 | 0.06 | 0.06 | 0.09 | 0.17 |
| 6 | 0.8 | 0.08 | 0.16 | 0.36 | 0.28 | 0.43 | 0.71 | 0.03 | 0.04 | 0.09 | 0.09 | 0.13 | 0.24 |
| 7 | 0.9 | 0.26 | 0.36 | 0.61 | 0.60 | 0.66 | 1.13 | 0.14 | 0.15 | 0.20 | 0.22 | 0.25 | 0.37 |
| 8 | 3.5 | 0.36 | 0.50 | 0.84 | 0.83 | 0.92 | 1.56 | 0.19 | 0.21 | 0.27 | 0.30 | 0.34 | 0.52 |
| 9 | 0.3 | 0.46 | 0.65 | 1.09 | 1.08 | 1.19 | 2.02 | 0.25 | 0.27 | 0.35 | 0.39 | 0.44 | 0.67 |
| 10 | 0.8 | 0.81 | 1.07 | 1.47 | 1.45 | 1.43 | 2.20 | 0.51 | 0.54 | 0.61 | 0.65 | 0.65 | 0.79 |
| 11 | 0.3 | 0.99 | 1.31 | 1.81 | 1.78 | 1.76 | 2.70 | 0.63 | 0.66 | 0.75 | 0.80 | 0.80 | 0.97 |
| 12 | 13.6 | 0.04 | 0.07 | 0.16 | 0.12 | 0.18 | 0.30 | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.05 |
| 13 | 9.2 | 0.06 | 0.11 | 0.25 | 0.19 | 0.30 | 0.49 | 0.01 | 0.02 | 0.03 | 0.03 | 0.04 | 0.08 |
| 14 | 0.7 | 0.08 | 0.15 | 0.36 | 0.27 | 0.42 | 0.69 | 0.02 | 0.02 | 0.04 | 0.04 | 0.06 | 0.12 |
| 15 | 0.4 | 0.28 | 0.40 | 0.67 | 0.66 | 0.71 | 1.21 | 0.12 | 0.13 | 0.14 | 0.15 | 0.16 | 0.22 |
| 16 | 1.9 | 0.40 | 0.57 | 0.95 | 0.93 | 1.01 | 1.72 | 0.17 | 0.18 | 0.20 | 0.22 | 0.23 | 0.31 |
| 17 | 0.5 | 0.52 | 0.74 | 1.23 | 1.21 | 1.31 | 2.23 | 0.23 | 0.23 | 0.25 | 0.28 | 0.29 | 0.40 |
| 18 | 0.6 | 0.93 | 1.25 | 1.69 | 1.63 | 1.58 | 2.41 | 0.50 | 0.50 | 0.51 | 0.54 | 0.55 | 0.56 |
| 19 | 0.2 | 1.14 | 1.53 | 2.07 | 2.01 | 1.94 | 2.96 | 0.62 | 0.61 | 0.63 | 0.66 | 0.68 | 0.68 |
| 20 | 0.2 | 0.81 | 0.89 | 0.93 | 0.90 | 0.84 | 1.23 | 0.53 | 0.51 | 0.50 | 0.51 | 0.51 | 0.50 |
| 21 | 0.2 | 2.55 | 2.53 | 2.45 | 2.35 | 2.30 | 4.11 | 1.56 | 1.44 | 1.33 | 1.25 | 1.20 | 1.14 |
| 22 | 29.8 | 0.04 | 0.08 | 0.19 | 0.14 | 0.21 | 0.35 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.03 |
| 23 | 11.6 | 0.07 | 0.13 | 0.30 | 0.22 | 0.34 | 0.56 | 0.01 | 0.02 | 0.02 | 0.02 | 0.03 | 0.05 |
| 24 | 1.5 | 0.09 | 0.18 | 0.42 | 0.31 | 0.48 | 0.79 | 0.02 | 0.02 | 0.03 | 0.03 | 0.04 | 0.07 |
| 25 | 0.5 | 0.17 | 0.25 | 0.42 | 0.41 | 0.45 | 0.77 | 0.07 | 0.07 | 0.07 | 0.07 | 0.08 | 0.09 |
| 26 | 0.2 | 0.27 | 0.40 | 0.68 | 0.66 | 0.72 | 1.24 | 0.11 | 0.10 | 0.11 | 0.12 | 0.12 | 0.14 |
| 27 | 0.2 | 0.38 | 0.56 | 0.95 | 0.92 | 1.01 | 1.73 | 0.15 | 0.15 | 0.15 | 0.16 | 0.17 | 0.19 |
| 28 | 1.4 | 0.40 | 0.51 | 0.65 | 0.63 | 0.58 | 0.88 | 0.21 | 0.20 | 0.20 | 0.21 | 0.21 | 0.21 |
| 29 | 0.6 | 0.64 | 0.82 | 1.04 | 1.00 | 0.93 | 1.41 | 0.34 | 0.32 | 0.32 | 0.33 | 0.34 | 0.34 |
| 30 | 0.2 | 0.89 | 1.15 | 1.45 | 1.40 | 1.30 | 1.97 | 0.47 | 0.45 | 0.45 | 0.46 | 0.47 | 0.48 |
| 31 | 0.3 | 1.18 | 1.53 | 1.93 | 1.86 | 1.73 | 2.62 | 0.63 | 0.60 | 0.60 | 0.61 | 0.62 | 0.63 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 32 | 1.9 | 0.75 | 0.84 | 0.89 | 0.85 | 0.78 | 1.19 | 0.45 | 0.43 | 0.42 | 0.42 | 0.42 | 0.42 |
| 33 | 1.6 | 1.20 | 1.34 | 1.43 | 1.36 | 1.25 | 1.91 | 0.73 | 0.69 | 0.67 | 0.68 | 0.67 | 0.67 |
| 34 | 0.7 | 1.67 | 1.87 | 1.99 | 1.90 | 1.75 | 2.66 | 1.01 | 0.97 | 0.94 | 0.95 | 0.94 | 0.93 |
| 35 | 0.3 | 2.22 | 2.48 | 2.64 | 2.53 | 2.33 | 3.54 | 1.34 | 1.28 | 1.24 | 1.26 | 1.25 | 1.24 |
| 36 | 1.3 | 1.47 | 1.44 | 1.40 | 1.30 | 1.34 | 2.60 | 0.81 | 0.73 | 0.66 | 0.60 | 0.57 | 0.53 |
| 37 | 1.2 | 2.35 | 2.31 | 2.24 | 2.09 | 2.14 | 4.16 | 1.30 | 1.17 | 1.06 | 0.97 | 0.91 | 0.85 |
| 38 | 0.4 | 3.28 | 3.22 | 3.12 | 2.92 | 2.99 | 5.80 | 1.81 | 1.63 | 1.47 | 1.35 | 1.27 | 1.19 |
| 39 | 0.2 | 4.36 | 4.28 | 4.15 | 3.87 | 3.98 | 7.71 | 2.41 | 2.17 | 1.96 | 1.79 | 1.69 | 1.58 |
| 40 | 0.3 | 3.31 | 3.16 | 2.77 | 2.64 | 4.65 | 9.20 | 2.30 | 2.05 | 1.86 | 1.65 | 1.50 | 1.36 |
| 41 | 40.5 | 0.05 | 0.09 | 0.22 | 0.16 | 0.25 | 0.41 | 0.01 | 0.02 | 0.02 | 0.03 | 0.04 | 0.07 |
| 42 | 9.4 | 0.08 | 0.16 | 0.37 | 0.28 | 0.42 | 0.70 | 0.02 | 0.03 | 0.04 | 0.05 | 0.07 | 0.12 |
| 43 | 0.9 | 0.12 | 0.22 | 0.52 | 0.39 | 0.59 | 0.98 | 0.03 | 0.04 | 0.06 | 0.06 | 0.09 | 0.17 |
| 44 | 3.0 | 0.16 | 0.23 | 0.38 | 0.37 | 0.41 | 0.70 | 0.07 | 0.07 | 0.08 | 0.08 | 0.09 | 0.12 |
| 45 | 0.6 | 0.27 | 0.39 | 0.66 | 0.64 | 0.70 | 1.20 | 0.11 | 0.12 | 0.13 | 0.14 | 0.15 | 0.21 |
| 46 | 0.4 | 0.38 | 0.54 | 0.92 | 0.90 | 0.98 | 1.68 | 0.16 | 0.16 | 0.18 | 0.20 | 0.21 | 0.30 |
| 47 | 3.0 | 0.34 | 0.44 | 0.57 | 0.55 | 0.52 | 0.78 | 0.19 | 0.18 | 0.19 | 0.20 | 0.20 | 0.20 |
| 48 | 0.7 | 0.58 | 0.76 | 0.98 | 0.95 | 0.89 | 1.34 | 0.32 | 0.32 | 0.32 | 0.34 | 0.35 | 0.35 |
| 49 | 0.5 | 0.81 | 1.06 | 1.37 | 1.32 | 1.24 | 1.88 | 0.45 | 0.44 | 0.45 | 0.47 | 0.48 | 0.49 |
| 50 | 1.7 | 0.67 | 0.75 | 0.80 | 0.77 | 0.71 | 1.08 | 0.43 | 0.42 | 0.41 | 0.42 | 0.42 | 0.41 |
| 51 | 1.1 | 1.15 | 1.29 | 1.38 | 1.32 | 1.22 | 1.85 | 0.74 | 0.71 | 0.70 | 0.72 | 0.71 | 0.71 |
| 52 | 0.5 | 1.60 | 1.80 | 1.92 | 1.85 | 1.71 | 2.58 | 1.03 | 0.99 | 0.98 | 1.00 | 0.99 | 0.99 |
| 53 | 0.4 | 2.13 | 2.39 | 2.56 | 2.46 | 2.27 | 3.42 | 1.36 | 1.32 | 1.30 | 1.33 | 1.32 | 1.31 |
| 54 | 0.8 | 1.59 | 1.57 | 1.52 | 1.44 | 1.43 | 2.60 | 0.98 | 0.91 | 0.84 | 0.79 | 0.75 | 0.72 |
| 55 | 0.8 | 2.72 | 2.69 | 2.60 | 2.47 | 2.45 | 4.45 | 1.68 | 1.55 | 1.43 | 1.35 | 1.29 | 1.23 |
| 56 | 0.4 | 3.80 | 3.75 | 3.63 | 3.45 | 3.42 | 6.22 | 2.35 | 2.17 | 2.00 | 1.88 | 1.80 | 1.72 |
| 57 | 0.3 | 5.05 | 4.98 | 4.82 | 4.58 | 4.54 | 8.26 | 3.12 | 2.88 | 2.66 | 2.50 | 2.40 | 2.28 |
| 58 | 0.3 | 2.35 | 2.25 | 2.05 | 1.92 | 2.85 | 5.33 | 1.75 | 1.61 | 1.50 | 1.35 | 1.28 | 1.19 |
| 59 | 0.2 | 7.47 | 7.16 | 6.50 | 6.11 | 9.04 | 16.92 | 5.55 | 5.11 | 4.78 | 4.29 | 4.05 | 3.79 |
| 60 | 28.5 | 0.03 | 0.06 | 0.13 | 0.10 | 0.16 | 0.26 | 0.01 | 0.02 | 0.03 | 0.03 | 0.05 | 0.09 |
| 61 | 5.1 | 0.05 | 0.10 | 0.23 | 0.17 | 0.27 | 0.44 | 0.02 | 0.03 | 0.05 | 0.05 | 0.08 | 0.15 |
| 62 | 0.5 | 0.07 | 0.14 | 0.32 | 0.25 | 0.38 | 0.63 | 0.03 | 0.04 | 0.08 | 0.08 | 0.11 | 0.21 |
| 63 | 1.8 | 0.15 | 0.21 | 0.35 | 0.34 | 0.38 | 0.64 | 0.08 | 0.09 | 0.11 | 0.12 | 0.14 | 0.21 |
| 64 | 0.5 | 0.25 | 0.36 | 0.59 | 0.59 | 0.65 | 1.10 | 0.13 | 0.15 | 0.19 | 0.21 | 0.24 | 0.37 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 65 | 0.4 | 0.36 | 0.50 | 0.84 | 0.83 | 0.92 | 1.56 | 0.19 | 0.21 | 0.27 | 0.30 | 0.34 | 0.52 |
| 66 | 1.1 | 0.33 | 0.42 | 0.53 | 0.52 | 0.49 | 0.72 | 0.21 | 0.22 | 0.24 | 0.26 | 0.26 | 0.27 |
| 67 | 0.6 | 0.56 | 0.71 | 0.91 | 0.89 | 0.83 | 1.24 | 0.37 | 0.38 | 0.41 | 0.44 | 0.44 | 0.47 |
| 68 | 0.4 | 0.79 | 1.01 | 1.29 | 1.26 | 1.18 | 1.76 | 0.52 | 0.54 | 0.59 | 0.62 | 0.63 | 0.67 |
| 69 | 0.2 | 1.00 | 1.28 | 1.63 | 1.59 | 1.49 | 2.22 | 0.66 | 0.68 | 0.74 | 0.79 | 0.79 | 0.84 |
| 70 | 0.4 | 0.67 | 0.73 | 0.78 | 0.76 | 0.72 | 1.01 | 0.49 | 0.49 | 0.49 | 0.51 | 0.50 | 0.50 |
| 71 | 0.4 | 1.14 | 1.26 | 1.34 | 1.31 | 1.23 | 1.72 | 0.84 | 0.84 | 0.84 | 0.87 | 0.86 | 0.86 |
| 72 | 0.3 | 1.62 | 1.79 | 1.90 | 1.85 | 1.74 | 2.44 | 1.19 | 1.19 | 1.20 | 1.23 | 1.23 | 1.21 |
| 73 | 0.3 | 2.05 | 2.26 | 2.40 | 2.34 | 2.20 | 3.09 | 1.51 | 1.50 | 1.51 | 1.56 | 1.55 | 1.53 |
| 74 | 0.2 | 1.67 | 1.67 | 1.62 | 1.61 | 1.58 | 2.09 | 1.20 | 1.14 | 1.08 | 1.06 | 1.04 | 1.00 |
| 75 | 17.0 | 0.02 | 0.04 | 0.10 | 0.08 | 0.12 | 0.20 | 0.01 | 0.02 | 0.05 | 0.04 | 0.07 | 0.12 |
| 76 | 3.8 | 0.04 | 0.07 | 0.17 | 0.13 | 0.20 | 0.34 | 0.02 | 0.04 | 0.08 | 0.07 | 0.11 | 0.20 |
| 77 | 0.7 | 0.05 | 0.10 | 0.24 | 0.18 | 0.29 | 0.48 | 0.03 | 0.05 | 0.12 | 0.10 | 0.16 | 0.28 |
| 78 | 0.2 | 0.13 | 0.18 | 0.30 | 0.30 | 0.34 | 0.57 | 0.09 | 0.11 | 0.17 | 0.18 | 0.21 | 0.33 |
| 79 | 0.2 | 0.21 | 0.30 | 0.49 | 0.49 | 0.56 | 0.94 | 0.15 | 0.18 | 0.27 | 0.30 | 0.34 | 0.55 |
| 80 | 0.4 | 0.30 | 0.42 | 0.69 | 0.70 | 0.79 | 1.33 | 0.21 | 0.26 | 0.39 | 0.42 | 0.49 | 0.78 |
| 81 | 0.2 | 0.78 | 0.95 | 1.16 | 1.16 | 1.06 | 1.55 | 0.63 | 0.69 | 0.79 | 0.83 | 0.81 | 0.97 |
| 82 | 0.2 | 1.00 | 1.21 | 1.49 | 1.49 | 1.36 | 1.99 | 0.81 | 0.89 | 1.01 | 1.06 | 1.03 | 1.24 |
| 83 | 11.9 | 0.02 | 0.03 | 0.08 | 0.06 | 0.10 | 0.16 | 0.02 | 0.03 | 0.08 | 0.06 | 0.10 | 0.16 |
| 84 | 3.9 | 0.03 | 0.06 | 0.13 | 0.10 | 0.16 | 0.28 | 0.03 | 0.06 | 0.13 | 0.10 | 0.16 | 0.28 |
| 85 | 0.7 | 0.04 | 0.08 | 0.18 | 0.15 | 0.22 | 0.38 | 0.04 | 0.08 | 0.18 | 0.15 | 0.22 | 0.38 |
| 86 | 0.3 | 0.19 | 0.25 | 0.39 | 0.40 | 0.47 | 0.77 | 0.19 | 0.25 | 0.39 | 0.40 | 0.47 | 0.77 |
| 87 | 0.6 | 0.26 | 0.34 | 0.54 | 0.56 | 0.65 | 1.06 | 0.26 | 0.34 | 0.54 | 0.56 | 0.65 | 1.06 |
| 88 | 0.2 | 0.33 | 0.43 | 0.68 | 0.71 | 0.82 | 1.35 | 0.33 | 0.43 | 0.68 | 0.71 | 0.82 | 1.35 |
| 89 | 8.8 | 0.02 | 0.03 | 0.06 | 0.05 | 0.08 | 0.14 | 0.03 | 0.05 | 0.11 | 0.09 | 0.14 | 0.23 |
| 90 | 3.7 | 0.03 | 0.04 | 0.10 | 0.09 | 0.13 | 0.23 | 0.05 | 0.08 | 0.19 | 0.15 | 0.23 | 0.39 |
| 91 | 0.7 | 0.04 | 0.06 | 0.13 | 0.12 | 0.18 | 0.32 | 0.06 | 0.11 | 0.27 | 0.21 | 0.32 | 0.54 |
| 92 | 0.4 | 0.14 | 0.18 | 0.27 | 0.29 | 0.35 | 0.56 | 0.21 | 0.29 | 0.49 | 0.49 | 0.57 | 0.96 |
| 93 | 0.9 | 0.20 | 0.25 | 0.38 | 0.40 | 0.48 | 0.78 | 0.28 | 0.40 | 0.68 | 0.68 | 0.79 | 1.33 |
| 94 | 0.3 | 0.25 | 0.32 | 0.48 | 0.52 | 0.61 | 1.00 | 0.36 | 0.51 | 0.87 | 0.87 | 1.01 | 1.71 |
| 95 | 7.5 | 0.01 | 0.02 | 0.03 | 0.03 | 0.05 | 0.09 | 0.03 | 0.06 | 0.14 | 0.10 | 0.16 | 0.27 |
| 96 | 3.6 | 0.02 | 0.03 | 0.05 | 0.06 | 0.08 | 0.15 | 0.05 | 0.10 | 0.23 | 0.18 | 0.27 | 0.45 |
| 97 | 0.6 | 0.03 | 0.04 | 0.07 | 0.08 | 0.11 | 0.21 | 0.07 | 0.13 | 0.32 | 0.24 | 0.37 | 0.62 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 98 | 0.3 | 0.11 | 0.12 | 0.17 | 0.19 | 0.23 | 0.37 | 0.22 | 0.32 | 0.57 | 0.55 | 0.65 | 1.12 |
| 99 | 0.5 | 0.15 | 0.17 | 0.23 | 0.26 | 0.32 | 0.51 | 0.30 | 0.44 | 0.78 | 0.76 | 0.89 | 1.54 |

Table D6. Wave-induced vertical motion allowances, Reach 1, h=52 ft, S-8 Channel, fully-loaded *Susan Maersk*, inbound and outbound transits.

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 1 | 7.9 | 0.02 | 0.03 | 0.08 | 0.06 | 0.10 | 0.17 | 0.02 | 0.03 | 0.06 | 0.05 | 0.08 | 0.14 |
| 2 | 2.9 | 0.03 | 0.05 | 0.12 | 0.10 | 0.15 | 0.25 | 0.02 | 0.04 | 0.10 | 0.08 | 0.12 | 0.21 |
| 3 | 0.4 | 0.04 | 0.07 | 0.17 | 0.13 | 0.21 | 0.35 | 0.03 | 0.06 | 0.13 | 0.11 | 0.17 | 0.30 |
| 4 | 10.0 | 0.03 | 0.06 | 0.15 | 0.11 | 0.18 | 0.30 | 0.02 | 0.03 | 0.06 | 0.05 | 0.08 | 0.14 |
| 5 | 9.6 | 0.05 | 0.10 | 0.23 | 0.18 | 0.28 | 0.47 | 0.03 | 0.04 | 0.09 | 0.09 | 0.13 | 0.23 |
| 6 | 0.8 | 0.08 | 0.14 | 0.32 | 0.25 | 0.39 | 0.65 | 0.04 | 0.06 | 0.13 | 0.12 | 0.18 | 0.32 |
| 7 | 0.9 | 0.24 | 0.33 | 0.55 | 0.55 | 0.61 | 1.02 | 0.16 | 0.18 | 0.26 | 0.28 | 0.32 | 0.50 |
| 8 | 3.5 | 0.33 | 0.46 | 0.76 | 0.76 | 0.85 | 1.42 | 0.22 | 0.25 | 0.36 | 0.39 | 0.45 | 0.69 |
| 9 | 0.3 | 0.43 | 0.60 | 0.98 | 0.98 | 1.10 | 1.84 | 0.28 | 0.33 | 0.46 | 0.50 | 0.58 | 0.90 |
| 10 | 0.8 | 0.77 | 1.00 | 1.35 | 1.34 | 1.33 | 2.01 | 0.57 | 0.63 | 0.74 | 0.79 | 0.77 | 1.03 |
| 11 | 0.3 | 0.95 | 1.22 | 1.66 | 1.65 | 1.63 | 2.47 | 0.70 | 0.77 | 0.91 | 0.97 | 0.94 | 1.26 |
| 12 | 13.6 | 0.03 | 0.06 | 0.15 | 0.11 | 0.17 | 0.29 | 0.01 | 0.01 | 0.03 | 0.03 | 0.04 | 0.08 |
| 13 | 9.2 | 0.05 | 0.10 | 0.24 | 0.18 | 0.28 | 0.46 | 0.02 | 0.02 | 0.04 | 0.05 | 0.07 | 0.12 |
| 14 | 0.7 | 0.08 | 0.14 | 0.34 | 0.26 | 0.40 | 0.65 | 0.02 | 0.03 | 0.06 | 0.07 | 0.10 | 0.17 |
| 15 | 0.4 | 0.27 | 0.38 | 0.63 | 0.62 | 0.68 | 1.15 | 0.14 | 0.15 | 0.18 | 0.20 | 0.21 | 0.31 |
| 16 | 1.9 | 0.39 | 0.54 | 0.90 | 0.88 | 0.96 | 1.63 | 0.19 | 0.21 | 0.25 | 0.28 | 0.30 | 0.44 |
| 17 | 0.5 | 0.50 | 0.71 | 1.16 | 1.15 | 1.25 | 2.11 | 0.25 | 0.27 | 0.32 | 0.36 | 0.39 | 0.57 |
| 18 | 0.6 | 0.91 | 1.20 | 1.61 | 1.57 | 1.52 | 2.30 | 0.55 | 0.56 | 0.61 | 0.65 | 0.66 | 0.71 |
| 19 | 0.2 | 1.11 | 1.47 | 1.97 | 1.93 | 1.86 | 2.82 | 0.67 | 0.69 | 0.75 | 0.79 | 0.80 | 0.87 |
| 20 | 0.2 | 0.81 | 0.88 | 0.92 | 0.90 | 0.84 | 1.18 | 0.58 | 0.57 | 0.56 | 0.58 | 0.57 | 0.57 |
| 21 | 0.2 | 2.82 | 2.81 | 2.73 | 2.68 | 2.61 | 3.89 | 1.93 | 1.82 | 1.71 | 1.65 | 1.61 | 1.54 |
| 22 | 29.8 | 0.04 | 0.08 | 0.18 | 0.14 | 0.21 | 0.35 | 0.01 | 0.01 | 0.01 | 0.02 | 0.03 | 0.05 |
| 23 | 11.6 | 0.07 | 0.12 | 0.29 | 0.22 | 0.34 | 0.56 | 0.02 | 0.02 | 0.02 | 0.03 | 0.04 | 0.07 |
| 24 | 1.5 | 0.09 | 0.17 | 0.41 | 0.31 | 0.47 | 0.78 | 0.02 | 0.02 | 0.03 | 0.04 | 0.06 | 0.10 |
| 25 | 0.5 | 0.17 | 0.25 | 0.42 | 0.41 | 0.45 | 0.77 | 0.07 | 0.07 | 0.07 | 0.08 | 0.08 | 0.11 |
| 26 | 0.2 | 0.27 | 0.39 | 0.67 | 0.65 | 0.71 | 1.22 | 0.11 | 0.11 | 0.12 | 0.13 | 0.14 | 0.18 |
| 27 | 0.2 | 0.38 | 0.55 | 0.93 | 0.91 | 1.00 | 1.71 | 0.15 | 0.15 | 0.16 | 0.18 | 0.19 | 0.24 |
| 28 | 1.4 | 0.40 | 0.51 | 0.64 | 0.62 | 0.58 | 0.87 | 0.22 | 0.21 | 0.21 | 0.22 | 0.22 | 0.23 |
| 29 | 0.6 | 0.63 | 0.82 | 1.03 | 0.99 | 0.92 | 1.40 | 0.35 | 0.34 | 0.34 | 0.35 | 0.36 | 0.36 |
| 30 | 0.2 | 0.88 | 1.14 | 1.43 | 1.39 | 1.29 | 1.95 | 0.48 | 0.47 | 0.47 | 0.49 | 0.50 | 0.50 |
| 31 | 0.3 | 1.17 | 1.51 | 1.91 | 1.84 | 1.71 | 2.59 | 0.64 | 0.62 | 0.63 | 0.65 | 0.66 | 0.67 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 32 | 1.9 | 0.75 | 0.84 | 0.89 | 0.85 | 0.79 | 1.19 | 0.47 | 0.45 | 0.44 | 0.44 | 0.44 | 0.44 |
| 33 | 1.6 | 1.20 | 1.34 | 1.42 | 1.36 | 1.26 | 1.90 | 0.75 | 0.72 | 0.70 | 0.71 | 0.71 | 0.70 |
| 34 | 0.7 | 1.67 | 1.87 | 1.98 | 1.90 | 1.75 | 2.66 | 1.04 | 1.00 | 0.98 | 0.99 | 0.99 | 0.98 |
| 35 | 0.3 | 2.22 | 2.48 | 2.63 | 2.53 | 2.33 | 3.53 | 1.39 | 1.33 | 1.30 | 1.32 | 1.31 | 1.30 |
| 36 | 1.3 | 1.53 | 1.51 | 1.46 | 1.38 | 1.41 | 2.60 | 0.89 | 0.81 | 0.74 | 0.69 | 0.65 | 0.62 |
| 37 | 1.2 | 2.44 | 2.41 | 2.34 | 2.21 | 2.26 | 4.16 | 1.42 | 1.29 | 1.18 | 1.10 | 1.05 | 0.99 |
| 38 | 0.4 | 3.41 | 3.37 | 3.26 | 3.09 | 3.15 | 5.81 | 1.98 | 1.81 | 1.65 | 1.54 | 1.46 | 1.38 |
| 39 | 0.2 | 4.53 | 4.48 | 4.34 | 4.10 | 4.18 | 7.72 | 2.63 | 2.40 | 2.19 | 2.04 | 1.94 | 1.84 |
| 40 | 0.3 | 3.63 | 3.48 | 3.11 | 2.88 | 4.76 | 9.16 | 2.61 | 2.36 | 2.18 | 1.94 | 1.81 | 1.67 |
| 41 | 40.5 | 0.05 | 0.10 | 0.22 | 0.17 | 0.25 | 0.42 | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.04 |
| 42 | 9.4 | 0.09 | 0.16 | 0.38 | 0.29 | 0.44 | 0.72 | 0.02 | 0.02 | 0.03 | 0.03 | 0.04 | 0.07 |
| 43 | 0.9 | 0.12 | 0.23 | 0.54 | 0.40 | 0.61 | 1.00 | 0.03 | 0.03 | 0.04 | 0.05 | 0.06 | 0.10 |
| 44 | 3.0 | 0.16 | 0.23 | 0.39 | 0.38 | 0.42 | 0.72 | 0.06 | 0.06 | 0.06 | 0.07 | 0.07 | 0.09 |
| 45 | 0.6 | 0.27 | 0.40 | 0.68 | 0.66 | 0.72 | 1.24 | 0.11 | 0.11 | 0.11 | 0.12 | 0.13 | 0.15 |
| 46 | 0.4 | 0.38 | 0.55 | 0.94 | 0.92 | 1.01 | 1.73 | 0.15 | 0.15 | 0.15 | 0.17 | 0.18 | 0.21 |
| 47 | 3.0 | 0.34 | 0.45 | 0.58 | 0.56 | 0.53 | 0.80 | 0.18 | 0.17 | 0.17 | 0.18 | 0.18 | 0.18 |
| 48 | 0.7 | 0.58 | 0.77 | 1.00 | 0.96 | 0.91 | 1.37 | 0.30 | 0.29 | 0.29 | 0.30 | 0.31 | 0.32 |
| 49 | 0.5 | 0.82 | 1.08 | 1.40 | 1.35 | 1.27 | 1.92 | 0.43 | 0.41 | 0.41 | 0.42 | 0.43 | 0.44 |
| 50 | 1.7 | 0.67 | 0.76 | 0.81 | 0.77 | 0.71 | 1.09 | 0.41 | 0.39 | 0.38 | 0.38 | 0.38 | 0.38 |
| 51 | 1.1 | 1.15 | 1.30 | 1.39 | 1.33 | 1.22 | 1.87 | 0.70 | 0.66 | 0.65 | 0.66 | 0.65 | 0.65 |
| 52 | 0.5 | 1.60 | 1.81 | 1.94 | 1.85 | 1.70 | 2.62 | 0.97 | 0.93 | 0.90 | 0.92 | 0.91 | 0.90 |
| 53 | 0.4 | 2.13 | 2.40 | 2.58 | 2.46 | 2.26 | 3.48 | 1.29 | 1.23 | 1.20 | 1.22 | 1.21 | 1.20 |
| 54 | 0.8 | 1.47 | 1.44 | 1.40 | 1.30 | 1.38 | 2.65 | 0.84 | 0.76 | 0.69 | 0.63 | 0.60 | 0.56 |
| 55 | 0.8 | 2.53 | 2.48 | 2.40 | 2.23 | 2.36 | 4.54 | 1.44 | 1.30 | 1.18 | 1.08 | 1.02 | 0.96 |
| 56 | 0.4 | 3.53 | 3.46 | 3.35 | 3.11 | 3.29 | 6.33 | 2.01 | 1.82 | 1.65 | 1.51 | 1.43 | 1.34 |
| 57 | 0.3 | 4.69 | 4.59 | 4.45 | 4.13 | 4.37 | 8.41 | 2.67 | 2.41 | 2.19 | 2.01 | 1.89 | 1.78 |
| 58 | 0.3 | 2.00 | 1.91 | 1.68 | 1.61 | 2.80 | 5.44 | 1.42 | 1.27 | 1.16 | 1.03 | 0.95 | 0.86 |
| 59 | 0.2 | 6.34 | 6.05 | 5.34 | 5.12 | 8.91 | 17.29 | 4.50 | 4.03 | 3.68 | 3.27 | 3.00 | 2.74 |
| 60 | 28.5 | 0.03 | 0.06 | 0.14 | 0.11 | 0.17 | 0.28 | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.06 |
| 61 | 5.1 | 0.05 | 0.10 | 0.25 | 0.19 | 0.29 | 0.47 | 0.02 | 0.02 | 0.03 | 0.04 | 0.06 | 0.10 |
| 62 | 0.5 | 0.08 | 0.15 | 0.35 | 0.26 | 0.41 | 0.67 | 0.02 | 0.03 | 0.05 | 0.05 | 0.08 | 0.14 |
| 63 | 1.8 | 0.15 | 0.22 | 0.37 | 0.37 | 0.40 | 0.69 | 0.07 | 0.07 | 0.09 | 0.10 | 0.10 | 0.15 |
| 64 | 0.5 | 0.26 | 0.38 | 0.64 | 0.63 | 0.69 | 1.18 | 0.12 | 0.13 | 0.15 | 0.16 | 0.18 | 0.26 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 65 | 0.4 | 0.37 | 0.54 | 0.91 | 0.89 | 0.98 | 1.67 | 0.17 | 0.18 | 0.21 | 0.23 | 0.25 | 0.37 |
| 66 | 1.1 | 0.33 | 0.43 | 0.56 | 0.54 | 0.51 | 0.77 | 0.19 | 0.19 | 0.20 | 0.21 | 0.22 | 0.22 |
| 67 | 0.6 | 0.57 | 0.74 | 0.96 | 0.93 | 0.88 | 1.32 | 0.33 | 0.33 | 0.35 | 0.37 | 0.37 | 0.38 |
| 68 | 0.4 | 0.81 | 1.06 | 1.36 | 1.32 | 1.24 | 1.87 | 0.47 | 0.47 | 0.50 | 0.52 | 0.53 | 0.53 |
| 69 | 0.2 | 1.03 | 1.33 | 1.72 | 1.67 | 1.57 | 2.36 | 0.60 | 0.60 | 0.63 | 0.66 | 0.67 | 0.67 |
| 70 | 0.4 | 0.67 | 0.75 | 0.80 | 0.77 | 0.71 | 1.06 | 0.45 | 0.44 | 0.43 | 0.44 | 0.44 | 0.44 |
| 71 | 0.4 | 1.15 | 1.28 | 1.37 | 1.32 | 1.22 | 1.82 | 0.77 | 0.75 | 0.74 | 0.76 | 0.76 | 0.75 |
| 72 | 0.3 | 1.63 | 1.82 | 1.94 | 1.87 | 1.73 | 2.57 | 1.09 | 1.06 | 1.05 | 1.08 | 1.07 | 1.06 |
| 73 | 0.3 | 2.06 | 2.30 | 2.45 | 2.37 | 2.19 | 3.25 | 1.37 | 1.34 | 1.33 | 1.36 | 1.36 | 1.35 |
| 74 | 0.2 | 1.51 | 1.51 | 1.46 | 1.43 | 1.38 | 2.25 | 0.97 | 0.91 | 0.85 | 0.81 | 0.78 | 0.75 |
| 75 | 17.0 | 0.03 | 0.05 | 0.12 | 0.09 | 0.14 | 0.23 | 0.01 | 0.02 | 0.04 | 0.03 | 0.05 | 0.09 |
| 76 | 3.8 | 0.04 | 0.08 | 0.19 | 0.15 | 0.23 | 0.38 | 0.02 | 0.03 | 0.06 | 0.06 | 0.08 | 0.15 |
| 77 | 0.7 | 0.06 | 0.11 | 0.27 | 0.21 | 0.32 | 0.53 | 0.03 | 0.04 | 0.08 | 0.08 | 0.12 | 0.22 |
| 78 | 0.2 | 0.14 | 0.20 | 0.33 | 0.33 | 0.37 | 0.63 | 0.08 | 0.09 | 0.13 | 0.14 | 0.16 | 0.26 |
| 79 | 0.2 | 0.23 | 0.33 | 0.55 | 0.55 | 0.62 | 1.05 | 0.13 | 0.15 | 0.21 | 0.23 | 0.27 | 0.42 |
| 80 | 0.4 | 0.33 | 0.46 | 0.78 | 0.78 | 0.88 | 1.49 | 0.19 | 0.22 | 0.30 | 0.33 | 0.39 | 0.60 |
| 81 | 0.2 | 0.81 | 1.02 | 1.27 | 1.25 | 1.15 | 1.71 | 0.58 | 0.61 | 0.67 | 0.71 | 0.70 | 0.77 |
| 82 | 0.2 | 1.04 | 1.30 | 1.62 | 1.60 | 1.48 | 2.19 | 0.74 | 0.78 | 0.86 | 0.90 | 0.90 | 0.99 |
| 83 | 11.9 | 0.02 | 0.04 | 0.09 | 0.07 | 0.11 | 0.19 | 0.02 | 0.03 | 0.06 | 0.05 | 0.08 | 0.13 |
| 84 | 3.9 | 0.04 | 0.07 | 0.16 | 0.12 | 0.19 | 0.32 | 0.03 | 0.04 | 0.10 | 0.09 | 0.13 | 0.23 |
| 85 | 0.7 | 0.05 | 0.09 | 0.22 | 0.17 | 0.27 | 0.45 | 0.04 | 0.06 | 0.14 | 0.12 | 0.18 | 0.32 |
| 86 | 0.3 | 0.21 | 0.28 | 0.46 | 0.47 | 0.54 | 0.90 | 0.16 | 0.21 | 0.32 | 0.33 | 0.39 | 0.63 |
| 87 | 0.6 | 0.29 | 0.39 | 0.64 | 0.65 | 0.75 | 1.25 | 0.23 | 0.29 | 0.44 | 0.46 | 0.54 | 0.88 |
| 88 | 0.2 | 0.36 | 0.50 | 0.82 | 0.83 | 0.95 | 1.58 | 0.29 | 0.36 | 0.55 | 0.59 | 0.68 | 1.11 |
| 89 | 8.8 | 0.02 | 0.03 | 0.08 | 0.06 | 0.10 | 0.17 | 0.02 | 0.04 | 0.09 | 0.08 | 0.12 | 0.20 |
| 90 | 3.7 | 0.03 | 0.06 | 0.13 | 0.11 | 0.16 | 0.28 | 0.04 | 0.07 | 0.16 | 0.13 | 0.20 | 0.34 |
| 91 | 0.7 | 0.05 | 0.08 | 0.18 | 0.15 | 0.23 | 0.39 | 0.05 | 0.10 | 0.22 | 0.18 | 0.28 | 0.47 |
| 92 | 0.4 | 0.16 | 0.21 | 0.34 | 0.36 | 0.42 | 0.70 | 0.19 | 0.25 | 0.42 | 0.42 | 0.50 | 0.83 |
| 93 | 0.9 | 0.23 | 0.30 | 0.48 | 0.50 | 0.59 | 0.97 | 0.26 | 0.35 | 0.58 | 0.59 | 0.69 | 1.16 |
| 94 | 0.3 | 0.29 | 0.38 | 0.61 | 0.63 | 0.75 | 1.24 | 0.33 | 0.45 | 0.74 | 0.75 | 0.88 | 1.48 |
| 95 | 7.5 | 0.01 | 0.02 | 0.05 | 0.04 | 0.07 | 0.12 | 0.03 | 0.05 | 0.12 | 0.09 | 0.15 | 0.24 |
| 96 | 3.6 | 0.02 | 0.04 | 0.08 | 0.08 | 0.11 | 0.20 | 0.05 | 0.09 | 0.21 | 0.16 | 0.25 | 0.41 |
| 97 | 0.6 | 0.03 | 0.05 | 0.11 | 0.10 | 0.15 | 0.28 | 0.07 | 0.12 | 0.28 | 0.22 | 0.34 | 0.57 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 98 | 0.3 | 0.12 | 0.15 | 0.23 | 0.25 | 0.30 | 0.50 | 0.20 | 0.29 | 0.51 | 0.50 | 0.60 | 1.02 |
| 99 | 0.5 | 0.17 | 0.21 | 0.31 | 0.34 | 0.41 | 0.68 | 0.28 | 0.40 | 0.70 | 0.69 | 0.82 | 1.40 |

# Appendix E: Net UKC for Light- (T=46 ft, h=50 ft) and Fully-loaded (T=47.5 ft, h=52 ft) *Susan Maersk* for Reach 1 in Savannah Channels S-1_Sta0, S-3_Sta39, and S-8_Sta 0

Table E1. Net UKC (ft), Reach 1, h=50 ft, S-1 Channel, light-loaded *Susan Maersk*, inbound and outbound transits.

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 1 | 7.9 | 3.35 | 2.86 | 2.18 | 1.38 | 0.22 | -1.07 | 3.35 | 2.86 | 2.17 | 1.36 | 0.18 | -1.10 |
| 2 | 2.9 | 3.34 | 2.84 | 2.15 | 1.34 | 0.12 | -1.14 | 3.33 | 2.84 | 2.13 | 1.32 | 0.06 | -1.18 |
| 3 | 0.4 | 3.32 | 2.83 | 2.11 | 1.30 | 0.00 | -1.22 | 3.32 | 2.82 | 2.08 | 1.28 | -0.08 | -1.27 |
| 4 | 10.0 | 3.33 | 2.84 | 2.12 | 1.32 | 0.05 | -1.19 | 3.34 | 2.85 | 2.17 | 1.36 | 0.16 | -1.12 |
| 5 | 9.6 | 3.31 | 2.81 | 2.05 | 1.25 | -0.16 | -1.34 | 3.31 | 2.82 | 2.12 | 1.31 | 0.01 | -1.23 |
| 6 | 0.8 | 3.28 | 2.77 | 1.97 | 1.17 | -0.38 | -1.50 | 3.29 | 2.79 | 2.07 | 1.25 | -0.14 | -1.34 |
| 7 | 0.9 | 3.07 | 2.55 | 1.77 | 0.92 | -0.37 | -2.46 | 3.09 | 2.59 | 1.92 | 1.06 | -0.17 | -1.98 |
| 8 | 3.5 | 2.95 | 2.42 | 1.59 | 0.71 | -0.68 | -3.05 | 2.98 | 2.47 | 1.79 | 0.91 | -0.40 | -2.38 |
| 9 | 0.3 | 2.82 | 2.28 | 1.39 | 0.50 | -1.00 | -3.68 | 2.86 | 2.35 | 1.66 | 0.76 | -0.63 | -2.81 |
| 10 | 0.8 | 2.40 | 1.83 | 1.05 | 0.02 | -1.52 | -4.76 | 2.48 | 1.94 | 1.21 | 0.26 | -1.10 | -3.57 |
| 11 | 0.3 | 2.18 | 1.58 | 0.77 | -0.30 | -1.95 | -5.63 | 2.28 | 1.72 | 0.97 | -0.01 | -1.45 | -4.16 |
| 12 | 13.6 | 3.34 | 2.84 | 2.11 | 1.32 | 0.05 | -1.20 | 3.35 | 2.86 | 2.21 | 1.39 | 0.26 | -1.05 |
| 13 | 9.2 | 3.32 | 2.80 | 2.03 | 1.24 | -0.17 | -1.35 | 3.33 | 2.84 | 2.18 | 1.36 | 0.18 | -1.11 |
| 14 | 0.7 | 3.29 | 2.77 | 1.94 | 1.16 | -0.42 | -1.52 | 3.31 | 2.82 | 2.15 | 1.33 | 0.08 | -1.18 |
| 15 | 0.4 | 3.05 | 2.53 | 1.67 | 0.83 | -0.49 | -2.85 | 3.12 | 2.62 | 1.97 | 1.13 | -0.02 | -1.65 |
| 16 | 1.9 | 2.92 | 2.38 | 1.43 | 0.57 | -0.87 | -3.64 | 3.01 | 2.51 | 1.85 | 1.00 | -0.20 | -1.94 |
| 17 | 0.5 | 2.78 | 2.22 | 1.19 | 0.31 | -1.25 | -4.44 | 2.90 | 2.40 | 1.73 | 0.87 | -0.38 | -2.24 |
| 18 | 0.6 | 2.28 | 1.67 | 0.76 | -0.26 | -1.90 | -5.66 | 2.49 | 1.97 | 1.27 | 0.36 | -0.88 | -2.83 |
| 19 | 0.2 | 2.03 | 1.39 | 0.42 | -0.64 | -2.43 | -6.74 | 2.28 | 1.76 | 1.04 | 0.12 | -1.17 | -3.25 |
| 20 | 0.2 | 2.57 | 2.03 | 1.33 | 0.35 | -1.03 | -3.58 | 2.75 | 2.26 | 1.59 | 0.73 | -0.41 | -2.07 |
| 21 | 0.2 | 0.20 | -0.24 | -0.88 | -1.87 | -4.61 | -9.16 | 0.99 | 0.61 | 0.04 | -0.76 | -1.70 | -3.00 |
| 22 | 29.8 | 3.33 | 2.82 | 2.07 | 1.28 | -0.05 | -1.26 | 3.35 | 2.86 | 2.22 | 1.41 | 0.31 | -1.01 |
| 23 | 11.6 | 3.31 | 2.78 | 1.97 | 1.19 | -0.33 | -1.45 | 3.33 | 2.84 | 2.20 | 1.38 | 0.25 | -1.06 |
| 24 | 1.5 | 3.28 | 2.73 | 1.85 | 1.09 | -0.62 | -1.66 | 3.31 | 2.82 | 2.18 | 1.36 | 0.19 | -1.10 |
| 25 | 0.5 | 3.18 | 2.66 | 1.85 | 1.02 | -0.20 | -2.21 | 3.24 | 2.76 | 2.11 | 1.30 | 0.23 | -1.19 |
| 26 | 0.2 | 3.07 | 2.52 | 1.62 | 0.77 | -0.57 | -2.97 | 3.16 | 2.68 | 2.03 | 1.21 | 0.12 | -1.34 |
| 27 | 0.2 | 2.94 | 2.38 | 1.37 | 0.50 | -0.96 | -3.78 | 3.07 | 2.59 | 1.94 | 1.12 | 0.01 | -1.51 |
| 28 | 1.4 | 2.92 | 2.38 | 1.63 | 0.71 | -0.55 | -2.87 | 3.05 | 2.56 | 1.91 | 1.08 | 0.01 | -1.43 |
| 29 | 0.6 | 2.65 | 2.07 | 1.25 | 0.28 | -1.13 | -4.03 | 2.86 | 2.37 | 1.71 | 0.86 | -0.23 | -1.72 |
| 30 | 0.2 | 2.36 | 1.74 | 0.86 | -0.18 | -1.74 | -5.26 | 2.65 | 2.16 | 1.49 | 0.64 | -0.48 | -2.03 |
| 31 | 0.3 | 2.03 | 1.37 | 0.40 | -0.72 | -2.45 | -6.67 | 2.41 | 1.92 | 1.24 | 0.37 | -0.77 | -2.39 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 32 | 1.9 | 2.64 | 2.06 | 1.36 | 0.37 | -1.03 | -3.70 | 2.88 | 2.40 | 1.75 | 0.91 | -0.17 | -1.65 |
| 33 | 1.6 | 2.19 | 1.57 | 0.82 | -0.27 | -1.89 | -5.36 | 2.58 | 2.11 | 1.45 | 0.59 | -0.52 | -2.08 |
| 34 | 0.7 | 1.72 | 1.04 | 0.25 | -0.94 | -2.80 | -7.11 | 2.26 | 1.80 | 1.13 | 0.25 | -0.89 | -2.53 |
| 35 | 0.3 | 1.17 | 0.44 | -0.40 | -1.73 | -3.85 | -9.14 | 1.90 | 1.44 | 0.76 | -0.14 | -1.32 | -3.06 |
| 36 | 1.3 | 1.65 | 1.19 | 0.56 | -0.57 | -3.10 | -7.12 | 2.28 | 1.87 | 1.29 | 0.51 | -0.47 | -1.79 |
| 37 | 1.2 | 0.61 | 0.18 | -0.45 | -1.78 | -5.20 | -10.83 | 1.62 | 1.26 | 0.71 | -0.05 | -1.01 | -2.30 |
| 38 | 0.4 | -0.49 | -0.90 | -1.52 | -3.05 | -7.43 | -14.74 | 0.92 | 0.61 | 0.10 | -0.64 | -1.57 | -2.84 |
| 39 | 0.2 | -1.76 | -2.14 | -2.76 | -4.53 | -10.00 | -19.28 | 0.12 | -0.13 | -0.60 | -1.33 | -2.22 | -3.47 |
| 40 | 0.3 | -1.35 | -1.63 | -2.15 | -4.77 | -12.91 | -22.51 | -0.20 | -0.31 | -0.77 | -1.44 | -2.23 | -3.41 |
| 41 | 40.5 | 3.33 | 2.80 | 2.02 | 1.24 | -0.18 | -1.34 | 3.35 | 2.86 | 2.22 | 1.41 | 0.35 | -0.99 |
| 42 | 9.4 | 3.29 | 2.74 | 1.86 | 1.10 | -0.61 | -1.63 | 3.33 | 2.84 | 2.20 | 1.39 | 0.31 | -1.02 |
| 43 | 0.9 | 3.25 | 2.67 | 1.70 | 0.96 | -1.01 | -1.91 | 3.30 | 2.82 | 2.18 | 1.36 | 0.27 | -1.06 |
| 44 | 3.0 | 3.20 | 2.67 | 1.86 | 1.03 | -0.19 | -2.19 | 3.26 | 2.78 | 2.14 | 1.33 | 0.29 | -1.08 |
| 45 | 0.6 | 3.07 | 2.51 | 1.58 | 0.74 | -0.61 | -3.08 | 3.18 | 2.70 | 2.06 | 1.25 | 0.21 | -1.18 |
| 46 | 0.4 | 2.95 | 2.35 | 1.32 | 0.46 | -1.01 | -3.93 | 3.10 | 2.63 | 1.99 | 1.18 | 0.13 | -1.28 |
| 47 | 3.0 | 2.99 | 2.44 | 1.67 | 0.80 | -0.46 | -2.78 | 3.12 | 2.64 | 2.00 | 1.18 | 0.14 | -1.24 |
| 48 | 0.7 | 2.71 | 2.12 | 1.25 | 0.34 | -1.09 | -4.09 | 2.93 | 2.46 | 1.81 | 0.99 | -0.06 | -1.45 |
| 49 | 0.5 | 2.44 | 1.82 | 0.86 | -0.09 | -1.68 | -5.34 | 2.76 | 2.28 | 1.64 | 0.82 | -0.24 | -1.65 |
| 50 | 1.7 | 2.71 | 2.13 | 1.44 | 0.47 | -0.91 | -3.55 | 2.98 | 2.50 | 1.86 | 1.04 | 0.00 | -1.39 |
| 51 | 1.1 | 2.24 | 1.60 | 0.86 | -0.22 | -1.85 | -5.42 | 2.69 | 2.22 | 1.58 | 0.76 | -0.30 | -1.71 |
| 52 | 0.5 | 1.79 | 1.08 | 0.31 | -0.88 | -2.75 | -7.20 | 2.41 | 1.96 | 1.32 | 0.49 | -0.58 | -2.02 |
| 53 | 0.4 | 1.26 | 0.49 | -0.33 | -1.64 | -3.79 | -9.25 | 2.10 | 1.65 | 1.01 | 0.18 | -0.90 | -2.37 |
| 54 | 0.8 | 1.85 | 1.42 | 0.80 | -0.35 | -3.25 | -7.68 | 2.52 | 2.13 | 1.56 | 0.79 | -0.19 | -1.51 |
| 55 | 0.8 | 0.76 | 0.37 | -0.24 | -1.64 | -5.86 | -12.49 | 1.91 | 1.58 | 1.06 | 0.32 | -0.63 | -1.91 |
| 56 | 0.4 | -0.28 | -0.63 | -1.23 | -2.86 | -8.35 | -17.07 | 1.33 | 1.06 | 0.59 | -0.12 | -1.04 | -2.30 |
| 57 | 0.3 | -1.49 | -1.79 | -2.37 | -4.27 | -11.22 | -22.37 | 0.66 | 0.46 | 0.04 | -0.63 | -1.51 | -2.74 |
| 58 | 0.3 | 1.24 | 0.84 | 0.13 | -1.75 | -7.73 | -15.24 | 1.88 | 1.59 | 1.07 | 0.35 | -0.56 | -1.82 |
| 59 | 0.2 | -3.42 | -3.61 | -4.49 | -8.70 | -25.44 | -46.35 | -1.39 | -1.25 | -1.51 | -2.01 | -2.67 | -3.73 |
| 60 | 28.5 | 3.34 | 2.83 | 2.10 | 1.30 | 0.02 | -1.21 | 3.36 | 2.87 | 2.23 | 1.42 | 0.36 | -0.98 |
| 61 | 5.1 | 3.32 | 2.79 | 1.99 | 1.21 | -0.27 | -1.41 | 3.34 | 2.85 | 2.21 | 1.40 | 0.32 | -1.01 |
| 62 | 0.5 | 3.29 | 2.74 | 1.88 | 1.11 | -0.55 | -1.60 | 3.33 | 2.84 | 2.20 | 1.38 | 0.29 | -1.04 |
| 63 | 1.8 | 3.20 | 2.67 | 1.86 | 1.03 | -0.18 | -2.18 | 3.26 | 2.78 | 2.14 | 1.33 | 0.28 | -1.10 |
| 64 | 0.5 | 3.07 | 2.51 | 1.59 | 0.74 | -0.60 | -3.06 | 3.18 | 2.69 | 2.06 | 1.24 | 0.19 | -1.22 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 65 | 0.4 | 2.94 | 2.35 | 1.31 | 0.45 | -1.02 | -3.94 | 3.09 | 2.61 | 1.98 | 1.16 | 0.09 | -1.33 |
| 66 | 1.1 | 2.99 | 2.44 | 1.67 | 0.80 | -0.46 | -2.76 | 3.12 | 2.63 | 1.99 | 1.17 | 0.12 | -1.27 |
| 67 | 0.6 | 2.71 | 2.13 | 1.26 | 0.34 | -1.08 | -4.06 | 2.93 | 2.44 | 1.80 | 0.98 | -0.08 | -1.50 |
| 68 | 0.4 | 2.43 | 1.81 | 0.85 | -0.11 | -1.71 | -5.36 | 2.74 | 2.26 | 1.61 | 0.78 | -0.29 | -1.73 |
| 69 | 0.2 | 2.17 | 1.52 | 0.48 | -0.52 | -2.27 | -6.53 | 2.57 | 2.09 | 1.44 | 0.61 | -0.48 | -1.94 |
| 70 | 0.4 | 2.71 | 2.14 | 1.44 | 0.47 | -0.91 | -3.53 | 2.97 | 2.49 | 1.84 | 1.02 | -0.03 | -1.44 |
| 71 | 0.4 | 2.24 | 1.60 | 0.86 | -0.23 | -1.85 | -5.39 | 2.67 | 2.20 | 1.56 | 0.72 | -0.35 | -1.79 |
| 72 | 0.3 | 1.76 | 1.06 | 0.28 | -0.92 | -2.79 | -7.24 | 2.38 | 1.92 | 1.27 | 0.42 | -0.66 | -2.15 |
| 73 | 0.3 | 1.34 | 0.57 | -0.25 | -1.55 | -3.64 | -8.91 | 2.11 | 1.66 | 1.01 | 0.15 | -0.94 | -2.47 |
| 74 | 0.2 | 1.96 | 1.50 | 0.84 | -0.27 | -2.82 | -6.82 | 2.57 | 2.16 | 1.58 | 0.80 | -0.19 | -1.51 |
| 75 | 17.0 | 3.35 | 2.84 | 2.12 | 1.32 | 0.07 | -1.17 | 3.36 | 2.87 | 2.22 | 1.41 | 0.32 | -1.01 |
| 76 | 3.8 | 3.32 | 2.81 | 2.03 | 1.25 | -0.15 | -1.32 | 3.34 | 2.85 | 2.21 | 1.39 | 0.26 | -1.05 |
| 77 | 0.7 | 3.30 | 2.77 | 1.94 | 1.17 | -0.39 | -1.48 | 3.33 | 2.83 | 2.19 | 1.37 | 0.20 | -1.09 |
| 78 | 0.2 | 3.20 | 2.68 | 1.89 | 1.05 | -0.16 | -2.07 | 3.25 | 2.76 | 2.11 | 1.30 | 0.22 | -1.22 |
| 79 | 0.2 | 3.08 | 2.55 | 1.65 | 0.80 | -0.54 | -2.81 | 3.16 | 2.67 | 2.03 | 1.20 | 0.09 | -1.41 |
| 80 | 0.4 | 2.96 | 2.40 | 1.40 | 0.53 | -0.93 | -3.58 | 3.07 | 2.58 | 1.93 | 1.10 | -0.04 | -1.61 |
| 81 | 0.2 | 2.38 | 1.77 | 0.90 | -0.14 | -1.69 | -5.13 | 2.63 | 2.13 | 1.46 | 0.59 | -0.55 | -2.18 |
| 82 | 0.2 | 2.10 | 1.45 | 0.52 | -0.58 | -2.28 | -6.30 | 2.42 | 1.92 | 1.24 | 0.35 | -0.82 | -2.52 |
| 83 | 11.9 | 3.35 | 2.85 | 2.14 | 1.34 | 0.11 | -1.15 | 3.35 | 2.86 | 2.21 | 1.39 | 0.27 | -1.04 |
| 84 | 3.9 | 3.32 | 2.82 | 2.06 | 1.27 | -0.09 | -1.29 | 3.33 | 2.84 | 2.18 | 1.36 | 0.17 | -1.11 |
| 85 | 0.7 | 3.30 | 2.79 | 1.99 | 1.20 | -0.29 | -1.42 | 3.32 | 2.82 | 2.15 | 1.33 | 0.07 | -1.18 |
| 86 | 0.3 | 3.08 | 2.56 | 1.72 | 0.86 | -0.45 | -2.60 | 3.13 | 2.63 | 1.97 | 1.12 | -0.06 | -1.71 |
| 87 | 0.6 | 2.96 | 2.43 | 1.51 | 0.64 | -0.78 | -3.24 | 3.03 | 2.53 | 1.86 | 1.00 | -0.24 | -2.01 |
| 88 | 0.2 | 2.85 | 2.31 | 1.32 | 0.43 | -1.10 | -3.85 | 2.93 | 2.43 | 1.76 | 0.89 | -0.41 | -2.29 |
| 89 | 8.8 | 3.34 | 2.85 | 2.15 | 1.35 | 0.14 | -1.13 | 3.34 | 2.85 | 2.17 | 1.36 | 0.18 | -1.10 |
| 90 | 3.7 | 3.32 | 2.82 | 2.09 | 1.28 | -0.05 | -1.27 | 3.32 | 2.83 | 2.12 | 1.31 | 0.02 | -1.22 |
| 91 | 0.7 | 3.29 | 2.80 | 2.02 | 1.22 | -0.23 | -1.40 | 3.30 | 2.80 | 2.07 | 1.26 | -0.13 | -1.33 |
| 92 | 0.4 | 3.10 | 2.59 | 1.83 | 0.97 | -0.31 | -2.22 | 3.11 | 2.61 | 1.90 | 1.04 | -0.20 | -2.00 |
| 93 | 0.9 | 2.99 | 2.47 | 1.67 | 0.79 | -0.58 | -2.71 | 3.01 | 2.50 | 1.77 | 0.89 | -0.44 | -2.41 |
| 94 | 0.3 | 2.88 | 2.36 | 1.51 | 0.61 | -0.86 | -3.21 | 2.90 | 2.39 | 1.64 | 0.73 | -0.68 | -2.82 |
| 95 | 7.5 | 3.35 | 2.85 | 2.18 | 1.37 | 0.20 | -1.09 | 3.34 | 2.85 | 2.14 | 1.34 | 0.12 | -1.15 |
| 96 | 3.6 | 3.32 | 2.83 | 2.13 | 1.32 | 0.06 | -1.19 | 3.32 | 2.82 | 2.07 | 1.27 | -0.09 | -1.29 |
| 97 | 0.6 | 3.30 | 2.81 | 2.09 | 1.28 | -0.07 | -1.28 | 3.29 | 2.79 | 2.00 | 1.21 | -0.27 | -1.42 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 98 | 0.3 | 3.13 | 2.63 | 1.95 | 1.09 | -0.15 | -1.86 | 3.11 | 2.60 | 1.81 | 0.94 | -0.36 | -2.26 |
| 99 | 0.5 | 3.04 | 2.54 | 1.84 | 0.96 | -0.35 | -2.19 | 3.01 | 2.49 | 1.64 | 0.76 | -0.64 | -2.75 |

Notes:

1. Negative values correspond to grounding.

Table E2. Net UKC (ft), Reach 1, h=50 ft, S-3 Channel, light-loaded *Susan Maersk*, inbound and outbound transits.

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 1 | 7.9 | 3.35 | 2.85 | 2.16 | 1.36 | 0.16 | -1.11 | 3.35 | 2.86 | 2.20 | 1.39 | 0.26 | -1.04 |
| 2 | 2.9 | 3.34 | 2.83 | 2.11 | 1.31 | 0.03 | -1.20 | 3.34 | 2.85 | 2.18 | 1.37 | 0.19 | -1.10 |
| 3 | 0.4 | 3.32 | 2.81 | 2.06 | 1.26 | -0.12 | -1.30 | 3.33 | 2.83 | 2.15 | 1.34 | 0.10 | -1.16 |
| 4 | 10.0 | 3.33 | 2.83 | 2.09 | 1.30 | -0.01 | -1.23 | 3.35 | 2.86 | 2.21 | 1.39 | 0.27 | -1.04 |
| 5 | 9.6 | 3.31 | 2.79 | 2.00 | 1.21 | -0.26 | -1.41 | 3.33 | 2.84 | 2.19 | 1.37 | 0.19 | -1.10 |
| 6 | 0.8 | 3.28 | 2.75 | 1.90 | 1.12 | -0.52 | -1.59 | 3.31 | 2.82 | 2.16 | 1.34 | 0.11 | -1.16 |
| 7 | 0.9 | 3.07 | 2.55 | 1.68 | 0.83 | -0.48 | -2.76 | 3.15 | 2.65 | 2.00 | 1.17 | 0.05 | -1.50 |
| 8 | 3.5 | 2.95 | 2.42 | 1.46 | 0.59 | -0.83 | -3.47 | 3.05 | 2.56 | 1.91 | 1.07 | -0.09 | -1.72 |
| 9 | 0.3 | 2.83 | 2.28 | 1.22 | 0.34 | -1.20 | -4.21 | 2.96 | 2.47 | 1.81 | 0.96 | -0.24 | -1.95 |
| 10 | 0.8 | 2.43 | 1.83 | 0.86 | -0.05 | -1.70 | -5.51 | 2.64 | 2.14 | 1.46 | 0.59 | -0.60 | -2.40 |
| 11 | 0.3 | 2.21 | 1.59 | 0.54 | -0.39 | -2.18 | -6.54 | 2.47 | 1.97 | 1.28 | 0.39 | -0.83 | -2.73 |
| 12 | 13.6 | 3.34 | 2.83 | 2.10 | 1.30 | 0.02 | -1.21 | 3.36 | 2.87 | 2.23 | 1.41 | 0.35 | -0.99 |
| 13 | 9.2 | 3.32 | 2.79 | 2.00 | 1.22 | -0.22 | -1.37 | 3.34 | 2.85 | 2.21 | 1.40 | 0.31 | -1.02 |
| 14 | 0.7 | 3.29 | 2.75 | 1.90 | 1.13 | -0.48 | -1.55 | 3.33 | 2.84 | 2.20 | 1.38 | 0.26 | -1.05 |
| 15 | 0.4 | 3.07 | 2.52 | 1.62 | 0.78 | -0.55 | -3.02 | 3.17 | 2.69 | 2.04 | 1.23 | 0.16 | -1.27 |
| 16 | 1.9 | 2.94 | 2.36 | 1.36 | 0.50 | -0.94 | -3.89 | 3.08 | 2.60 | 1.96 | 1.14 | 0.06 | -1.41 |
| 17 | 0.5 | 2.81 | 2.21 | 1.09 | 0.23 | -1.34 | -4.75 | 2.99 | 2.52 | 1.87 | 1.05 | -0.04 | -1.55 |
| 18 | 0.6 | 2.34 | 1.71 | 0.66 | -0.25 | -1.96 | -6.06 | 2.66 | 2.17 | 1.52 | 0.69 | -0.41 | -1.93 |
| 19 | 0.2 | 2.10 | 1.44 | 0.30 | -0.63 | -2.50 | -7.22 | 2.49 | 2.01 | 1.36 | 0.51 | -0.60 | -2.15 |
| 20 | 0.2 | 2.61 | 2.05 | 1.36 | 0.38 | -1.05 | -3.76 | 2.88 | 2.40 | 1.76 | 0.95 | -0.12 | -1.56 |
| 21 | 0.2 | 0.87 | 0.44 | -0.20 | -1.52 | -4.99 | -10.60 | 1.87 | 1.51 | 0.97 | 0.21 | -0.75 | -2.05 |
| 22 | 29.8 | 3.34 | 2.82 | 2.07 | 1.28 | -0.05 | -1.26 | 3.36 | 2.87 | 2.23 | 1.42 | 0.37 | -0.98 |
| 23 | 11.6 | 3.31 | 2.78 | 1.96 | 1.19 | -0.32 | -1.44 | 3.34 | 2.85 | 2.21 | 1.40 | 0.34 | -1.00 |
| 24 | 1.5 | 3.28 | 2.73 | 1.85 | 1.09 | -0.61 | -1.64 | 3.33 | 2.84 | 2.20 | 1.39 | 0.32 | -1.02 |
| 25 | 0.5 | 3.19 | 2.66 | 1.85 | 1.02 | -0.20 | -2.21 | 3.26 | 2.78 | 2.14 | 1.33 | 0.29 | -1.07 |
| 26 | 0.2 | 3.08 | 2.52 | 1.61 | 0.77 | -0.56 | -2.97 | 3.19 | 2.71 | 2.08 | 1.27 | 0.22 | -1.15 |
| 27 | 0.2 | 2.97 | 2.38 | 1.36 | 0.51 | -0.94 | -3.77 | 3.12 | 2.64 | 2.01 | 1.20 | 0.15 | -1.24 |
| 28 | 1.4 | 2.95 | 2.40 | 1.63 | 0.75 | -0.52 | -2.86 | 3.10 | 2.61 | 1.97 | 1.16 | 0.12 | -1.25 |
| 29 | 0.6 | 2.69 | 2.11 | 1.26 | 0.33 | -1.08 | -4.00 | 2.93 | 2.45 | 1.81 | 0.99 | -0.06 | -1.44 |
| 30 | 0.2 | 2.42 | 1.79 | 0.87 | -0.11 | -1.67 | -5.22 | 2.75 | 2.27 | 1.63 | 0.81 | -0.24 | -1.64 |
| 31 | 0.3 | 2.11 | 1.44 | 0.42 | -0.62 | -2.36 | -6.62 | 2.54 | 2.07 | 1.43 | 0.60 | -0.46 | -1.87 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 32 | 1.9 | 2.67 | 2.09 | 1.40 | 0.44 | -0.97 | -3.66 | 2.95 | 2.48 | 1.84 | 1.03 | 0.00 | -1.39 |
| 33 | 1.6 | 2.25 | 1.62 | 0.89 | -0.16 | -1.79 | -5.30 | 2.69 | 2.23 | 1.60 | 0.79 | -0.25 | -1.65 |
| 34 | 0.7 | 1.80 | 1.11 | 0.35 | -0.80 | -2.67 | -7.02 | 2.42 | 1.97 | 1.34 | 0.53 | -0.52 | -1.94 |
| 35 | 0.3 | 1.28 | 0.53 | -0.27 | -1.53 | -3.68 | -9.02 | 2.10 | 1.67 | 1.04 | 0.23 | -0.82 | -2.26 |
| 36 | 1.3 | 1.94 | 1.50 | 0.88 | -0.22 | -2.99 | -7.22 | 2.59 | 2.19 | 1.62 | 0.85 | -0.14 | -1.45 |
| 37 | 1.2 | 1.07 | 0.66 | 0.05 | -1.22 | -5.03 | -10.99 | 2.12 | 1.77 | 1.24 | 0.49 | -0.46 | -1.76 |
| 38 | 0.4 | 0.16 | -0.22 | -0.82 | -2.27 | -7.18 | -14.97 | 1.62 | 1.33 | 0.83 | 0.12 | -0.81 | -2.08 |
| 39 | 0.2 | -0.90 | -1.24 | -1.83 | -3.49 | -9.67 | -19.58 | 1.04 | 0.82 | 0.37 | -0.31 | -1.21 | -2.46 |
| 40 | 0.3 | 0.00 | -0.34 | -0.96 | -3.44 | -12.62 | -23.95 | 1.06 | 0.89 | 0.45 | -0.20 | -1.05 | -2.26 |
| 41 | 40.5 | 3.33 | 2.81 | 2.04 | 1.26 | -0.14 | -1.31 | 3.35 | 2.86 | 2.22 | 1.40 | 0.32 | -1.01 |
| 42 | 9.4 | 3.29 | 2.75 | 1.89 | 1.12 | -0.53 | -1.58 | 3.32 | 2.83 | 2.19 | 1.38 | 0.26 | -1.06 |
| 43 | 0.9 | 3.26 | 2.69 | 1.75 | 1.00 | -0.90 | -1.83 | 3.30 | 2.81 | 2.17 | 1.35 | 0.19 | -1.10 |
| 44 | 3.0 | 3.21 | 2.68 | 1.89 | 1.06 | -0.14 | -2.09 | 3.26 | 2.78 | 2.14 | 1.32 | 0.27 | -1.13 |
| 45 | 0.6 | 3.08 | 2.53 | 1.63 | 0.79 | -0.54 | -2.90 | 3.18 | 2.70 | 2.05 | 1.24 | 0.17 | -1.26 |
| 46 | 0.4 | 2.96 | 2.39 | 1.39 | 0.53 | -0.91 | -3.68 | 3.10 | 2.62 | 1.98 | 1.16 | 0.08 | -1.38 |
| 47 | 3.0 | 3.00 | 2.46 | 1.71 | 0.83 | -0.41 | -2.63 | 3.12 | 2.63 | 1.99 | 1.17 | 0.11 | -1.29 |
| 48 | 0.7 | 2.73 | 2.16 | 1.32 | 0.40 | -0.99 | -3.84 | 2.93 | 2.45 | 1.80 | 0.97 | -0.10 | -1.54 |
| 49 | 0.5 | 2.48 | 1.87 | 0.95 | -0.01 | -1.55 | -4.98 | 2.75 | 2.27 | 1.62 | 0.78 | -0.30 | -1.78 |
| 50 | 1.7 | 2.75 | 2.18 | 1.48 | 0.52 | -0.83 | -3.35 | 2.97 | 2.49 | 1.84 | 1.01 | -0.05 | -1.48 |
| 51 | 1.1 | 2.29 | 1.66 | 0.92 | -0.14 | -1.72 | -5.08 | 2.68 | 2.20 | 1.55 | 0.71 | -0.37 | -1.86 |
| 52 | 0.5 | 1.86 | 1.18 | 0.40 | -0.77 | -2.56 | -6.72 | 2.41 | 1.93 | 1.27 | 0.42 | -0.68 | -2.22 |
| 53 | 0.4 | 1.36 | 0.62 | -0.21 | -1.50 | -3.54 | -8.61 | 2.09 | 1.62 | 0.95 | 0.08 | -1.04 | -2.65 |
| 54 | 0.8 | 1.81 | 1.37 | 0.74 | -0.39 | -2.99 | -7.05 | 2.43 | 2.02 | 1.44 | 0.67 | -0.32 | -1.63 |
| 55 | 0.8 | 0.68 | 0.28 | -0.33 | -1.69 | -5.42 | -11.41 | 1.74 | 1.40 | 0.86 | 0.11 | -0.84 | -2.13 |
| 56 | 0.4 | -0.38 | -0.75 | -1.36 | -2.93 | -7.73 | -15.56 | 1.09 | 0.81 | 0.31 | -0.41 | -1.33 | -2.60 |
| 57 | 0.3 | -1.62 | -1.94 | -2.54 | -4.37 | -10.41 | -20.36 | 0.34 | 0.12 | -0.32 | -1.02 | -1.91 | -3.15 |
| 58 | 0.3 | 0.99 | 0.61 | -0.06 | -1.90 | -7.16 | -13.58 | 1.60 | 1.32 | 0.78 | 0.06 | -0.84 | -2.10 |
| 59 | 0.2 | -4.22 | -4.37 | -5.09 | -9.16 | -23.64 | -41.10 | -2.27 | -2.11 | -2.41 | -2.94 | -3.57 | -4.63 |
| 60 | 28.5 | 3.34 | 2.84 | 2.12 | 1.32 | 0.07 | -1.17 | 3.35 | 2.86 | 2.22 | 1.40 | 0.30 | -1.02 |
| 61 | 5.1 | 3.32 | 2.80 | 2.03 | 1.24 | -0.17 | -1.34 | 3.34 | 2.84 | 2.20 | 1.38 | 0.22 | -1.08 |
| 62 | 0.5 | 3.29 | 2.77 | 1.94 | 1.16 | -0.41 | -1.51 | 3.32 | 2.82 | 2.17 | 1.35 | 0.14 | -1.14 |
| 63 | 1.8 | 3.21 | 2.70 | 1.92 | 1.09 | -0.10 | -1.98 | 3.25 | 2.76 | 2.11 | 1.29 | 0.20 | -1.26 |
| 64 | 0.5 | 3.08 | 2.56 | 1.69 | 0.84 | -0.47 | -2.72 | 3.15 | 2.66 | 2.01 | 1.18 | 0.06 | -1.49 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 65 | 0.4 | 2.95 | 2.42 | 1.46 | 0.59 | -0.83 | -3.47 | 3.05 | 2.56 | 1.91 | 1.07 | -0.09 | -1.72 |
| 66 | 1.1 | 3.00 | 2.47 | 1.75 | 0.85 | -0.37 | -2.49 | 3.08 | 2.59 | 1.93 | 1.09 | 0.01 | -1.48 |
| 67 | 0.6 | 2.73 | 2.16 | 1.39 | 0.43 | -0.93 | -3.59 | 2.87 | 2.37 | 1.70 | 0.85 | -0.27 | -1.87 |
| 68 | 0.4 | 2.46 | 1.86 | 1.03 | 0.01 | -1.49 | -4.70 | 2.66 | 2.16 | 1.48 | 0.60 | -0.56 | -2.25 |
| 69 | 0.2 | 2.21 | 1.59 | 0.70 | -0.37 | -1.99 | -5.69 | 2.47 | 1.96 | 1.27 | 0.38 | -0.82 | -2.60 |
| 70 | 0.4 | 2.75 | 2.19 | 1.48 | 0.53 | -0.78 | -3.16 | 2.91 | 2.42 | 1.75 | 0.90 | -0.20 | -1.75 |
| 71 | 0.4 | 2.30 | 1.69 | 0.94 | -0.12 | -1.63 | -4.75 | 2.58 | 2.08 | 1.39 | 0.51 | -0.64 | -2.33 |
| 72 | 0.3 | 1.85 | 1.19 | 0.39 | -0.77 | -2.48 | -6.34 | 2.25 | 1.74 | 1.04 | 0.12 | -1.08 | -2.91 |
| 73 | 0.3 | 1.44 | 0.74 | -0.11 | -1.35 | -3.25 | -7.77 | 1.95 | 1.44 | 0.72 | -0.23 | -1.47 | -3.43 |
| 74 | 0.2 | 1.74 | 1.28 | 0.63 | -0.35 | -2.39 | -5.61 | 2.22 | 1.79 | 1.19 | 0.39 | -0.59 | -1.91 |
| 75 | 17.0 | 3.35 | 2.85 | 2.15 | 1.35 | 0.15 | -1.12 | 3.35 | 2.86 | 2.20 | 1.39 | 0.26 | -1.05 |
| 76 | 3.8 | 3.33 | 2.82 | 2.09 | 1.29 | -0.03 | -1.24 | 3.33 | 2.84 | 2.17 | 1.35 | 0.15 | -1.12 |
| 77 | 0.7 | 3.31 | 2.80 | 2.02 | 1.23 | -0.21 | -1.37 | 3.32 | 2.82 | 2.13 | 1.32 | 0.05 | -1.20 |
| 78 | 0.2 | 3.21 | 2.70 | 1.97 | 1.13 | -0.05 | -1.81 | 3.23 | 2.73 | 2.08 | 1.25 | 0.12 | -1.43 |
| 79 | 0.2 | 3.10 | 2.58 | 1.79 | 0.93 | -0.35 | -2.38 | 3.13 | 2.63 | 1.97 | 1.12 | -0.07 | -1.76 |
| 80 | 0.4 | 2.98 | 2.45 | 1.59 | 0.72 | -0.66 | -2.98 | 3.03 | 2.53 | 1.86 | 0.99 | -0.27 | -2.09 |
| 81 | 0.2 | 2.43 | 1.85 | 1.08 | 0.04 | -1.38 | -4.22 | 2.54 | 2.01 | 1.30 | 0.36 | -0.88 | -2.90 |
| 82 | 0.2 | 2.16 | 1.56 | 0.75 | -0.35 | -1.88 | -5.14 | 2.30 | 1.76 | 1.03 | 0.06 | -1.25 | -3.45 |
| 83 | 11.9 | 3.35 | 2.86 | 2.18 | 1.37 | 0.20 | -1.09 | 3.35 | 2.86 | 2.18 | 1.37 | 0.20 | -1.09 |
| 84 | 3.9 | 3.33 | 2.83 | 2.13 | 1.32 | 0.05 | -1.19 | 3.33 | 2.83 | 2.13 | 1.32 | 0.05 | -1.19 |
| 85 | 0.7 | 3.31 | 2.81 | 2.08 | 1.27 | -0.08 | -1.29 | 3.31 | 2.81 | 2.08 | 1.27 | -0.08 | -1.29 |
| 86 | 0.3 | 3.10 | 2.60 | 1.88 | 1.02 | -0.23 | -2.10 | 3.10 | 2.60 | 1.88 | 1.02 | -0.23 | -2.10 |
| 87 | 0.6 | 3.00 | 2.48 | 1.73 | 0.86 | -0.47 | -2.54 | 3.00 | 2.48 | 1.73 | 0.86 | -0.47 | -2.54 |
| 88 | 0.2 | 2.90 | 2.37 | 1.59 | 0.70 | -0.71 | -2.97 | 2.90 | 2.37 | 1.59 | 0.70 | -0.71 | -2.97 |
| 89 | 8.8 | 3.35 | 2.86 | 2.19 | 1.38 | 0.24 | -1.07 | 3.34 | 2.85 | 2.14 | 1.34 | 0.11 | -1.15 |
| 90 | 3.7 | 3.33 | 2.83 | 2.16 | 1.34 | 0.12 | -1.15 | 3.32 | 2.81 | 2.06 | 1.27 | -0.09 | -1.29 |
| 91 | 0.7 | 3.31 | 2.81 | 2.12 | 1.30 | 0.00 | -1.24 | 3.29 | 2.79 | 1.99 | 1.20 | -0.29 | -1.43 |
| 92 | 0.4 | 3.14 | 2.64 | 1.98 | 1.13 | -0.07 | -1.74 | 3.11 | 2.59 | 1.79 | 0.93 | -0.36 | -2.34 |
| 93 | 0.9 | 3.05 | 2.54 | 1.88 | 1.01 | -0.26 | -2.05 | 3.00 | 2.48 | 1.61 | 0.73 | -0.66 | -2.88 |
| 94 | 0.3 | 2.95 | 2.45 | 1.77 | 0.89 | -0.45 | -2.36 | 2.89 | 2.36 | 1.42 | 0.53 | -0.96 | -3.42 |
| 95 | 7.5 | 3.35 | 2.86 | 2.22 | 1.40 | 0.30 | -1.02 | 3.34 | 2.84 | 2.12 | 1.32 | 0.06 | -1.18 |
| 96 | 3.6 | 3.33 | 2.84 | 2.20 | 1.37 | 0.22 | -1.08 | 3.32 | 2.80 | 2.02 | 1.24 | -0.18 | -1.35 |
| 97 | 0.6 | 3.32 | 2.83 | 2.17 | 1.35 | 0.15 | -1.13 | 3.29 | 2.77 | 1.94 | 1.16 | -0.39 | -1.50 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 98 | 0.3 | 3.18 | 2.69 | 2.04 | 1.21 | 0.08 | -1.44 | 3.12 | 2.59 | 1.71 | 0.86 | -0.48 | -2.51 |
| 99 | 0.5 | 3.10 | 2.61 | 1.96 | 1.13 | -0.05 | -1.63 | 3.02 | 2.49 | 1.51 | 0.64 | -0.80 | -3.09 |

Notes:

1. Negative values correspond to grounding.

Table E3. Net UKC (ft), Reach 1, h=50 ft, S-8 Channel, light-loaded *Susan Maersk*, inbound and outbound transits.

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 1 | 7.9 | 3.35 | 2.86 | 2.17 | 1.37 | 0.19 | -1.09 | 3.35 | 2.86 | 2.19 | 1.38 | 0.23 | -1.07 |
| 2 | 2.9 | 3.34 | 2.84 | 2.13 | 1.33 | 0.08 | -1.17 | 3.34 | 2.85 | 2.16 | 1.35 | 0.13 | -1.13 |
| 3 | 0.4 | 3.32 | 2.82 | 2.09 | 1.29 | -0.05 | -1.25 | 3.32 | 2.83 | 2.12 | 1.31 | 0.02 | -1.21 |
| 4 | 10.0 | 3.34 | 2.83 | 2.11 | 1.31 | 0.03 | -1.21 | 3.34 | 2.85 | 2.19 | 1.38 | 0.22 | -1.08 |
| 5 | 9.6 | 3.31 | 2.80 | 2.02 | 1.23 | -0.20 | -1.37 | 3.32 | 2.83 | 2.16 | 1.34 | 0.12 | -1.15 |
| 6 | 0.8 | 3.28 | 2.76 | 1.94 | 1.15 | -0.43 | -1.53 | 3.30 | 2.81 | 2.12 | 1.30 | 0.00 | -1.24 |
| 7 | 0.9 | 3.08 | 2.56 | 1.73 | 0.88 | -0.41 | -2.59 | 3.12 | 2.63 | 1.97 | 1.13 | -0.04 | -1.70 |
| 8 | 3.5 | 2.96 | 2.43 | 1.53 | 0.67 | -0.73 | -3.22 | 3.03 | 2.53 | 1.86 | 1.00 | -0.22 | -2.00 |
| 9 | 0.3 | 2.83 | 2.29 | 1.32 | 0.44 | -1.07 | -3.90 | 2.92 | 2.42 | 1.74 | 0.87 | -0.40 | -2.31 |
| 10 | 0.8 | 2.43 | 1.84 | 0.97 | 0.01 | -1.57 | -5.07 | 2.58 | 2.06 | 1.36 | 0.45 | -0.81 | -2.88 |
| 11 | 0.3 | 2.22 | 1.61 | 0.68 | -0.32 | -2.02 | -6.00 | 2.39 | 1.87 | 1.15 | 0.22 | -1.09 | -3.32 |
| 12 | 13.6 | 3.34 | 2.83 | 2.11 | 1.31 | 0.04 | -1.20 | 3.35 | 2.86 | 2.22 | 1.41 | 0.31 | -1.01 |
| 13 | 9.2 | 3.32 | 2.80 | 2.02 | 1.23 | -0.19 | -1.35 | 3.34 | 2.85 | 2.20 | 1.39 | 0.25 | -1.06 |
| 14 | 0.7 | 3.29 | 2.76 | 1.92 | 1.15 | -0.44 | -1.53 | 3.32 | 2.83 | 2.19 | 1.36 | 0.19 | -1.11 |
| 15 | 0.4 | 3.07 | 2.53 | 1.65 | 0.81 | -0.51 | -2.90 | 3.15 | 2.66 | 2.01 | 1.19 | 0.09 | -1.42 |
| 16 | 1.9 | 2.94 | 2.39 | 1.41 | 0.55 | -0.89 | -3.72 | 3.06 | 2.57 | 1.92 | 1.09 | -0.05 | -1.62 |
| 17 | 0.5 | 2.80 | 2.24 | 1.16 | 0.29 | -1.27 | -4.54 | 2.96 | 2.47 | 1.82 | 0.98 | -0.18 | -1.82 |
| 18 | 0.6 | 2.33 | 1.71 | 0.73 | -0.22 | -1.89 | -5.79 | 2.60 | 2.10 | 1.42 | 0.56 | -0.60 | -2.28 |
| 19 | 0.2 | 2.09 | 1.44 | 0.38 | -0.60 | -2.41 | -6.89 | 2.42 | 1.92 | 1.24 | 0.36 | -0.83 | -2.58 |
| 20 | 0.2 | 2.61 | 2.05 | 1.36 | 0.38 | -1.02 | -3.63 | 2.83 | 2.35 | 1.70 | 0.86 | -0.23 | -1.76 |
| 21 | 0.2 | 0.60 | 0.16 | -0.46 | -1.67 | -4.75 | -9.81 | 1.51 | 1.14 | 0.58 | -0.19 | -1.14 | -2.44 |
| 22 | 29.8 | 3.34 | 2.82 | 2.07 | 1.28 | -0.04 | -1.25 | 3.35 | 2.86 | 2.22 | 1.41 | 0.35 | -0.99 |
| 23 | 11.6 | 3.31 | 2.78 | 1.97 | 1.19 | -0.32 | -1.44 | 3.34 | 2.85 | 2.21 | 1.40 | 0.32 | -1.01 |
| 24 | 1.5 | 3.28 | 2.73 | 1.85 | 1.09 | -0.60 | -1.64 | 3.32 | 2.83 | 2.19 | 1.38 | 0.28 | -1.04 |
| 25 | 0.5 | 3.19 | 2.66 | 1.86 | 1.03 | -0.19 | -2.19 | 3.26 | 2.77 | 2.13 | 1.32 | 0.28 | -1.11 |
| 26 | 0.2 | 3.08 | 2.53 | 1.62 | 0.78 | -0.55 | -2.94 | 3.18 | 2.70 | 2.06 | 1.25 | 0.20 | -1.20 |
| 27 | 0.2 | 2.96 | 2.38 | 1.37 | 0.52 | -0.93 | -3.73 | 3.11 | 2.63 | 1.99 | 1.18 | 0.11 | -1.31 |
| 28 | 1.4 | 2.95 | 2.40 | 1.64 | 0.74 | -0.52 | -2.83 | 3.09 | 2.60 | 1.96 | 1.14 | 0.09 | -1.30 |
| 29 | 0.6 | 2.69 | 2.11 | 1.27 | 0.33 | -1.08 | -3.97 | 2.91 | 2.43 | 1.79 | 0.96 | -0.10 | -1.51 |
| 30 | 0.2 | 2.42 | 1.80 | 0.89 | -0.12 | -1.67 | -5.17 | 2.73 | 2.25 | 1.60 | 0.77 | -0.30 | -1.74 |
| 31 | 0.3 | 2.10 | 1.44 | 0.44 | -0.63 | -2.35 | -6.56 | 2.51 | 2.04 | 1.39 | 0.55 | -0.53 | -2.00 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 32 | 1.9 | 2.67 | 2.10 | 1.40 | 0.43 | -0.97 | -3.64 | 2.94 | 2.46 | 1.82 | 1.00 | -0.05 | -1.46 |
| 33 | 1.6 | 2.24 | 1.62 | 0.89 | -0.18 | -1.80 | -5.26 | 2.67 | 2.21 | 1.57 | 0.74 | -0.32 | -1.77 |
| 34 | 0.7 | 1.80 | 1.12 | 0.36 | -0.82 | -2.67 | -6.97 | 2.39 | 1.94 | 1.30 | 0.47 | -0.62 | -2.10 |
| 35 | 0.3 | 1.27 | 0.53 | -0.27 | -1.57 | -3.69 | -8.95 | 2.07 | 1.62 | 0.98 | 0.14 | -0.95 | -2.48 |
| 36 | 1.3 | 1.88 | 1.43 | 0.78 | -0.35 | -3.00 | -7.13 | 2.52 | 2.11 | 1.54 | 0.77 | -0.22 | -1.54 |
| 37 | 1.2 | 0.98 | 0.56 | -0.10 | -1.42 | -5.04 | -10.84 | 2.00 | 1.65 | 1.11 | 0.36 | -0.60 | -1.90 |
| 38 | 0.4 | 0.02 | -0.37 | -1.03 | -2.56 | -7.20 | -14.77 | 1.46 | 1.16 | 0.66 | -0.07 | -1.00 | -2.28 |
| 39 | 0.2 | -1.08 | -1.43 | -2.11 | -3.87 | -9.70 | -19.31 | 0.82 | 0.59 | 0.13 | -0.56 | -1.46 | -2.71 |
| 40 | 0.3 | -0.32 | -0.64 | -1.40 | -3.86 | -12.57 | -23.32 | 0.74 | 0.58 | 0.13 | -0.52 | -1.36 | -2.56 |
| 41 | 40.5 | 3.33 | 2.80 | 2.03 | 1.25 | -0.15 | -1.32 | 3.35 | 2.86 | 2.22 | 1.41 | 0.35 | -0.99 |
| 42 | 9.4 | 3.29 | 2.74 | 1.88 | 1.12 | -0.55 | -1.59 | 3.33 | 2.84 | 2.20 | 1.39 | 0.31 | -1.02 |
| 43 | 0.9 | 3.26 | 2.68 | 1.73 | 0.99 | -0.93 | -1.85 | 3.31 | 2.82 | 2.18 | 1.37 | 0.28 | -1.05 |
| 44 | 3.0 | 3.21 | 2.68 | 1.88 | 1.05 | -0.15 | -2.12 | 3.27 | 2.78 | 2.15 | 1.34 | 0.30 | -1.07 |
| 45 | 0.6 | 3.08 | 2.52 | 1.62 | 0.77 | -0.56 | -2.96 | 3.19 | 2.71 | 2.07 | 1.26 | 0.22 | -1.17 |
| 46 | 0.4 | 2.97 | 2.38 | 1.36 | 0.51 | -0.94 | -3.76 | 3.11 | 2.64 | 2.00 | 1.19 | 0.14 | -1.26 |
| 47 | 3.0 | 3.01 | 2.46 | 1.70 | 0.83 | -0.42 | -2.67 | 3.13 | 2.65 | 2.01 | 1.19 | 0.15 | -1.22 |
| 48 | 0.7 | 2.74 | 2.16 | 1.30 | 0.40 | -1.01 | -3.91 | 2.95 | 2.48 | 1.83 | 1.02 | -0.03 | -1.42 |
| 49 | 0.5 | 2.49 | 1.87 | 0.93 | -0.01 | -1.57 | -5.09 | 2.79 | 2.31 | 1.67 | 0.85 | -0.21 | -1.62 |
| 50 | 1.7 | 2.75 | 2.17 | 1.48 | 0.52 | -0.84 | -3.41 | 3.00 | 2.52 | 1.88 | 1.06 | 0.02 | -1.37 |
| 51 | 1.1 | 2.29 | 1.66 | 0.93 | -0.14 | -1.73 | -5.17 | 2.72 | 2.25 | 1.61 | 0.79 | -0.26 | -1.67 |
| 52 | 0.5 | 1.86 | 1.17 | 0.40 | -0.76 | -2.58 | -6.84 | 2.46 | 2.00 | 1.36 | 0.53 | -0.53 | -1.96 |
| 53 | 0.4 | 1.36 | 0.60 | -0.20 | -1.48 | -3.57 | -8.78 | 2.16 | 1.71 | 1.07 | 0.24 | -0.84 | -2.30 |
| 54 | 0.8 | 1.92 | 1.49 | 0.87 | -0.26 | -3.05 | -7.29 | 2.56 | 2.16 | 1.59 | 0.82 | -0.16 | -1.48 |
| 55 | 0.8 | 0.88 | 0.49 | -0.12 | -1.47 | -5.51 | -11.82 | 1.98 | 1.64 | 1.12 | 0.38 | -0.57 | -1.86 |
| 56 | 0.4 | -0.11 | -0.46 | -1.05 | -2.63 | -7.86 | -16.13 | 1.43 | 1.15 | 0.67 | -0.04 | -0.96 | -2.23 |
| 57 | 0.3 | -1.26 | -1.56 | -2.14 | -3.97 | -10.58 | -21.12 | 0.78 | 0.58 | 0.15 | -0.53 | -1.42 | -2.65 |
| 58 | 0.3 | 1.34 | 0.94 | 0.24 | -1.58 | -7.27 | -14.39 | 1.95 | 1.65 | 1.12 | 0.41 | -0.51 | -1.78 |
| 59 | 0.2 | -3.09 | -3.29 | -4.14 | -8.15 | -23.98 | -43.66 | -1.17 | -1.05 | -1.33 | -1.84 | -2.52 | -3.59 |
| 60 | 28.5 | 3.34 | 2.83 | 2.11 | 1.32 | 0.05 | -1.19 | 3.36 | 2.87 | 2.23 | 1.41 | 0.33 | -1.00 |
| 61 | 5.1 | 3.32 | 2.80 | 2.01 | 1.23 | -0.20 | -1.37 | 3.34 | 2.85 | 2.21 | 1.39 | 0.28 | -1.04 |
| 62 | 0.5 | 3.29 | 2.76 | 1.91 | 1.14 | -0.46 | -1.54 | 3.32 | 2.83 | 2.19 | 1.37 | 0.23 | -1.08 |
| 63 | 1.8 | 3.21 | 2.69 | 1.90 | 1.07 | -0.13 | -2.06 | 3.26 | 2.77 | 2.13 | 1.31 | 0.25 | -1.16 |
| 64 | 0.5 | 3.08 | 2.54 | 1.65 | 0.80 | -0.52 | -2.86 | 3.17 | 2.68 | 2.04 | 1.22 | 0.14 | -1.32 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 65 | 0.4 | 2.96 | 2.39 | 1.40 | 0.54 | -0.90 | -3.66 | 3.08 | 2.60 | 1.95 | 1.13 | 0.02 | -1.48 |
| 66 | 1.1 | 3.00 | 2.46 | 1.72 | 0.84 | -0.40 | -2.59 | 3.11 | 2.62 | 1.97 | 1.14 | 0.08 | -1.35 |
| 67 | 0.6 | 2.73 | 2.16 | 1.34 | 0.41 | -0.98 | -3.77 | 2.91 | 2.42 | 1.77 | 0.93 | -0.15 | -1.64 |
| 68 | 0.4 | 2.46 | 1.86 | 0.96 | -0.02 | -1.56 | -4.95 | 2.72 | 2.23 | 1.57 | 0.72 | -0.39 | -1.93 |
| 69 | 0.2 | 2.22 | 1.58 | 0.62 | -0.41 | -2.08 | -6.02 | 2.54 | 2.06 | 1.39 | 0.53 | -0.60 | -2.19 |
| 70 | 0.4 | 2.75 | 2.18 | 1.48 | 0.52 | -0.82 | -3.30 | 2.96 | 2.47 | 1.81 | 0.98 | -0.09 | -1.56 |
| 71 | 0.4 | 2.29 | 1.67 | 0.92 | -0.14 | -1.70 | -4.99 | 2.65 | 2.17 | 1.50 | 0.65 | -0.45 | -2.00 |
| 72 | 0.3 | 1.84 | 1.16 | 0.37 | -0.80 | -2.58 | -6.68 | 2.35 | 1.87 | 1.19 | 0.32 | -0.81 | -2.44 |
| 73 | 0.3 | 1.43 | 0.71 | -0.13 | -1.40 | -3.37 | -8.20 | 2.08 | 1.59 | 0.91 | 0.02 | -1.14 | -2.83 |
| 74 | 0.2 | 1.89 | 1.43 | 0.80 | -0.29 | -2.57 | -6.15 | 2.44 | 2.02 | 1.43 | 0.64 | -0.35 | -1.67 |
| 75 | 17.0 | 3.35 | 2.85 | 2.14 | 1.34 | 0.11 | -1.14 | 3.36 | 2.86 | 2.21 | 1.40 | 0.29 | -1.03 |
| 76 | 3.8 | 3.33 | 2.82 | 2.06 | 1.27 | -0.08 | -1.28 | 3.34 | 2.85 | 2.19 | 1.37 | 0.22 | -1.08 |
| 77 | 0.7 | 3.30 | 2.79 | 1.99 | 1.20 | -0.28 | -1.42 | 3.32 | 2.83 | 2.17 | 1.35 | 0.13 | -1.14 |
| 78 | 0.2 | 3.21 | 2.70 | 1.93 | 1.10 | -0.09 | -1.92 | 3.24 | 2.75 | 2.10 | 1.28 | 0.18 | -1.31 |
| 79 | 0.2 | 3.09 | 2.58 | 1.73 | 0.88 | -0.42 | -2.56 | 3.15 | 2.66 | 2.00 | 1.17 | 0.02 | -1.56 |
| 80 | 0.4 | 2.98 | 2.44 | 1.51 | 0.64 | -0.77 | -3.23 | 3.06 | 2.56 | 1.90 | 1.06 | -0.14 | -1.82 |
| 81 | 0.2 | 2.42 | 1.83 | 1.04 | -0.02 | -1.50 | -4.59 | 2.60 | 2.09 | 1.39 | 0.50 | -0.69 | -2.48 |
| 82 | 0.2 | 2.15 | 1.53 | 0.70 | -0.43 | -2.03 | -5.62 | 2.38 | 1.86 | 1.16 | 0.23 | -1.00 | -2.91 |
| 83 | 11.9 | 3.35 | 2.85 | 2.16 | 1.36 | 0.16 | -1.11 | 3.35 | 2.86 | 2.19 | 1.38 | 0.24 | -1.06 |
| 84 | 3.9 | 3.33 | 2.83 | 2.10 | 1.30 | -0.01 | -1.23 | 3.33 | 2.84 | 2.15 | 1.34 | 0.12 | -1.15 |
| 85 | 0.7 | 3.31 | 2.80 | 2.04 | 1.24 | -0.17 | -1.34 | 3.31 | 2.82 | 2.12 | 1.30 | 0.00 | -1.23 |
| 86 | 0.3 | 3.09 | 2.58 | 1.81 | 0.95 | -0.32 | -2.31 | 3.12 | 2.62 | 1.95 | 1.09 | -0.13 | -1.88 |
| 87 | 0.6 | 2.98 | 2.46 | 1.64 | 0.76 | -0.60 | -2.84 | 3.02 | 2.51 | 1.83 | 0.95 | -0.34 | -2.24 |
| 88 | 0.2 | 2.88 | 2.35 | 1.47 | 0.58 | -0.87 | -3.34 | 2.92 | 2.41 | 1.72 | 0.82 | -0.54 | -2.59 |
| 89 | 8.8 | 3.35 | 2.85 | 2.18 | 1.37 | 0.19 | -1.10 | 3.34 | 2.85 | 2.16 | 1.35 | 0.15 | -1.12 |
| 90 | 3.7 | 3.32 | 2.83 | 2.13 | 1.32 | 0.04 | -1.20 | 3.32 | 2.83 | 2.09 | 1.29 | -0.03 | -1.25 |
| 91 | 0.7 | 3.30 | 2.81 | 2.08 | 1.27 | -0.10 | -1.30 | 3.30 | 2.80 | 2.03 | 1.23 | -0.20 | -1.37 |
| 92 | 0.4 | 3.12 | 2.62 | 1.92 | 1.06 | -0.17 | -1.94 | 3.11 | 2.60 | 1.85 | 0.99 | -0.27 | -2.15 |
| 93 | 0.9 | 3.02 | 2.51 | 1.79 | 0.92 | -0.40 | -2.33 | 3.01 | 2.49 | 1.70 | 0.82 | -0.53 | -2.61 |
| 94 | 0.3 | 2.92 | 2.41 | 1.67 | 0.77 | -0.62 | -2.72 | 2.90 | 2.38 | 1.54 | 0.65 | -0.80 | -3.08 |
| 95 | 7.5 | 3.35 | 2.86 | 2.20 | 1.39 | 0.26 | -1.05 | 3.34 | 2.84 | 2.13 | 1.33 | 0.09 | -1.16 |
| 96 | 3.6 | 3.33 | 2.84 | 2.17 | 1.35 | 0.15 | -1.13 | 3.32 | 2.81 | 2.05 | 1.26 | -0.12 | -1.32 |
| 97 | 0.6 | 3.31 | 2.82 | 2.14 | 1.32 | 0.06 | -1.20 | 3.29 | 2.78 | 1.98 | 1.19 | -0.32 | -1.45 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 98 | 0.3 | 3.16 | 2.66 | 2.01 | 1.17 | -0.02 | -1.62 | 3.12 | 2.60 | 1.76 | 0.91 | -0.40 | -2.36 |
| 99 | 0.5 | 3.08 | 2.58 | 1.92 | 1.07 | -0.18 | -1.86 | 3.02 | 2.50 | 1.58 | 0.71 | -0.70 | -2.89 |

Notes:

1. Negative values correspond to grounding.

Table E4. Net UKC (ft), Reach 1, h=52 ft, S-1 Channel, fully-loaded *Susan Maersk*, inbound and outbound transits.

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 1 | 7.9 | 3.87 | 3.40 | 2.73 | 1.96 | 0.95 | -0.38 | 3.87 | 3.39 | 2.72 | 1.95 | 0.94 | -0.41 |
| 2 | 2.9 | 3.87 | 3.39 | 2.70 | 1.94 | 0.91 | -0.46 | 3.86 | 3.38 | 2.67 | 1.92 | 0.88 | -0.50 |
| 3 | 0.4 | 3.86 | 3.37 | 2.66 | 1.90 | 0.86 | -0.54 | 3.85 | 3.35 | 2.62 | 1.88 | 0.82 | -0.60 |
| 4 | 10.0 | 3.86 | 3.37 | 2.67 | 1.91 | 0.88 | -0.51 | 3.87 | 3.39 | 2.72 | 1.95 | 0.93 | -0.42 |
| 5 | 9.6 | 3.84 | 3.34 | 2.59 | 1.85 | 0.78 | -0.67 | 3.85 | 3.37 | 2.67 | 1.90 | 0.87 | -0.54 |
| 6 | 0.8 | 3.82 | 3.30 | 2.51 | 1.79 | 0.68 | -0.84 | 3.84 | 3.35 | 2.62 | 1.86 | 0.80 | -0.66 |
| 7 | 0.9 | 3.66 | 3.12 | 2.30 | 1.51 | 0.46 | -1.19 | 3.71 | 3.20 | 2.46 | 1.66 | 0.62 | -0.90 |
| 8 | 3.5 | 3.57 | 3.00 | 2.10 | 1.31 | 0.24 | -1.56 | 3.64 | 3.11 | 2.32 | 1.51 | 0.46 | -1.16 |
| 9 | 0.3 | 3.48 | 2.87 | 1.90 | 1.10 | 0.01 | -1.95 | 3.56 | 3.02 | 2.18 | 1.36 | 0.29 | -1.43 |
| 10 | 0.8 | 3.12 | 2.47 | 1.53 | 0.74 | -0.22 | -2.12 | 3.23 | 2.68 | 1.86 | 1.04 | 0.09 | -1.58 |
| 11 | 0.3 | 2.95 | 2.26 | 1.24 | 0.45 | -0.51 | -2.55 | 3.09 | 2.50 | 1.65 | 0.82 | -0.12 | -1.89 |
| 12 | 13.6 | 3.86 | 3.37 | 2.66 | 1.91 | 0.87 | -0.51 | 3.88 | 3.41 | 2.76 | 1.98 | 0.98 | -0.34 |
| 13 | 9.2 | 3.84 | 3.33 | 2.57 | 1.85 | 0.77 | -0.68 | 3.87 | 3.40 | 2.73 | 1.95 | 0.94 | -0.41 |
| 14 | 0.7 | 3.82 | 3.29 | 2.48 | 1.77 | 0.66 | -0.87 | 3.86 | 3.38 | 2.70 | 1.92 | 0.90 | -0.49 |
| 15 | 0.4 | 3.62 | 3.06 | 2.19 | 1.41 | 0.37 | -1.36 | 3.73 | 3.25 | 2.56 | 1.75 | 0.74 | -0.68 |
| 16 | 1.9 | 3.51 | 2.90 | 1.94 | 1.16 | 0.09 | -1.82 | 3.66 | 3.17 | 2.46 | 1.64 | 0.62 | -0.87 |
| 17 | 0.5 | 3.39 | 2.74 | 1.68 | 0.90 | -0.19 | -2.29 | 3.60 | 3.10 | 2.36 | 1.53 | 0.49 | -1.06 |
| 18 | 0.6 | 2.97 | 2.25 | 1.23 | 0.47 | -0.46 | -2.49 | 3.26 | 2.76 | 2.03 | 1.20 | 0.22 | -1.22 |
| 19 | 0.2 | 2.76 | 1.98 | 0.87 | 0.11 | -0.80 | -3.00 | 3.12 | 2.60 | 1.85 | 1.01 | 0.04 | -1.44 |
| 20 | 0.2 | 3.04 | 2.52 | 1.85 | 1.08 | 0.15 | -1.40 | 3.22 | 2.76 | 2.13 | 1.33 | 0.35 | -0.91 |
| 21 | 0.2 | 0.66 | 0.20 | -0.34 | -1.11 | -2.04 | -3.96 | 1.43 | 1.06 | 0.55 | -0.20 | -1.14 | -2.33 |
| 22 | 29.8 | 3.85 | 3.35 | 2.62 | 1.88 | 0.83 | -0.59 | 3.88 | 3.42 | 2.77 | 1.99 | 1.00 | -0.31 |
| 23 | 11.6 | 3.82 | 3.31 | 2.51 | 1.80 | 0.70 | -0.80 | 3.87 | 3.41 | 2.76 | 1.97 | 0.97 | -0.35 |
| 24 | 1.5 | 3.80 | 3.26 | 2.39 | 1.71 | 0.56 | -1.03 | 3.86 | 3.40 | 2.74 | 1.96 | 0.95 | -0.40 |
| 25 | 0.5 | 3.72 | 3.18 | 2.38 | 1.61 | 0.58 | -1.01 | 3.81 | 3.35 | 2.70 | 1.91 | 0.92 | -0.40 |
| 26 | 0.2 | 3.61 | 3.03 | 2.13 | 1.36 | 0.31 | -1.48 | 3.76 | 3.30 | 2.65 | 1.85 | 0.85 | -0.50 |
| 27 | 0.2 | 3.50 | 2.87 | 1.86 | 1.10 | 0.02 | -1.97 | 3.72 | 3.25 | 2.59 | 1.78 | 0.78 | -0.61 |
| 28 | 1.4 | 3.48 | 2.91 | 2.15 | 1.38 | 0.45 | -1.12 | 3.65 | 3.19 | 2.55 | 1.75 | 0.77 | -0.50 |
| 29 | 0.6 | 3.24 | 2.59 | 1.75 | 1.00 | 0.09 | -1.66 | 3.50 | 3.04 | 2.40 | 1.60 | 0.61 | -0.66 |
| 30 | 0.2 | 2.98 | 2.26 | 1.34 | 0.59 | -0.28 | -2.23 | 3.35 | 2.89 | 2.24 | 1.43 | 0.44 | -0.84 |
| 31 | 0.3 | 2.68 | 1.88 | 0.86 | 0.13 | -0.72 | -2.88 | 3.17 | 2.71 | 2.05 | 1.23 | 0.24 | -1.03 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 32 | 1.9 | 3.11 | 2.56 | 1.88 | 1.13 | 0.21 | -1.46 | 3.36 | 2.91 | 2.29 | 1.50 | 0.52 | -0.75 |
| 33 | 1.6 | 2.63 | 2.04 | 1.32 | 0.59 | -0.29 | -2.19 | 3.05 | 2.61 | 1.98 | 1.18 | 0.21 | -1.06 |
| 34 | 0.7 | 2.14 | 1.49 | 0.74 | 0.02 | -0.82 | -2.97 | 2.71 | 2.28 | 1.66 | 0.85 | -0.12 | -1.38 |
| 35 | 0.3 | 1.56 | 0.85 | 0.06 | -0.63 | -1.43 | -3.87 | 2.32 | 1.90 | 1.28 | 0.47 | -0.51 | -1.76 |
| 36 | 1.3 | 2.13 | 1.68 | 1.10 | 0.37 | -0.56 | -2.89 | 2.76 | 2.37 | 1.81 | 1.07 | 0.12 | -1.11 |
| 37 | 1.2 | 1.08 | 0.63 | 0.08 | -0.63 | -1.52 | -4.49 | 2.08 | 1.73 | 1.22 | 0.50 | -0.42 | -1.63 |
| 38 | 0.4 | -0.04 | -0.48 | -1.00 | -1.68 | -2.53 | -6.18 | 1.36 | 1.06 | 0.59 | -0.10 | -1.01 | -2.19 |
| 39 | 0.2 | -1.33 | -1.77 | -2.25 | -2.89 | -3.71 | -8.14 | 0.53 | 0.28 | -0.13 | -0.79 | -1.68 | -2.83 |
| 40 | 0.3 | -0.77 | -1.05 | -1.32 | -1.90 | -4.02 | -9.52 | 0.37 | 0.16 | -0.29 | -0.78 | -1.64 | -2.76 |
| 41 | 40.5 | 3.84 | 3.33 | 2.56 | 1.84 | 0.77 | -0.68 | 3.88 | 3.42 | 2.78 | 2.00 | 1.01 | -0.28 |
| 42 | 9.4 | 3.80 | 3.26 | 2.40 | 1.72 | 0.58 | -1.00 | 3.87 | 3.41 | 2.77 | 1.99 | 0.99 | -0.31 |
| 43 | 0.9 | 3.76 | 3.19 | 2.24 | 1.60 | 0.40 | -1.30 | 3.86 | 3.40 | 2.76 | 1.97 | 0.98 | -0.34 |
| 44 | 3.0 | 3.72 | 3.19 | 2.39 | 1.62 | 0.60 | -0.99 | 3.82 | 3.37 | 2.73 | 1.95 | 0.96 | -0.32 |
| 45 | 0.6 | 3.60 | 3.01 | 2.09 | 1.33 | 0.28 | -1.54 | 3.78 | 3.32 | 2.68 | 1.89 | 0.91 | -0.39 |
| 46 | 0.4 | 3.49 | 2.85 | 1.81 | 1.05 | -0.02 | -2.06 | 3.73 | 3.27 | 2.64 | 1.85 | 0.85 | -0.45 |
| 47 | 3.0 | 3.53 | 2.96 | 2.19 | 1.43 | 0.48 | -1.08 | 3.70 | 3.25 | 2.62 | 1.83 | 0.85 | -0.42 |
| 48 | 0.7 | 3.28 | 2.62 | 1.75 | 1.00 | 0.08 | -1.68 | 3.57 | 3.12 | 2.49 | 1.70 | 0.71 | -0.56 |
| 49 | 0.5 | 3.04 | 2.30 | 1.33 | 0.60 | -0.30 | -2.26 | 3.44 | 3.00 | 2.37 | 1.57 | 0.58 | -0.69 |
| 50 | 1.7 | 3.19 | 2.64 | 1.95 | 1.20 | 0.29 | -1.39 | 3.46 | 3.02 | 2.40 | 1.62 | 0.64 | -0.63 |
| 51 | 1.1 | 2.69 | 2.07 | 1.34 | 0.62 | -0.24 | -2.21 | 3.16 | 2.73 | 2.12 | 1.33 | 0.35 | -0.91 |
| 52 | 0.5 | 2.21 | 1.53 | 0.76 | 0.07 | -0.75 | -3.00 | 2.87 | 2.46 | 1.85 | 1.06 | 0.08 | -1.18 |
| 53 | 0.4 | 1.66 | 0.90 | 0.09 | -0.57 | -1.34 | -3.91 | 2.54 | 2.14 | 1.54 | 0.74 | -0.23 | -1.49 |
| 54 | 0.8 | 2.34 | 1.91 | 1.33 | 0.65 | -0.41 | -3.04 | 3.01 | 2.63 | 2.08 | 1.36 | 0.41 | -0.82 |
| 55 | 0.8 | 1.24 | 0.83 | 0.28 | -0.33 | -1.45 | -5.04 | 2.38 | 2.06 | 1.56 | 0.88 | -0.03 | -1.24 |
| 56 | 0.4 | 0.19 | -0.20 | -0.72 | -1.26 | -2.44 | -6.95 | 1.78 | 1.52 | 1.07 | 0.43 | -0.46 | -1.64 |
| 57 | 0.3 | -1.03 | -1.40 | -1.88 | -2.34 | -3.59 | -9.16 | 1.09 | 0.90 | 0.50 | -0.09 | -0.95 | -2.10 |
| 58 | 0.3 | 1.79 | 1.42 | 1.03 | 0.32 | -1.93 | -6.01 | 2.41 | 2.10 | 1.58 | 0.94 | 0.04 | -1.14 |
| 59 | 0.2 | -2.77 | -2.94 | -2.82 | -3.39 | -8.40 | -18.60 | -0.82 | -0.81 | -1.07 | -1.42 | -2.12 | -3.11 |
| 60 | 28.5 | 3.86 | 3.36 | 2.64 | 1.90 | 0.85 | -0.54 | 3.88 | 3.42 | 2.79 | 2.00 | 1.02 | -0.27 |
| 61 | 5.1 | 3.83 | 3.32 | 2.53 | 1.82 | 0.72 | -0.75 | 3.88 | 3.41 | 2.78 | 1.99 | 1.00 | -0.30 |
| 62 | 0.5 | 3.81 | 3.27 | 2.41 | 1.73 | 0.59 | -0.97 | 3.87 | 3.41 | 2.77 | 1.98 | 0.99 | -0.33 |
| 63 | 1.8 | 3.72 | 3.19 | 2.39 | 1.62 | 0.60 | -0.99 | 3.82 | 3.36 | 2.73 | 1.94 | 0.96 | -0.34 |
| 64 | 0.5 | 3.61 | 3.02 | 2.10 | 1.33 | 0.29 | -1.53 | 3.78 | 3.31 | 2.68 | 1.88 | 0.90 | -0.42 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 65 | 0.4 | 3.49 | 2.84 | 1.80 | 1.05 | -0.03 | -2.07 | 3.73 | 3.27 | 2.62 | 1.83 | 0.84 | -0.49 |
| 66 | 1.1 | 3.53 | 2.96 | 2.19 | 1.43 | 0.49 | -1.07 | 3.70 | 3.25 | 2.61 | 1.83 | 0.84 | -0.43 |
| 67 | 0.6 | 3.28 | 2.63 | 1.76 | 1.01 | 0.09 | -1.67 | 3.56 | 3.11 | 2.48 | 1.69 | 0.70 | -0.58 |
| 68 | 0.4 | 3.03 | 2.29 | 1.32 | 0.59 | -0.31 | -2.27 | 3.43 | 2.98 | 2.35 | 1.55 | 0.56 | -0.72 |
| 69 | 0.2 | 2.80 | 1.99 | 0.93 | 0.21 | -0.67 | -2.82 | 3.31 | 2.86 | 2.23 | 1.42 | 0.43 | -0.85 |
| 70 | 0.4 | 3.19 | 2.64 | 1.95 | 1.20 | 0.29 | -1.38 | 3.46 | 3.01 | 2.39 | 1.60 | 0.63 | -0.64 |
| 71 | 0.4 | 2.69 | 2.07 | 1.34 | 0.62 | -0.25 | -2.21 | 3.14 | 2.71 | 2.10 | 1.31 | 0.33 | -0.94 |
| 72 | 0.3 | 2.18 | 1.50 | 0.74 | 0.04 | -0.78 | -3.03 | 2.83 | 2.41 | 1.81 | 1.01 | 0.03 | -1.23 |
| 73 | 0.3 | 1.73 | 1.00 | 0.19 | -0.49 | -1.26 | -3.77 | 2.55 | 2.15 | 1.54 | 0.74 | -0.23 | -1.50 |
| 74 | 0.2 | 2.44 | 1.99 | 1.41 | 0.69 | -0.31 | -2.70 | 3.06 | 2.67 | 2.10 | 1.37 | 0.42 | -0.82 |
| 75 | 17.0 | 3.86 | 3.37 | 2.67 | 1.92 | 0.88 | -0.49 | 3.88 | 3.42 | 2.78 | 1.99 | 1.00 | -0.30 |
| 76 | 3.8 | 3.84 | 3.34 | 2.58 | 1.85 | 0.78 | -0.66 | 3.87 | 3.41 | 2.76 | 1.98 | 0.98 | -0.35 |
| 77 | 0.7 | 3.82 | 3.30 | 2.49 | 1.78 | 0.67 | -0.85 | 3.87 | 3.40 | 2.74 | 1.96 | 0.95 | -0.39 |
| 78 | 0.2 | 3.74 | 3.21 | 2.42 | 1.64 | 0.61 | -0.96 | 3.82 | 3.35 | 2.70 | 1.91 | 0.91 | -0.43 |
| 79 | 0.2 | 3.63 | 3.06 | 2.16 | 1.39 | 0.34 | -1.44 | 3.77 | 3.30 | 2.63 | 1.83 | 0.83 | -0.56 |
| 80 | 0.4 | 3.53 | 2.90 | 1.90 | 1.13 | 0.04 | -1.94 | 3.72 | 3.24 | 2.56 | 1.75 | 0.74 | -0.69 |
| 81 | 0.2 | 3.01 | 2.31 | 1.38 | 0.63 | -0.26 | -2.18 | 3.34 | 2.87 | 2.21 | 1.39 | 0.41 | -0.86 |
| 82 | 0.2 | 2.77 | 1.99 | 0.98 | 0.24 | -0.62 | -2.72 | 3.19 | 2.72 | 2.04 | 1.22 | 0.23 | -1.04 |
| 83 | 11.9 | 3.86 | 3.38 | 2.69 | 1.93 | 0.90 | -0.46 | 3.88 | 3.41 | 2.76 | 1.98 | 0.98 | -0.34 |
| 84 | 3.9 | 3.85 | 3.35 | 2.61 | 1.87 | 0.81 | -0.62 | 3.87 | 3.39 | 2.72 | 1.95 | 0.93 | -0.42 |
| 85 | 0.7 | 3.83 | 3.32 | 2.53 | 1.81 | 0.72 | -0.77 | 3.86 | 3.38 | 2.70 | 1.92 | 0.89 | -0.49 |
| 86 | 0.3 | 3.65 | 3.10 | 2.24 | 1.46 | 0.40 | -1.31 | 3.74 | 3.25 | 2.54 | 1.74 | 0.71 | -0.76 |
| 87 | 0.6 | 3.56 | 2.97 | 2.02 | 1.24 | 0.15 | -1.73 | 3.68 | 3.18 | 2.44 | 1.63 | 0.58 | -0.96 |
| 88 | 0.2 | 3.47 | 2.84 | 1.81 | 1.04 | -0.08 | -2.13 | 3.63 | 3.12 | 2.35 | 1.52 | 0.46 | -1.15 |
| 89 | 8.8 | 3.87 | 3.39 | 2.70 | 1.94 | 0.92 | -0.44 | 3.87 | 3.39 | 2.72 | 1.95 | 0.94 | -0.41 |
| 90 | 3.7 | 3.85 | 3.36 | 2.63 | 1.88 | 0.83 | -0.59 | 3.86 | 3.37 | 2.67 | 1.91 | 0.87 | -0.53 |
| 91 | 0.7 | 3.83 | 3.33 | 2.57 | 1.83 | 0.75 | -0.73 | 3.84 | 3.35 | 2.61 | 1.86 | 0.80 | -0.65 |
| 92 | 0.4 | 3.70 | 3.17 | 2.36 | 1.57 | 0.51 | -1.11 | 3.72 | 3.21 | 2.44 | 1.64 | 0.59 | -0.97 |
| 93 | 0.9 | 3.62 | 3.06 | 2.19 | 1.40 | 0.31 | -1.46 | 3.65 | 3.12 | 2.30 | 1.50 | 0.42 | -1.26 |
| 94 | 0.3 | 3.55 | 2.96 | 2.02 | 1.23 | 0.11 | -1.80 | 3.59 | 3.03 | 2.16 | 1.35 | 0.25 | -1.54 |
| 95 | 7.5 | 3.87 | 3.40 | 2.73 | 1.96 | 0.95 | -0.39 | 3.86 | 3.38 | 2.69 | 1.93 | 0.90 | -0.46 |
| 96 | 3.6 | 3.86 | 3.38 | 2.68 | 1.92 | 0.88 | -0.50 | 3.85 | 3.35 | 2.62 | 1.87 | 0.81 | -0.62 |
| 97 | 0.6 | 3.85 | 3.36 | 2.64 | 1.88 | 0.83 | -0.60 | 3.83 | 3.32 | 2.55 | 1.82 | 0.73 | -0.76 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 98 | 0.3 | 3.74 | 3.24 | 2.49 | 1.69 | 0.64 | -0.90 | 3.70 | 3.16 | 2.33 | 1.55 | 0.48 | -1.18 |
| 99 | 0.5 | 3.69 | 3.16 | 2.37 | 1.57 | 0.49 | -1.14 | 3.63 | 3.06 | 2.16 | 1.38 | 0.27 | -1.53 |

Notes:

1. Negative values correspond to grounding.

Table E5. Net UKC (ft), Reach 1, h=52 ft, S-3 Channel, fully-loaded *Susan Maersk*, inbound and outbound transits.

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 1 | 7.9 | 3.87 | 3.39 | 2.70 | 1.95 | 0.92 | -0.42 | 3.88 | 3.41 | 2.75 | 1.98 | 0.98 | -0.34 |
| 2 | 2.9 | 3.86 | 3.37 | 2.66 | 1.91 | 0.86 | -0.52 | 3.87 | 3.40 | 2.73 | 1.96 | 0.94 | -0.40 |
| 3 | 0.4 | 3.84 | 3.35 | 2.60 | 1.87 | 0.80 | -0.64 | 3.86 | 3.38 | 2.70 | 1.93 | 0.90 | -0.47 |
| 4 | 10.0 | 3.85 | 3.36 | 2.63 | 1.89 | 0.85 | -0.55 | 3.88 | 3.41 | 2.76 | 1.98 | 0.98 | -0.34 |
| 5 | 9.6 | 3.83 | 3.32 | 2.54 | 1.82 | 0.73 | -0.74 | 3.87 | 3.40 | 2.74 | 1.96 | 0.95 | -0.40 |
| 6 | 0.8 | 3.81 | 3.27 | 2.44 | 1.74 | 0.61 | -0.94 | 3.86 | 3.39 | 2.71 | 1.93 | 0.91 | -0.47 |
| 7 | 0.9 | 3.63 | 3.07 | 2.19 | 1.42 | 0.38 | -1.36 | 3.75 | 3.28 | 2.60 | 1.80 | 0.79 | -0.60 |
| 8 | 3.5 | 3.53 | 2.93 | 1.96 | 1.19 | 0.12 | -1.79 | 3.70 | 3.22 | 2.53 | 1.72 | 0.70 | -0.75 |
| 9 | 0.3 | 3.43 | 2.78 | 1.71 | 0.94 | -0.15 | -2.25 | 3.64 | 3.16 | 2.45 | 1.63 | 0.60 | -0.90 |
| 10 | 0.8 | 3.08 | 2.36 | 1.33 | 0.57 | -0.39 | -2.43 | 3.38 | 2.89 | 2.19 | 1.37 | 0.39 | -1.02 |
| 11 | 0.3 | 2.90 | 2.12 | 0.99 | 0.24 | -0.72 | -2.93 | 3.26 | 2.77 | 2.05 | 1.22 | 0.24 | -1.20 |
| 12 | 13.6 | 3.85 | 3.36 | 2.64 | 1.90 | 0.86 | -0.53 | 3.88 | 3.42 | 2.78 | 2.00 | 1.01 | -0.28 |
| 13 | 9.2 | 3.83 | 3.32 | 2.55 | 1.83 | 0.74 | -0.72 | 3.88 | 3.41 | 2.77 | 1.99 | 1.00 | -0.31 |
| 14 | 0.7 | 3.81 | 3.28 | 2.44 | 1.75 | 0.62 | -0.92 | 3.87 | 3.41 | 2.76 | 1.98 | 0.98 | -0.35 |
| 15 | 0.4 | 3.61 | 3.03 | 2.13 | 1.36 | 0.33 | -1.44 | 3.77 | 3.30 | 2.66 | 1.87 | 0.88 | -0.45 |
| 16 | 1.9 | 3.49 | 2.86 | 1.85 | 1.09 | 0.03 | -1.95 | 3.72 | 3.25 | 2.60 | 1.80 | 0.81 | -0.54 |
| 17 | 0.5 | 3.37 | 2.69 | 1.57 | 0.81 | -0.27 | -2.46 | 3.66 | 3.20 | 2.55 | 1.74 | 0.75 | -0.63 |
| 18 | 0.6 | 2.96 | 2.18 | 1.11 | 0.39 | -0.54 | -2.64 | 3.39 | 2.93 | 2.29 | 1.48 | 0.49 | -0.79 |
| 19 | 0.2 | 2.75 | 1.90 | 0.73 | 0.01 | -0.90 | -3.19 | 3.27 | 2.82 | 2.17 | 1.36 | 0.36 | -0.91 |
| 20 | 0.2 | 3.08 | 2.54 | 1.87 | 1.12 | 0.20 | -1.46 | 3.36 | 2.92 | 2.30 | 1.51 | 0.53 | -0.73 |
| 21 | 0.2 | 1.34 | 0.90 | 0.35 | -0.33 | -1.26 | -4.34 | 2.33 | 1.99 | 1.47 | 0.77 | -0.16 | -1.37 |
| 22 | 29.8 | 3.85 | 3.35 | 2.61 | 1.88 | 0.83 | -0.58 | 3.88 | 3.42 | 2.79 | 2.01 | 1.02 | -0.26 |
| 23 | 11.6 | 3.82 | 3.30 | 2.50 | 1.80 | 0.70 | -0.79 | 3.88 | 3.41 | 2.78 | 2.00 | 1.01 | -0.28 |
| 24 | 1.5 | 3.80 | 3.25 | 2.38 | 1.71 | 0.56 | -1.02 | 3.87 | 3.41 | 2.77 | 1.99 | 1.00 | -0.30 |
| 25 | 0.5 | 3.72 | 3.18 | 2.38 | 1.61 | 0.59 | -1.00 | 3.82 | 3.36 | 2.73 | 1.95 | 0.96 | -0.32 |
| 26 | 0.2 | 3.62 | 3.03 | 2.12 | 1.36 | 0.32 | -1.47 | 3.78 | 3.33 | 2.69 | 1.90 | 0.92 | -0.37 |
| 27 | 0.2 | 3.51 | 2.87 | 1.85 | 1.10 | 0.03 | -1.96 | 3.74 | 3.28 | 2.65 | 1.86 | 0.87 | -0.42 |
| 28 | 1.4 | 3.49 | 2.92 | 2.15 | 1.39 | 0.46 | -1.11 | 3.68 | 3.23 | 2.60 | 1.81 | 0.83 | -0.44 |
| 29 | 0.6 | 3.25 | 2.61 | 1.76 | 1.02 | 0.11 | -1.64 | 3.55 | 3.11 | 2.48 | 1.69 | 0.70 | -0.57 |
| 30 | 0.2 | 3.00 | 2.28 | 1.35 | 0.62 | -0.26 | -2.20 | 3.42 | 2.98 | 2.35 | 1.56 | 0.57 | -0.71 |
| 31 | 0.3 | 2.71 | 1.90 | 0.87 | 0.16 | -0.69 | -2.85 | 3.26 | 2.83 | 2.20 | 1.41 | 0.42 | -0.86 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 32 | 1.9 | 3.14 | 2.59 | 1.91 | 1.17 | 0.26 | -1.42 | 3.44 | 3.00 | 2.38 | 1.60 | 0.62 | -0.65 |
| 33 | 1.6 | 2.69 | 2.09 | 1.37 | 0.66 | -0.21 | -2.14 | 3.16 | 2.74 | 2.13 | 1.34 | 0.37 | -0.90 |
| 34 | 0.7 | 2.22 | 1.56 | 0.81 | 0.12 | -0.71 | -2.89 | 2.88 | 2.46 | 1.86 | 1.07 | 0.10 | -1.16 |
| 35 | 0.3 | 1.67 | 0.95 | 0.16 | -0.51 | -1.29 | -3.77 | 2.55 | 2.15 | 1.56 | 0.76 | -0.21 | -1.47 |
| 36 | 1.3 | 2.42 | 1.99 | 1.40 | 0.72 | -0.30 | -2.83 | 3.08 | 2.70 | 2.14 | 1.42 | 0.47 | -0.76 |
| 37 | 1.2 | 1.54 | 1.12 | 0.56 | -0.07 | -1.10 | -4.39 | 2.59 | 2.26 | 1.74 | 1.05 | 0.13 | -1.08 |
| 38 | 0.4 | 0.61 | 0.21 | -0.32 | -0.90 | -1.95 | -6.03 | 2.08 | 1.80 | 1.33 | 0.67 | -0.23 | -1.42 |
| 39 | 0.2 | -0.47 | -0.85 | -1.35 | -1.85 | -2.94 | -7.94 | 1.48 | 1.26 | 0.84 | 0.23 | -0.65 | -1.81 |
| 40 | 0.3 | 0.58 | 0.27 | 0.03 | -0.62 | -3.61 | -9.43 | 1.59 | 1.38 | 0.94 | 0.37 | -0.46 | -1.59 |
| 41 | 40.5 | 3.84 | 3.34 | 2.58 | 1.86 | 0.79 | -0.64 | 3.88 | 3.41 | 2.78 | 1.99 | 1.00 | -0.30 |
| 42 | 9.4 | 3.81 | 3.27 | 2.43 | 1.74 | 0.62 | -0.93 | 3.87 | 3.40 | 2.76 | 1.97 | 0.97 | -0.35 |
| 43 | 0.9 | 3.77 | 3.21 | 2.28 | 1.63 | 0.45 | -1.21 | 3.86 | 3.39 | 2.74 | 1.96 | 0.95 | -0.40 |
| 44 | 3.0 | 3.73 | 3.20 | 2.42 | 1.65 | 0.63 | -0.93 | 3.82 | 3.36 | 2.72 | 1.94 | 0.95 | -0.35 |
| 45 | 0.6 | 3.62 | 3.04 | 2.14 | 1.38 | 0.34 | -1.43 | 3.78 | 3.31 | 2.67 | 1.88 | 0.89 | -0.44 |
| 46 | 0.4 | 3.51 | 2.89 | 1.88 | 1.12 | 0.06 | -1.91 | 3.73 | 3.27 | 2.62 | 1.82 | 0.83 | -0.53 |
| 47 | 3.0 | 3.55 | 2.99 | 2.23 | 1.47 | 0.52 | -1.01 | 3.70 | 3.25 | 2.61 | 1.82 | 0.84 | -0.43 |
| 48 | 0.7 | 3.31 | 2.67 | 1.82 | 1.07 | 0.15 | -1.57 | 3.57 | 3.11 | 2.48 | 1.68 | 0.69 | -0.58 |
| 49 | 0.5 | 3.08 | 2.37 | 1.43 | 0.70 | -0.20 | -2.11 | 3.44 | 2.99 | 2.35 | 1.55 | 0.56 | -0.72 |
| 50 | 1.7 | 3.22 | 2.68 | 2.00 | 1.25 | 0.33 | -1.31 | 3.46 | 3.01 | 2.39 | 1.60 | 0.62 | -0.64 |
| 51 | 1.1 | 2.74 | 2.14 | 1.42 | 0.70 | -0.18 | -2.08 | 3.15 | 2.72 | 2.10 | 1.30 | 0.33 | -0.94 |
| 52 | 0.5 | 2.29 | 1.63 | 0.88 | 0.17 | -0.67 | -2.81 | 2.86 | 2.44 | 1.82 | 1.02 | 0.05 | -1.22 |
| 53 | 0.4 | 1.76 | 1.04 | 0.24 | -0.44 | -1.23 | -3.65 | 2.53 | 2.11 | 1.50 | 0.69 | -0.28 | -1.54 |
| 54 | 0.8 | 2.30 | 1.86 | 1.28 | 0.58 | -0.39 | -2.83 | 2.91 | 2.52 | 1.96 | 1.23 | 0.29 | -0.95 |
| 55 | 0.8 | 1.17 | 0.74 | 0.20 | -0.45 | -1.41 | -4.68 | 2.21 | 1.88 | 1.37 | 0.67 | -0.25 | -1.46 |
| 56 | 0.4 | 0.09 | -0.32 | -0.83 | -1.43 | -2.38 | -6.45 | 1.54 | 1.26 | 0.80 | 0.14 | -0.76 | -1.95 |
| 57 | 0.3 | -1.16 | -1.55 | -2.02 | -2.56 | -3.50 | -8.49 | 0.77 | 0.55 | 0.14 | -0.48 | -1.36 | -2.51 |
| 58 | 0.3 | 1.54 | 1.18 | 0.75 | 0.10 | -1.81 | -5.56 | 2.14 | 1.82 | 1.30 | 0.67 | -0.24 | -1.42 |
| 59 | 0.2 | -3.58 | -3.73 | -3.70 | -4.09 | -8.00 | -17.15 | -1.66 | -1.68 | -1.98 | -2.27 | -3.01 | -4.02 |
| 60 | 28.5 | 3.86 | 3.37 | 2.67 | 1.92 | 0.88 | -0.49 | 3.88 | 3.41 | 2.77 | 1.99 | 0.99 | -0.32 |
| 61 | 5.1 | 3.84 | 3.33 | 2.57 | 1.85 | 0.77 | -0.67 | 3.87 | 3.40 | 2.75 | 1.97 | 0.96 | -0.38 |
| 62 | 0.5 | 3.82 | 3.29 | 2.48 | 1.77 | 0.66 | -0.86 | 3.86 | 3.39 | 2.72 | 1.94 | 0.93 | -0.44 |
| 63 | 1.8 | 3.74 | 3.22 | 2.45 | 1.68 | 0.66 | -0.87 | 3.81 | 3.34 | 2.69 | 1.90 | 0.90 | -0.44 |
| 64 | 0.5 | 3.64 | 3.07 | 2.21 | 1.43 | 0.39 | -1.33 | 3.76 | 3.28 | 2.61 | 1.81 | 0.80 | -0.60 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 65 | 0.4 | 3.53 | 2.93 | 1.96 | 1.19 | 0.12 | -1.79 | 3.70 | 3.22 | 2.53 | 1.72 | 0.70 | -0.75 |
| 66 | 1.1 | 3.56 | 3.01 | 2.27 | 1.50 | 0.55 | -0.95 | 3.68 | 3.21 | 2.56 | 1.76 | 0.78 | -0.50 |
| 67 | 0.6 | 3.33 | 2.72 | 1.89 | 1.13 | 0.21 | -1.47 | 3.52 | 3.05 | 2.39 | 1.58 | 0.60 | -0.70 |
| 68 | 0.4 | 3.10 | 2.42 | 1.51 | 0.76 | -0.14 | -1.99 | 3.37 | 2.89 | 2.21 | 1.40 | 0.41 | -0.90 |
| 69 | 0.2 | 2.89 | 2.15 | 1.17 | 0.43 | -0.45 | -2.45 | 3.23 | 2.75 | 2.06 | 1.23 | 0.25 | -1.07 |
| 70 | 0.4 | 3.22 | 2.70 | 2.02 | 1.26 | 0.32 | -1.24 | 3.40 | 2.94 | 2.31 | 1.51 | 0.54 | -0.73 |
| 71 | 0.4 | 2.75 | 2.17 | 1.46 | 0.71 | -0.19 | -1.95 | 3.05 | 2.59 | 1.96 | 1.15 | 0.18 | -1.09 |
| 72 | 0.3 | 2.27 | 1.64 | 0.90 | 0.17 | -0.70 | -2.67 | 2.70 | 2.24 | 1.60 | 0.79 | -0.19 | -1.44 |
| 73 | 0.3 | 1.84 | 1.17 | 0.40 | -0.32 | -1.16 | -3.32 | 2.38 | 1.93 | 1.29 | 0.46 | -0.51 | -1.76 |
| 74 | 0.2 | 2.22 | 1.76 | 1.18 | 0.41 | -0.54 | -2.32 | 2.69 | 2.29 | 1.72 | 0.96 | 0.00 | -1.23 |
| 75 | 17.0 | 3.87 | 3.39 | 2.70 | 1.94 | 0.92 | -0.43 | 3.88 | 3.41 | 2.75 | 1.98 | 0.97 | -0.35 |
| 76 | 3.8 | 3.85 | 3.36 | 2.63 | 1.89 | 0.84 | -0.57 | 3.87 | 3.39 | 2.72 | 1.95 | 0.93 | -0.43 |
| 77 | 0.7 | 3.84 | 3.33 | 2.56 | 1.84 | 0.75 | -0.71 | 3.86 | 3.38 | 2.68 | 1.92 | 0.88 | -0.51 |
| 78 | 0.2 | 3.76 | 3.25 | 2.50 | 1.72 | 0.70 | -0.80 | 3.80 | 3.32 | 2.63 | 1.84 | 0.83 | -0.56 |
| 79 | 0.2 | 3.68 | 3.13 | 2.31 | 1.53 | 0.48 | -1.17 | 3.74 | 3.25 | 2.53 | 1.72 | 0.70 | -0.78 |
| 80 | 0.4 | 3.59 | 3.01 | 2.11 | 1.32 | 0.25 | -1.56 | 3.68 | 3.17 | 2.41 | 1.60 | 0.55 | -1.01 |
| 81 | 0.2 | 3.11 | 2.48 | 1.64 | 0.86 | -0.02 | -1.78 | 3.26 | 2.74 | 2.01 | 1.19 | 0.23 | -1.20 |
| 82 | 0.2 | 2.89 | 2.22 | 1.31 | 0.53 | -0.32 | -2.22 | 3.08 | 2.54 | 1.79 | 0.96 | 0.01 | -1.47 |
| 83 | 11.9 | 3.87 | 3.40 | 2.72 | 1.96 | 0.94 | -0.39 | 3.87 | 3.40 | 2.72 | 1.96 | 0.94 | -0.39 |
| 84 | 3.9 | 3.86 | 3.37 | 2.67 | 1.92 | 0.88 | -0.51 | 3.86 | 3.37 | 2.67 | 1.92 | 0.88 | -0.51 |
| 85 | 0.7 | 3.85 | 3.35 | 2.62 | 1.87 | 0.82 | -0.61 | 3.85 | 3.35 | 2.62 | 1.87 | 0.82 | -0.61 |
| 86 | 0.3 | 3.70 | 3.18 | 2.41 | 1.62 | 0.57 | -1.00 | 3.70 | 3.18 | 2.41 | 1.62 | 0.57 | -1.00 |
| 87 | 0.6 | 3.63 | 3.09 | 2.26 | 1.46 | 0.39 | -1.29 | 3.63 | 3.09 | 2.26 | 1.46 | 0.39 | -1.29 |
| 88 | 0.2 | 3.56 | 3.00 | 2.12 | 1.31 | 0.22 | -1.58 | 3.56 | 3.00 | 2.12 | 1.31 | 0.22 | -1.58 |
| 89 | 8.8 | 3.87 | 3.40 | 2.74 | 1.97 | 0.96 | -0.37 | 3.86 | 3.38 | 2.69 | 1.93 | 0.90 | -0.46 |
| 90 | 3.7 | 3.86 | 3.39 | 2.70 | 1.93 | 0.91 | -0.46 | 3.84 | 3.35 | 2.61 | 1.87 | 0.81 | -0.62 |
| 91 | 0.7 | 3.85 | 3.37 | 2.67 | 1.90 | 0.86 | -0.55 | 3.83 | 3.32 | 2.53 | 1.81 | 0.72 | -0.77 |
| 92 | 0.4 | 3.75 | 3.25 | 2.53 | 1.73 | 0.69 | -0.79 | 3.68 | 3.14 | 2.31 | 1.53 | 0.47 | -1.19 |
| 93 | 0.9 | 3.69 | 3.18 | 2.42 | 1.62 | 0.56 | -1.01 | 3.61 | 3.03 | 2.12 | 1.34 | 0.25 | -1.56 |
| 94 | 0.3 | 3.64 | 3.11 | 2.32 | 1.50 | 0.43 | -1.23 | 3.53 | 2.92 | 1.93 | 1.15 | 0.03 | -1.94 |
| 95 | 7.5 | 3.88 | 3.41 | 2.77 | 1.99 | 0.99 | -0.32 | 3.86 | 3.37 | 2.66 | 1.92 | 0.88 | -0.50 |
| 96 | 3.6 | 3.87 | 3.40 | 2.75 | 1.96 | 0.96 | -0.38 | 3.84 | 3.33 | 2.57 | 1.84 | 0.77 | -0.68 |
| 97 | 0.6 | 3.86 | 3.39 | 2.73 | 1.94 | 0.93 | -0.44 | 3.82 | 3.30 | 2.48 | 1.78 | 0.67 | -0.85 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 98 | 0.3 | 3.78 | 3.31 | 2.63 | 1.83 | 0.81 | -0.60 | 3.67 | 3.11 | 2.23 | 1.47 | 0.39 | -1.35 |
| 99 | 0.5 | 3.74 | 3.26 | 2.57 | 1.76 | 0.72 | -0.74 | 3.59 | 2.99 | 2.02 | 1.26 | 0.15 | -1.77 |

Notes:

1. Negative values correspond to grounding.

Table E6. Net UKC (ft), Reach 1, h=52 ft, S-8 Channel, fully-loaded *Susan Maersk*, inbound and outbound transits.

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 1 | 7.9 | 3.87 | 3.40 | 2.72 | 1.96 | 0.94 | -0.40 | 3.87 | 3.40 | 2.74 | 1.97 | 0.96 | -0.37 |
| 2 | 2.9 | 3.86 | 3.38 | 2.68 | 1.92 | 0.89 | -0.48 | 3.87 | 3.39 | 2.70 | 1.94 | 0.92 | -0.44 |
| 3 | 0.4 | 3.85 | 3.36 | 2.63 | 1.89 | 0.83 | -0.58 | 3.86 | 3.37 | 2.67 | 1.91 | 0.87 | -0.53 |
| 4 | 10.0 | 3.86 | 3.37 | 2.65 | 1.91 | 0.86 | -0.53 | 3.87 | 3.40 | 2.74 | 1.97 | 0.96 | -0.37 |
| 5 | 9.6 | 3.84 | 3.33 | 2.57 | 1.84 | 0.76 | -0.70 | 3.86 | 3.39 | 2.71 | 1.93 | 0.91 | -0.46 |
| 6 | 0.8 | 3.81 | 3.29 | 2.48 | 1.77 | 0.65 | -0.88 | 3.85 | 3.37 | 2.67 | 1.90 | 0.86 | -0.55 |
| 7 | 0.9 | 3.65 | 3.10 | 2.25 | 1.47 | 0.43 | -1.25 | 3.73 | 3.25 | 2.54 | 1.74 | 0.72 | -0.73 |
| 8 | 3.5 | 3.56 | 2.97 | 2.04 | 1.26 | 0.19 | -1.65 | 3.67 | 3.18 | 2.44 | 1.63 | 0.59 | -0.92 |
| 9 | 0.3 | 3.46 | 2.83 | 1.82 | 1.04 | -0.06 | -2.07 | 3.61 | 3.10 | 2.34 | 1.52 | 0.46 | -1.13 |
| 10 | 0.8 | 3.12 | 2.43 | 1.45 | 0.68 | -0.29 | -2.24 | 3.32 | 2.80 | 2.06 | 1.23 | 0.27 | -1.26 |
| 11 | 0.3 | 2.94 | 2.21 | 1.14 | 0.37 | -0.59 | -2.70 | 3.19 | 2.66 | 1.89 | 1.05 | 0.10 | -1.49 |
| 12 | 13.6 | 3.86 | 3.37 | 2.65 | 1.91 | 0.87 | -0.52 | 3.88 | 3.42 | 2.77 | 1.99 | 1.00 | -0.31 |
| 13 | 9.2 | 3.84 | 3.33 | 2.56 | 1.84 | 0.76 | -0.69 | 3.87 | 3.41 | 2.76 | 1.97 | 0.97 | -0.35 |
| 14 | 0.7 | 3.81 | 3.29 | 2.46 | 1.76 | 0.64 | -0.88 | 3.87 | 3.40 | 2.74 | 1.95 | 0.94 | -0.40 |
| 15 | 0.4 | 3.62 | 3.05 | 2.17 | 1.40 | 0.36 | -1.38 | 3.75 | 3.28 | 2.62 | 1.82 | 0.83 | -0.54 |
| 16 | 1.9 | 3.50 | 2.89 | 1.90 | 1.14 | 0.08 | -1.86 | 3.70 | 3.22 | 2.55 | 1.74 | 0.74 | -0.67 |
| 17 | 0.5 | 3.39 | 2.72 | 1.64 | 0.87 | -0.21 | -2.34 | 3.64 | 3.16 | 2.48 | 1.66 | 0.65 | -0.80 |
| 18 | 0.6 | 2.98 | 2.23 | 1.19 | 0.45 | -0.48 | -2.53 | 3.34 | 2.87 | 2.19 | 1.37 | 0.38 | -0.94 |
| 19 | 0.2 | 2.78 | 1.96 | 0.83 | 0.09 | -0.82 | -3.05 | 3.22 | 2.74 | 2.05 | 1.23 | 0.24 | -1.10 |
| 20 | 0.2 | 3.08 | 2.55 | 1.88 | 1.12 | 0.20 | -1.41 | 3.31 | 2.86 | 2.24 | 1.44 | 0.47 | -0.80 |
| 21 | 0.2 | 1.07 | 0.62 | 0.07 | -0.66 | -1.57 | -4.12 | 1.96 | 1.61 | 1.09 | 0.37 | -0.57 | -1.77 |
| 22 | 29.8 | 3.85 | 3.35 | 2.62 | 1.88 | 0.83 | -0.58 | 3.88 | 3.42 | 2.79 | 2.00 | 1.01 | -0.28 |
| 23 | 11.6 | 3.82 | 3.31 | 2.51 | 1.80 | 0.70 | -0.79 | 3.87 | 3.41 | 2.78 | 1.99 | 1.00 | -0.30 |
| 24 | 1.5 | 3.80 | 3.26 | 2.39 | 1.71 | 0.57 | -1.01 | 3.87 | 3.41 | 2.77 | 1.98 | 0.98 | -0.33 |
| 25 | 0.5 | 3.72 | 3.18 | 2.38 | 1.61 | 0.59 | -1.00 | 3.82 | 3.36 | 2.73 | 1.94 | 0.96 | -0.34 |
| 26 | 0.2 | 3.62 | 3.04 | 2.13 | 1.37 | 0.33 | -1.45 | 3.78 | 3.32 | 2.68 | 1.89 | 0.90 | -0.41 |
| 27 | 0.2 | 3.51 | 2.88 | 1.87 | 1.11 | 0.04 | -1.94 | 3.74 | 3.28 | 2.64 | 1.84 | 0.85 | -0.47 |
| 28 | 1.4 | 3.49 | 2.92 | 2.16 | 1.40 | 0.46 | -1.10 | 3.67 | 3.22 | 2.59 | 1.80 | 0.82 | -0.46 |
| 29 | 0.6 | 3.26 | 2.61 | 1.77 | 1.03 | 0.12 | -1.63 | 3.54 | 3.09 | 2.46 | 1.67 | 0.68 | -0.59 |
| 30 | 0.2 | 3.01 | 2.29 | 1.37 | 0.63 | -0.25 | -2.18 | 3.41 | 2.96 | 2.33 | 1.53 | 0.54 | -0.73 |
| 31 | 0.3 | 2.72 | 1.92 | 0.89 | 0.18 | -0.67 | -2.82 | 3.25 | 2.81 | 2.17 | 1.37 | 0.38 | -0.90 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 32 | 1.9 | 3.14 | 2.59 | 1.91 | 1.17 | 0.25 | -1.42 | 3.42 | 2.98 | 2.36 | 1.58 | 0.60 | -0.67 |
| 33 | 1.6 | 2.69 | 2.09 | 1.38 | 0.66 | -0.22 | -2.13 | 3.14 | 2.71 | 2.10 | 1.31 | 0.33 | -0.93 |
| 34 | 0.7 | 2.22 | 1.56 | 0.82 | 0.12 | -0.71 | -2.89 | 2.85 | 2.43 | 1.82 | 1.03 | 0.05 | -1.21 |
| 35 | 0.3 | 1.67 | 0.95 | 0.17 | -0.51 | -1.29 | -3.76 | 2.50 | 2.10 | 1.50 | 0.70 | -0.27 | -1.53 |
| 36 | 1.3 | 2.36 | 1.92 | 1.34 | 0.64 | -0.37 | -2.83 | 3.00 | 2.62 | 2.06 | 1.33 | 0.39 | -0.85 |
| 37 | 1.2 | 1.45 | 1.02 | 0.46 | -0.19 | -1.22 | -4.39 | 2.47 | 2.14 | 1.62 | 0.92 | -0.01 | -1.22 |
| 38 | 0.4 | 0.48 | 0.06 | -0.46 | -1.07 | -2.11 | -6.04 | 1.91 | 1.62 | 1.15 | 0.48 | -0.42 | -1.61 |
| 39 | 0.2 | -0.64 | -1.05 | -1.54 | -2.08 | -3.14 | -7.95 | 1.26 | 1.03 | 0.61 | -0.02 | -0.90 | -2.07 |
| 40 | 0.3 | 0.26 | -0.05 | -0.31 | -0.86 | -3.72 | -9.39 | 1.28 | 1.07 | 0.62 | 0.08 | -0.77 | -1.90 |
| 41 | 40.5 | 3.84 | 3.33 | 2.58 | 1.85 | 0.79 | -0.65 | 3.88 | 3.42 | 2.78 | 2.00 | 1.01 | -0.27 |
| 42 | 9.4 | 3.80 | 3.27 | 2.42 | 1.73 | 0.60 | -0.95 | 3.87 | 3.41 | 2.77 | 1.99 | 1.00 | -0.30 |
| 43 | 0.9 | 3.77 | 3.20 | 2.26 | 1.62 | 0.43 | -1.23 | 3.86 | 3.40 | 2.76 | 1.97 | 0.98 | -0.33 |
| 44 | 3.0 | 3.73 | 3.20 | 2.41 | 1.64 | 0.62 | -0.95 | 3.83 | 3.37 | 2.74 | 1.95 | 0.97 | -0.32 |
| 45 | 0.6 | 3.62 | 3.03 | 2.12 | 1.36 | 0.32 | -1.47 | 3.78 | 3.32 | 2.69 | 1.90 | 0.91 | -0.38 |
| 46 | 0.4 | 3.51 | 2.88 | 1.86 | 1.10 | 0.03 | -1.96 | 3.74 | 3.28 | 2.65 | 1.85 | 0.86 | -0.44 |
| 47 | 3.0 | 3.55 | 2.98 | 2.22 | 1.46 | 0.51 | -1.03 | 3.71 | 3.26 | 2.63 | 1.84 | 0.86 | -0.41 |
| 48 | 0.7 | 3.31 | 2.66 | 1.80 | 1.06 | 0.13 | -1.60 | 3.59 | 3.14 | 2.51 | 1.72 | 0.73 | -0.55 |
| 49 | 0.5 | 3.07 | 2.35 | 1.40 | 0.67 | -0.23 | -2.15 | 3.46 | 3.02 | 2.39 | 1.60 | 0.61 | -0.67 |
| 50 | 1.7 | 3.22 | 2.67 | 1.99 | 1.25 | 0.33 | -1.32 | 3.48 | 3.04 | 2.42 | 1.64 | 0.66 | -0.61 |
| 51 | 1.1 | 2.74 | 2.13 | 1.41 | 0.69 | -0.18 | -2.10 | 3.19 | 2.77 | 2.15 | 1.36 | 0.39 | -0.88 |
| 52 | 0.5 | 2.29 | 1.62 | 0.86 | 0.17 | -0.66 | -2.85 | 2.92 | 2.50 | 1.90 | 1.10 | 0.13 | -1.13 |
| 53 | 0.4 | 1.76 | 1.03 | 0.22 | -0.44 | -1.22 | -3.71 | 2.60 | 2.20 | 1.60 | 0.80 | -0.17 | -1.43 |
| 54 | 0.8 | 2.42 | 1.99 | 1.40 | 0.72 | -0.34 | -2.88 | 3.05 | 2.67 | 2.11 | 1.39 | 0.44 | -0.79 |
| 55 | 0.8 | 1.36 | 0.95 | 0.40 | -0.21 | -1.32 | -4.77 | 2.45 | 2.13 | 1.62 | 0.94 | 0.02 | -1.19 |
| 56 | 0.4 | 0.36 | -0.03 | -0.55 | -1.09 | -2.25 | -6.56 | 1.88 | 1.61 | 1.15 | 0.51 | -0.39 | -1.57 |
| 57 | 0.3 | -0.80 | -1.16 | -1.65 | -2.11 | -3.33 | -8.64 | 1.22 | 1.02 | 0.61 | 0.01 | -0.85 | -2.01 |
| 58 | 0.3 | 1.89 | 1.52 | 1.12 | 0.41 | -1.76 | -5.67 | 2.47 | 2.16 | 1.64 | 0.99 | 0.09 | -1.09 |
| 59 | 0.2 | -2.45 | -2.62 | -2.54 | -3.10 | -7.87 | -17.52 | -0.61 | -0.60 | -0.88 | -1.25 | -1.96 | -2.97 |
| 60 | 28.5 | 3.86 | 3.37 | 2.66 | 1.91 | 0.87 | -0.51 | 3.88 | 3.42 | 2.78 | 2.00 | 1.01 | -0.29 |
| 61 | 5.1 | 3.84 | 3.33 | 2.55 | 1.83 | 0.75 | -0.70 | 3.87 | 3.41 | 2.77 | 1.98 | 0.98 | -0.33 |
| 62 | 0.5 | 3.81 | 3.28 | 2.45 | 1.76 | 0.63 | -0.90 | 3.87 | 3.40 | 2.75 | 1.97 | 0.96 | -0.37 |
| 63 | 1.8 | 3.74 | 3.21 | 2.43 | 1.65 | 0.64 | -0.92 | 3.82 | 3.36 | 2.71 | 1.92 | 0.94 | -0.38 |
| 64 | 0.5 | 3.63 | 3.05 | 2.16 | 1.39 | 0.35 | -1.41 | 3.77 | 3.30 | 2.65 | 1.86 | 0.86 | -0.49 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 65 | 0.4 | 3.52 | 2.89 | 1.89 | 1.13 | 0.06 | -1.90 | 3.72 | 3.25 | 2.59 | 1.79 | 0.79 | -0.60 |
| 66 | 1.1 | 3.56 | 3.00 | 2.24 | 1.48 | 0.53 | -1.00 | 3.70 | 3.24 | 2.60 | 1.81 | 0.82 | -0.45 |
| 67 | 0.6 | 3.32 | 2.69 | 1.84 | 1.09 | 0.16 | -1.55 | 3.56 | 3.10 | 2.45 | 1.65 | 0.67 | -0.61 |
| 68 | 0.4 | 3.08 | 2.37 | 1.44 | 0.70 | -0.20 | -2.10 | 3.42 | 2.96 | 2.30 | 1.50 | 0.51 | -0.76 |
| 69 | 0.2 | 2.86 | 2.10 | 1.08 | 0.35 | -0.53 | -2.59 | 3.29 | 2.83 | 2.17 | 1.36 | 0.37 | -0.90 |
| 70 | 0.4 | 3.22 | 2.68 | 2.00 | 1.25 | 0.33 | -1.29 | 3.44 | 2.99 | 2.37 | 1.58 | 0.60 | -0.67 |
| 71 | 0.4 | 2.74 | 2.15 | 1.43 | 0.70 | -0.18 | -2.05 | 3.12 | 2.68 | 2.06 | 1.26 | 0.28 | -0.98 |
| 72 | 0.3 | 2.26 | 1.61 | 0.86 | 0.15 | -0.69 | -2.80 | 2.80 | 2.37 | 1.75 | 0.94 | -0.03 | -1.29 |
| 73 | 0.3 | 1.83 | 1.13 | 0.35 | -0.35 | -1.15 | -3.48 | 2.52 | 2.09 | 1.47 | 0.66 | -0.32 | -1.58 |
| 74 | 0.2 | 2.38 | 1.92 | 1.34 | 0.59 | -0.34 | -2.48 | 2.92 | 2.52 | 1.95 | 1.21 | 0.26 | -0.98 |
| 75 | 17.0 | 3.86 | 3.38 | 2.68 | 1.93 | 0.90 | -0.46 | 3.88 | 3.41 | 2.76 | 1.99 | 0.99 | -0.32 |
| 76 | 3.8 | 3.85 | 3.35 | 2.61 | 1.87 | 0.81 | -0.61 | 3.87 | 3.40 | 2.74 | 1.96 | 0.96 | -0.38 |
| 77 | 0.7 | 3.83 | 3.32 | 2.53 | 1.81 | 0.72 | -0.76 | 3.86 | 3.39 | 2.72 | 1.94 | 0.92 | -0.45 |
| 78 | 0.2 | 3.75 | 3.23 | 2.47 | 1.69 | 0.67 | -0.86 | 3.81 | 3.34 | 2.67 | 1.88 | 0.88 | -0.49 |
| 79 | 0.2 | 3.66 | 3.10 | 2.25 | 1.47 | 0.42 | -1.28 | 3.76 | 3.28 | 2.59 | 1.79 | 0.77 | -0.65 |
| 80 | 0.4 | 3.56 | 2.97 | 2.02 | 1.24 | 0.16 | -1.72 | 3.70 | 3.21 | 2.50 | 1.69 | 0.65 | -0.83 |
| 81 | 0.2 | 3.08 | 2.41 | 1.53 | 0.77 | -0.11 | -1.94 | 3.31 | 2.82 | 2.13 | 1.31 | 0.34 | -1.00 |
| 82 | 0.2 | 2.85 | 2.13 | 1.18 | 0.42 | -0.44 | -2.42 | 3.15 | 2.65 | 1.94 | 1.12 | 0.14 | -1.22 |
| 83 | 11.9 | 3.87 | 3.39 | 2.71 | 1.95 | 0.93 | -0.42 | 3.87 | 3.40 | 2.74 | 1.97 | 0.96 | -0.36 |
| 84 | 3.9 | 3.85 | 3.36 | 2.64 | 1.90 | 0.85 | -0.55 | 3.86 | 3.39 | 2.70 | 1.93 | 0.91 | -0.46 |
| 85 | 0.7 | 3.84 | 3.34 | 2.58 | 1.85 | 0.77 | -0.68 | 3.85 | 3.37 | 2.66 | 1.90 | 0.86 | -0.55 |
| 86 | 0.3 | 3.68 | 3.15 | 2.34 | 1.55 | 0.50 | -1.13 | 3.73 | 3.22 | 2.48 | 1.69 | 0.65 | -0.86 |
| 87 | 0.6 | 3.60 | 3.04 | 2.16 | 1.37 | 0.29 | -1.48 | 3.66 | 3.14 | 2.36 | 1.56 | 0.50 | -1.11 |
| 88 | 0.2 | 3.53 | 2.93 | 1.98 | 1.19 | 0.09 | -1.81 | 3.60 | 3.07 | 2.25 | 1.43 | 0.36 | -1.34 |
| 89 | 8.8 | 3.87 | 3.40 | 2.72 | 1.96 | 0.94 | -0.40 | 3.87 | 3.39 | 2.71 | 1.94 | 0.92 | -0.43 |
| 90 | 3.7 | 3.86 | 3.37 | 2.67 | 1.91 | 0.88 | -0.51 | 3.85 | 3.36 | 2.64 | 1.89 | 0.84 | -0.57 |
| 91 | 0.7 | 3.84 | 3.35 | 2.62 | 1.87 | 0.81 | -0.62 | 3.84 | 3.33 | 2.58 | 1.84 | 0.76 | -0.70 |
| 92 | 0.4 | 3.73 | 3.22 | 2.46 | 1.66 | 0.62 | -0.93 | 3.70 | 3.18 | 2.38 | 1.60 | 0.54 | -1.06 |
| 93 | 0.9 | 3.66 | 3.13 | 2.32 | 1.52 | 0.45 | -1.20 | 3.63 | 3.08 | 2.22 | 1.43 | 0.35 | -1.39 |
| 94 | 0.3 | 3.60 | 3.05 | 2.19 | 1.39 | 0.29 | -1.47 | 3.56 | 2.98 | 2.06 | 1.27 | 0.16 | -1.71 |
| 95 | 7.5 | 3.88 | 3.41 | 2.75 | 1.98 | 0.97 | -0.35 | 3.86 | 3.38 | 2.68 | 1.93 | 0.89 | -0.47 |
| 96 | 3.6 | 3.87 | 3.39 | 2.72 | 1.94 | 0.93 | -0.43 | 3.84 | 3.34 | 2.59 | 1.86 | 0.79 | -0.64 |
| 97 | 0.6 | 3.86 | 3.38 | 2.69 | 1.92 | 0.89 | -0.51 | 3.82 | 3.31 | 2.52 | 1.80 | 0.70 | -0.80 |

| Wave ID | Days/yr | Inbound Ship speed (kt) | | | | | | Outbound Ship speed (kt) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 | 6 | 8 | 10 | 12 | 14 | 16 |
| 98 | 0.3 | 3.77 | 3.28 | 2.57 | 1.77 | 0.74 | -0.73 | 3.69 | 3.14 | 2.29 | 1.52 | 0.44 | -1.25 |
| 99 | 0.5 | 3.72 | 3.22 | 2.49 | 1.68 | 0.63 | -0.91 | 3.61 | 3.03 | 2.10 | 1.33 | 0.22 | -1.63 |

Notes:

1. Negative values correspond to grounding.

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# Ship Forces on the Shoreline of the Savannah Harbor Project

Stephen T. Maynord

August 2006

Coastal and Hydraulics Laboratory

Executive Summary


Ship forces having the potential to cause shoreline erosion were evaluated at the Savannah Harbor to compare the without project (existing) and the with project (deepened) channels. Results of this study will be used by the Savannah District in a separate study to evaluate shoreline erosion.

An analysis of ship forces requires determination of comparable ship speeds in the without project (existing) and with project (deepened) channels. Field data were used to determine ship speed in the without project (existing) channel. An analytical model for ship speed, along with the assumption of equal power setting in the without project and with project channels, was used to determine ship speed in the with project channel.

Based on the Savannah District's ship traffic analysis, the total number of ships will not change in without project (existing) and with project (deepened) channels. Four traffic alternatives were evaluated that primarily differ in the number of post-Panamax ships compared to Panamax ships. Without project (existing) and with project (deepened) conditions primarily differ in draft of the post-Panamax ships and speed of all ships.

A composite value of the various ship effects was used to compare the without project (existing) and with project (deepened) channels. The composite value is based on the magnitude of ship effect for 6 different vessel classes as well as the proportion of each vessel class in the overall fleet.

At Fort Pulaski, dominant ship effects include short period bow and stern waves and long period drawdown and return velocity. The composite return velocity and drawdown per ship are 3.2 to 6.2% less in the with project (deepened) channel. The trend of slightly less drawdown and return velocity in the with project deepened channel was found in both years 2030 and 2050 and for all 4 traffic alternatives. Due to the slightly higher speed in the with project (deepened) channel, short period bow and stern waves are the shoreline attack force that increases in the with project (deepened) channel at Fort Pulaski. The composite short period bow and stern wave height per ship for years 2030 and 2050 is 1.5 to 4.4% greater in the deepened channel.

At Tybee Island, the only significant ship effect reaching the shoreline is the long period drawdown or pressure wave. It is uncertain if the south jetty blocks ship effects at high tides because ship effects generated outside the jetties reach the TI shoreline. The composite drawdown in the channel between the jetties per ship is 2.3 to 5.9% less in the with project (deepened) channel. The actual drawdown at the TI shoreline will be about 1/3 of the drawdown in the channel between the jetties.

Ship effects were tabulated and plotted for the City Front and Confined Disposal Facility sites.

ERDC/CHL
August 2006

# Draft of Ship Forces on the Shoreline of the Savannah Harbor Project

Stephen T. Maynord

*Coastal and Hydraulic Laboratory*
*U.S. Army Engineer Research and Development Center*
*3909 Halls Ferry Road*
*Vicksburg, MS 39150-6199*

Final report

Prepared for U.S. Army Corps of Engineers

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

**Abstract:** Ship forces having the potential to cause shoreline erosion were evaluated at Savannah Harbor to compare the without project (existing) and the with project (deepened) channels. Comparable ship speeds were determined in the without project and with project channels based on field data and an analytical model. Four traffic alternatives were evaluated that primarily differ in the number of post-Panamax ships compared to Panamax ships. At Fort Pulaski, dominant ship effects include short period bow and stern waves and long period drawdown and return velocity. The composite return velocity and drawdown per ship are 3.2 to 6.2% less in the with project channel. Due to the slightly higher speed in the with project channel, short period bow and stern waves are the shoreline attack force that increases in the with project channel at Fort Pulaski. The composite short period bow and stern wave height per ship for years 2030 and 2050 is 1.5 to 4.4% greater in the deepened channel. At Tybee Island, the only significant ship effect reaching the shoreline is the long period drawdown or pressure wave. The composite drawdown in the channel between the jetties per ship is 2.3 to 5.9% less in the with project channel.

# Contents

# Figures and Tables

## Figures



## Tables

# Preface

The work reported herein was conducted for the US Army Engineer District, Savannah (SAS), by the US Army Engineer Research and Development Center (ERDC) during 2005-2006. The field work was performed during September, 2005 by personnel of ERDC and SAS. From ERDC, Messrs. Thad Pratt, John Kirklin, Chris Callegan, and Dr. Stephen Maynord participated in the field studies. From SAS, Mr. Wilbur Wiggins participated in the data collection.

The study was under the direction of Mr. Tom Richardson, Director, Coastal and Hydraulics Laboratory (CHL); Dr. William Martin, Assistant Director, CHL; Dr. Rose Kress, Chief of the Navigation Division; and Mr. Dennis Webb, Chief of the Navigation Branch, CHL. The report was written by Dr. Maynord.

At the time of publication of this report, Director of ERDC was Dr. James R. Houston, and Commander was COL Richard Jenkins.

# Unit Conversion Factors

| Multiply | By | To Obtain |
|---|---|---|
| cubic feet | 0.02831685 | cubic meters |
| degrees (angle) | 0.01745329 | radians |
| Degrees Fahrenheit | (F-32)/1.8 | degrees Celsius |
| Feet | 0.3048 | meters |
| foot-pounds force | 1.355818 | joules |
| horsepower (550 foot-pounds force per second) | 745.6999 | watts |
| Knots | 0.5144444 | meters per second |
| miles (U.S. statute) | 1,609.347 | meters |
| miles per hour | 0.44704 | meters per second |
| pounds (force) | 4.448222 | newtons |
| pounds (force) per square foot | 47.88026 | pascals |
| Slugs | 14.59390 | kilograms |
| square feet | 0.09290304 | square meters |

# 1 Introduction

## Purpose

At the request of the US Army Engineer District, Savannah (SAS), the US Army Engineer Research and Development Center (ERDC) conducted an evaluation of ship forces that may cause shoreline erosion in the without project (existing) channel and in the with project (deepened) channel of the Savannah Harbor project. ERDC was asked to determine ship induced waves, drawdown, and velocity increase at the shoreline. In a follow-on study, the District will use results of this study to determine any changes in shoreline erosion in the existing and deepened channels.

## Approach

The study was accomplished using (a) field measurement of ship forces and (b) analytical/empirical models to compare ship forces in the without project (existing) and with project (deepened) channels. The District asked ERDC to provide a comparison of ship forces in the existing and the deepened channels for the Fort Pulaski and Tybee Island sites (Figure 1). For the City Front and the Confined Disposal Facility sites, the District asked ERDC to provide a table showing ship forces in the existing channel. The term “channel” in this report refers to the entire width of the waterway, not just the navigable portion of the waterway.

## Ship Induced Forces

The shorelines of the Savannah Harbor channel are subjected to a variety of ship induced forces. These forces result from waves generated at the bow and stern of the ship, water level lowering or drawdown from the displacement of the ship, and increased velocity from both waves and return velocity. Return velocity, like drawdown, results from the moving ship displacing water as it travels ahead. The water accelerates around the ship, moving from bow to stern. The increased water velocity alongside the ship is the return velocity. The movement of water from bow to stern also results in lowering of the water level adjacent to the ship that is the drawdown. The drawdown, that some refer to as a pressure wave, can travel large distances from the ship as will be seen in the Tybee Island data. Return velocity is parallel to and opposite to the direction of ship travel.

## Savannah Harbor Characteristics

The Savannah Harbor channel is on the lower limit of what is termed a confined channel. Confined channels are those in which the ship cross sectional area takes up a significant part of the channel cross sectional area. Confined channels are often described by the blockage ratio that is the ratio of ship cross sectional area / channel cross sectional area. Blockage ratio should not be confused with "block coefficient" used subsequently that describes the hull shape of a ship. Depending on ship speed, ships having blockage ratio of more than 0.02-0.05 exhibit significant displacement effects that include drawdown and return velocity. Many confined channels have maximum blockage ratios of 0.15- 0.2. The Savannah Harbor channel has blockage ratio from about 0.02-0.095 that places it on the lower end of confined channels. Consequently, drawdown and return velocity impacts should be less than in channels with higher blockage ratio.

Confined channels can have ship passages that create a large rise in water level just after the drawdown. The water level rise is most often a single wave that inundates shoreline areas above the ambient water level. The drawdown plus the water level rise is frequently referred to as a "transverse stern wave" and has been observed numerous times by this author on the Sabine Neches Waterway (SNWW) near Port Arthur, Texas (Maynord, 2003). The SNWW is a channel more confined than the Savannah Harbor channel because it has a larger blockage ratio. The magnitude of the rise in water level above the ambient water level is a function of ship speed, shoreline geometry, channel size, and proximity of the ship to the shoreline. SAS provided a video that showed such an occurrence on the Savannah Harbor project.

During the field study, numerous ships produced a water level rise of about 1 ft. Only the "Mol Velocity" that was an inbound ship at the Confined Disposal Facility created a water level rise or transverse stern wave comparable to that seen on the video. As shown in appendix Figure B-5, the Mol Velocity created a 2.5 ft drawdown followed by a 3-4 ft rise in water level above the ambient water level. While transverse stern waves are often the dominant force on the shoreline in confined channels, the frequency of occurrence on the Savannah Harbor channel appears low based on the field data.

Another characteristic of the Savannah Harbor channel is that the traffic is predominately container ships which have relatively high ship speeds compared to other types of ships such as tankers and bulk carriers. The relatively low blockage ratio in the Savannah Harbor also results in higher ship speeds. In deep draft navigation channels dominated by tankers or bulk carriers, ship speed is relatively slow and the ships forces at the shoreline of main concern are the long period effects related to the ship induced drawdown such as the transverse stern wave. The higher speed of the container ships and the low blockage ratio at Savannah Harbor raise the possibility that short period bow and stern waves are the dominant force on the shoreline.

A third characteristic of the Savannah Harbor channel is the presence of large tides and large tidal velocities. The large tidal range tends to spread the attack of ship effects over a significant portion of the shoreline rather than occurring at the same location on the shoreline as would be the case in the absence if tides. A negative aspect of large tidal velocities is that return velocity adds to the ambient velocity for ships going against the tide, resulting in net velocities well above ambient velocities.

## Savannah Harbor Ship Forces

Summarizing, the ship forces having potential to impact shoreline erosion at Savannah Harbor are as follows:

a. Short period waves formed at bow and stern of ship.

b. Long period drawdown and return velocity caused by the displacement of the moving ship. Based on the low frequency of occurrence in the field data, transverse stern waves, which are also caused by the displacement effects of the ship, will not be considered in the analysis.

One of the most critical questions in ship effects studies of existing and deepened channels is as follows: "What is the speed of comparable ships in the without project (existing) and the with project (deepened) channels?" The study outcome strongly depends on the answer to this question.

# 2 Field Study

## Gage Locations

The field study was conducted from 15 September – 22 September 2005. Water level measurements were conducted at both sides of the channel at City Front (CF), the north side of the channel at the Confined Disposal Facility (CDF), the south side of the channel at Fort Pulaski (FP), and the shoreline at Tybee Island (TI) south of the jetties as shown in Figure 1. The District had concerns about ship effects at high tides and the field study was timed to coincide with a Spring tide. By selecting the Spring tide full moon, the maximum moonlight conditions were present to improve the performance of the cameras used for nighttime data collection.

The locations of the single pressure cell used at the each of the two CF sites and the two 13-ft long capacitance rods used at each of the CDF, FP, and TI sites are shown in Table 1. The wave stands containing the two capacitance rods, video camera, and recorder at TI and FP are shown in Figures 2 and 3. Two gages were provided for redundancy; there was no attempt to extract wave direction from the data. Because the District was concerned about ship effects at high tides reaching 9 ft MLLW, the 13 ft long capacitance rods were positioned to measure water levels up to about 11.5 to 12.0 ft MLLW. This placed the lower limit of the capacitance rods at about –1 to –1.5 ft MLLW. The lateral position of the gages was selected where the channel bottom elevation was about –2 ft MLLW. As can be seen in the measured data in the appendices, ship passages at extreme low tides often caused a water level drawdown lower than the bottom of the capacitance gages. When this happened, the data was a flat line until the water level rose back onto the gage. See for example Figures B-10, C-4, and C-31 in the appendix. Unwatering of the gage only occurred at FP and CDF. Unwatering did not happen at CF because the pressure cells were adequately submerged. Unwatering of the capacitance gages did not happen at TI because of the reduced magnitude of drawdown.

The large tidal range in the Savannah Harbor channel makes the measurement of ship induced water level changes difficult. In addition to the problems with measurement of the entire tidal range mentioned previously, the ship effects at low tides are measured with the gages close to the shoreline in shallow water versus the ship effects at high tides that are measured with gages in deeper water farther from the shoreline. Shallow water and shoreline proximity affect both the long period effects and short period bow and stern waves from the ship. Decreasing depth has several effects on waves. The most significant being shoaling which is the increase in wave height as waves move into shallow water. The increase in height occurs until the wave steepness reaches the point at which the wave breaks. These observations on shallow water effects explain some of the variability in the data but do not reduce the validity of the results.

## Camera Locations

Cameras were mounted on the wave stands at CDF, FP, and TI to monitor passage of ship traffic. A camera at CF was mounted on the north side of the channel at the coordinates shown in Table 1. Cameras having low light capability were used in an attempt to observe ship characteristics during the night.

## Discharge, Velocity, and Water Level Data

Discharge and velocity data from Acoustic Doppler Current Profiler (ADCP) measurements taken on September 19 at the 4 gage locations are shown in Table 2. Cross sections from the ADCP measurements at the 4 locations are shown in Figures 4-8. The observed preliminary water levels from the NOAA tide gage at FP are shown in Figure 9. Water levels and channel bathymetry are presented in MLLW. Winds during the field study were generally low which was important at the TI gage to prevent problems with separating wind waves from ship waves. Until about midday on the 19$^{th}$, winds were from the south at about 4 knots. After midday on the 19$^{th}$, winds were from the east-northeast at about 10 knots. The TI gage was protected somewhat from wind waves from the east-northeast by Tybee Island Point as shown in Figure 1.

## Pilot Information

Along with the camera information, ship transit information was obtained from the Savannah Bar Pilots that included the ship name, the time and date the pilot boarded the ship, direction of travel, dock location, time of docking for inbound transits, and draft (assumed to be average draft because bow and stern draft was not provided). In addition to these parameters, various sources were used to obtain ship type, tonnage, overall length, and beam. This data is shown in Table 3. Each camera and wave gage had known time stamps. Team members recorded daytime ship passage events at the Coast Guard station just west of the FP gage. All of these data were used to determine when specific ships passed each wave gage as shown in Table 3.

## Measured Water Level Data

The time histories of water level at the four locations along the channel are shown in Appendix A-D. The results for the two capacitance gages were similar so only one was plotted.

## Summary of Field Study Results

The field study provided an understanding of the important shoreline forces in the Savannah Harbor channel as well as needed data. Results of the field study showed that short period bow and stern waves are important and provided data to select and modify a short period wave equation. The field study also provided speed data that was previously not available and insight into whether the south jetty would block ship effects from reaching TI.

# 3 Pilot Interview

As stated previously, ship speed is one of the most critical questions in a ship effects evaluation. Wilbur Wiggins of the Savannah District interviewed Master Captain Tommy Brown of the Savannah Bar Pilots using questions prepared by ERDC. The objective of these questions is to collect as much pertinent information as possible about ship operation in the existing and deepened channels.

a. What is the policy for running big ships (such as those with draft near design channel depths) and small ships (such as unloaded) relative to tide levels and direction of tides? Vessels have to be operated at a safe maneuvering speed but have to be run at a "competitive rate" – can't go slow (like 6 knots) – would take too much time to transit in and out of the harbor.
b. Of the 5 power levels of dead slow, slow, half, maneuver full, and full available to be used in ship transit, what power level is typically used in transiting the existing SH channel? Operates under maneuver full unless ship too powerful – have to use different speed for different ships – ship speed also varies by location in the harbor (faster in entrance channel to slow by city front) Does this power level vary with ship type and if so, what is the power level for each ship type Power level varies – may run 17 knots w/ powerful container vessels versus 12 knots for tankers and general cargo vessels
c. What power level do you anticipate in the deepened channel with deeper draft vessels? About the same – possibly slower, depending on how each ship handles
d. Where are areas along the channel where you tend to not run along the channel centerline (because of channel alignment or other factors) and where do you run in each of those reaches? Normally run the centerline of the channel unless meeting another vessel
e. What are typical and maximum speeds in the existing channel for container ships? For tankers or bulk carriers? Container – 12 to 14 knots, tanker/bulk 10-12 knots, not too powerful
f. What will be typical and maximum speeds in the deepened channel for the different ship types? Should be about the same
g. How does nighttime operation affect ship operation and ship speed? Does not affect
h. Are there other pertinent issues we have not raised that will help us understand ship operation and ship speed in existing and deepened channels? No

i. After analysis of the ship transit data, it was apparent that few of the post- Panamax ships were present during the field study to obtain both speed and ship effects data. Captain Brown was asked whether the speed of Panamax ships (for which substantial speed data was collected in the field study) differs from post Panamax ships in the existing channel. Captain Brown said he did not think that the speed would differ between Panamax and post-Panamax vessels.

From the pilot interview, the ship speeds of 12-14 knots are consistent with the speeds observed in the field study. The statement about use of maneuver full in both existing and deepened channels is consistent with other channels studied by this author.

# 4 Ship Traffic Frequency

Table 4 shows the characterization of the 6 ship types used in the SAS's analysis of future ship traffic including length, beam, and design draft. Table 5 shows the actual traffic distribution during the field study according to the 6 vessel types used in the traffic analysis. Each field study ship was placed in one of the 6 categories having beam closest to the actual beam. The average draft, beam, length, and actual tonnage are shown for the field study ships in each of the 6 categories in Table 5. Notice that the average draft of the field data ships in all but the Feedermax ship category is about 80% of the design draft.

Ship traffic is quantified by the number of calls with each call being equal to one inbound and one outbound transit. Based on the SAS's traffic analysis, the total number of calls will be the same for both without and with project for all traffic scenarios for any given year. For example, year 2030 has 4030 calls and year 2050 has 7801 calls for all traffic scenarios for both without and with project. Table 6 shows number of vessel calls for 4 traffic scenarios for future years 2030 and 2050. The 4 traffic scenarios are the Gulf Engineers and Consultants (GEC) forecast, GEC with 10% shift from Panamax (PA) to Post-Panamax (PP), GEC with 20% shift from PA to PP, and GEC with 30% shift from PA to PP. The only difference between the 4 scenarios is the number of PP and PA ships. The number of Sub-Panamax (SP), Handysize (HS), Feedermax (FM), and Feeder ships do not change. In 2030 the total number of PP and PA ships is 3544 for all 4 scenarios. In 2050 the total number of PP and PA ships is 7009 for all 4 scenarios. To determine the change in traffic between the GEC and the % shift scenarios, the specified percentage (such as 10%) of the total number of PP and PA ships is added to the number of PP ships and subtracted from the number of PA ships.

The vessel effect comparisons presented herein are for without project versus with project conditions for the years 2030 and 2050. Two draft conditions will be used in the analysis as follows: a) design draft and b) 80% of design draft as found during the field study. The only difference between the without project and with project traffic is the draft of the PP ships and the speed that ships will travel in the existing versus future deepened channel. All other ships, including Panamax, can draft their design draft in the without project (existing) channel. In the without project (existing) channel, PP ships are limited to 40.7 ft of draft compared to 45.3 ft in the with project (deepened) channel. The comparisons of without to with project will use a typical power setting and thus typical speed determined from the field study. Without and with project will also be compared using a higher power and thus higher ship speed. As will be shown subsequently, the typical speed in the with project deepened channel is slightly greater than the typical speed in the without project existing channel. In the same manner, the high speed in the with project deepened channel is slightly greater than the high speed in the without project existing channel.

# 5 Ship Speed Analysis

Ship speed in the Savannah Harbor field study was determined in several ways. First, team observers were present during daylight hours at the Coast Guard (CG) Station for several days during the study. Using a stop-watch, the time required for the bow and stern of the ship to pass a fixed point on the horizon was used with overall ship length to determine ship speed over ground. In a similar manner, the cameras were used to determine passage time for bow to stern at a fixed point on the screen and this differential time was used with overall ship length to determine ship speed over ground. Bow to stern passage time is a reliable means of determining ship speed. The low-light cameras were used in this study to try to use the bow to stern time differential for nighttime ship passage. The low light cameras resulted in limited success because identifying the precise location of the bow and stern remained difficult even with the low light cameras. This technique works best when there are various small light sources in the background that go off and on as the ship blocks the light sources. While numerous lights were present at CF and some lights were present north of the TI camera, none were present at FP and too much light was present at CDF from the Liquid Natural Gas facility on the south side of the channel.

Another speed technique that can be used at night with the cameras is to determine the field of view width of the screen and use the time of passage across the screen to determine ship speed. This worked well at TI because the camera was 4500 ft away from the channel and with the amount of camera zoom used, the angle of the field of view at TI was about 22 degrees and view width at the channel centerline was about 1730 ft. By having a small angle in the screen width, the errors that arise from the ship not being on the channel centerline are small. At FP, the view angle was 27 deg, which was also adequate. At CDF, the channel and camera were close together which required a wide camera zoom and resulted in about a 68 deg angle of the field of view. The extreme width of angle causes significant errors in speed for ships not on the channel centerline. The final method to determine ship speed is to use the time of ship passage at two points along the channel with their distance apart to determine an average speed over the reach. Time of passage at either end of the reach can be obtained from cameras, capacitance gages, or pressure cells that measure ship effects with the exception of the capacitance gages at TI because of their large distance from the channel. The reach average technique was used from TI to FP (10070 ft apart), FP to CDF (44400 ft apart), and CDF to CF (28700 ft apart). In this study, daytime passage with operating cameras always used bow to stern time from the camera. Nighttime passage with operating cameras used bow to stern at CF, CDF, and FP. Nighttime passage with operating cameras at TI used field of view width. When cameras were not operating, only average reach speeds could be determined and the capacitance gages and pressure cells provided time of passage. Table 7 shows the speeds determined for each ship in the study.

Figures 10 and 11 show inbound and outbound ship speeds relative to ground along the project reach. Speeds are summarized in Table 8. Both directions show speed decreasing toward CF and decreased speed at the Coast Guard dock that is close to the Pilot's dock. Inbound ships show the speed has decreased by up to 1.5 knots between the FP and the Coast Guard. Outbound ships show the speed has increased by up to 1.5 knots between the Coast Guard and FP. The FP camera speed is about equal to the average reach speed between CDF and FP. The average reach speed from CDF to FP is somewhat misleading because the camera speeds on each end of the CDF-FP reach are generally less than the average along the reach. Only one explanation is possible, the ship was going faster than the reach average over a significant portion of the reach. Based on the data, inbound and outbound speeds are similar.

The speeds were also analyzed for differences between night and daytime speeds as shown in Table 8. Data show a tendency for lesser nighttime speeds but it should be noted that nighttime speeds are generally the least accurate because of the greater uncertainty in the location of the bow and stern when using cameras. The data were also analyzed for effects of ship size on ship speed. A simple relation describing ship size is an estimate of the actual tonnage equal to (product of the length, beam, and draft)*block coefficient ($C_b$)*weight of water/2000 lbs per ton. Since block coefficient is not known for all ships, the PIANC table for typical ship dimensions and $C_b$ was used to identify the appropriate $C_b$. This actual tonnage estimate is plotted against ship speed for the various locations along the channel in Figures 12 to 18. The data show a small increase in speed for decreasing ship size at CF camera and CF-CDF average which likely reflects the confined and congested area in the vicinity of CF that could have a greater influence on larger ships. At CDF and all locations downstream, variation of speed with ship size is not significant.

This paragraph answers the critical question presented in the introduction of how to determine comparable speeds in without project (existing) and with project (deepened) channels. This study is based on the premise that it is not valid to simply assume that speeds will be equal in the without project existing and the with project deepened channels because channel size affects ship speed. In the analysis of ship effects at FP and TI presented subsequently, ships in the existing channel will traverse the channel at the overall average speed given in Table 8 for both locations. This overall average speed will be used as the typical speed for ships in the without project existing channel. While the trend of all ships in the existing channel and existing fleet is no significant change in speed with ship size, the analysis herein focuses on comparing the same ship in existing and deepened channels. For example, consider the Panamax ships that are the most frequent ships in both existing and deepened channels. In both channels, the ship size at design draft conditions is 40.7 ft draft X 951 ft length X 106 ft beam. Based on this writers experience in study of other channels and the pilot interview, the Panamax ship will traverse both existing and deepened channels using maneuver full power. Since the deepened channel is 5 ft deeper and 4% greater in area, the Panamax ship will have a slightly higher speed in the deepened channel. To determine the typical ship speed in the deepened channel requires use of the assumption that the power setting will remain the same in existing and deepened channels. Note that this assumption is not that maneuver full will always be used for all ships, only that the power level will be the same in both channels. Since applied ship power is the same in both channels, the resisting force of both ships in both channels will be the same. Resisting force is determined using techniques in Maynord (2000) and depends on channel characteristics, return velocity and drawdown, ship size and type, and speed that are all known for the existing channel. The Schijf equation in the NAVEFF model (Maynord, 1996) was used to determine average return velocity and drawdown. Equating resistance force in existing and deepened channels and knowing ship size and type and channel characteristics in the deepened channel allows determining ship speed in the deepened channel. As will be shown subsequently, ship speed increased only 0.5 to 1.8% (0.05 to 0.25 knots) in the deepened channel. This small increase in ship speed reflects the fact that the channel area only increased about 4% in the deepened channel. The small increase in speed is consistent with the pilot's statement that ship speed in the deepened channel will be about the same.

# 6 Short Period Wave Model

The short period wave equation used herein was a modification of the equation used by Blaauw et al (1984) and Knight (1999) for maximum short period waves formed at bow and stern of the ship given as

$$H_{max} = \beta \frac{B}{L_e} s^{-1/3} \left( \frac{V}{\sqrt{g}} \right)^{2.67}$$

Equation 1

Where

$H_{max}$ is the maximum wave height
$\beta$ is a coefficient,
B is the beam of the ship,
$L_e$ is the entrance length of the ship,
s is the lateral distance from the ship,
V is the ship speed through the water,
g is the gravitational acceleration

Blaauw and Knight used a single coefficient to represent $\beta B/ L_e$ and specified that single coefficient for particular vessels and vessel sizes. The modification used herein is to keep the coefficients separate with $B/ L_e$ representing ship hull shape effects and $\beta$ representing ship size effects. The ratio $B/ L_e$ is determined using limited data from

$$\frac{B}{L_e} = 1.11 C_b - 0.33$$

Equation 2

Based on the range of $C_b$ in Table 5, B/Le only varies from 0.42 to 0.55. The coefficient $\beta$ was determined using the field study data from the FP and CDF gages. FP and CDF are 800 ft and 600 ft respectively from the center of the channel. The field data have many factors varying which makes the determination of $\beta$ approximate. These factors include (1) wave shoaling at low tides described previously that would increase wave heights by 50 to 75% over deepwater wave heights, (2) unknown and variable lateral position of the ship, (3) different ship hull shapes and sizes, (4) upbound and downbound ships, (5) speed uncertainty that is particularly a problem because the wave equations use speed to about the third power, and (6) FP is a reach where the outbound ships are generally accelerating and inbound ships are generally decelerating. Only those ships having the best speed data were used in the analysis that generally came from daytime camera speeds. There were 22 inbound ships and 14 outbound ships. For all ships, β was determined to be

$$\beta = 0.0002 * beam * draft$$

Equation 3

Where

beam and draft are both in feet

Because this coefficient in the wave equation requires specific units, it should not be used as a general equation for wave height in navigation channels and is restricted to the Savannah Harbor analysis. The coefficient β is limited to a minimum of 0.2. The values derived from the product of *B/Le* and β for the Savannah Harbor data range from 0.2 to 0.64 and are similar to the range of values used by Blaauw et al (1984) and Knight (1999). The data are plotted in Figure 19 with observed wave height versus computed wave height. Several of the values on the right side of the plot having low computed wave height were ships that passed at low tide levels that would have likely resulted in shoaling of the wave heights by a factor of ranging up to 1.5.

Kamphuis (1987) found correlation of shoreline recession with wave power. Wave power per unit length of shoreline is determined as

$$P = \frac{\rho g^2 H^2 T}{16\pi}$$

Equation 4

Where

ρ is the water density
H is wave height
T is the wave period

Kamphuis used wave power in the breaking zone. Equation 4 is applicable to wave power for deep water waves and will be used herein only to compare existing and deepened channels.

# 7 Fort Pulaski Ship Forces Analysis

The without project (existing) and with project (deepened) cross sections at the FP gage are shown in Figure 6. The deepened 48-ft deep channel cross section assumes advance maintenance of 2 ft at FP. In ship effects studies, channel cross-section area is an important factor and the effective width and cross-section area are determined that eliminate the shallow areas on each side of the channel. The effective channel area was determined to be between bottom contours of –15 ft MLLW based on the bottom contour giving the lowest displacement effects. In the FP cross section in Figure 6, the channel width at a bottom contour of –15 ft MLLW is 1600 ft and effective channel area at a mean tide level of 3.7 ft MLLW is 63980 sq ft. With the navigation channel deepened to –50 ft MLLW, the effective channel area is 66800 sq ft and effective width remains at 1600 ft. The increase in effective area is only about 4.4%.

The typical speed of the design ships (80% of design draft and design draft) in the existing channel are set equal to the observed average speed from the field study of 11.7 knots. The design ships are also evaluated at a speed of 2 knots greater than the speed observed in the field study or 13.7 knots for the FP site in the existing channel. The higher speed was used to address a broader range of conditions and to see if conclusions were affected by the ship speed used in the analysis. The 2 knot speed increase at FP was selected because 13.7 knots is near the maximum speed observed in the field study. As will be seen subsequently, the selected ship power or speed did not affect the conclusions.

Ship speed in the deepened channel was based on techniques described in the "Ship Speed Analysis" section. Ship speeds in the deepened channel are only 0.5 to 1.8% greater except for the post-Panamax ships where draft increased from 40.7 ft to 45.3 ft in the deepened channel. For the 45.3 ft draft post-Panamax ship in the deepened channel, ship speed decreased 4-5%. The smallest category of ship, Feeder, is not used in Table 9 because the % of ships of this type is negligible. In all cases, each ship in the deepened channel had slightly less drawdown and return velocity as shown in Table 9. The conclusion of slightly less drawdown and return velocity in the with project deepened channel is true for both the typical speed comparison and for the high speed comparison. For example, at typical speeds and 80% draft, the post-Panamax ship had 1.87 ft of drawdown in the without project existing channel and 1.78 ft of drawdown in the with project deepened channel. In the same manner, at high speeds and 80% draft, the post-Panamax ship had 3.64 ft of drawdown in the without project existing channel and 3.58 ft of drawdown in the with project deepened channel. The same trends and conclusions result from typical and high speed comparisons although absolute magnitude of return velocity and drawdown differs for the two speeds. Short period bow and stern wave heights are also shown in Table 9. Because ship speed is slightly greater in the deepened channel than in the existing channel, short period bow and stern waves that depend on ship speed to an exponent of 2.67 will be greater in the deepened channel. The conclusion of slightly greater short period bow and stern wave heights in the with project deepened channel is true for both the typical speed comparison and for the high speed comparison.

Using the frequency of calls in Table 6 to incorporate the different fleet characteristics, a composite return velocity, drawdown, and short period bow and stern wave height can be developed for comparing the without project (existing) and with project (deepened) channels. For example, composite drawdown in the existing channel with the 80% draft, 2030 GEC traffic estimate, and typical ship speed is (% of PP)*(PP drawdown) + (% of PA)*(PA drawdown) + (% of SP)*(SP drawdown) + (% of HS)*(HS drawdown) + (% of FM)*(FM drawdown) = 0.052*1.87 + 0.827*1.14 + 0.063*0.96 + 0.053*0.66 + 0.004*0.40 = 1.14 ft. Tables 10-13 show all the composite parameters for FP for the 4 traffic scenarios. Conclusions and trends are the same for 2030 and 2050 and for the 4 traffic scenarios. For example, composite drawdown for typical speed, typical (80%) draft in the existing channel for 2030 GEC traffic is 1.14 ft versus composite drawdown for typical speed, typical (80%) draft in the deepened channel for 2030 traffic of 1.08 ft. Composite drawdown for high speed, typical (80%) draft in the existing channel for 2030 traffic is 2.09 ft versus composite drawdown for high speed, typical (80%) draft in the deepened channel for 2030 GEC traffic of 2.00 ft. The comparison of without project to with project composite values show the same trends and conclusions for both typical speed and higher ship speed. Considering all values in Tables 10-13, composite return velocity and drawdown at FP are about 3.2 to 6.2% less in the with project (deepened) channel.

Composite short period bow and stern wave heights at FP in Tables 10-13 show no significant difference between 2030 and 2050 but show small changes in the with project channel between traffic scenarios. All composite wave heights in Tables 10-13 range from 1.5 to 4.4% greater in the deepened channel.

Wave power, found by Kamphuis (1987) to correlate with shoreline recession, was calculated with equation 4. Bow and stern wave periods from the field study were 3-3.5 sec. The composite short period wave height increases of 1.5 to 4.4% result in wave power increases of 2.3 to 19%.

# 8 Tybee Island Ship Forces Analysis

One unusual characteristic of the ship effects evaluation at TI is the presence of the partially submerged jetty on the South side of the ship channel and a less partially submerged jetty on the north side of the channel. The south jetty is about 3400 ft north of the TI gages and has a variable top elevation that averages about 4 ft above MLLW. The north jetty has an average top elevation of about 7 ft MLLW. The jetties are about 2400 ft apart. The presence of these jetties makes it important to analyze differences between ships at low and high tides as well as inbound versus outbound. As stated previously, ship effects at the shoreline of navigation channels are generally short period bow and stern waves and long period drawdown or pressure wave effects. Short period bow and stern waves will likely decay in amplitude before reaching the TI shoreline that is about 4500 ft from the center of the ship channel. Bow and stern wave height generally decays with $(\text{distance})^{-1/3}$ (Sorensen, 1966). At 4500 ft from the ship, the secondary wave will be about 10% of the wave height at the ship. Any significant ship effects reaching the TI shoreline will likely be the result of the long period drawdown or pressure wave that can travel significant distances. At low tides, the jetty blocks south movement of ship effects while the ship is within the jetties. Even at high tides, the south jetty provides a significant barrier to long period ship effects. Any ship effects reaching the shoreline at the TI gages at low tides must come from outside of the east end of the jetties along a line that is about 5500 ft from TI gages to the center of the ship channel.

The ships were separated into those passing with tides of 4 ft MLLW or less and those with 7 ft MLLW or greater. Ship passages during the intermediate range of 4 to 7 ft MLLW were excluded because small depths over the jetty may or may not pass significant ship effects over the top of the jetty. The ships were also separated into inbound and outbound resulting in four different groups. Within each of the four groups, the ship effects patterns and magnitudes exhibit significant differences due to differences in draft, speed, tide direction and magnitude, ship type, and ship lateral position. Table 14 shows each ship in the 4 categories along with the drawdown at the TI wave gage. Each of the 4 categories have a ship or ships that produce drawdown of 1 ft or greater. There appears to be no strong correlation of drawdown with either stage or direction of travel. It is not possible to conclusively determine whether significant ship drawdown passes over the South jetty at high tides. The main correlation in the data is that large fast ships cause the most impact. There are several ships that defy the trend of bigger faster. Under inbound high stage ships, the MSC Eleni and Stuttgart Express are large fast ships that created little impact. The only ship in the inbound high stage category that causes any significant impact is the Jens Maersk that is somewhat compromised because it met the Talisman at TI. There is no obvious explanation for the lack of impact unless the ships were going slow before entering the jetties and fast by the time they reached the location where the TI camera monitored their speed. Several outbound high stage ships caused 6-8 sec period waves that had a height of about 1 ft. These included the Hanjin Wilmington and Mol Velocity.

Summarizing, TI experiences ship effects at both high tides over the south jetty as well as low tides below the top of the south jetty. Ship effects are caused by long period drawdown that moves from the ship channel to the TI shoreline. The drawdown causes a variety of effects when reaching the shallow shoreline area including 6-8 sec period waves having height of up to 1 ft and/or surge above the still water level. Drawdown magnitude at the TI shoreline is almost always less than that measured for the same ship at FP.

The design ship analysis for TI will be similar to the FP analysis but only drawdown will be used to quantify ship effects. In the TI cross section in Figure 5, the channel width at a bottom contour of −15 ft MLLW is 1620 ft and effective channel area at a mean tide level of 3.7 ft MLLW is 64175 sq ft. With the navigation channel deepened to −50 ft MLLW, the effective channel area is 66793 sq ft and effective width remains at 1620 ft. The increase in effective area is only about 4.3%. The effective areas and widths at FP and TI are almost identical. The typical speed of the design ships in the existing channel is set equal to the observed average speed from the field study of 12.9 knots. A faster design ship traveling at 1.5 knots greater than the typical speed will also be used in the analysis. An increase of 1.5 knots at TI was used because the Schijf equation for return velocity and drawdown does not apply using a 2 knot increase. This is not significant because a 1.5 versus a 2 knot speed increase will not affect the findings. Both the typical (80% of design draft) and design draft will be used in the analysis as shown in Table 15. In all cases, the design ship in the deepened channel had slightly less drawdown than the existing channel. Note that the computed drawdown is based on the ship located inside the jetties whereas the actual drawdown at TI shoreline may be generated while the ship is outside the jetties. The Table 15 values are for comparison purposes of without and with project. The Table 15 drawdown is generally much larger than the values that were measured at the location 4500 ft away from the center of the ship channel. In the field data, drawdown for all tests in Table 14 averaged 0.55 ft compared to PA ships in the existing channel at typical speeds having drawdown of 1.62 ft. Based on this comparison, drawdown magnitude at TI shoreline will be about 1/3 of drawdown computed for the ship between the jetties shown in Table 15.

Tables 16-19 present the composite drawdown using the drawdown from Table 15 and the traffic frequency from Table 6 to incorporate fleet composition. Conclusions and trends are the same for 2030 and 2050 and for the 4 traffic scenarios. Conclusions and trends are the same using typical speed and higher ship speed. Composite drawdown is 2.3 to 5.9% less in the with project (deepened) channel.

# 9 Confined Disposal Facility and City Front Ship Effects

At CDF and CF, SAS requested a table showing ship effects in the existing channel. Drawdown is used to quantify ship effects in the existing channel as shown in Table 20 for the CDF ships having significant effects. Field data for the Table 20 ships are presented in the Appendix. Due to the similarity of conditions at CDF and FP, an analysis for CDF like the FP analysis would likely result in the same conclusions as for FP.

The CF site differs from the other channel sites (CDF and FP) because ship speed, that is the most important parameter for short period waves, is too low for short period bow and stern waves to be an impact. For example, using equation 1, only one ship at CF had computed wave height exceeding 0.5 ft. The long period drawdown will be the primary ship effect to quantify at CF. The lack of significant short period bow and stern waves is the reason pressure cells were employed at the CF sites. Table 21 shows ship-induced drawdown for the CF ships. Field data for the Table 21 ships is presented in the Appendix.

# 10 Summary and Conclusions

Ship forces having the potential to cause shoreline erosion were evaluated at the Savannah Harbor to compare the without project (existing) and the with project (deepened) channels. Results of this study will be used by the Savannah District in a separate study to evaluate shoreline erosion.

An analysis of ship forces requires determination of comparable ship speeds in the without project (existing) and with project (deepened) channels. Field data were used to determine ship speed in the without project (existing) channel. An analytical model for ship speed, along with the assumption of equal power setting in the without project and with project channels, was used to determine ship speed in the with project channel.

Based on the Districts ship traffic analysis, the total number of ships will not change in without project (existing) and with project (deepened) channels. Four traffic alternatives were evaluated that primarily differ in the number of post-Panamax ships compared to Panamax ships. Without project (existing) and with project (deepened) conditions primarily differ in draft of the post-Panamax ships and speed of all ships.

A composite value of the various ship effects was used to compare the without project (existing) and with project (deepened) channels. The composite value is based on the magnitude of ship effect for 6 different vessel classes as well as the proportion of each vessel class in the overall fleet.

At Fort Pulaski, dominant ship effects include short period bow and stern waves and long period drawdown and return velocity. As shown in Tables 10-13, the composite return velocity and drawdown per ship are 3.2 to 6.2% less in the with project (deepened) channel. Conclusions and trends are the same for 2030 and 2050 and for the 4 traffic scenarios. Due to the slightly higher speed in the with project (deepened) channel, short period bow and stern waves are the shoreline attack force that increases in the with project (deepened) channel at Fort Pulaski. The composite short period bow and stern wave height per ship for years 2030 and 2050 is 1.5 to 4.4% greater in the deepened channel. Small changes in composite short period bow and stern waves were observed between the 4 traffic alternatives.

At Tybee Island, the only significant ship effect reaching the shoreline is the long period drawdown or pressure wave. It is uncertain if the south jetty blocks ship effects at high tides because ship effects generated outside the jetties reach the TI shoreline. As shown in Tables 16-19, the composite drawdown in the channel between the jetties per ship is 2.3 to 5.9% less in the with project (deepened) channel. The actual drawdown at the TI shoreline will be about 1/3 of the drawdown in the channel between the jetties.

Ship effects were tabulated and plotted for the City Front and Confined Disposal Facility sites.

# 11 References

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**Table 1. Gage Locations**

| Location | Side of Channel | Depth, time at instrument | Starting, end date/time of Gage | Starting, end date/time of Camera | State Plane, ft Georgia East 1001 |
|---|---|---|---|---|---|
| City Front | South | 10-12 ft 9/17 at 1323 EST | 9/17 at 1323 EST, 9/21 at 0600 EST | No camera on South | 989350, 758867 |
| City Front | North | 10-12 ft 9/17 at 1313 EST | 9/17 at 1313 EST, 9/21 at 0600 EST | 9/17 at 1430 EST, 9/21 at 0756 EST | 989966, 759588 Camera at 990049, 759744 |
| Confined Disposal Facility | North | 2.4 ft at 9/19 1450 EST | 9/18 at 1200 EST, 9/21 at 0600 EST | 9/15 at 1620 EST, 9/21 at 0600 EST | 1015691, 766862 |
| Fort Pulaski | South | 2.3 ft at 9/19 1416 EST | 9/16 at 1400 EST, 9/20 at 1400 EST | 9/18 at 1445 EST, 9/20 at 1400 EST | 1050315, 741509 |
| Tybee Island | South* | 3.6 ft at 9/19 1328 EST | 9/16 at 1200 EST, 9/20 at 1200 EST | 9/16 at 1215 EST, 9/20 at 1200 EST | 1062178, 739026 center of view in camera in channel = 1060478, 743335 |

*South of jetty on TI

**Table 2. Discharge and velocity from ADCP measurements.**

| Location | avg time EST | Tide Level at Ft Pulaski [ft] | Total Q [$ft^3/s$] | Total Area [$ft^2$] | Width [ft] | Q/Area [ft/s] | Tide Direction |
|---|---|---|---|---|---|---|---|
| Tybee, inside jetties | 7:37:00 | 8.20 | 158947 | 74074 | 1852 | 2.1 | Flood |
| Tybee, inside jetties | 7:45:00 | 8.35 | 154275 | 86204 | 2227 | 1.8 | Flood |
| Fort Pulaski | 7:58:00 | 8.46 | -179768 | 77943 | 2045 | 2.3 | Flood |
| CDF | 8:20:00 | 8.60 | -115335 | 64451 | 1842 | 1.8 | Flood |
| CDF | 8:27:00 | 8.64 | -113793 | 64344 | 1710 | 1.8 | Flood |
| Tybee, gage to jetty | 13:35:00 | 1.50 | 61689 | 30923 | 3452 | 2.0 | Ebb |
| Tybee, inside jetties | 13:54:00 | 1.00 | -214458 | 65271 | 2239 | 3.3 | Ebb |
| Fort Pulaski | 14:07:00 | 0.70 | 210841 | 67189 | 2129 | 3.1 | Ebb |
| CDF | 14:40:00 | 0.10 | 138200 | 50467 | 1443 | 2.7 | Ebb |
| City Front | 15:10:00 | -0.20 | -73799 | 36504 | 944 | 2.0 | Ebb |

**Table 3. Ship Log with Ship Characteristics and passage time at gages for inbound ships.**

| Name | type | gross tonnage | length, ft | beam, ft | draft, ft | Direct | date | Dock | CF | CDF | FP | TI | POB time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INBOUND: | | | | | | | | | | | | | |
| flintereems | gen cargo | 4503 | 367 | 49.2 | 20 | in | 15-Sep | 1615 | | 1509 | | | 1320 |
| khannur | lng | 96235 | 961 | 136.8 | 37.1 | in | 15-Sep | 1645 | | | | | 1330 |
| maersk garonne | cont | 50698 | 958 | 105.9 | 32.66 | in | 15-Sep | 2045 | | 1854 | | | 1720 |
| ym south | cont | 46697 | 906 | 105.6 | 37.9 | in | 15-Sep | 2300 | | 2036 | | | 1810 |
| Jiang An Cheng | | 16703 | 571 | 83.97 | 23.75 | in | 15-Sep | 115 | | 2322 | | | 2130 |
| leyla kalkavan | cont | 9978 | 489 | 74.46 | 22.9 | in | 15-Sep | 200 | | 16 | | | 2245 |
| xin fang cheng | cont | 41482 | 861 | 105.9 | 31.8 | in | 16-Sep | 620 | | 417 | | | 250 |
| new york express | cont | 54437 | 965 | 105.9 | 29.5 | in | 16-Sep | 725 | | 530 | | | 400 |
| kyriakoula | oil tanker | 40680 | 750 | 105 | 28 | in | 16-Sep | | | 1555 | 1520 | 1514 | 1405 |
| sun right | cont | 53359 | 965 | 105 | 37.9 | in | 16-Sep | 1725 | | 1549 | 1512 | 1502 | 1420 |
| mol americas | cont | 16803 | 604 | 82 | 27.1 | in | 16-Sep | 1915 | | 1800 | 1730 | 1725 | 1645 |
| jens maersk | cont | 30166 | 710 | 105.6 | 33.8 | in | 16-Sep | 2050 | | 1902 | 1836 | 1828 | 1750 |
| cma cgm potomac | cont | 31154 | 705 | 101.7 | 30.2 | in | 16-Sep | 2320 | | 2142 | 2104 | 2054 | 2005 |
| zim israel | cont | 37204 | 754 | 105.6 | 27.6 | in | 17-Sep | 415 | | 242 | 203 | 149 | 55 |
| msc christina | cont | 37579 | 745 | 105.9 | 32.25 | in | 17-Sep | 450 | | 314 | 230 | 222 | 130 |
| mol elbe | cont | 50352 | 959 | 105.6 | 34 | in | 17-Sep | 505 | | 329 | 247 | 238 | 150 |
| msc eleni | cont | 54881 | 932 | 137.8 | 36.25 | in | 17-Sep | 1055 | | 918 | 842 | 834 | 750 |
| midnight sun | oil tanker | 27915 | 590 | 105.6 | 27.6 | in | 17-Sep | 1700 | 1600 | 1523 | 1447 | 1433 | 1335 |
| darya rani | bulk | 26054 | 610 | 99.71 | 25.9 | in | 17-Sep | 1805 | 1642 | 1611 | 1535 | 1526 | 1430 |
| alyona | cargo | 32226 | 674 | 101.7 | 26 | in | 17-Sep | 2355 | 2233 | 2156 | | 2102 | 2015 |
| zim iberia | cont | 41507 | 833 | 105.9 | 33 | in | 18-Sep | 550 | 432 | 352 | 310 | 303 | 145 |
| al mariyah | cont | 32534 | 694 | 105.9 | 28.7 | in | 18-Sep | 1125 | 1023 | 953 | 918 | 910 | 825 |
| msc elena | cont | 30971 | 662 | 105.9 | 33.3 | in | 18-Sep | 1235 | 1130 | 1055 | 1020 | 1010 | 925 |
| emmanuel tomasos | oil tanker | 23217 | 599 | 90.86 | 28 | in | 18-Sep | 1535 | 1444 | 1406 | 1326 | 1311 | 1215 |
| hanjin wilmington | cont | 51754 | 950 | 105.6 | 34.4 | in | 18-Sep | 1755 | 1655 | 1627 | 1547 | 1540 | 1445 |
| condor | cont | 14241 | 521 | 79.05 | 26.75 | in | 18-Sep | 1950 | 1850 | 1818 | 1742 | 1736 | 1650 |
| Victoria Bridge | cont | 53400 | 965 | 105.6 | 36.1 | in | 18-Sep | 225 | 37 | 4 | 2320 | | 2200 |
| essen express | cont | 53815 | 965 | 105.9 | 35.5 | in | 19-Sep | 710 | 538 | 509 | 430 | 424 | 330 |
| kavo alexandros II | bulk | 16608 | 551 | 85.94 | 30 | in | 19-Sep | 915 | | 824 | 747 | 741 | 650 |
| angel accord | bulk | 20212 | 581 | 93.15 | 23.1 | in | 19-Sep | 1820 | 1747 | 1714 | 1630 | 1620 | 1530 |
| mol velocity | cont | 53519 | 965 | 105.9 | 30.5 | in | 19-Sep | 1945 | 1828 | 1758 | 1722 | 1715 | 1630 |
| borc | gen cargo | 20139 | 531.5 | 88.56 | 35.2 | in | 19-Sep | 2040 | | 1930 | 1849 | 1840 | 1735 |
| jervis bay | cont | 50350 | 959 | 105.9 | 30.6 | in | 19-Sep | 2150 | | 1944 | 1908 | 1901 | 1815 |
| ismini | oil tanker | 37405 | 717 | 105.6 | 38 | in | 19-Sep | 2230 | 2117 | 2044 | 2010 | 2002 | 1905 |
| stuttgart express | cont | 53815 | 965 | 105.9 | 37.6 | in | 19-Sep | 125 | 2356 | 2320 | 2246 | 2240 | 2150 |
| aurora | tanker | 16454 | 528 | 91.84 | 22.8 | in | 20-Sep | 840 | | 718 | 642 | 635 | 555 |
| cecile ericksen | bulk | 3461 | 373 | 50.84 | 20.5 | in | 20-Sep | 1125 | | 1035 | 959 | | 855 |
| cp rome | cont | 26131 | 642 | 100 | 33.5 | in | 20-Sep | 2210 | 2123 | 2051 | | | 1930 |
| ville de taurus | cont | 37549 | 850 | 105 | | in | 21-Sep | 415 | 306 | 225 | | | 30 |
| onego spirit | bulk | 10490 | 469 | 72.16 | 22.3 | in | 21-Sep | 925 | | | | | 545 |
| stolt capability | oil tanker | 24625 | 580 | 101.7 | 26.6 | in | 21-Sep | 1020 | 506 | | | | 730 |
| msc insa | cont | 51608 | 868 | 105.9 | 37.7 | in | 21-Sep | 1235 | | | | | 915 |
| hilli | lng | 96235 | 961 | 136.8 | 36.4 | in | 21-Sep | 1355 | | | | | 1100 |
| besire kalkavan | cont | 9978 | 489 | 74.46 | 25.25 | in | 21-Sep | 45 | | | | | 2140 |
| xin nan tong | cont | 41482 | 864 | 105.6 | 30.5 | in | 21-Sep | 250 | | | | | 2330 |

**POB = time pilot boards ship**

**Table 3. Concluded.**

| OUTBOUND:(SAIL) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | type | gross tonnage | length, ft | beam, ft | draft, ft | Direct | date | POB time | CF | CDF | FP | TI | |
| schackenborg | Ro-ro | 14775 | 530 | 79.7 | 21.7 | out | 15-Sep | 140 | | | | | |
| saimaagracht | gen cargo | 18231 | 608 | 82.98 | 22.1 | out | 15-Sep | 1830 | | 1958 | | | |
| northern fortune | cont | 30509 | 664 | 102 | 34.75 | out | 15-Sep | 1900 | | 2049 | | | |
| ANL georgia | cont | 40465 | 850 | 105.6 | 35.1 | out | 15-Sep | 1945 | | 2121 | | | |
| general lee | gen cargo | 1614 | 206 | 50.18 | 9.5 | out | 15-Sep | 2035 | | 2130 | | | |
| ym shanghai | cont | 40268 | 259 | 105.9 | 33.5 | out | 15-Sep | 2045 | | 2233 | | | |
| cape bird | oil tanker | 25108 | 577 | 101.7 | 28 | out | 15-Sep | 2200 | | 2344 | | | |
| khannur | lng | 96235 | 961 | 136.8 | 37.1 | out | 16-Sep | 1220 | | | | 1323 | |
| talisman | bulk ? | 67140 | 790 | 99.38 | 30.8 | out | 16-Sep | 1655 | | 1745 | 1815 | 1828 | |
| xin fang cheng | cont | 41482 | 861 | 105.9 | 31.8 | out | 16-Sep | 1825 | | 1934 | 2006 | 2019 | |
| ym south | cont | 46697 | 904 | 105.6 | 36.75 | out | 16-Sep | 1905 | | 2042 | 2122 | 2131 | |
| maersk garonne | cont | 50698 | 958 | 105.9 | 35.1 | out | 16-Sep | 1905 | | 2055 | 2135 | 2143 | |
| star drivanger | gen cargo | 27735 | 600 | 101.7 | 29.3 | out | 16-Sep | 2035 | | 2126 | 2209 | 2219 | |
| leyla kalkavan | cont | 9978 | 489 | 74.46 | 27.8 | out | 17-Sep | 110 | | 204 | 237 | 243 | |
| new york express | cont | 54437 | 965 | 105.9 | 33.8 | out | 17-Sep | 135 | | 304 | 347 | 357 | |
| star florida | gen cargo | 23345 | 615 | 96.76 | 22.7 | out | 17-Sep | 205 | | 322 | 358 | 407 | |
| jens maersk | cont | 30166 | 710 | 105.6 | 33.5 | out | 17-Sep | 220 | | 342 | 425 | 433 | |
| kyriakoula | oil tanker | 40680 | 755 | 105 | 27.7 | out | 17-Sep | 325 | | 514 | 601 | 612 | |
| mol americas | cont | 16803 | 605 | 82 | 27.5 | out | 17-Sep | 600 | | 738 | 818 | 828 | |
| sun right | cont | 53359 | 965 | 105 | 37.4 | out | 17-Sep | 740 | | 928 | 1007 | 1019 | |
| cma cgm potomac | cont | 31154 | 705 | 101.7 | 35.4 | out | 17-Sep | 1025 | 1130 | 1200 | 1235 | 1245 | |
| flintereems | gen cargo | 4503 | 367 | 49.2 | 15.4 | out | 17-Sep | 1230 | | 1256 | 1331 | 1338 | |
| kochnev | gen cargo | 6030 | 371 | 62.98 | 25.6 | out | 17-Sep | 1330 | | 1506 | 1548 | 1556 | |
| Jiang An Cheng | | 16703 | 571 | 83.97 | 32.8 | out | 17-Sep | 1510 | 1538 | 1606 | 1650 | 1701 | |
| mol elbe | cont | 50352 | 959 | 105 | 33.25 | out | 17-Sep | 1810 | 1918 | 1950 | 2038 | 2044 | |
| msc christina | cont | 37579 | 797 | 105.9 | 32.25 | out | 17-Sep | 1905 | 2007 | 2038 | 2113 | 2125 | |
| zim israel | cont | 37204 | 775 | 105.6 | 27.6 | out | 17-Sep | 2100 | 2137 | 2205 | 2239 | 2250 | |
| msc eleni | cont | 54881 | 932 | 137.8 | 35.75 | out | 17-Sep | 2345 | 42 | 106 | 140 | 147 | |
| midnight sun | oil tanker | 27915 | 590 | 105.6 | 26.9 | out | 18-Sep | 1230 | 1328 | 1358 | 1435 | 1443 | |
| alyona | cargo | 32226 | 674 | 101.7 | 26.6 | out | 18-Sep | 1935 | 1944 | 2017 | 2104 | 2112 | |
| zim iberia | cont | 41507 | 833 | 105.9 | 33.6 | out | 18-Sep | 1930 | 2033 | 2100 | 2140 | 2147 | |
| darya rani | bulk | 26054 | 610 | 99.71 | 27.25 | out | 18-Sep | 2035 | 2043 | 2110 | 2152 | 2205 | |
| sumida | cont | 13400 | 524 | 82 | 28.7 | out | 18-Sep | 2105 | 2158 | 2225 | 2304 | | |
| al mariyah | cont | 32534 | 694 | 105.9 | 30.2 | out | 18-Sep | 2115 | 2212 | 2239 | 2315 | 2321 | |
| msc elena | cont | 30971 | 662 | 105.9 | 33.4 | out | 19-Sep | 140 | 216/25 | 318 | 350 | 359 | |
| condor | cont | 14241 | 521 | 79.05 | 27.75 | out | 19-Sep | 1310 | 1353 | 1423 | 1452 | 1458 | |
| emanuelle tomasos | oil tanker | 23217 | 599 | 90.86 | 24.6 | out | 19-Sep | 1350 | 1426 | 1454 | 1527 | 1533 | |
| nelson | bulk | 13677 | 508.5 | 75.11 | 17.7 | out | 19-Sep | 1745 | | 1855 | 1939 | 1948 | |
| victoria bridge | cont | 53400 | 965 | 105.6 | 35.75 | out | 19-Sep | 1805 | 1910 | 1945 | 2041 | 2049 | |
| hanjin wilmington | cont | 51754 | 950 | 105.6 | 35.75 | out | 19-Sep | 1905 | 2015 | 2118 | 2148 | 2156 | |
| julia | oil tanker | 12165 | 518 | 73.14 | 30.3 | out | 20-Sep | 35 | | 140 | 222 | 229 | |
| essen express | cont | 53815 | 965 | 105.9 | 36.4 | out | 20-Sep | 155 | 234 | 312 | 348 | 356 | |
| mol velocity | cont | 53519 | 965 | 105.9 | 34.4 | out | 20-Sep | 740 | 836 | 918 | 957 | 1004 | |
| kavo alexandros II | bulk | 16608 | 551 | 85.94 | 29.1 | out | 20-Sep | 910 | **938** | 1004 | 1046 | 1055 | |
| angel accord | bulk | 20212 | 581 | 93.15 | 22.2 | out | 20-Sep | 1830 | 1913 | 1950 | | | |
| stuttgart express | cont | 53815 | 965 | 105.9 | 40.1 | out | 20-Sep | 2005 | 2055 | 2150 | | | |
| antares | gen cargo | 4793 | 571 | 83.97 | 14 | out | 20-Sep | 2215 | 2256 | 2314 | | | |
| aurora | tanker | 16454 | 528 | 91.84 | 22.7 | out | 20-Sep | 2240 | **2256** | 2336 | | | |
| jervis bay | cont | 50350 | 959 | 105.9 | 35.6 | out | 21-Sep | 30 | 124 | 157 | | | |
| borc | gen cargo | 20139 | 531.5 | 88.56 | 19.25 | out | 21-Sep | 150 | | | | | |
| cp rome | cont | 26131 | 642 | 100 | 33.8 | out | 21-Sep | 715 | | | | | |
| ismini | oil tanker | 37405 | 717 | 105.6 | 28.6 | out | 21-Sep | 720 | | | | | |
| cecile ericksen | bulk | 3461 | 373 | 50.84 | 16.5 | out | 21-Sep | 1350 | | | | | |
| ville de taurus | cont | 37549 | 850 | 105 | 36.1 | out | 21-Sep | 1725 | | | | | |
| msc insa | cont | 51608 | 868 | 105.9 | 37.3 | out | 21-Sep | 2000 | | | | | |

Table 4. Classes of Containership Traffic for Savannah Harbor

| Vessel Type | Length, ft | Beam, ft | Design Draft, ft |
|---|---|---|---|
| Post-Panamax | 1044 | 140 | 45.3 |
| Panamax | 951 | 106 | 40.7 |
| Sub-Panamax | 716.3 | 99.8 | 37.7 |
| Handysize | 579.1 | 85.1 | 31.8 |
| Feedermax | 427.5 | 67.7 | 25.2 |
| Feeder | 344.7 | 56.1 | 20.0 |

Table 5. Field Study Ships categorized according to vessel type used in Savannah District Fleet Forecast. Category based on ship beam.

| Vessel, type | # of ship transits | Field Study Summary | | | | |
|---|---|---|---|---|---|---|
| | | Range of draft, ft | Average draft, ft (% of design draft) | Average Beam, ft | Average Length, ft | Tonnage of average ship |
| Post-Panamax | 5 | 35.8-37.1 | 36.5 (81) | 137.2 | 949 | 114200 (0.75)* |
| Panamax | 49 | 26.9-40.1 | 33.4(82) | 105.7 | 852 | 65300 (0.68) |
| Sub-Panamax | 16 | 22.2-35.4 | 28.5(76) | 99.7 | 641 | 42200 (0.72) |
| Handysize | 18 | 14.0-35.2 | 25.8(81) | 85.2 | 558 | 28800 (0.73) |
| Feedermax | 9 | 17.7-30.3 | 24.1(96) | 71.4 | 469 | 18800 (0.73) |
| Feeder | 5 | 9.5-20.5 | 16.4(82) | 50.1 | 337 | 7000 (0.79) |

*Typical $C_b$

**Table 6. Containership Traffic for Savannah Harbor. Numbers are for both without and with project. Values in () are % of total calls.**

| Vessel Type | GEC | | 10% Increase | | 20% Increase | | 30% Increase | |
|---|---|---|---|---|---|---|---|---|
| | **2030** | **2050** | **2030** | **2050** | **2030** | **2050** | **2030** | **2050** |
| Post-Panamax | 211 (5.2) | 291 (3.7) | 565 (14.0) | 992 (12.7) | 920 (22.8) | 1693 (21.7) | 1274 (31.6) | 2394 (30.7) |
| Panamax | 3333 (82.7) | 6718 (86.1) | 2979 (73.9) | 6017 (77.1) | 2624 (65.1) | 5316 (68.1) | 2270 (56.3) | 4615 (59.2) |
| Sub-Panamax | 252 (6.3) | 458 (5.9) | 252 (6.3) | 458 (5.9) | 252 (6.3) | 458 (5.9) | 252 (6.3) | 458 (5.9) |
| Handysize | 215 (5.3) | 315 (4.0) | 215 (5.3) | 315 (4.0) | 215 (5.3) | 315 (4.0) | 215 (5.3) | 315 (4.0) |
| Feedermax | 18 (0.4) | 18 (0.2) | 18 (0.4) | 18 (0.2) | 18 (0.4) | 18 (0.2) | 18 (0.4) | 18 (0.2) |
| Feeder | 1 (0.00) | 1 (0.00) | 1 (0.00) | 1 (0.00) | 1 (0.00) | 1 (0.00) | 1 (0.00) | 1 (0.00) |
| Total Calls | 4030 | 7801 | 4030 | 7801 | 4030 | 7801 | 4030 | 7801 |

Table 7. Ship Log with speeds for each ship, inbound ships.

| Name | Dir | Day | CF camera speed, knots | CF - CDF average speed, knots | CDF camera speed, knots | CDF - FP average speed, knots | CG observation team speed, knots | FP camera speed, knots | FP - TI average speed, knots | TI camera speed, knots |
|---|---|---|---|---|---|---|---|---|---|---|
| INBOUND: | | | | | | | | | | |
| flintereems | in | 15 | | | 8.7 | | | | | |
| khannur | in | 15 | | | | | | | | |
| maersk garonne | in | 15 | | | 9.0 | | | | | |
| ym south | in | 15 | | | 6.9 | | | | | |
| Jiang An Cheng | in | 15 | | | 6.8 | | | | | |
| leyla kalkavan | in | 15 | | | 4.6 | | | | | |
| xin fang cheng | in | 16 | | | 8.4 | | | | | |
| new york express | in | 16 | | | 7.7 | | | | | |
| kyriakoula | in | 16 | | | | | | | | |
| sun right | in | 16 | | | 11.7 | 11.7 | | | 12.3 | 15.1 |
| mol americas | in | 16 | | | 5.0 | 15.0 | 13.8 | 13.8 | 12.6 | 15.6 |
| jens maersk | in | 16 | | | 13.6 | 16.1 | | | 13.2 | 16.3 |
| cma cgm potomac | in | 16 | | | 12.3 | 11.1 | | | 11.7 | 13.0 |
| zim israel | in | 17 | | | 5.5 | 10.1 | | | 9.7 | 10.9 |
| msc christina | in | 17 | | | 7.4 | 10.1 | | | 11.6 | 13.0 |
| mol elbe | in | 17 | | | 8.9 | 10.8 | | | 8.8 | 12.1 |
| msc eleni | in | 17 | | | 10.4 | 12.0 | | | 11.0 | 14.2 |
| midnight sun | in | 17 | 5.63 | 7.8 | 10.6 | 10.5 | 9.3 | | 10.7 | 10.3 |
| darya rani | in | 17 | 6.70 | 9.2 | 9.5 | 11.7 | 11.6 | | 12.4 | 12.0 |
| alyona | in | 17 | 7.41 | 7.8 | 7.4 | 10.7 | | | 8.0 | 11.6 |
| zim iberia | in | 18 | 5.16 | 7.1 | 6.9 | 10.4 | | | 11.1 | 11.3 |
| al mariyah | in | 18 | 6.52 | 9.5 | 10.8 | 12.2 | 8.3 | | 13.5 | 13.7 |
| msc elena | in | 18 | 5.75 | 8.2 | 10.9 | 11.9 | 8.0 | | 14.4 | 13.5 |
| emmanuel tomasos | in | 18 | 5.28 | 7.4 | 8.9 | 9.8 | 4.4 | | 7.9 | 9.4 |
| hanjin wilmington | in | 18 | 6.64 | 9.1 | 10.3 | 10.9 | 9.1 | 10.4 | 11.2 | 11.7 |
| condor | in | 18 | 8.12 | 8.7 | 12.3 | 12.6 | 10.0 | 14.1 | 16.5 | 18.1 |
| Victoria Bridge | in | 18 | 6.34 | 8.1 | 8.3 | 10.6 | | 9.8 | | |
| essen express | in | 19 | 6.52 | 9.4 | 11.4 | 12.1 | | 9.5 | 12.1 | 12.1 |
| kavo alexandros II | in | 19 | | | 9.6 | 12.2 | 10.7 | 13.0 | 14.1 | 14.2 |
| angel accord | in | 19 | | 8.4 | 9.3 | 10.1 | 9.8 | 10.1 | 10.3 | 11.1 |
| mol velocity | in | 19 | | 9.1 | 12.5 | 12.5 | 9.5 | 10.4 | 12.8 | 15.5 |
| borc | in | 19 | | | 8.8 | 10.8 | | 10.8 | 11.6 | 11.3 |
| jervis bay | in | 19 | | | 10.1 | 12.0 | | 11.9 | 14.1 | 14.3 |
| ismini | in | 19 | | 8.4 | 9.9 | 13.2 | | 12.9 | 15.5 | 12.2 |
| stuttgart express | in | 19 | | 7.5 | 11.0 | 13.5 | | 12.7 | 14.3 | 15.2 |
| aurora | in | 20 | | | 10.8 | 12.2 | | 10.4 | | |
| cecile ericksen | in | 20 | | | 11.1 | 11.7 | 10.4 | 11.6 | | |
| cp rome | in | 20 | 9.72 | 9.0 | 11.6 | | | | | |
| ville de taurus | in | 21 | 5.93 | 6.7 | 8.7 | | | | | |
| onego spirit | in | 21 | | | | | | | | |
| stolt capability | in | 21 | 11.44 | | | | | | | |
| msc insa | in | 21 | | | | | | | | |
| hilli | in | 21 | | | | | | | | |
| besire kalkavan | in | 21 | | | | | | | | |
| xin nan tong | in | 21 | | | | | | | | |

CG = Coast Guard

**Table 7. Concluded**

| OUTBOUND:(SAIL) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| schackenborg | out | 15 | | | | | | | | |
| saimaagracht | out | 15 | | | 5.3 | | | | | |
| northern fortune | out | 15 | | | 5.3 | | | | | |
| ANL georgia | out | 15 | | | 6.3 | | | | | |
| general lee | out | 15 | | | 5.8 | | | | | |
| ym shanghai | out | 15 | | | 6.6 | | | | | |
| cape bird | out | 15 | | | 5.0 | | | | | |
| khannur | out | 16 | | | | | | | | 11.1 |
| talisman | out | 16 | | | 10.8 | 11.0 | | | 11.7 | 14.2 |
| xin fang cheng | out | 16 | | | 12.5 | 13.5 | | | 7.7 | 14.2 |
| ym south | out | 16 | | | 8.8 | 11.3 | | | 10.3 | 12.2 |
| maersk garonne | out | 16 | | | 9.2 | 11.1 | | | 11.8 | 13.5 |
| star drivanger | out | 16 | | | 6.3 | 10.0 | | | 10.7 | 11.9 |
| leyla kalkavan | out | 17 | | | 10.7 | 14.6 | | | 11.5 | 13.8 |
| new york express | out | 17 | | | 9.7 | 10.0 | | | 11.0 | 11.3 |
| star florida | out | 17 | | | 10.7 | 12.2 | | | 10.8 | 11.7 |
| jens maersk | out | 17 | | | 10.6 | 10.5 | | | 15.6 | 12.7 |
| kyriakoula | out | 17 | | | 7.6 | 9.7 | | | 9.8 | 10.9 |
| mol americas | out | 17 | | | 11.6 | 11.6 | | | 11.4 | 14.3 |
| sun right | out | 17 | | | 9.7 | 11.2 | 10.4 | 10.7W | 12.6 | 14.3 |
| cma cgm potomac | out | 17 | | | 11.6 | 12.9 | 10.5 | 11.0A | 13.3 | 14.9 |
| flintereems | out | 17 | | | 11.4 | 12.7 | 12.0 | 12.5A | 13.0 | 12.1 |
| kochnev | out | 17 | | | 11.0 | 10.8 | 9.6 | 10.0A | 10.8 | 10.5 |
| Jiang An Cheng | out | 17 | 6.6 | 9.8 | 9.7 | 10.1 | 8.7 | 10.0A | 10.6 | 10.6 |
| mol elbe | out | 17 | 5.2 | 8.7 | 10.0 | 12.5 | | | 11.6 | 11.9 |
| msc christina | out | 17 | 6.0 | 9.0 | 8.0 | | | | | 12.7 |
| zim israel | out | 17 | 8.1 | 9.8 | 10.7 | 13.2 | | | 10.4 | 13.9 |
| msc eleni | out | 17 | 7.1 | 10.8 | 10.3 | 13.0 | | | 14.4 | 13.3 |
| midnight sun | out | 18 | 6.6 | 9.8 | 10.3W | 11.9 | 10.6 | 10.6A | 11.4 | 13.0 |
| zim iberia | out | 18 | 8.1 | 8.1 | 7.5 | 9.7 | | 12.3 | 13.3 | 13.0 |
| alyona | out | 18 | 6.2 | 10.6 | 7.8 | 11.2 | | 10.3 | 11.0 | 10.1 |
| darya rani | out | 18 | 8.2 | 10.2 | 7.2 | | | | | 11.3 |
| sumida | out | 18 | 6.8 | 10.1 | 7.8 | 12.2 | | 12.0 | | |
| al mariyah | out | 18 | 7.0 | 10.8 | 9.0 | 11.9 | | 13.3 | 14.4 | 13.8 |
| msc elena | out | 19 | 7.8 | 11.9 | 10.9 | 12.4 | | 12.3 | 13.5 | 11.9 |
| condor | out | 19 | 7.7 | 9.8 | 14.7W | 14.6 | 13.5 | 12.9 | 14.5 | 16.2 |
| emanuelle tomasos | out | 19 | 7.2 | 10.0 | 12.3W | 13.9 | 13.5 | 14.2W | 15.2 | 16.1 |
| nelson | out | 19 | | | 9.4 | 9.9 | | 10.0 | 10.7 | 10.4 |
| victoria bridge | out | 19 | 6.4 | 5.8 | 7.7 | 9.7 | | 9.5 | 10.9 | 11.2 |
| hanjin wilmington | out | 19 | 2.4 | | | | | 14.8 | 14.5 | 12.5 |
| julia | out | 20 | | | 7.0 | 10.9 | | 11.4 | 12.5 | 10.6 |
| essen express | out | 20 | | 7.6 | 9.1 | 11.6 | | 11.7 | 13.5 | 11.9 |
| mol velocity | out | 20 | | 6.7 | 10.8W | 11.2 | 9.9 | 11.7W | 12.7 | 13.3 |
| kavo alexandros II | out | 20 | | | 9.6 | 9.9 | 9.4 | 9.9W | 11.0 | 11.3 |
| angel accord | out | 20 | 6.9 | 7.9 | 10.1W | | | | | |
| stuttgart express | out | 20 | 5.4 | 5.3 | 6.8 | | | | | |
| antares | out | 20 | | | | | | | | |
| aurora | out | 20 | | | | | | | | |
| jervis bay | out | 21 | 8.1 | 8.8 | 9.5 | | | | | |
| borc | out | 21 | | | 8.2 | | | | | |
| cp rome | out | 21 | | | | | | | | |
| ismini | out | 21 | | | | | | | | |
| cecile ericksen | out | 21 | | | | | | | | |
| ville de taurus | out | 21 | | | | | | | | |
| msc insa | out | 21 | | | | | | | | |

W = ship used in wave analysis A=ship used in wave analysis but speed adopted from Coast Guard and adjacent reach averaged speeds.

Table 8. Summary of ship speeds along channel from field study.

| Location | Speed Type | Inbound, knots | Outbound, knots | Day, knots | Night, knots | Overall Average, knots |
|---|---|---|---|---|---|---|
| City Front | Camera | 7.1 | 6.7 | NA | NA | 6.9 |
| CF to CDF | Reach average | 8.4 | 9.1 | NA | NA | 8.8 |
| CDF | Camera | 9.5 | 9.1 | 10.5 | 8.4 | 9.3 |
| CDF to FP | Reach average | 11.7 | 11.6 | 11.8 | 11.5 | 11.7 |
| CG | Observers | 9.8 | 10.8 | 10.3 | NA | 10.3 |
| FP | Camera | 11.5 | 11.8 | 11.6 | 11.7 | 11.7 |
| FP to TI | Reach average | 12.1 | 12.1 | 12.2 | 11.9 | 12.1 |
| TI | Camera | 13.1 | 12.6 | 13.2 | 12.4 | 12.9 |

Table 9. Ship effects analysis for Fort Pulaski. Return velocity and drawdown are averages over cross section based on Schijf equation in NAVEFF.

| Draft / channel | Ship | Typical ship speed, knots | High ship speed, knots | Return Velocity/ Drawdown for typical speed, ft/sec | Return Velocity/ Drawdown, for high speed, ft/sec | Short period bow and stern wave height for typical/ high speed, ft |
|---|---|---|---|---|---|---|
| Typical (80%) draft/ existing (63980)* | PP-1044 X 140 X 36.2 | 11.7 | 13.7 | 2.85/1.87 | 4.61/3.64 | 1.43/2.18 |
| " | PA-951 X 106 X 32.6 | " | " | 1.77/1.14 | 2.75/2.09 | 0.98/1.49 |
| " | SP-716 X 99.8 X 30.2 | " | " | 1.51/0.96 | 2.30/1.73 | 0.85/1.30 |
| " | HS-579 X 85.1 X 25.4 | " | " | 1.04/0.66 | 1.53/1.14 | 0.61/0.93 |
| " | FM-428 X 67.7 X 20.2 | " | " | 0.64/0.40 | 0.92/0.67 | 0.39/0.59 |
| Typical (80%) draft/ deep-ened (66800) | PP-1044 X 140 X 36.2 | 11.85 | 13.85 | 2.69/1.78 | 4.49/3.58 | 1.48/2.25 |
| " | PA-951 X 106 X 32.6 | 11.8 | 13.9 | 1.67/1.08 | 2.59/1.99 | 1.00/1.55 |
| " | SP-716 X 99.8 X 30.2 | 11.8 | 13.9 | 1.43/0.92 | 2.17/1.66 | 0.87/1.35 |
| " | HS-579 X 85.1 X 25.4 | 11.75 | 13.85 | 0.98/0.62 | 1.45/1.08 | 0.62/0.96 |
| " | FM-428 X 67.7 X 20.2 | 11.75 | 13.8 | 0.60/0.38 | 0.86/0.63 | 0.39/0.60 |
| Design draft/ existing (63980) | PP-1044 X 140 X 40.7** | 11.7 | 13.7 | 3.33/2.22 | 5.08/4.05 | 1.61/2.45 |
| " | PA-951 X 106 X 40.7 | " | " | 2.32/1.51 | 3.81/2.96 | 1.22/1.86 |
| " | SP-716 X 99.8 X 37.7 | " | " | 1.96/1.26 | 3.10/2.37 | 1.06/1.62 |
| " | HS-579 X 85.1 X 31.8 | " | " | 1.34/0.85 | 2.01/1.51 | 0.76/1.16 |
| " | FM-428 X 67.7 X 25.2 | | | 0.81/0.51 | 1.17/0.86 | 0.48/0.73 |
| Design draft/ deepened (66800) | PP-1044 X 140 X 45.3 | 11.25 | 13.00 | 3.19/2.04 | 5.02/3.82 | 1.61/2.37 |
| " | PA-951 X 106 X 40.7 | 11.85 | 13.95 | 2.20/1.44 | 3.58/2.82 | 1.26/1.95 |
| " | SP-716 X | 11.85 | 13.95 | 1.87/1.21 | 2.94/2.28 | 1.10/1.70 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 99.8 X 37.7 | | | | | |
| " | HS-579 X 85.1 X 31.8 | 11.8 | 13.9 | 1.27/0.81 | 1.90/1.44 | 0.78/1.21 |
| " | FM-428 X 67.7 X 25.2 | 11.75 | 13.85 | 0.76/0.48 | 1.11/0.82 | 0.49/0.76 |

*(channel area, sq ft)

**limited by channel depth

**Table 10. Composite return velocity ($V_r$), drawdown, and short period bow and stern wave height for Fort Pulaski based on Table 9 and ship frequency in Table 6 for GEC scenario. Values in () shows percent change from without project to with project.**

| Draft/channel/ traffic year | Composite for Typical Speed | | | Composite for High Speed | | |
|---|---|---|---|---|---|---|
| | $V_r$, ft/sec | Drawdown, ft | Wave height, ft | $V_r$, ft/sec | Drawdown, ft | Wave height, ft |
| Typical Draft/ existing/2030 | 1.77 | 1.14 | 0.97 | 2.75 | 2.09 | 1.48 |
| Typical Draft/ deepened/2030 | 1.67 (-5.6%) | 1.08 (-5.3%) | 0.99 (+2.1%) | 2.59 (-5.8%) | 2.00 (-4.3%) | 1.54 (+4.1%) |
| Design Draft/ existing/2030 | 2.29 | 1.49 | 1.20 | 3.72 | 2.89 | 1.83 |
| Design Draft/ deepened/2030 | 2.17 (-5.2%) | 1.42 (-4.7%) | 1.24 (+3.3%) | 3.51 (-5.6%) | 2.76 (-4.5%) | 1.91 (+4.4%) |
| Typical Draft/ existing/2050 | 1.76 | 1.14 | 0.97 | 2.74 | 2.08 | 1.48 |
| Typical Draft/ deepened/2050 | 1.66 (-5.7%) | 1.08 (-5.3%) | 0.99 (+2.1%) | 2.59 (-5.5%) | 1.99 (-4.3%) | 1.54 (+4.1%) |
| Design Draft/ existing/2050 | 2.29 | 1.49 | 1.20 | 3.74 | 2.90 | 1.84 |
| Design Draft/ deepened/2050 | 2.18 (-4.8%) | 1.42 (-4.7%) | 1.24 (+3.3%) | 3.52 (-5.9%) | 2.76 (-4.8%) | 1.92 (+4.3%) |

Table 11. Composite return velocity, drawdown, and short period bow and stern wave height for Fort Pulaski based on Table 9 and ship frequency in Table 6 for 10% scenario. Values in () shows percent change from without project to with project.

| Draft/channel/ traffic year | Composite for Typical Speed | | | Composite for High Speed | | |
|---|---|---|---|---|---|---|
| | Vr, ft/sec | Drawdown, ft | Wave height, ft | Vr, ft/sec | Drawdown, ft | Wave height, ft |
| Typical Draft/ existing/2030 | 1.86 | 1.20 | 1.01 | 2.91 | 2.23 | 1.54 |
| Typical Draft/ deepened/2030 | 1.76 (-5.4%) | 1.14 (-5.0%) | 1.04 (+3.0%) | 2.76 (-5.2%) | 2.14 (-4.0%) | 1.60 (+3.9%) |
| Design Draft/ existing/2030 | 2.38 | 1.55 | 1.24 | 3.83 | 2.99 | 1.88 |
| Design Draft/ deepened/2030 | 2.26 (-5.0%) | 1.47 (-5.2%) | 1.27 (+2.4%) | 3.64 (-5.0%) | 2.84 (-5.0%) | 1.95 (+3.8%) |
| Typical Draft/ existing/2050 | 1.86 | 1.20 | 1.01 | 2.91 | 2.22 | 1.54 |
| Typical Draft/ deepened/2050 | 1.76 (-5.4%) | 1.14 (-5.0%) | 1.04 (+3.0%) | 2.76 (-5.2%) | 2.13 (-4.1%) | 1.60 (+3.9%) |
| Design Draft/ existing/2050 | 2.38 | 1.56 | 1.24 | 3.85 | 3.00 | 1.89 |
| Design Draft/ deepened/2050 | 2.27 (-4.6%) | 1.47 (-5.8%) | 1.27 (+2.4%) | 3.65 (-5.2%) | 2.85 (-5.0%) | 1.96 (+3.7%) |

**Table 12. Composite return velocity, drawdown, and short period bow and stern wave height for Fort Pulaski based on Table 9 and ship frequency in Table 6 for 20% scenario. Values in () shows percent change from without project to with project.**

| Draft/channel/ traffic year | Composite for Typical Speed | | | Composite for High Speed | | |
|---|---|---|---|---|---|---|
| | Vr, ft/sec | Drawdown, ft | Wave height, ft | Vr, ft/sec | Drawdown, ft | Wave height, ft |
| Typical Draft/ existing/2030 | 1.96 | 1.27 | 1.05 | 3.07 | 2.36 | 1.60 |
| Typical Draft/ deepened/2030 | 1.85 (-5.6%) | 1.20 (-5.5%) | 1.08 (+2.9%) | 2.93 (-4.6%) | 2.28 (-3.4%) | 1.66 (+3.8%) |
| Design Draft/ existing/2030 | 2.47 | 1.62 | 1.27 | 3.95 | 3.08 | 1.94 |
| Design Draft/ deepened/2030 | 2.35 (-4.9%) | 1.52 (-6.2%) | 1.30 (+2.4%) | 3.77 (-4.6%) | 2.93 (-4.9%) | 1.98 (+2.1%) |
| Typical Draft/ existing/2050 | 1.96 | 1.27 | 1.05 | 3.07 | 2.36 | 1.60 |
| Typical Draft/ deepened/2050 | 1.85 (-5.6%) | 1.20 (-5.5%) | 1.08 (+2.9%) | 2.93 (-4.6%) | 2.28 (-3.4%) | 1.66 (+3.8%) |
| Design Draft/ existing/2050 | 2.47 | 1.62 | 1.27 | 3.96 | 3.10 | 1.94 |
| Design Draft/ deepened/2050 | 2.35 (-4.9%) | 1.53 (-5.6%) | 1.31 (+3.1%) | 3.78 (-4.5%) | 2.94 (-5.2%) | 1.99 (+2.6%) |

**Table 13. Composite return velocity, drawdown, and short period bow and stern wave height for Fort Pulaski based on Table 9 and ship frequency in Table 6 for 30% scenario. Values in () shows percent change from without project to with project.**

| Draft/channel/ traffic year | Composite for Typical Speed | | | Composite for High Speed | | |
|---|---|---|---|---|---|---|
| | Vr, ft/sec | Drawdown, ft | Wave height, ft | Vr, ft/sec | Drawdown, ft | Wave height, ft |
| Typical Draft/ existing/2030 | 2.05 | 1.33 | 1.09 | 3.24 | 2.50 | 1.66 |
| Typical Draft/ deepened/2030 | 1.94 (-5.4%) | 1.26 (-5.3%) | 1.12 (+2.8%) | 3.10 (-4.3%) | 2.42 (-3.2%) | 1.72 (+3.6%) |
| Design Draft/ existing/2030 | 2.56 | 1.68 | 1.31 | 4.06 | 3.18 | 1.99 |
| Design Draft/ deepened/2030 | 2.44 (-4.7%) | 1.58 (-6.0%) | 1.33 (+1.5%) | 3.89 (-4.2%) | 3.02 (-5.0%) | 2.02 (+1.5%) |
| Typical Draft/ existing/2050 | 2.05 | 1.33 | 1.09 | 3.24 | 2.50 | 1.67 |
| Typical Draft/ deepened/2050 | 1.94 (-5.4%) | 1.27 (-4.5%) | 1.12 (+2.8%) | 3.10 (-4.3%) | 2.42 (-3.2%) | 1.73 (+3.6%) |
| Design Draft/ existing/2050 | 2.57 | 1.68 | 1.31 | 4.08 | 3.20 | 2.00 |
| Design Draft/ deepened/2050 | 2.44 (-5.1%) | 1.58 (-6.0%) | 1.34 (+2.3%) | 3.91 (-4.2%) | 3.03 (-5.3%) | 2.03 (+1.5%) |

Table 14. Tybee Island ship drawdown.

| Category | Ship name | Gross Tonnage, speed, knots over ground | Maximum Drawdown, ft | Tide, ft MLLW and direction |
|---|---|---|---|---|
| Inbound/Stage < 4 ft MLLW | Sun Right | 53359, 15.1 | 1.1 | 1.5, flood |
| " | Zim Israel | 37204, 10.9 | 0.2 | -0.1, bottom |
| " | MSC Christina | 37579, 13.0 | 0.75 | -0.2, bottom |
| " | Mol Elbe | 50352, 12.1 | 0.85 | -0.2, bottom |
| " | Midnight Sun | 27915, 10.3 | 0.2 | -0.4, bottom |
| " | Darya Rani | 26054, 12.0 | 0.2 | 0.2, weak flood |
| " | Zim Iberia | 41507, 11.3 | 0.9 | -0.3, bottom |
| " | Hanjin Wilmington | 51754, 11.7 | 0.25 | -0.1, bottom |
| " | Condor | 14241, 18.1 | 0.3 | 3.0, flood |
| " | Essen Express | 53815, 12.1 | 0.9 | -0.1, bottom |
| " | Angel Accord | 20212, 11.1 | 0.2 | -0.2, bottom |
| " | Mol Velocity | 53519, 15.5 | 0.8 | 0.7, flood |
| " | Jervis Bay | 50350, 14.3 | 0.2 | 4.4, flood |
| " | Borc | 20139, 11.3 | 0.1 | 3.6, flood |
| Inbound/Stage > 7 ft MLLW | MSC Elini | 54841, 14.2 | 0.2 | 8.2, weak ebb |
| | MSC Elena | 30971, 13.5 | 0.1 | 6.3, ebb |
| | Kavo Alexandros II | 16608, 14.2 | 0.1 | 7.8,ebb |
| | Jens Maersk | 30166, 14.2 | 1.4 | 8.4, flood |
| | Stuttgart Express | 53815, 15.2 | 0.25 | 8.4, weak ebb |
| Outbound/Stage < 4 ft MLLW | Khannur | 96235, 11.1 | 0.5 | -0.4, bottom |
| | New York Express | 54437, 11.3 | 1.3 | 2.0, flood |
| | Star Florida | 23345, 11.7 | 0.8 | 2.5, flood |
| | Jens Maersk | 30166, 12.7 | 1.65 | 3.4, flood |
| | CMA CGM Potomac | 31154, 14.9 | 0.45 | 1.6, ebb |
| | Kochnev | 6030, 10.5 | 0.2 | 0.9, flood |
| | MSC Eleni | 54881, 13.3 | 0.5 | 0.8, ebb |
| | Midnight Sun | 27915, 13.0 | 0.2 | 0.1 ebb |
| | MSC Elena | 30971, 11.9 | 0.5 | -0.4, bottom |
| | Condor | 14241, 16.2 | 0.25 | 0.9, ebb |
| | Emmanuelle Tomassos | 23217, 16.1 | 0.35 | 0.2, weak ebb |
| | Essen Express | 53815, 11.9 | 0.5 | 0.3, weak ebb |

| | | | | |
|---|---|---|---|---|
| Outbound/Stage > 7 ft MLLW | YM South | 46697, 12.2 | 0.5 | 7.3, ebb |
| | Maersk Garonne | 50698, 13.5 | 0.7 | 7.0, ebb |
| | Kyriakoula | 40680, 10.9 | 0.45 | 7.1, flood |
| | Mol America | 16803, 14.3 | 0.35 | 8.3, top |
| | Mol Elbe | 50352, 11.9 | 0.35 | 9.1, top |
| | MSC Christina | 37579, 12.7 | 0.75 | 8.7, weak ebb |
| | Zim Iberia | 41507, 13.0 | 0.95 | 8.8, top |
| | Darya Rani | 26054, 11.3 | 0.2 | 8.6, weak ebb |
| | Victoria Bridge | 53400, 11.2 | 0.65 | 7.9, flood |
| | Hanjin Wilmington | 51754, 12.5 | 1.1 | 8.6, top |
| | Mol Velocity | 53519, 13.3 | 1.35 | 8.7, top |
| | Kavo Alexandros II | 16608, 11.3 | 0.25 | 8.7, top |

**Table 15. Design ship analysis for Tybee Island. Return velocity and drawdown are averages over cross section based on Schijf equation.**

| Design Ship / channel | Ship | Typical ship speed, knots | High ship speed, knots | Drawdown for typical speed, ft | Drawdown for high speed, ft |
|---|---|---|---|---|---|
| Typical (80%) draft/ existing (64175)* | PP-1044 X 140 X 36.2 | 12.9 | 14.4 | 2.85 | 4.01 |
| " | PA-951 X 106 X 32.6 | " | " | 1.62 | 2.78 |
| " | SP-716 X 99.8 X 30.2 | " | " | 1.36 | 2.24 |
| " | HS-579 X 85.1 X 25.4 | " | " | 0.91 | 1.42 |
| " | FM-428 X 67.7 X 20.2 | " | " | 0.54 | 0.82 |
| Typical (80%) draft/ deepened (66793) | PP-1044 X 140 X 36.2 | 13.15 | 14.55 | 2.76 | 3.95 |
| " | PA-951 X 106 X 32.6 | 13.05 | 14.65 | 1.55 | 2.66 |
| " | SP-716 X 99.8 X 30.2 | 13.05 | 14.6 | 1.3 | 2.13 |
| " | HS-579 X 85.1 X 25.4 | 13.0 | 14.55 | 0.87 | 1.35 |
| " | FM-428 X 67.7 X 20.2 | 13.0 | 14.5 | 0.52 | 0.78 |
| Design draft/ existing (64175) | PP-1044 X 140 X 40.7** | 12.9 | 14.4 | 3.53 | 4.46 |
| " | PA-951 X 106 X 40.7 | " | " | 2.21 | 3.47 |
| " | SP-716 X 99.8 X 37.7 | " | " | 1.82 | 3.08 |
| " | HS-579 X 85.1 X 31.8 | " | " | 1.19 | 1.92 |
| " | FM-428 X 67.7 X 25.2 | | | 0.7 | 1.07 |
| Design draft/ deepened (66793) | PP-1044 X 140 X 45.3 | 12.55 | 13.6 | 3.22 | 4.24 |
| " | PA-951 X 106 X 40.7 | 13.1 | 14.5 | 2.13 | 3.4 |
| " | SP-716 X 99.8 X 37.7 | 13.05 | 14.6 | 1.73 | 3.01 |
| " | HS-579 X 85.1 X 31.8 | 13.05 | 14.6 | 1.14 | 1.83 |
| " | FM-428 X 67.7 X 25.2 | 13.0 | 14.55 | 0.66 | 1.02 |

*(channel area, sq ft)

**limited by channel depth

**Table 16. Composite drawdown for Tybee Island based on Table 15 and ship frequency in Table 6 for GEC traffic scenario. Values in () shows percent change from without project to with project.**

| Draft/channel/ traffic year | Composite drawdown for typical speed, ft | Composite drawdown for high speed, ft |
|---|---|---|
| Typical Draft/ existing/2030 | 1.63 | 2.73 |
| Typical Draft/ deepened/2030 | 1.56 (-4.3%) | 2.62 (-4.0%) |
| Design Draft/ existing/2030 | 2.19 | 3.4 |
| Design Draft/ deepened/2030 | 2.10 (-4.1%) | 3.32 (-2.4%) |
| Typical Draft/ existing/2050 | 1.62 | 2.73 |
| Typical Draft/ deepened/2050 | 1.55 (-4.3%) | 2.62 (-4.0%) |
| Design Draft/ existing/2050 | 2.19 | 3.42 |
| Design Draft/ deepened/2050 | 2.10 (-4.1%) | 3.34 (-2.3%) |

**Table 17. Composite drawdown for Tybee Island based on Table 15 and ship frequency in Table 6 for 10% traffic scenario. Values in () shows percent change from without project to with project.**

| Draft/channel/ traffic year | Composite drawdown for typical speed, ft | Composite drawdown for high speed, ft |
|---|---|---|
| Typical Draft/ existing/2030 | 1.73 | 2.84 |
| Typical Draft/ deepened/2030 | 1.66 (-4.0%) | 2.73 (-3.9%) |
| Design Draft/ existing/2030 | 2.31 | 3.49 |
| Design Draft/ deepened/2030 | 2.20 (-4.8%) | 3.40 (-2.6%) |
| Typical Draft/ existing/2050 | 1.73 | 2.84 |
| Typical Draft/ deepened/2050 | 1.66 (-4.0%) | 2.74 (-3.5%) |
| Design Draft/ existing/2050 | 2.31 | 3.50 |
| Design Draft/ deepened/2050 | 2.20 (-4.8%) | 3.41 (-2.6%) |

**Table 18. Composite drawdown for Tybee Island based on Table 15 and ship frequency in Table 6 for 20% traffic scenario. Values in () shows percent change from without project to with project.**

| Draft/channel/ traffic year | Composite drawdown for typical speed, ft | Composite drawdown for high speed, ft |
|---|---|---|
| Typical Draft/ existing/2030 | 1.84 | 2.95 |
| Typical Draft/ deepened/2030 | 1.77 (-3.8%) | 2.84 (-3.7%) |
| Design Draft/ existing/2030 | 2.43 | 3.58 |
| Design Draft/ deepened/2030 | 2.29 (-5.8%) | 3.47 (-3.1%) |
| Typical Draft/ existing/2050 | 1.84 | 2.96 |
| Typical Draft/ deepened/2050 | 1.77 (-3.8%) | 2.85 (-3.7%) |
| Design Draft/ existing/2050 | 2.43 | 3.59 |
| Design Draft/ deepened/2050 | 2.30 (-5.3%) | 3.49 (-2.8%) |

**Table 19. Composite drawdown for Tybee Island based on Table 15 and ship frequency in Table 6 for 30% traffic scenario. Values in () shows percent change from without project to with project.**

| Draft/channel/ traffic year | Composite drawdown for typical speed, ft | Composite drawdown for high speed, ft |
|---|---|---|
| Typical Draft/ existing/2030 | 1.95 | 3.05 |
| Typical Draft/ deepened/2030 | 1.88 (-3.6%) | 2.96 (-3.0%) |
| Design Draft/ existing/2030 | 2.54 | 3.66 |
| Design Draft/ deepened/2030 | 2.39 (-5.9%) | 3.55 (-3.0%) |
| Typical Draft/ existing/2050 | 1.95 | 3.07 |
| Typical Draft/ deepened/2050 | 1.88 (-3.6%) | 2.97 (-3.3%) |
| Design Draft/ existing/2050 | 2.55 | 3.68 |
| Design Draft/ deepened/2050 | 2.40 (-5.9%) | 3.57 (-3.0%) |

**Table 20. Drawdown in existing channel for CDF ships.**

| CDF - Inbound | | |
|---|---|---|
| **Name** | **Date** | **Drawdown (ft)** |
| Emmanuel Tomassos | 18 | 1.1 |
| Hanjin Wilmington | 18 | 1.4* |
| Essen Express | 19 | 1.5* |
| Angel Accord | 19 | 0.4 |
| Mol Velocity | 19 | 2.7* |
| Stuttgart Express | 19 | 0.9 |
| Ville de Taurus | 21 | 1.3 |
| **CDF - Outbound** | | |
| **Name** | **Date** | **Drawdown (ft)** |
| Midnight Sun | 18 | 0.6 |
| MSC Elena | 19 | 1.9* |
| Emmanuel Tomassos | 19 | 1.0 |
| Condor | 19 | 2.0 |
| Essen Express | 20 | 1.4 |
| Mol Velocity | 20 | 2.4 |
| Angel Accord | 20 | 1.5 |
| Jervis Bay | 21 | 1.5 |

* Drawdown below bottom of gage

Table 21. Drawdown in existing channel for CF ships.

| CF - Inbound | | |
|---|---|---|
| Name | Date | Drawdown (ft) |
| Darya Rani | 17 | 0.2 |
| Aloyna | 17 | 0.2 |
| Zim Iberia | 18 | 0.2 |
| Al Mariyah | 18 | 0.1 |
| MSC Eleni | 18 | 0.2 |
| Emmanuel Tomassos | 18 | 0.4 |
| Hanjin Wilmington | 18 | 0.4 |
| Condor | 18 | 0.2 |
| Victoria Bridge | 19 | 0.6 |
| Essen Express | 19 | 0.5 |
| Angel Accord | 19 | 0.2 |
| Mol Velocity | 19 | 0.4 |
| Ismini | 19 | 0.6 |
| Stuttgart Express | 19 | 0.5 |
| CP Rome | 20 | 0.4 |

| CF - Outbound | | |
|---|---|---|
| Name | Date | Drawdown (ft) |
| Jian an Cheng | 17 | 0.55 |
| Mole Elbe | 17 | 0.25 |
| MSC Christina | 17 | 0.3 |
| Zim Israel | 17 | 0.5 |
| MSC Eleni | 18 | 0.2 |
| Midnight Sun | 18 | 0.2 |
| Alyona | 18 | 0.3 |
| Zim Iberia | 18 | 0.8 |
| Darya Rani | 18 | 0.55 |
| Sumida | 18 | 0.2 |
| Al Mariyah | 18 | 0.2 |
| MSC Elena | 19 | 0.3 |
| Condor | 19 | 0.2 |
| Emanuel Tomassos | 19 | 0.1 |
| Victoria Bridge | 19 | 0.7 |
| Hanjin Wilmington | 19 | 0.35 |
| Essen Express | 20 | 0.3 |
| Mol Velocity | 20 | 0.55 |
| Kavo Alexandros II | 20 | 0.2 |
| Angel Accord | 20 | 0.4 |
| Stuttgart Express | 20 | 0.5 |
| Jervis Bay | 21 | 0.4 |

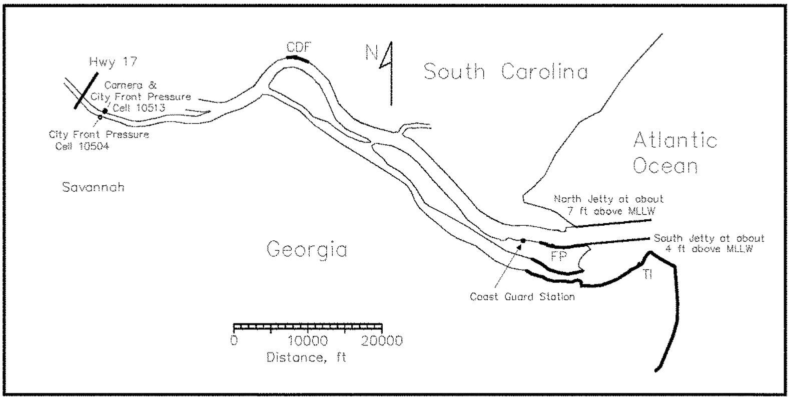



**Figure 1. Locations of gages and cameras.**

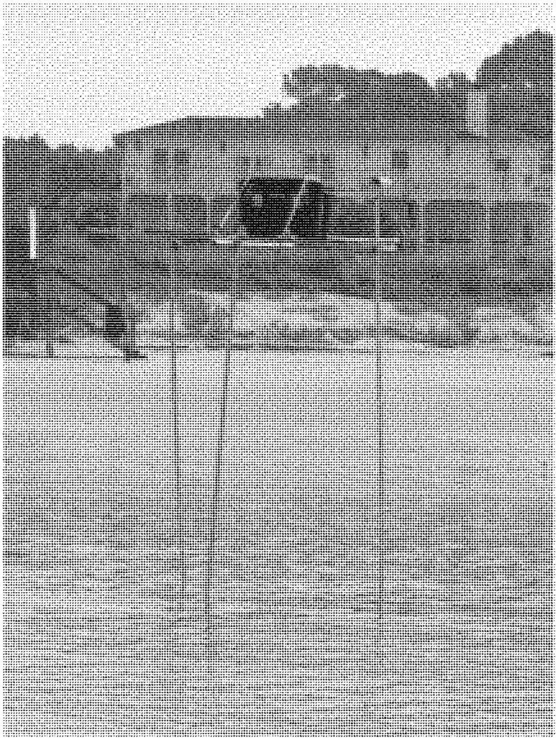


Figure 2. Picture of capacitance gage at Tybee Island

Figure 3. Picture of capacitance gage at Fort Pulaski

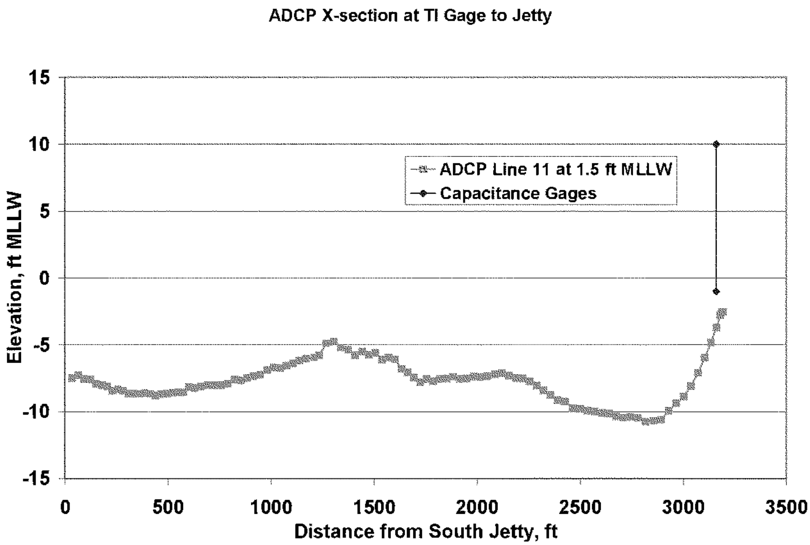



Figure 4. Cross section at Tybee Island- south Jetty to wave gage.

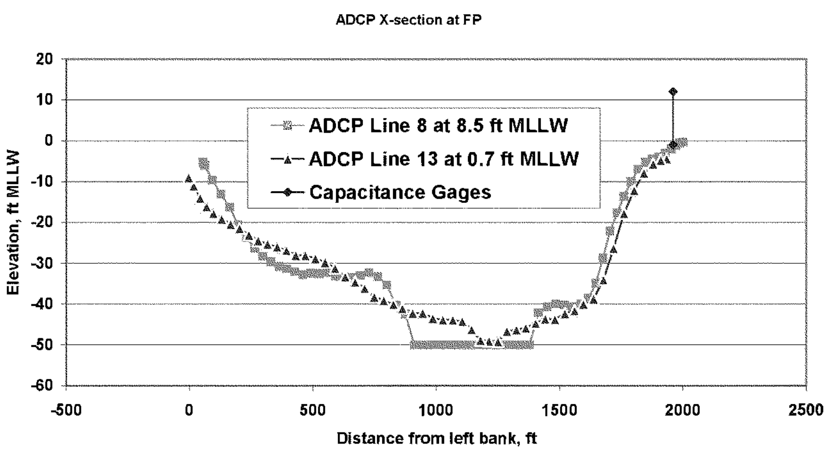



Figure 5. Cross section at Tybee Island- between jetties

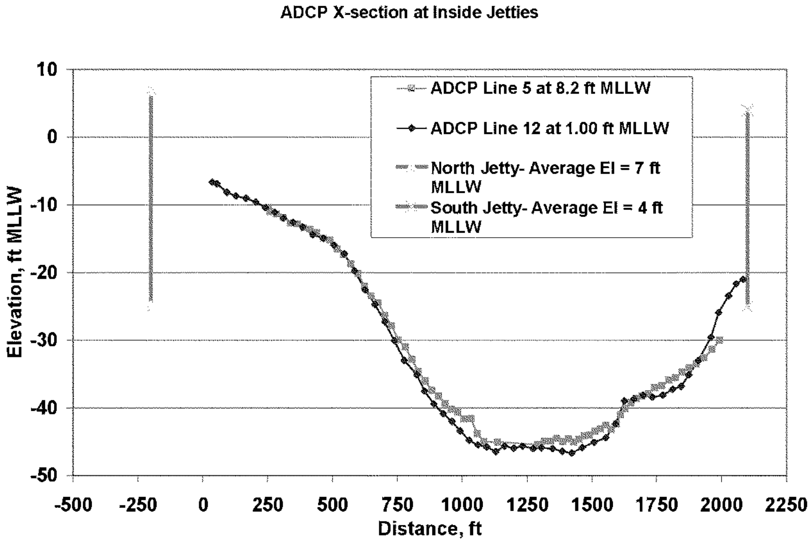



Figure 6. Cross section at Fort Pulaski

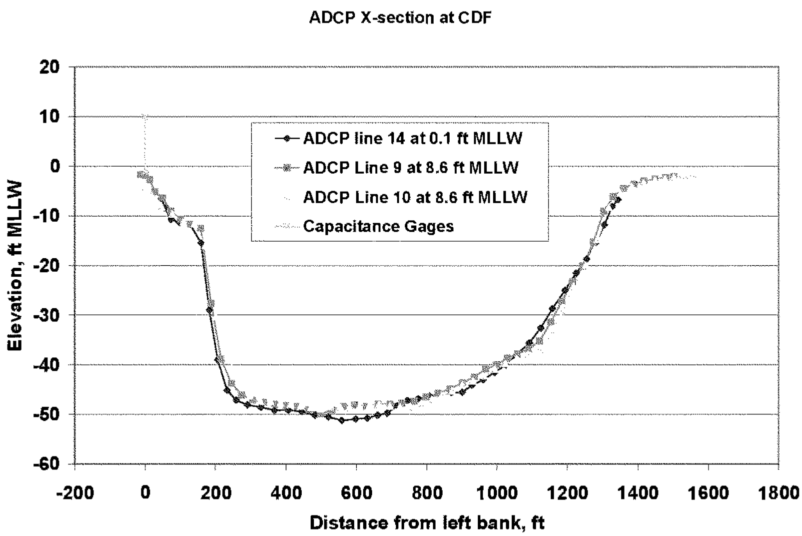



Figure 7. Cross section at CDF

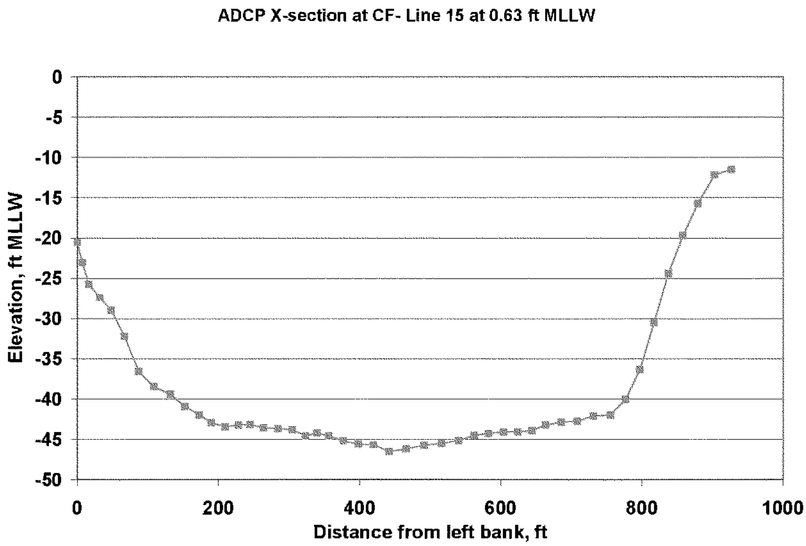



Figure 8. Cross section at City Front

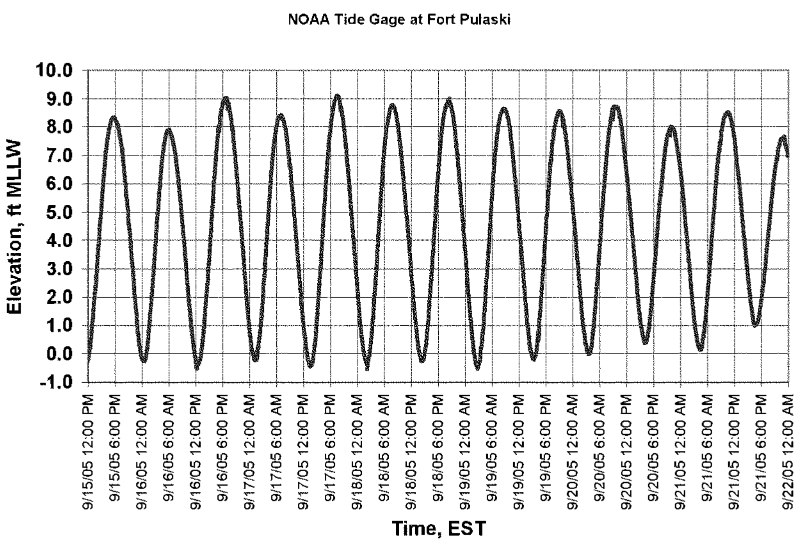



Figure 9. Tides at Fort Pulaski during field study.

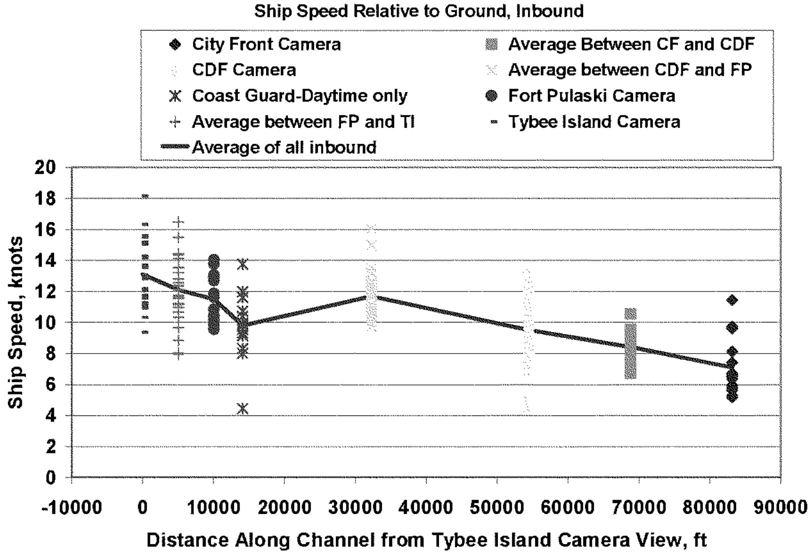



Figure 10. Ship speed along reach for inbound ships.

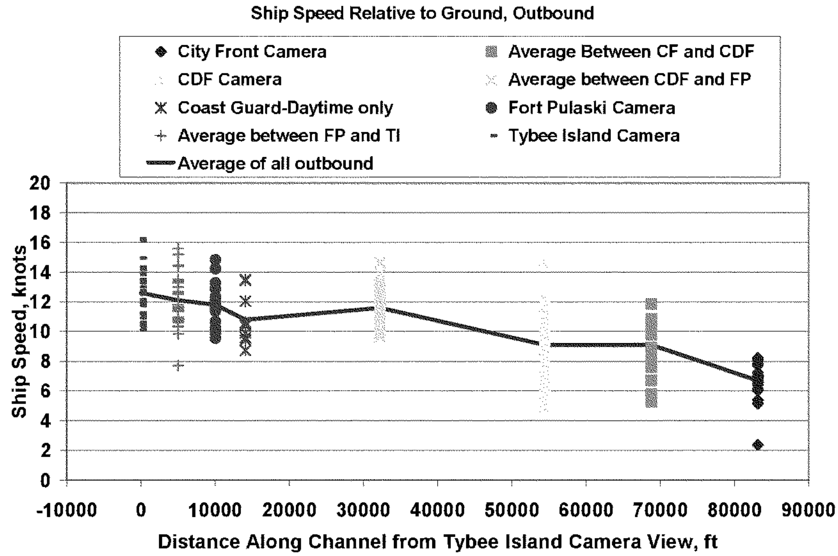



Figure 11. Ship speed along reach for outbound ships.

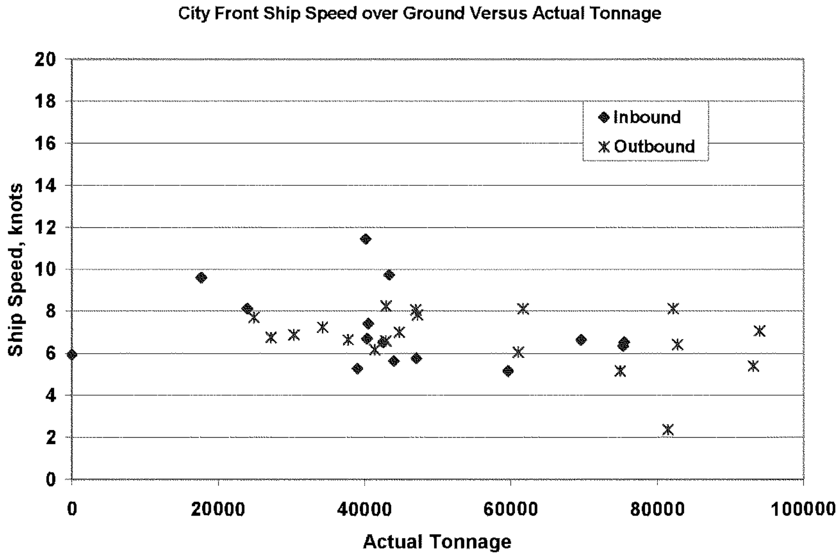



Figure 12. Ship speed versus ship size at City Front.

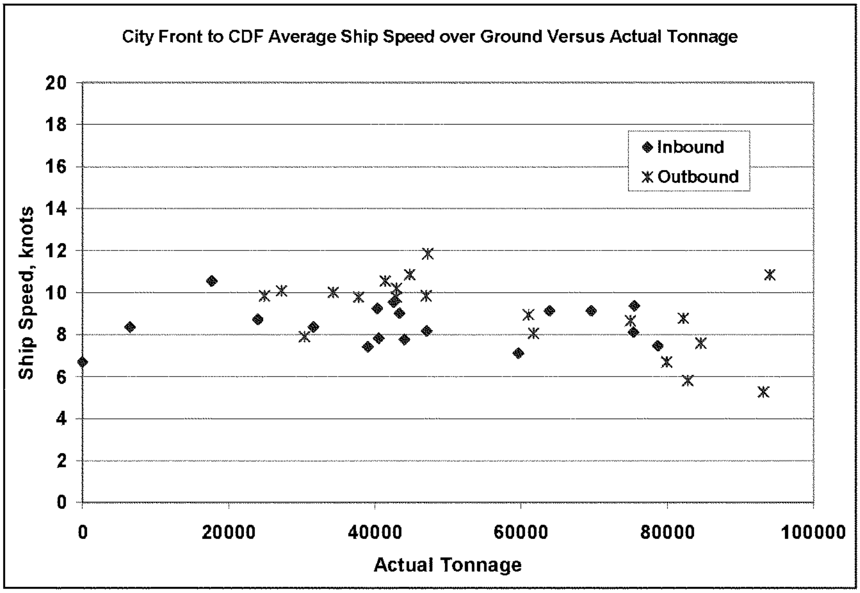



Figure 13. Ship speed versus ship size averaged over CF to CDF reach.

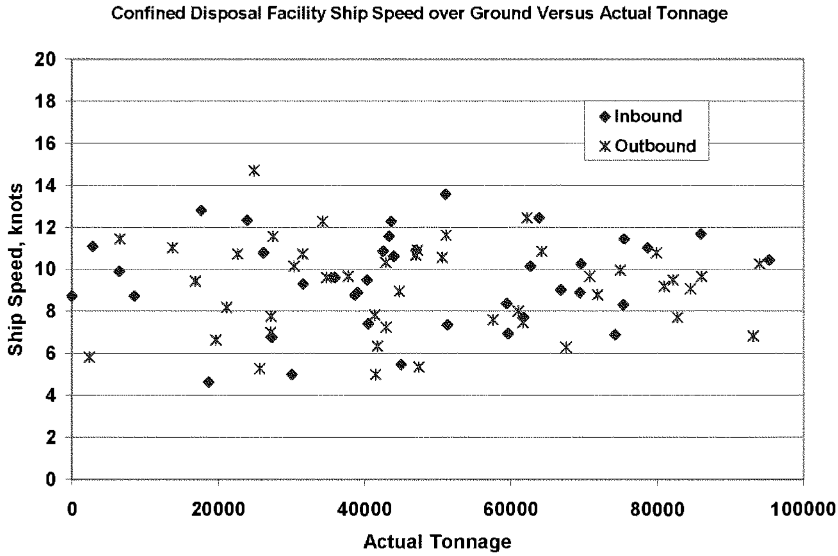



Figure 14. Ship Speed versus ship size at CDF camera.

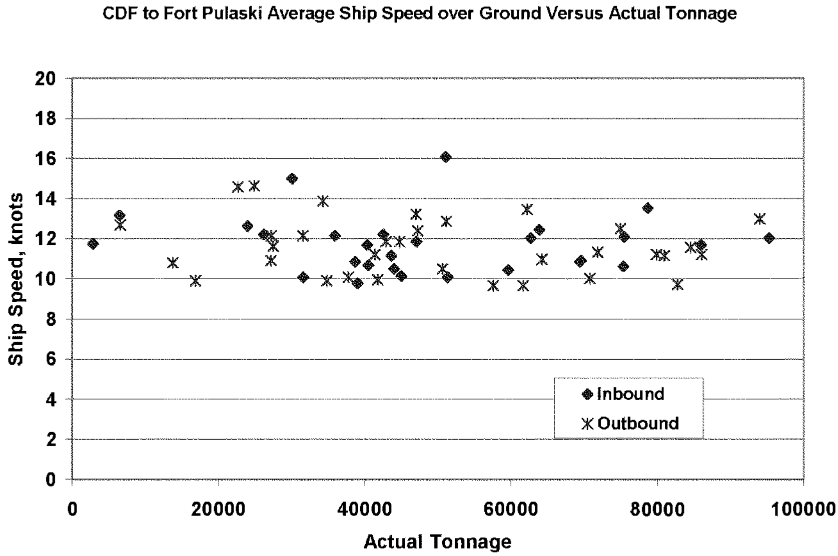



Figure 15. Ship speed versus ship size averaged over CDF to Fort Pulaski reach.

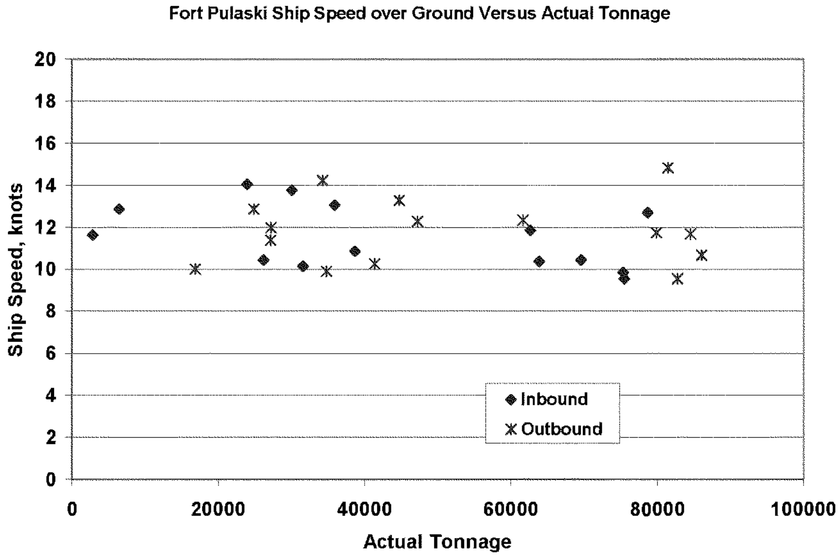



Figure 16. Ship Speed versus ship size at Fort Pulaski camera.

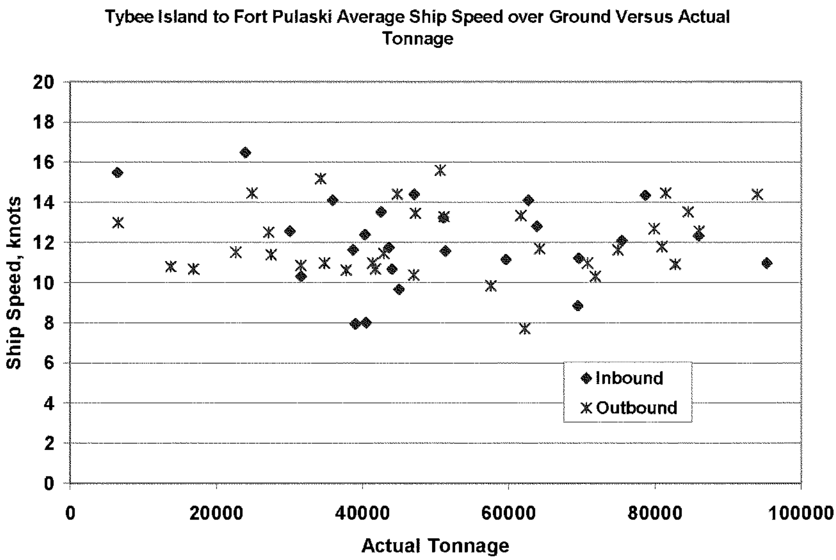



Figure 17. Ship speed versus ship size averaged over reach between Fort Pulaski and TI.

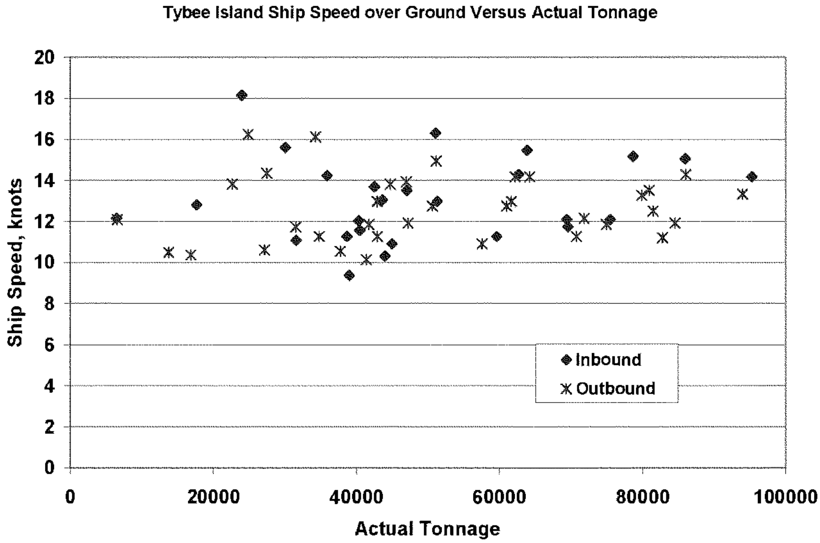



Figure 18. Ship speed versus ship size at Tybee Island.

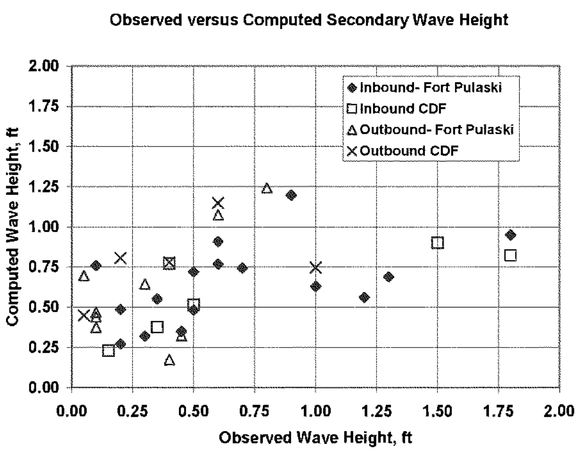



Figure 19. Observed versus computed short period bow and stern wave height using modified Gates and Herbich equation.

July 1, 2005

Joseph T. Hoke, Jr., P.E.
U.S. Army Corps of Engineers
Savannah District
P.O. Box 889
Savannah, GA 31402-0889

Dear Mr. Hoke,

We have reviewed the Savannah Harbor hydrodynamic and water quality models presented in *Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project* (SHEP) prepared by Tetra Tech, Inc. on May 20, 2005. The purpose of the review was to determine whether or not the present models are suitable to evaluate impacts resulting from proposed harbor deepening. The review included an interim meeting of the model review group in Atlanta on June 16-17, at which model performance was discussed in detail. The model review group identified a number of issues and concerns that should be investigated and resolved before the models are used for final project impact evaluations (see meeting summary attached below). Depending on the results of these investigations, model re-calibration may be necessary.

Our position is final impact evaluations should wait until these investigations are complete, the model review group has the opportunity to consider the results, and any required model adjustment is performed. In the near term, the Department is not opposed to the use of the present models for preliminary screening purposes.

In addition to the concerns listed in the attached document, the following items would need to be addressed before the Department could accept the models for use in final impact analysis:

1. The hydrodynamic model projects too little salt water up the Middle River (see report figures J-21, J-23, K-21, and K-23). We understand that the neural network modeling linking the river segments to the marshes depends on salinity predictions at USGS-gaged locations on the Front and Little Back Rivers and not on the Middle River. However, stations MR-10 and MR-12R (and by extension, MR-12) were identified by the Federal agencies as important locations for the salinity calibration. We also note the model predicts Middle River is well mixed, so the model under-predicts salinity in Middle River in the mid-depth and bottom layers as well as the surface layer.

2. The report does not adequately account for the occasional, dramatic differences between predicted and observed dissolved oxygen which occur primarily in the 1997 confirmation simulation but also to some degree in the 1999 calibration simulation (see report figures P-1, P-3, P-11, P-5, Q-1, Q-2, Q-3, Q-4, Q-5, and Q-6). We understand that, in some cases, these differences are thought to reflect instrumentation problems with the dissolved oxygen monitoring equipment rather than inaccuracies in the water quality model. We understand that the dissolved oxygen dataset is currently being screened and possibly corrected when sampling error is identified. This effort should be concluded and documented, and the model and report should be modified as necessary. Finally, any significant differences between model and data that remain should be acknowledged and explained to the extent possible.

3. The potential impact of oxygen demand loading from the dredge spoil areas has not been identified. Loadings from the dredge spoil areas should be addressed by the future Total Maximum Daily Load (TMDL) rather than the SHEP if project alternatives do not increase loadings to the Savannah or Back Rivers. However, if project alternatives are in fact expected to increase loadings above existing levels, then any impacts on dissolved oxygen should be addressed by the SHEP.

4. Our acceptance of the hydrodynamic and water quality models for water quality certification will depend on more than the ability of the models to evaluate water quality impacts. In order for the Department to accept the models for certification purposes, we would also have to determine that the hydrodynamic and water quality models satisfy the requirements of the wetlands and fisheries impact evaluations. It is our understanding that these requirements have not yet been established. Until they are, we cannot give final acceptance of the hydrodynamic and water quality models for water quality certification.

Overall, we find the model calibration results to be encouraging. The Savannah Harbor system is complex, and the present models represent this complex system very well in many respects. We anticipate the issues identified above and in the attached meeting summary can be addressed prior to final impact evaluations. We appreciate the opportunity to review and comment on the models and look forward to continued cooperation on this important matter.

Sincerely,

Alton C. Boozer

Alton C. Boozer
Chief, Bureau of Water

ACB/wmc

**Savannah Harbor Expansion Model Review Meeting**
**June 16-17, 2005**
**Savannah Harbor Expansion Interagency Water Quality Team Meeting**
**June 17, 2005**
**Tetra Tech, Inc. – Atlanta, GA**

**Attendees:**
Roy Burke, GAEPD
Paul Lamarre, GAEPD
Wade Cantrell, SCDHEC
Bill Bailey, USACE Savannah District
Joe Hoke, USACE Savannah District
Jim Greenfield, USEPA Region 4
Paul Conrads, USGS (via phone)
Larry Neal, MACTEC
Margaret Tanner, MACTEC
Steven Davie, Tetra Tech, Inc.
Will Anderson, Tetra Tech, Inc.
Yuri Plis, Tetra Tech, Inc.

**Agenda:**
1. WASP model – consistency with enhanced grid and status of TMDL process
2. Status of calibration report from Tetra Tech
   - Issues/concerns from Federal and State agencies
   - Dr. Kim's (ITR USACE) comments
   - July 1, 2005 deadline for agency position
3. Application of the models for impact simulations (inputs and outputs)
   - Comments from states and other users

**I. Status of TMDL (Jim Greenfield):**
- EPA will now use one model for the harbor – enhanced grid
- WQ standard for dissolved oxygen still being developed, EPA headquarters is going to talk to GAEPD about proposing the standard
- SCDHEC will still have to develop a site specific criteria for SC waters
- Recruitment (fish) model will be used to develop the criteria values; being used in the Escatawpa River Estuary for the dissolved oxygen criterion (3.0 g/L); using daily dissolved oxygen values and comparing to acute and chronic limits
- 2004 loads being used to update the TMDL – using July, August, and September average DMR data – Jim send to MACTEC for review
- Riverside Power Plant decommissioned
- Kerr McGee immediate oxygen demand load is now removed
- Need to check heat loads with GA Power (MACTEC to verify this with GA Power)

**II. Issues and Concerns on Final Report on Hydrodynamic and Water Quality Models:**

1. Discussed Dr. Kim's comments and went around the table discussing issues and concerns from each agency/group represented.
2. Larry Neal summarized his organization's concerns in a handout.
3. The group then had a wide-ranging discussion of that included a number of issues. These are summarized in the next two sub-sections. The first paragraph is the group's attempt to develop categories for the comments that describe the amount of effort expected to address a concern. The second paragraph states the concern and the category of future effort (in bold) expected to address it. These issues should be considered further before using the models to identify impacts of the recommended plan.

**Ways to address concerns with the models and the reports**

The group categorized the concerns according to the level of action that is appropriate to fully address each concern. The following four categories were developed, roughly in order of the effort expected:

**A** Explain better in the report, no modeling action needed.
**B** Keep in mind when interpreting the model results.
**C** Additional sensitivity model runs are needed.
**D** Recalibrate / revise model.
(note: a "**C**" action could turn into a "**D**" action depending on the results)

**Summary of issues and concerns and actions to address each concern [option from above]:**

1. **[B]** Marsh water quality loads:
   a. **[A]** Inclusion in the enhanced grid
   b. **[A]** Equal comparison between the TMDL and enhanced grids
   c. **[C]** Is the CBODu too high?
   d. **[C]** Mass exchange – flows and concentration
   e. **[C]** Surface to bottom – CBODu vertical differences are a function of how marsh areas were loaded into the enhanced model
2. **[C]** Offshore boundary:
   a. Salinity 34 to 36 ppt versus 32.5 to 35 ppt
      i. Mass flux surface to bottom – may need to re-distribute at FR-26
   b. Dissolved oxygen saturation 95 to 105% versus 90%
   c. Temperature
   d. Larry Neal gave info "World Ocean Atlas 2001" with data
   e. CBOD decay rate – confirmed 0.5 multiplier on ocean cells
3. **[C]** Surface salinity:
   a. Model appears to under predict surface salinity on the Front River. How does this impact the marsh succession modeling? The EFDC will output salinity for the neural net application, which feeds the marsh succession model. Right now, the neural net is using the USGS gages located between the Talmadge Bridge and I-95, located on Front and Back Rivers. These gages are considered to be mid-depth. The EFDC model is

predicting salinity well at the bottom and at mid-depth but under predicting salinity at the surface.

4. **[A & B]** Ebb flows and currents:
   a. Under prediction of the ebb flows and currents on the Little Back and Back Rivers
5. **[A]** Water level at SR-17 on the Upper Savannah River
   a. Potential of adding marsh storage areas upstream of I-95 Bridge
   b. Show comparisons at the USGS Hardeeville gage (show plot)
6. **[C & A]** Global versus source-specific BOD decay rates
   a. Sensitivity of calibration
   b. Sensitivity on allocation scenarios (more for TMDL)
7. **[A]** Check all point sources and heat loads, especially Plant MacIntosh (MACTEC to verify)
8. [none] BOD loads from Corps' confined dredged sediment placement sites in SC and potential impacts on dissolved oxygen (future TMDL issue)
9. **[A]** Grid convergence test:
   a. Show results of the TMDL grid with the same depth;
   b. Show results on TMDL grid, enhanced grid, and convergence grid on the same plots;
   c. Show comparisons on the Middle and Little Back Rivers;
   d. Perform moving average of results to reduce tidal noise; and
   e. Quantification of grid convergence test results.
10. **[B & C]** Delay in EFDC model salinity results at US FWS Dock comparisons of model versus data
11. **[A]** Clearer description of 1999 versus 2002 bathymetry and why the 2002 bathymetry data is representative of 1997 through 2003 conditions in the harbor
12. UA/SA Analysis: The group concluded that the inability to run the models over a 7-year duration was the result of synthetic data that was developed to fill in a data gap around December 2000. The group concluded that the inability of the model to run over the entire 7-year period of data does not reflect on the structure of the model or its performance, and should not be a consideration of the model's usefulness for its intended purposes of predicting impacts of the Savannah Harbor Expansion Project, developing a dissolved oxygen TMDL, or permitting point source discharges.

## III. Model Application for Identifying Impacts to Water Quality.

The Interagency Water Quality Team then discussed application of the models for identifying impacts to water quality from the Savannah Harbor Expansion Project.

1. The impact evaluation runs should use a varying flow, rather than the uniform flow that was previously proposed by Savannah District.

2. Dissolved oxygen should be reported at increments of 0.1 mg/L, rather than the 0.5 mg/L that was proposed by Savannah District.

3. Model results in hourly outputs will be sufficient.

4. BOD loads should use the loads reported in 2004, rather than what was reported in 1999. The loads should be averaged over the entire summer. The loads should be run through both the RIV1 model and WASP.

5. Potential impacts to the assimilative capacity of the harbor would need to be identified. This should be performed with the following model inputs:

- August 1999 tides, flows, temperature, and salinity
- Loads from upstream sources should include CBOD and ammonia

NOTE: A. flows would be varying, rather than uniform as previously proposed
B. flows measured at Clyo are considered representative of the critical conditions and the 7Q10 flow did occur during 1999

6. Natural condition runs would need to be performed. This should be performed with the following model inputs:

- Without point sources – no heat and BOD loads in harbor and upstream
- Without nonpoint sources – no stormwater loads, but marshes should be included
- Existing bathymetry (as expressed in calibrated model)

7. Further identification of potential impacts to temperature would be developed as part of the impact runs for Fisheries, which will include runs over January,

8. For water quality impact evaluation runs, the following scenarios would need to be evaluated:

A. Natural condition without deepening
B. Natural condition with deepening
C. 2004 point source loads with deepening
D. 2004 point source loads without deepening

9. The Corps expects to perform the following runs to evaluate potential effects of deepening the navigation channel:

1. existing = 42 feet
2. 44 feet
3. 45 feet
4. 46 feet
5. 47 feet
6. 48 feet

10. The team recognized that the various scenarios and model outputs that had been requested will require a great deal of effort and would produce a very large quantity of information. The team also recognized that some of that information may, ultimately, not be useful. To minimize the time spent developing, presenting, and interpreting model outputs, the team recommended they meet again as soon as the initial water quality model runs had been completed. The hope is that the initial outputs would show what type of information is truly needed to identify impacts from the proposed actions and

differentiate between the plans. This would allow other information to no longer be developed, presented or interpreted. The team recommended that the initial runs consist of (A) 2004 point source loadings, (B) natural conditions, and (C) maximum permitted loadings. Each of these three scenarios should be run for both the existing channel depth and the maximum deepening being considered.

Prepared by:
Steven Davie
Tetra Tech, Inc.

**Georgia Department of Natural Resources**
2 Martin Luther King, Jr. Drive, S.E., Suite 1152 East Tower, Atlanta, Georgia 30334-9000
Noel Holcomb, Commissioner
Carol A. Couch, Ph.D., Director
Environmental Protection Division
404/656-4713

July 1, 2005

Mr. William Bailey
U.S. Army Corps of Engineers, Savannah District
Post Office Box 889
Savannah, Georgia 31402-0889

Subject: Savannah Harbor Expansion Project
Harbor Models Suitability

Dear Mr. Bailey:

The U.S. Army Corps of Engineers is currently developing a Tier II EIS for the proposed Savannah Harbor Expansion Project (SHEP). To identify and assess potential environmental impacts complex hydrodynamic and water quality models have been developed. The development process included representatives from four Federal Agencies, Georgia EPD and South Carolina DHEC, and stakeholders representing the Harbor dischargers. Model development recently culminated with the issuance of the final report: Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project dated May 2005.

On June 16 and 17 of this year the Savannah Harbor Expansion Interagency Water Quality Team, including representatives from EPD, met to discuss comments on these models and unresolved issues. These deliberations were summarized in the minutes of this meeting provided to each Team member on June 27th. In brief, the Team agreed that the models were ready to use for screening Harbor deepening alternatives. However, the Team added that the remaining issues summarized in the minutes should be addressed and resolved before quantifying specific impacts. Based on recommendations from my technical staff, Georgia EPD concurs with the Team's assertions.

Sincerely,

Linda MacGregor

Linda MacGregor, P.E.
Branch Chief
Watershed Protection Branch

cc: Keith Parsons

# United States Department of the Interior

FISH AND WILDLIFE SERVICE
176 Croghan Spur Road, Suite 200
Charleston, South Carolina 29407

DE
PM-C

July 5, 2005

w/encl.
DE
DC
DX
DP

Colonel Mark S. Held
District Engineer
U.S. Army Corps of Engineers
P.O. Box 889
Savannah, GA 31402-0889

Dear Colonel Held:

The Fish and Wildlife Service (Service) has completed a review of the report "Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project" prepared by Tetra Tech, Inc. for the U.S. Army Corps of Engineers, Savannah District. The U.S. Geological Survey (USGS) is assisting the Fish and Wildlife Service (Service) in evaluating the hydrodynamic and water quality models for the Savannah Harbor Expansion Study. Copies of the USGS letter and review comments to the Service are enclosed for your consideration.

The three-dimensional hydrodynamic model selected for this project is based on the Environmental Fluid Dynamics Code (EFDC), a physics-based turbulence closure model that has been applied in a number of estuarine and riverine systems in the southeastern United States. The Savannah Harbor expansion version of the EFDC is based on the model originally developed by Tetra Tech for the Environmental Protection Agency to determine the total maximum daily load for dissolved oxygen in the lower Savannah River. This model and the associated water quality model have been improved with an enhanced grid and other modifications.

On June 16-17, Federal and State Agencies met with the model developers to discuss their comments and concerns on the models. At the meeting, the concerns of each agency were identified along with recommended approaches to address the concern. Recommended approaches included additional explanation in the report, additional sensitivity simulations, and recalibration/revision of the model. In addition, USGS documented a number of these issues, as well as other issues, in their specific review comments. It is anticipated that most of the concerns could be addressed with additional documentation for the report and sensitivity runs. However, additional sensitivity runs may indicate that model modification could significantly improve performance. In that case, additional model calibration and revision would be needed.

The hydrodynamic and water quality models are the critical impact assessment tools for the entire harbor expansion project. Most of the other impact assessments will be based on predictions from the model. Therefore, it is imperative that the hydrodynamic model be as reliable as possible and scientifically defensible. However, in applying these tools, the users must be cognizant that any model in a complex system, such as the Savannah estuary, will have limitations in how well it will predict reality. Therefore, even if a model is judged to be acceptable for use, there will always be some level of uncertainty in its performance. One important area of uncertainty will be in evaluating the predicted effects of mitigation plans involving flow diversions from the Front River to the Middle and Back River (see USGS comment number 9).

An adaptive management approach, as described in Corp's Environmental Circular 1105-2-409, "Planning in a Collaborative Environment," dated 31 May 2005, is a way to deal with uncertainty. This document discusses the necessity of a well designed monitoring program as a cornerstone to adaptive management. The document also discusses phased project implementation, in which the initial phase is constructed and monitored, and a future phase may be constructed as planned, modified, or not constructed. The decision on the future phase is based on the monitoring results and defined decision criteria.

For the Savannah Harbor deepening Project, phased implementation could involve deepening of the navigation channel by an identified increment with appropriate mitigation measures, followed by monitoring and a defined decision process. This approach would require collection of adequate pre-project baseline water quality and biological data prior to project implementation. Much of this data has been collected but data gaps need to be identified and filled. Then, a comprehensive post-project monitoring plan would need to be developed and implemented so that project impacts and mitigation effectiveness can be documented. The monitoring data could be compared to previous model predictions to determine the adequacy of impact predictions and mitigation measures. We recommend further discussion of this approach as project planning continues.

Based on the information reviewed, we would support use of the hydrodynamic and water quality models for initial evaluation of Savannah Harbor deepening impacts. If the additional sensitivity runs indicate that performance could be significantly improved, then additional model calibration and revision will be recommended before definitive impact evaluation and mitigation assessment.

A great deal of time and money has been expended to develop an acceptable model and we are hopeful that the additional work can be completed and applied to successfully conclude this effort. We appreciate the efforts of you and your staff to coordinate this project with the Service

If you have any questions or wish to discuss this issue, please contact Ed EuDaly at 843-727-4707 x 220.

Sincerely,

Timothy N. Hall
Field Supervisor

TNH/EME

cc:

Mr. John Hefner, U.S. Fish and Wildlife Service, Atlanta, GA
Mr. Tom Prusa, U.S. Fish and Wildlife Service, Savannah Coastal Refuges, Savannah, GA
Mr. Gerald Miller, Environmental Protection Agency, Atlanta, GA
Mr. Prescott Brownell, National Marine Fisheries Service, Charleston, SC
Mr. Paul Conrads, U.S. Geological Survey, Columbia, SC

# United States Department of the Interior

U.S. GEOLOGICAL SURVEY

South Carolina Water Science Center
Stephenson Center, Suite 129
720 Gracern Road
Columbia, SC 29210-7651
Phone: (803) 750-6100
FAX: (803) 750-6181

June 28, 2005

Mr. Ed EuDaly
U.S. Fish and Wildlife Service
Suite 200
176 Croghan Spur Road
Charleston, SC 29407

Dear Mr. EuDaly,

I have completed my review of the report "Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor-Final Report May 20, 2005" prepared by Tetra Tech (Tt) for the U.S. Army Corps of Engineers – Savannah District. The report and its appendices describe the hydrodynamic, salinity transport, and dissolved-oxygen models and their application, calibration, validation, and confirmation to the Lower Savannah River and Harbor. The Environmental Fluid Dynamic Code (EFDC) model was originally developed for U.S. Environmental Protection Agency-Region IV by Tt for determining the TMDL for dissolved oxygen for Savannah Harbor. A previous review of the EFDC application to Savannah Harbor (Paul Conrads, written communication April 24, 2004) noted that although the modeling efforts by Georgia Ports Authority (GPA) and EPA share common goals of a defensible model, there were differences in their applications and goals that would need to be resolved if one hydrodynamic and water-quality model would be used to meet the needs of Harbor Expansion and TMDL determination.

The report represents the refinement of the EFDC model. The report addresses many of the comments and concerns from the previous review of the TMDL model report but more detailed descriptions or additional sensitivity runs are required to fully document the application and performance of the model. My major concern with the model is its inability to simulate ebb-tide currents in the Front River and ebb-tide stream flows throughout the system. In addition, there are areas in the model domain in the upper reaches of the Little Back River where the model does not simulate reversing tidal flows. Although these flows are small, this area of the model domain is significant if mitigation scenarios include diverting flows from the Front River the Middle and Little Back Rivers. My specific comments on the report are attached.

A Savannah Harbor Expansion Model Review meeting was held June 16-17 for Federal and State Agencies to discuss their comments and concerns with the model developers. During that meeting, the salient concerns of each agency were identified along with approaches to address the concern. Approaches included additional explanation in the report, explanation in the interpretation of mitigation scenarios results, additional sensitivity simulations, and recalibration/revision of the model. The majority of the concerns could be addressed with additional explanations in the report and sensitivity runs. Depending on the results of the sensitivity runs, additional model recalibration/revision may be warranted. A summary of the Savannah Harbor Expansion Model Review Meeting is attached.

Knowing there are inherent errors and uncertainties in the model, special attention should be given to the selection of input conditions for impact and mitigation scenarios and in the evaluation of the results. Using historical input conditions instead of synthetic conditions will allow the evaluation of the error of the baseline simulation to actual historical conditions. Using synthetic boundary conditions (computed tidal water level, constant or average flows, and statistically derived meteorological conditions) does not allow for the evaluation of the baseline model predictions to actual conditions. The model presented in the report can be used for making preliminary evaluation of the impact of the potential deepening of the harbor. In the event that sensitivity simulations indicate that model recalibration/revision is warranted, it is recommended that final evaluations of harbor deepening impacts and mitigation scenarios should proceed after the needed revisions are made.

The model development and review for Savannah Harbor Expansion Model has been a long process. It is encouraging to see the model development and review in the final stages of producing an acceptable model. We appreciate the opportunity to participate in this process. The goal of all of the participants has been to produce the best tool for determining future impacts of the Savannah Harbor Expansion Project on Savannah River resources. Please call me at (803) 750-6140 if you have any questions or need additional information.

Sincerely,

Paul A. Conrads
Hydrologist

Review Comments

by Paul Conrads , U.S. Geological Survey, Columbia, SC

On
"Development of the Hydrodynamic Model and Water Quality Models for the Savannah Harbor Expansion Project"
prepared by Tetra Tech (Tt)
for the U.S. Corps of Engineers–Savannah District

1. The report did document convergence testing to evaluate the adequacy of the spatial and temporal resolution of the model grid and time step used in the model. Additional documentation is needed to show that the convergence test is adequate. figure A-3 shows differences in salinity predictions between the two simulations of 1-2 part per thousand (ppt). More important than the small differences in the predictions is whether there is a divergence between the two simulations. Although over sixty days are shown in Figure A-4, due to the resolution of the graph, it is difficult to see if the two simulations are diverging. Additional documentation should include results for sites in the Middle, Little Back, and Back Rivers. To show the two simulations diverge, a filter to remove the tidal signal could be applied to the results and displayed along with the simulations.

2. The report did document the sensitivity of the EFDC and WASP7 to selected parameters and boundary inputs. For the EFDC model, eight parameters and inputs are listed but only the results only 4 parameters or inputs are presented. The results of all eight parameters and inputs should be included in the tables. It is worth noting that the results of the sensitivity of the boundary freshwater flow and salinity for certain sites are non-linear. For example, in figure 12-1 the salinity response for a 1 ppt salinity change is not evenly distributed around the baseline simulation. These results are not unexpected but show the importance of carefully selecting boundary conditions for mitigation scenarios. For the sensitivity of the water-quality model, additional sites in the Middle, Little Back, and Back Rivers should be shown.

3. A large effort was expended to improve the bathymetry from the original application of EFDC for the TMDL model. Many of the improvements in the calibration of the model can be attributed to the refined bathymetry. Figure 4-6 and 4-7 compares cross-sections for two locations from the 1999 and 2002 bathymetric surveys. Although there are the obvious similarities between the two cross sections, there are differences of 2-3 feet in the depth (figure 4-6) and 100 feet in the width (figure 4-7). These differences indicate that there may be a 5 to 10 percent increase in the area in the 2002 survey. If the volume of the system (as represented from the two surveys) is different, is it appropriate to use the 2002 bathymetric data for the calibration data set of 1999?

4. In the description of the offshore water-level boundary (page 29), it is unclear whether USGS or National Ocean Service (NOS) data is being used. The text references a NOS gage at Fort Pulaski but gives a USGS station number.

5. In the discussion of SOD and reaeration ($K_2$) (Section 8.4.3 and 8.4.4), there are two plots, figures 8-12 and 8-13, that compare SOD and $K_2$ rates in different locations of the system. These values can vary significantly through the system. Unfortunately, the figures are not referenced in the text and should be discussed.

6. The following comments on the model performance and comparing the measured data and model predictions for selected stations. The EFDC was developed using the data collected by GPA and the USGS. Problems with the GPA data sets were noted in the previous report on the EFDC application. Many revisions to the data released by GPA have occurred with the development of the two models. Although not a technical concern with the EFDC application, one must remember that there could be significant error with the measured data being compared to the model predictions.

7. Water-level predictions in the model are generally good with the better simulations in the lower reaches of the Front and Back Rivers. Farther upstream, the model over-predicts the tides and under-predicts the higher water elevation of the riverine flows. For example, figure B-12 (page B-8) shows water-level calibration at I-95 (station SR-14) and the model is over-predicting the high tides by as much as a half a meter. Figure B-13 (page B-9) shows water-level at station SR-17. The measured data show little tidal variation (less than 0.3 meters) and higher water-surface elevations characteristic of the more riverine dominated segments of the system. The model simulates a tide range of approximately a foot and the mean water levels under-predicts the measured data by a meter. The model does dampen the tidal wave between SR-14 and SR-17 by a meter. Site SR-14 (I-95) is the upper reaches of concern for the marshes in the vicinity of the Savannah National Wildlife Refuge (SNWR) so model error in the upper reaches have less direct impact on the predictions around SNWR.

8. The velocity and flow predictions in the model generally under-predicts the ebb-tide currents and flow. This is most clearly seen in the plots of the bottom currents for FR-04 and FR-06 (figures D-2 and D-4, respectively). The inability to predict the ebb-tide currents may be related to the model over-predicting tidal dynamics in the upper reaches and under-predicting riverine dynamics (see comment 7). Ebb-tide currents and flows appear to be difficult to accurately predict in this system with the recently applied three-dimensional models. The TMDL EFDC model and a previous model developed by GPA also under-predicted ebb-tide currents and flow.

9. Evaluation of the flow simulations is more difficult due to the scarcity of the data. Modeling flows in the Middle, Little Back, and Back Rivers is very difficult due

to the complexity of this branched network of shallow tidal rivers and creeks. Lack of the continuous tidal flow data and inflow data from Union Creek make the modeling effort more difficult. The flow predictions have improved from previous applications of the model but are only satisfactory. Possible mitigation scenarios include diverting a portion of the flow from the Savannah River to the Middle and Little Back Rivers. The inability of the model to capture the ebb-tide flow dynamics in these reaches should be remembered while interpreting scenarios where increased flows in the vicinity of SNWR are significant.

0. The model generally predicts the overall trend of the salinity dynamics of the system well. One behavior that appears at a few of the sites (BR-05 bottom, BR-07 surface, FR-06 bottom, FR-22 bottom, MR-12R surface – figures J-10, J-11, J-13, J-15 J-23) is the model over-predicting low-tide salinity concentrations. When the low-tide salinity is over predicted, usually the 50$^{th}$ percentile values are also over predicted although the high-tide salinity intrusion is under predicted.

11. There is a significant lag in the recession of the salinity intrusion for Lucknow Canal (figure J-27, page J-18). The model is able to predict the magnitude of the salinity intrusion on September 22, 1999 but exhibits a 5 or 6 day lag on the recession. For the next intrusion on October 9, 1999, the lagged is carried through to the peak intrusion and recession of the salinity. The lag may be a result of the way the marshes are schematized in the model as large storage volumes. As this volume increases in salinity, there is a reservoir (or storage) of higher salinity water that takes quite a few tidal cycles to flow back into the system. Similar behavior is seen at the U.S. Fish and Wildlife dock (figure J-26, page J-17), although not as pronounced as at Lucknow Canal.

12. The Middle, Little Back, and Back Rivers are considered well mixed systems. The salinity simulations support this and there are not significant vertical salinity gradients in these areas. Many of the water-quality constituents (for example CBODu in figures O-11-14) show significant stratification that is uncharacteristic of a well mixed system. The stratification is probably a result of how the marsh loads are input into the system and the lack of mixing between the vertical layers in the model.

13. A seven-year water-level and salinity simulation (1997-2003) were presented to confirm the performance of the EFDC model to the long-term USGS data. The salinity simulations are particularly useful in evaluating how well the model is able to capture the salinity dynamics through the full historical range of flows for the Savannah River. The 7-year period includes the high flows of the El Nino in 1998 and the recent extend drought. Figures M-3 and M-4 show the 7-year comparison for Fish and Wildlife Dock and Luchnow Canal. In both plots, the model is able to capture the increased salinity intrusion during the extended 5-year drought and the freshening of the system with the end of the drought at the end of 2002.

14. Unlike the salinity model where there are long-term data sets for flows, offshore water levels and salinities to evaluate the performance of the model over the full range of historical conditions, the DO model only has a limited amount of data during the summer of 1997 and 1999 to calibrate and evaluate the model. The DO model is calibrated to a small range of flow, temperature, and tidal conditions. Unfortunately, the limited characterization of input loads, especially for the offshore boundary and marshes, the incompleteness of the dissolved-oxygen record, and the limited number measured rates, makes it difficult to develop a clear understanding of the DO oxygen dynamics of the system. The situation for Savannah with limited measurements of field conditions, rate kinetics, and input characterizations is not atypical of the development of DO model to complex estuarine systems. Given the above caveats, the model should be used to make evaluations of relative impacts and should not be used for making absolute impacts on DO.

15. There appears to be a large source of oxygen-consuming constituents in the system in August 1999. The measured data for stations Fr-21, FR-06, FR-22, and BR-05 show ammonia values of greater than 0.12 mg/L (Appendix N, figures N-3, N-4, and N-7) where the typical background concentrations are between 0.02 and 0.05 mg/L. Unfortunately, the source of the input of ammonia is not characterized in any of the point-source and marsh inputs to the model. The transformation of ammonia to nitrate consumes a large amount of oxygen. Although the concentrations are small, the volume of water is large so the amount of oxygen consumed during this 14-day period might not be insignificant. Without knowing the source of the ammonia load, the model developers are correct in not fabricating a load to match the in stream ammonia data. The comment is made to illustrate the difficulty and limitations of the data and the model to fully capture the DO dynamics of the system.

16. It is difficult to get an appreciation of the relative contributions of the BOD and nitrogen loading input to the system. A bar or pie chart the average or total load from point sources, storm water, ocean, upstream, and marsh loading would be helpful.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southeast Regional Office
263 13th Avenue South
St. Petersburg, Florida 33701

August 17, 2005

Colonel Mark S. Held
District Engineer
Department of the Army, Corps of Engineers
P.O. Box 889
Savannah, Georgia 31402-0889

Dear Colonel Held:

The National Marine Fisheries Service (NMFS) has reviewed the May 25, 2005, report titled "Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project" (Models) provided by Mr. Joseph Hoke of your staff. We have coordinated with U.S. Fish and Wildlife Service and U.S. Geological Survey staff and we have reviewed their technical comments and recommendations.

Development of the Models has been a lengthy process with extensive interagency technical review steps. Based on our review of the report and the comments of the review team members, we believe that the Models will be valuable for use in assessing large-scale impacts to estuarine habitats in connection with the Savannah Harbor Expansion Project. At the same time, we note that the information produced by any mechanistic model cannot fully negate the importance of other science-based environmental assessments. We also note that continuous development and adaptation of the model will be needed once the model runs and outputs are measured against real observed changes in the ecological system that is being studied.

As noted by the U.S. Fish and Wildlife Service in their July 5, 2005, comment letter, an adaptive management approach, as outlined in the Corps' planning guidance (EC-1105-2-409, May 31, 2005) may be appropriate for implementation of the Savannah Harbor Expansion Project and associated environmental mitigation and enhancement features. An adaptive approach, facilitated by careful application of the Models, integrated with a well designed long-term environmental monitoring program, should be considered by the Corps, Georgia Ports Authority, and the interagency team.

NMFS supports application and continued development of the Models for the Savannah Harbor Expansion Project. We appreciate the opportunity to work with you and your staff during development of the Models, and we look forward to their application.

Please direct related questions or comments to the attention of Mr. Prescott Brownell at our South Atlantic Branch Office. He may be reached at P.O. Box 12559, Charleston, South Carolina 29422, or at (843) 953-7204.

Sincerely,

Miles M. Croom
Assistant Regional Administrator
Habitat Conservation Division

cc:
GADNR
SCDNR
USFWS

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 4
ATLANTA FEDERAL CENTER
61 FORSYTH STREET
ATLANTA, GEORGIA 30303-8960

DE
PM-C

AUG 2 5 2005

Colonel Mark S. Held
District Engineer
Savannah District
P. O. Box 889
Savannah, GA 31402-0889

cf: DE
DC
DP
DX

Subject: **Final Report - *Hydrodynamic and Water Quality Model for the Savannah Harbor* [May 20, 2005]**

Dear Colonel Held:

The U.S. Environmental Protection Agency, Region 4 (EPA) has completed its review of the subject report prepared by Tetra Tech (TT) for the U.S. Army Corps of Engineers - Savannah District (District). The report and its appendices describe the hydrodynamic, salinity transport, and dissolved oxygen models being used to characterize ambient conditions in the Lower Savannah River and Harbor environs. These documents also discuss the specifics as to how these models will be applied to predict water quality impacts based upon changes in pollution loading and proposed Harbor dredging. The documentation also includes information related to model calibration, validation, and confirmation.

Because this river system is complex hydro-dynamically, it was necessary to develop these water quality assessment tools in an evolutionary manner. TT originally formulated the Environmental Fluid Dynamic Code (EFDC) model for EPA to use in determining the Total Maximum Daily Loading (TMDL) for dissolved oxygen conditions in the Savannah Harbor. TT has subsequently updated/modified this model with a higher resolution model to better evaluate the water quality impacts of the various harbor dredging scenarios to enhance the navigation channel.

While the above report addresses most of the comments/concerns cited by EPA in its previous review of the TMDL model report, we understand that a more detailed analysis is currently underway to further document the model's application/performance. Jim Greenfield of my staff has been involved in the on-going water quality modeling efforts and is confident that any remaining issues can be addressed after additional model sensitivity runs are performed and evaluated.

The model development and review for upgrading Savannah Harbor has been a long and demanding process for all stakeholders. However, it is encouraging that we are in the final stages of producing an acceptable model for use in making the critical water quality decisions regarding this Harbor project and the TMDL. We will continue to provide support for the successful completion of this water quality modeling effort which is a priority for both of our Agencies.

Sincerely,

James D. Giattina, Director
Water Management Division

South Carolina Water Science Center
Stephenson Center, Suite 129
720 Gracern Road
Columbia, SC 29210-7651
Phone: (803) 750-6100
FAX: (803) 750-6181

February 28, 2006

Mr. Ed EuDaly
U.S. Fish and Wildlife Service
Suite 200
176 Croghan Spur Road
Charleston, SC 29407

Dear Mr. EuDaly,

I have completed my review of the report "Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor-Final Report January 30, 2006" prepared by Tetra Tech (Tt) for the U.S. Army Corps of Engineers – Savannah District. This report and its appendices is the final report from the draft report we commented on in July 2005. The emphasis of my review focused on the predictive ability of the model in the vicinity of the Savannah National Wildlife Refuge (SNWR). Changes to the model since the review of the previous draft have improved the model. Water-level predictions in the upper reaches at Station SR17 have significantly improved and demonstrate the model appropriately simulates the riverine and tidal influences on water level in this area. The salinity predictions in the Middle and Little Back Rivers also have been improved.

I assumed that the comments from the previous review of the draft report would be addressed in this report. Four of our comments were not addressed. Two of the comments were requests for results from the convergence testing and sensitivity analysis to be shown for locations in the vicinity of the SNWF. The other two comments were a request for clarification of the source of Fort Pulaski data and a figure summarizing the relative contribution of loading of oxygen-consuming constituents for the model. Addressing these comments would not have required significant resources. For the convergence testing and sensitivity analysis, the request was only to present results for additional sites rather than additional testing and analysis. For the clarification of data sources, rewording of a sentence would have be sufficient to address the comment. For a summary of the loading to the system, one additional figure needed to be presented. It may be that my assumption that all the comments would be addressed in this report is incorrect and the comments will be addressed in a separate or subsequent document.

There are two areas where I have concerns about the predictive ability of the model and using model results for various mitigation scenarios. The flow simulation for the Middle and Little Back River often do not simulate reversing flows although the data from 1999 show reversing flows. Similar concern is expressed for the ebb current flows on the Front River. These concerns also were communicated in our previous review of the model. The latest version of the model does not make any significant improvement in these areas. Also of concern are the simulations of dissolved-oxygen concentrations from the model. The predictions will need to be used with great caution. The ability of the model to capture the overall trend of the dissolved oxygen, as represented by the coefficient of determination ($R^2$), indicated that only three of the 17 sites evaluated were able to explain over 50 percent of the variability in dissolved-oxygen concentration (Table P-2). The majority of sites (9 of 17) explained 25 percent, or less, of the variability. The results for the Savannah River Estuary Model are not atypical of water quality models of other Southeastern Estuarine system and reflect the difficulty in modeling these types of system. The challenge is in determining how to interpret and utilize results from a model with known limitations to its predictive ability for certain parameters.

The Savannah River Estuary is a complex system to measure, analyze, and ultimately, to predict. The data collection and modeling effort, by both Applied Technology and Management and Tetra Tech, over the past ten years has demonstrated the difficulty of the monitoring and modeling the system. The model and the report demonstrate there is a limited understanding and modeling ability of the flow/velocity dynamics in the Middle, Little Back, and Back Rivers and of the dissolved-oxygen dynamics for the system as a whole. These limitations demonstrate the need for continued monitoring and analysis of the system to improve on our understanding of the system. The limitations also demonstrate the need for an adaptive management approach to accommodate further understanding of the system.

The model development and review for Savannah Harbor Expansion Model has been a long process. The goal of all of the participants has been to produce the best tool for determining future impacts of the Savannah Harbor Expansion Project on Savannah River resources. Despite the limitations of the model, the model presented in the report is the best currently available model of the system. Please call me at (803) 750-6140 if you have any questions or need additional information.

Sincerely,

Paul A. Conrads
Hydrologist

Enclosure

Review Comments

by Paul Conrads, U.S. Geological Survey, Columbia, SC

On
"Development of the Hydrodynamic Model and Water Quality Models for the Savannah Harbor Expansion Project FINAL January 30, 2006"
prepared by Tetra Tech (Tt)
for the U.S. Corps of Engineers–Savannah District

1. From our previous review (June 28, 2005), the following comments do not appear to have been addressed:
    a. Comment 1 on the convergence testing: "Additional documentation should include results for sites in the Middle, Little Back, and Back Rivers." Only results from the original three sites on the Savannah and Front River were shown in latest report.
    b. Comment 2 on the sensitivity analysis: "For the sensitivity of the water-quality model, additional sites in the Middle, Little Back, and Back Rivers should be shown." Only results on the Savannah and Front River sites are either presented in the tables or in the figures. No results are presented for sites on the Middle, Little Back, and Back Rivers.
    c. Comment 4. It is still unclear whether NOAA or USGS data is used for the approximation of the offshore boundary.
    d. Comment 16. "It is difficult to get an appreciation of the relative contributions of the BOD and nitrogen loading input to the system. A bar or pie chart the average or total load from point sources, storm water, ocean, upstream, and marsh loading would be helpful." The relative contribution of the loading from various sources is not summarized is a table or figure.
2. Sensitivity analysis shows that the sites near the SNWR are sensitive to small (10 percent) changes in flow. Flow information below Clyo, such as the contribution of intervening basins/tributaries, for example Union Creek, has not been measured and documented. The model assumes a 10-percent increase due to change in the drainage area and a constant inflow from Union Creek. These assumptions should be kept in mind when evaluated mitigation scenarios and future monitoring needs.
3. The water-level simulations in the latest version of the model have been much improved. Specifically, the simulation at SR-17 (figure B-14) in the previous model showed too much tidal influence and not enough riverine influence. The latest calibration shows an appropriate balance between the two forces.
4. The model still generally under predicts the ebb-tide currents and flow in the system. It was previously speculated (Comment 8, previous review) that the under predictions may be due to the model not satisfactorily simulating the riverine dynamics in the system. The improvements in the riverine dynamics

(as seen in figure B-14) did not correspond to an improvement in ebb-tide currents and flow predictions. Overall flow statistics have improved slightly in the latest calibration.

5. Salinity simulations in the vicinity of SNWR have improved (compare figures J-18, J-26, J-27 in both reports). The lag in salinity response noted in previous review (Comment 11) still evident but significantly improved with latest calibration.
6. The over prediction of BODu in the Middle River has been reduced but the model still predicts two to three times too much $BOD_u$.
7. The complexity of dissolved oxygen dynamics in Southeastern estuaries are difficult to simulate. Often dissolved-oxygen models are not able to make absolute prediction and typically do not simulate the diel and diurnal variability in dissolved oxygen, as seen in the differences in standard deviations of measured and predicted data. Hopefully, the model captures the overall trend. The coefficient of determination ($R^2$) statistic measures the ability of the model to capture the overall trend of the data. Fourteen of the 17 sites have $R^2$'s of less than 0.5 and 9 of 17 have $R^2$'s of less than 0.25. Therefore, the majority of sites could only explain 25 percent, or less, of the variability in dissolved oxygen. The U.S. Fish and Wildlife Service should use caution when evaluating impacts to dissolved oxygen based on model prediction.

March 1, 2006

Colonel Mark S. Held
District Engineer
U.S. Army Corps of Engineers
P.O. Box 889
Savannah, GA 31402-0889

Dear Colonel Held:

The Fish and Wildlife Service (Service) has completed a review of the report "Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project" dated January 30, 2006 prepared by Tetra Tech, Inc. for the U.S. Army Corps of Engineers, Savannah District. The U.S. Geological Survey (USGS) is assisting the Fish and Wildlife Service (Service) in evaluating the hydrodynamic and water quality models for the Savannah Harbor Expansion Study. Copies of the USGS letter and review comments to the Service are enclosed for your review.

The three-dimensional hydrodynamic model selected for this project is based on the Environmental Fluid Dynamics Code (EFDC), a physics-based turbulence closure model that has been applied in a number of estuarine and riverine systems in the southeastern United States. The Savannah Harbor expansion version of the EFDC is based on the model originally developed by Tetra Tech for the Environmental Protection Agency to determine the total maximum daily load (TMDL) for dissolved oxygen in the lower Savannah River. This TMDL model has been improved with an enhanced grid and other modifications.

The Service letter of July 5, 2006 and the USGS letter dated June 28, 2005 identified concerns on the models and recommended approaches to address the concerns. Recommended approaches included additional explanation in the final report, additional sensitivity simulations, and recalibration/revision of the model. We anticipated that most of these concerns could be addressed with additional documentation for the report and sensitivity runs. At subsequent meetings and conference calls the Service reiterated the need to address these concerns and document the outcome in the final report. We are disappointed that several of the concerns were not addressed in the final report (please see enclosed USGS letter).

The Service recommends that the following previously requested information be provided in a supplemental report:

- Convergence testing results at additional sites in Middle River, Back River and Little Back River

- Sensitivity analysis results at additional sites in Middle River, Back River and Little Back River

- Clarify whether NOAA or USGS data is used for approximation of the offshore boundary

- A chart providing relative contributions (from point sources, storm water, ocean, upstream and marsh) of biochemical oxygen demand and nitrogen loading input to the system.

Information in the final report indicates that water level and tidal and riverine dynamics in the upper reaches of the model have been significantly improved. Salinity predictions in the Middle River and Little Back River and Savannah National Wildlife Refuge have also been improved. If the supplemental report does not disclose any unforeseen significant model problems, we believe that salinity prediction performance is adequate to use in project planning. However, we must caution that there continues to be a limited understanding and modeling ability of the velocity and flow dynamics in the Middle River, Little Back River and Back River. This limitation will cause some uncertainty regarding salinity and water quality predictions for mitigation alternatives that involve channel modifications in the Savannah River system.

With regard to dissolved oxygen, the model has limited ability to simulate the variability and trends in the data. Fourteen of 17 sites have $R^2$ values of less than 0.5 (explain 50 percent of the variability of the data) and nine of 17 sites have $R^2$ values of less than 0.25. These results indicate a limited understanding and modeling ability of the dissolved oxygen dynamics for the Savannah River estuary. However, the dissolved oxygen model results are similar to results in other southeastern estuaries and reflect the difficulty in modeling these systems. As a result, a great deal of caution will be needed in utilizing model dissolved oxygen predictions.

Our July 5, 2005 letter stated that users must be cognizant that any model in a complex system, such as the Savannah estuary, will have limitations in how well it will predict reality. An adaptive management approach, as described in Corp's Environmental Circular 1105-2-409, "Planning in a Collaborative Environment", dated 31 May 2005, is a way to deal with uncertainty. This document discusses the necessity of a well designed monitoring program as a cornerstone to adaptive management. The document also discusses phased project implementation, in which the initial phase is constructed and monitored, and a future phase may be constructed as planned, modified, or not constructed. The decision on the future phase is based on the monitoring results and defined decision criteria. If an environmentally acceptable alternative can be identified, we would recommend implementing an adaptive management approach.

Based on the information reviewed, we conclude that: (1) additional documentation is needed to address the Service and USGS concerns provided with our July 5, 2005 letter; (2) if the documentation does not disclose significant unforeseen problems, salinity and water level predictions have been improved and are adequate for impact analysis; (3) dissolved oxygen model predictions are highly uncertain and will need to be used with a great deal of caution; and (4) for any acceptable alternatives, an adaptive management approach is needed to deal with model uncertainty.

We appreciate the efforts of you and your staff to coordinate this project with the Service. If you have any questions or wish to discuss this issue, please contact Ed EuDaly at 843-727-4707 x 227.

Sincerely,

Tim Hall
Field Supervisor

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 4
ATLANTA FEDERAL CENTER
61 FORSYTH STREET
ATLANTA, GEORGIA 30303-8960

MAR 0 8 2006

Mr. Pete Oddi, P.E., PMP
Deputy District Engineer for
Programs and Project Management
Savannah District, Corps of Engineers
P.O. Box 889
Savannah, GA 31402-0889

Dear Mr. Oddi:

Thank you for your January 31, 2006, letter requesting our review of the report "Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor-Final, January 30, 2005." As you know, the U.S. Environmental Protection Agency Region 4 (EPA-R4) has been actively involved in the development of the Savannah Harbor Expansion Model. The report and its appendices describe the hydrodynamic, salinity transport, and dissolved-oxygen models and their application, calibration, validation, and confirmation to the Lower Savannah River and Harbor. The Environmental Fluid Dynamic Code (EFDC) model was originally developed for EPA-by Tetra Tech for determining the TMDL for dissolved oxygen for Savannah Harbor. This model has been updated by Tetra Tech for the U.S. Army Corps of Engineers (USACE), Savannah Harbor Dredging Project. The new model represents the refinement of the EFDC model from the original EPA TMDL model and the final modeling report addresses the outstanding concerns raised by EPA and other stakeholders during the review of the 2005 draft report.

These models are acceptable for continued use in the Savannah Harbor Expansion Project to identify the effects of potential changes in the estuary water quality and hydrodynamics from proposed harbor activities. However, as with any complex model, we expect the model to be continually updated and refined as new information and data are available and the improved models should be used for final TMDL development and evaluation of harbor activities.

2

The model development and review of the Savannah Harbor Expansion Model has been a long process for both agencies. It is encouraging to see the model development reach the final stages where it can be used by both the USACE and EPA in making the critical water quality decisions for the harbor. If EPA may be of further assistance, please feel free to contact Jim Greenfield at 404/562-9238.

Sincerely,

J. Scott Gordon

James D. Giattina, Director
Water Management Division

**Georgia Department of Natural Resources**
2 Martin Luther King, Jr. Drive, S.E., Suite 1152 East Tower, Atlanta, Georgia 30334-9000
Noel Holcomb, Commissioner
Carol A. Couch, Ph.D., Director
Environmental Protection Division
404/656-4713

March 14, 2006

Mr. Peter Oddi
U.S. Army Corps of Engineers, Savannah District
Post Office Box 889
Savannah, Georgia 31402-0889

Subject: Savannah Harbor Expansion Project
Harbor Models Acceptability

Dear Mr. Oddi:

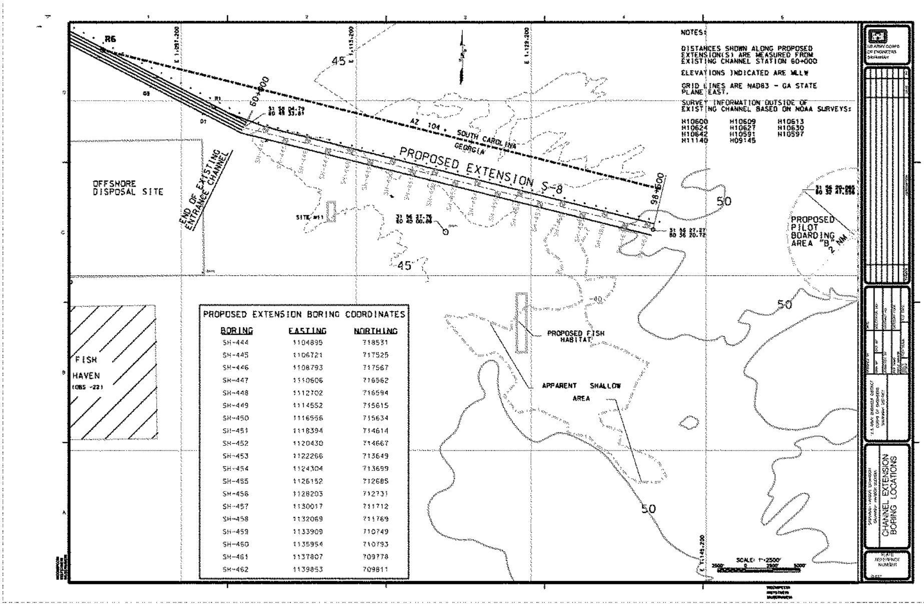
The U.S. Army Corps of Engineers (Corps) is currently developing a Tier II environmental impact statement (EIS) for the proposed Savannah Harbor Expansion Project (SHEP). To identify and assess potential environmental impacts complex hydrodynamic and water quality models have been developed. The development process included representatives from four Federal Agencies, Georgia EPD and South Carolina DHEC, and stakeholders representing the Harbor dischargers. Model development recently culminated with the issuance of the final report: Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project dated January 30, 2006. This report incorporates modifications responding to comments from the technical review group on the May 2005 version of the report. The Corps now requests Georgia EPD's position on the acceptability of these models for the purpose of predicting project impacts and suitable mitigation for those impacts.

Georgia EPD staff has reviewed the final project report and acknowledge the changes made in response to the technical review group comments. In addition, Georgia EPD agrees that these models are the best available tools to use in assessing impacts of the SHEP and possible mitigation alternatives. Georgia EPD therefore approves the use of these models to assess the impacts and mitigation of the proposed Harbor deepening. However, proposed Harbor expansion alternatives, and their environmental impacts and mitigation, will be reviewed by Georgia EPD on a case-by-case basis for their technical merit and their ability to protect water quality standards.

Sincerely,

Linda MacGregor, P.E.
Branch Chief
Watershed Protection Branch

cc: Keith Parsons




PROPOSED EXTENSION BORING COORDINATES

| BORING | EASTING | NORTHING |
|---|---|---|
| SH-444 | 1104895 | 718531 |
| SH-445 | 1106721 | 717525 |
| SH-446 | 1108793 | 717567 |
| SH-447 | 1110606 | 716562 |
| SH-448 | 1112702 | 716594 |
| SH-449 | 1114552 | 715615 |
| SH-450 | 1116556 | 715634 |
| SH-451 | 1118394 | 714614 |
| SH-452 | 1120430 | 714667 |
| SH-453 | 1122266 | 713649 |
| SH-454 | 1124304 | 713699 |
| SH-455 | 1126152 | 712685 |
| SH-456 | 1128203 | 712731 |
| SH-457 | 1130017 | 711712 |
| SH-458 | 1132069 | 711769 |
| SH-459 | 1133909 | 710749 |
| SH-460 | 1135954 | 710793 |
| SH-461 | 1137807 | 709778 |
| SH-462 | 1139853 | 709811 |

*February 2007*

# Chloride Impact Evaluation

## *Impacts of Harbor Deepening Only*

The chloride impact evaluation input data was developed by the Savannah Harbor Expansion Water Quality Technical Evaluation Group. The group developed two model input scenarios for evaluation, see below.

| Run Scenario | River Flow | Evaluation Period |
|---|---|---|
| Basic Evaluation | Critical Flow Conditions | 1-May 1999 to 1-November 1999 |
| Sensitivity Analysis #1 | Average Flow Conditions | 1-May 1997 to 1-November 1997 |

In addition to the scenarios recommended by the Technical Evaluation Group, we also evaluated Spring/Summer of 2001. 2001 has lower freshwater flows than that of 1999 and indicates a greater chloride impact on Abercorn Creek than the impact during 1999, as shown on Figure 1, pg. 17.

| Run Scenario | River Flow | Evaluation Period |
|---|---|---|
| Sensitivity Analysis #2 | Low Flow Conditions | 1-May 2001 to 1-November 2001 |

Each of the three run scenarios were analyzed for each deepening condition: Existing, 44-ft, 45-ft, 46-ft, and 48-ft depths. A total of 15 runs were completed.

The chloride values were computed as described in the *Savannah Harbor Expansion Project- Chloride Data Analysis and Model Development* report dated November 15, 2006 prepared by Tetra Tech.

Results from each run are displayed in this report. The output for each scenario/deepening combination includes (1) a table showing percent exceedance and (2) maximum and minimum chloride values and (3) number of days the chloride at the intake is greater than 12 ppm. All output was measured at EFDC cell (I=8, J=130). This cell is representative of the water quality conditions at the location of the City of Savannah's water intake pipe on Abercorn Creek.

# *Basic Evaluation*

Simulation Period: May 1, 1999 to November 1, 1999

## *Existing Conditions (42 ft Deep Navigation Channel)*

| % Exceedance | Chloride (ppm) |
|---|---|
| 99 | 11.70 |
| 95 | 11.96 |
| 90 | 12.14 |
| 85 | 12.30 |
| 80 | 12.42 |
| 75 | 12.49 |
| 70 | 12.60 |
| 65 | 12.71 |
| 60 | 12.92 |
| 55 | 13.01 |
| 50 | 13.13 |
| 45 | 13.20 |
| 40 | 13.27 |
| 35 | 13.36 |
| 30 | 13.43 |
| 25 | 13.50 |
| 20 | 13.56 |
| 15 | 13.62 |
| 10 | 13.67 |
| 5 | 13.73 |
| 1 | 13.86 |

| | | |
|---|---|---|
| Maximum value: | 13.88 | ppm |
| Minimum value: | 11.63 | ppm |

# of days chloride values were above 12 ppm: ***173***

***44 ft Deep Channel***

| % Exceedance | Chloride (ppm) |
|---|---|
| 99 | 11.70 |
| 95 | 11.96 |
| 90 | 12.14 |
| 85 | 12.30 |
| 80 | 12.42 |
| 75 | 12.49 |
| 70 | 12.60 |
| 65 | 12.71 |
| 60 | 12.92 |
| 55 | 13.01 |
| 50 | 13.13 |
| 45 | 13.20 |
| 40 | 13.27 |
| 35 | 13.36 |
| 30 | 13.43 |
| 25 | 13.50 |
| 20 | 13.56 |
| 15 | 13.62 |
| 10 | 13.67 |
| 5 | 13.73 |
| 1 | 13.86 |

| | | |
|---|---|---|
| Maximum value: | 13.89 | ppm |
| Minimum value: | 11.63 | ppm |

# of days chloride values were above 12 ppm: ***173***

***45 ft Deep Channel***

| % Exceedance | Chloride (ppm) |
|---|---|
| 99 | 11.70 |
| 95 | 11.96 |
| 90 | 12.14 |
| 85 | 12.30 |
| 80 | 12.42 |
| 75 | 12.49 |
| 70 | 12.60 |
| 65 | 12.71 |
| 60 | 12.92 |
| 55 | 13.01 |
| 50 | 13.13 |
| 45 | 13.20 |
| 40 | 13.27 |
| 35 | 13.36 |
| 30 | 13.44 |
| 25 | 13.50 |
| 20 | 13.57 |
| 15 | 13.62 |
| 10 | 13.67 |
| 5 | 13.74 |
| 1 | 13.86 |

| | | |
|---|---|---|
| Maximum value: | 13.89 | ppm |
| Minimum value: | 11.63 | ppm |

# of days chloride values were above 12 ppm: ***173***

***46 ft Deep Channel***

| % Exceedance | Chloride (ppm) |
|---|---|
| 99 | 11.70 |
| 95 | 11.96 |
| 90 | 12.14 |
| 85 | 12.30 |
| 80 | 12.42 |
| 75 | 12.49 |
| 70 | 12.60 |
| 65 | 12.71 |
| 60 | 12.92 |
| 55 | 13.01 |
| 50 | 13.13 |
| 45 | 13.20 |
| 40 | 13.27 |
| 35 | 13.36 |
| 30 | 13.44 |
| 25 | 13.51 |
| 20 | 13.57 |
| 15 | 13.63 |
| 10 | 13.67 |
| 5 | 13.74 |
| 1 | 13.86 |

| | | |
|---|---|---|
| Maximum value: | 13.89 | ppm |
| Minimum value: | 11.63 | ppm |

# of days chloride values were above 12 ppm: ***173***

***48 ft Deep Channel***

| % Exceedance | Chloride (ppm) |
|---|---|
| 99 | 11.70 |
| 95 | 11.96 |
| 90 | 12.15 |
| 85 | 12.30 |
| 80 | 12.42 |
| 75 | 12.49 |
| 70 | 12.60 |
| 65 | 12.71 |
| 60 | 12.92 |
| 55 | 13.01 |
| 50 | 13.13 |
| 45 | 13.20 |
| 40 | 13.28 |
| 35 | 13.36 |
| 30 | 13.44 |
| 25 | 13.51 |
| 20 | 13.57 |
| 15 | 13.63 |
| 10 | 13.68 |
| 5 | 13.75 |
| 1 | 13.86 |

Maximum value: 13.89 ppm
Minimum value: 11.63 ppm

# of days chloride values were above 12 ppm: ***173***

# *Sensitivity Analysis #1*

Simulation Period: May 1, 1997 to November 1, 1997

## *Existing Conditions (42 ft Deep Navigation Channel)*

| % Exceedance | Chloride (ppm) |
|---|---|
| 99 | 9.94 |
| 95 | 10.34 |
| 90 | 10.95 |
| 85 | 11.37 |
| 80 | 11.49 |
| 75 | 11.57 |
| 70 | 11.66 |
| 65 | 11.75 |
| 60 | 11.82 |
| 55 | 11.93 |
| 50 | 12.06 |
| 45 | 12.23 |
| 40 | 12.33 |
| 35 | 12.52 |
| 30 | 12.69 |
| 25 | 12.90 |
| 20 | 13.03 |
| 15 | 13.13 |
| 10 | 13.47 |
| 5 | 13.67 |
| 1 | 13.89 |

| | | |
|---|---|---|
| Maximum value: | 13.98 | ppm |
| Minimum value: | 9.92 | ppm |

# of days chloride values were above 12 ppm: ***95***

***44 ft Deep Channel***

| % Exceedance | Chloride (ppm) |
|---|---|
| 99 | 9.94 |
| 95 | 10.34 |
| 90 | 10.95 |
| 85 | 11.37 |
| 80 | 11.49 |
| 75 | 11.57 |
| 70 | 11.66 |
| 65 | 11.75 |
| 60 | 11.82 |
| 55 | 11.93 |
| 50 | 12.06 |
| 45 | 12.23 |
| 40 | 12.33 |
| 35 | 12.52 |
| 30 | 12.69 |
| 25 | 12.90 |
| 20 | 13.03 |
| 15 | 13.13 |
| 10 | 13.47 |
| 5 | 13.67 |
| 1 | 13.89 |

| | | |
|---|---|---|
| Maximum value: | 13.98 | ppm |
| Minimum value: | 9.92 | ppm |

# of days chloride values were above 12 ppm: ***95***

***45 ft Deep Channel***

| % Exceedance | Chloride (ppm) |
|---|---|
| 99 | 9.94 |
| 95 | 10.34 |
| 90 | 10.95 |
| 85 | 11.37 |
| 80 | 11.49 |
| 75 | 11.57 |
| 70 | 11.66 |
| 65 | 11.75 |
| 60 | 11.82 |
| 55 | 11.93 |
| 50 | 12.06 |
| 45 | 12.23 |
| 40 | 12.33 |
| 35 | 12.52 |
| 30 | 12.69 |
| 25 | 12.90 |
| 20 | 13.03 |
| 15 | 13.13 |
| 10 | 13.48 |
| 5 | 13.67 |
| 1 | 13.89 |

| | | |
|---|---|---|
| Maximum value: | 13.98 | ppm |
| Minimum value: | 9.92 | ppm |

# of days chloride values were above 12 ppm: ***95***

***46 ft Deep Channel***

| % Exceedance | Chloride (ppm) |
|---|---|
| 99 | 9.94 |
| 95 | 10.34 |
| 90 | 10.95 |
| 85 | 11.37 |
| 80 | 11.49 |
| 75 | 11.57 |
| 70 | 11.66 |
| 65 | 11.75 |
| 60 | 11.82 |
| 55 | 11.93 |
| 50 | 12.06 |
| 45 | 12.23 |
| 40 | 12.33 |
| 35 | 12.52 |
| 30 | 12.69 |
| 25 | 12.90 |
| 20 | 13.03 |
| 15 | 13.13 |
| 10 | 13.48 |
| 5 | 13.68 |
| 1 | 13.89 |

| | | |
|---|---|---|
| Maximum value: | 13.98 | ppm |
| Minimum value: | 9.92 | ppm |

# of days chloride values were above 12 ppm: ***95***

***48 ft Deep Channel***

| % Exceedance | Chloride (ppm) |
|---|---|
| 99 | 9.94 |
| 95 | 10.34 |
| 90 | 10.95 |
| 85 | 11.37 |
| 80 | 11.49 |
| 75 | 11.57 |
| 70 | 11.66 |
| 65 | 11.75 |
| 60 | 11.82 |
| 55 | 11.93 |
| 50 | 12.06 |
| 45 | 12.23 |
| 40 | 12.33 |
| 35 | 12.52 |
| 30 | 12.69 |
| 25 | 12.90 |
| 20 | 13.03 |
| 15 | 13.13 |
| 10 | 13.49 |
| 5 | 13.68 |
| 1 | 13.90 |

| | | |
|---|---|---|
| Maximum value: | 13.98 | ppm |
| Minimum value: | 9.92 | ppm |

# of days chloride values were above 12 ppm: ***95***

# *Sensitivity Analysis #2*

Simulation Period: May 1, 2001 to November 1, 2001

## *Existing Conditions (42 ft Deep Navigation Channel)*

| % Exceedance | Chloride (ppm) |
|---|---|
| 99 | 11.48 |
| 95 | 12.90 |
| 90 | 13.36 |
| 85 | 13.51 |
| 80 | 13.65 |
| 75 | 13.74 |
| 70 | 13.83 |
| 65 | 13.90 |
| 60 | 13.96 |
| 55 | 14.00 |
| 50 | 14.04 |
| 45 | 14.07 |
| 40 | 14.13 |
| 35 | 14.17 |
| 30 | 14.22 |
| 25 | 14.28 |
| 20 | 14.35 |
| 15 | 14.45 |
| 10 | 14.50 |
| 5 | 14.53 |
| 1 | 14.58 |

| | | |
|---|---|---|
| Maximum value: | 14.66 | ppm |
| Minimum value: | 11.28 | ppm |

# of days chloride values were above 12 ppm: ***180***

***44 ft Deep Channel***

| % Exceedance | Chloride (ppm) |
|---|---|
| 99 | 11.48 |
| 95 | 12.91 |
| 90 | 13.37 |
| 85 | 13.51 |
| 80 | 13.65 |
| 75 | 13.74 |
| 70 | 13.83 |
| 65 | 13.90 |
| 60 | 13.96 |
| 55 | 14.01 |
| 50 | 14.04 |
| 45 | 14.08 |
| 40 | 14.13 |
| 35 | 14.19 |
| 30 | 14.23 |
| 25 | 14.29 |
| 20 | 14.36 |
| 15 | 14.46 |
| 10 | 14.52 |
| 5 | 14.55 |
| 1 | 14.62 |

| | | |
|---|---|---|
| Maximum value: | 14.71 | ppm |
| Minimum value: | 11.28 | ppm |

# of days chloride values were above 12 ppm: ***180***

***45 ft Deep Channel***

| % Exceedance | Chloride (ppm) |
|---|---|
| 99 | 11.48 |
| 95 | 12.91 |
| 90 | 13.37 |
| 85 | 13.52 |
| 80 | 13.65 |
| 75 | 13.74 |
| 70 | 13.83 |
| 65 | 13.90 |
| 60 | 13.97 |
| 55 | 14.01 |
| 50 | 14.05 |
| 45 | 14.08 |
| 40 | 14.14 |
| 35 | 14.19 |
| 30 | 14.24 |
| 25 | 14.30 |
| 20 | 14.37 |
| 15 | 14.47 |
| 10 | 14.53 |
| 5 | 14.56 |
| 1 | 14.63 |

| | | |
|---|---|---|
| Maximum value: | 14.73 | ppm |
| Minimum value: | 11.28 | ppm |

# of days chloride values were above 12 ppm: *180*

***46 ft Deep Channel***

| % Exceedance | Chloride (ppm) |
|---|---|
| 99 | 11.48 |
| 95 | 12.91 |
| 90 | 13.37 |
| 85 | 13.52 |
| 80 | 13.65 |
| 75 | 13.74 |
| 70 | 13.83 |
| 65 | 13.90 |
| 60 | 13.97 |
| 55 | 14.02 |
| 50 | 14.05 |
| 45 | 14.09 |
| 40 | 14.14 |
| 35 | 14.20 |
| 30 | 14.25 |
| 25 | 14.31 |
| 20 | 14.38 |
| 15 | 14.47 |
| 10 | 14.54 |
| 5 | 14.57 |
| 1 | 14.65 |

| | | |
|---|---|---|
| Maximum value: | 14.77 | ppm |
| Minimum value: | 11.28 | ppm |

# of days chloride values were above 12 ppm: ***180***

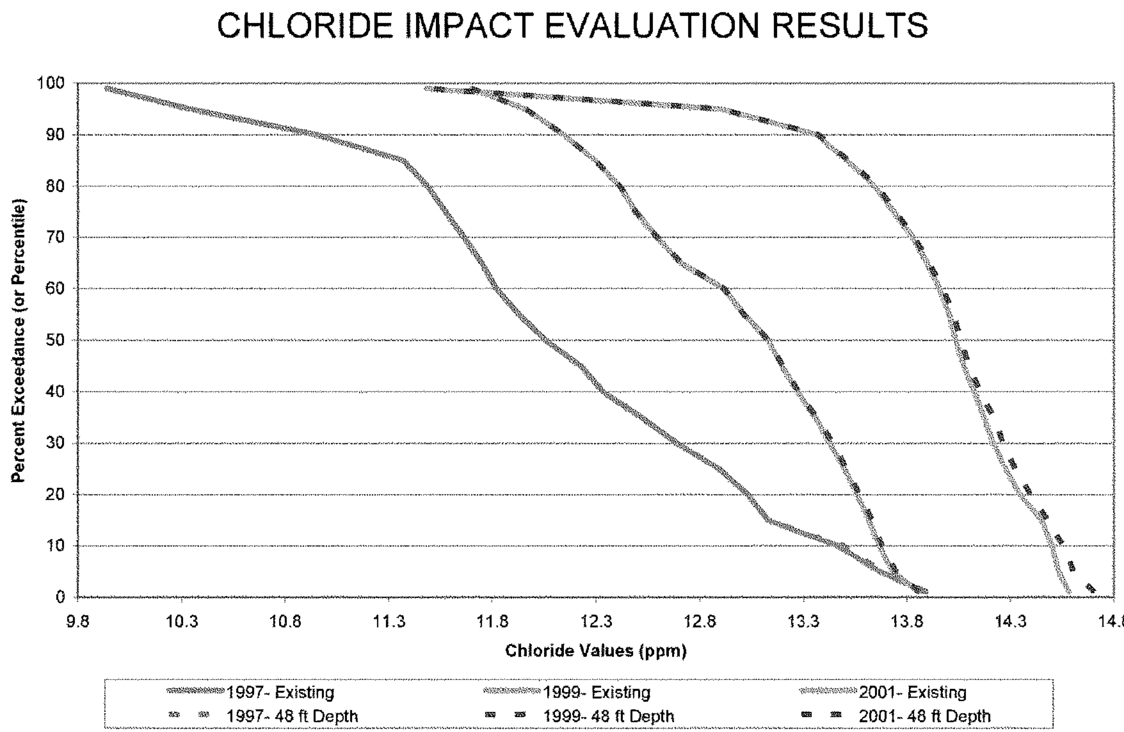
***48 ft Deep Channel***

| % Exceedance | Chloride (ppm) |
|---|---|
| 99 | 11.48 |
| 95 | 12.91 |
| 90 | 13.38 |
| 85 | 13.52 |
| 80 | 13.66 |
| 75 | 13.75 |
| 70 | 13.84 |
| 65 | 13.91 |
| 60 | 13.97 |
| 55 | 14.03 |
| 50 | 14.06 |
| 45 | 14.10 |
| 40 | 14.15 |
| 35 | 14.22 |
| 30 | 14.27 |
| 25 | 14.32 |
| 20 | 14.40 |
| 15 | 14.48 |
| 10 | 14.56 |
| 5 | 14.61 |
| 1 | 14.71 |

| | | |
|---|---|---|
| Maximum value: | 14.84 | ppm |
| Minimum value: | 11.28 | ppm |

# of days chloride values were above 12 ppm: *180*

Figure 1



CHLORIDE IMPACT EVALUATION RESULTS
Percent Exceedance (or Percentile)
100
90
80
70
60
50
40
30
20
10
0
9.8
10.3
10.8
11.3
11.8
12.3
12.8
13.3
13.8
14.3
14.8
Chloride Values (ppm)
1997- Existing
1997- 48 ft Depth
1999- Existing
1999- 48 ft Depth
2001- Existing
2001- 48 ft Depth

9-23-05

# Hurricane Surge Modeling

***Purpose:***

The purpose of the hurricane surge modeling is to determine the impacts of deepening the navigation channel and its effect on the propagation of a hurricane storm surge traveling upstream through the estuary and river system.

***Model Boundary Conditions:***

The tidal boundary was modified to incorporate a synthetic storm surge. The modeling time period selected was late August of 1997 (8-18-97 to 8-23-97). This time period was selected for several reasons:

1. 1997 closely represents historic average flow conditions at Clyo (the upstream flow boundary),
2. August is close to peak hurricane season when the likelihood of a large storm hitting the Savannah coastline would be more probable, and
3. spring tidal conditions occur on August 19.

The hurricane surge data set was developed by Applied Technology and Management, Inc. (ATM). The data set is based on measured water surface elevations collected at the USGS Customs House gage located in Charleston, SC during Hurricane Hugo which made landfall on September 21, 1989. ATM separated the hurricane storm surge component from the harmonic tidal component. The max increase in water surface elevation for the hurricane storm surge component collected at this gauging station is 7.69 ft. However, the storm surge as Hurricane Hugo made landfall varied with some places receiving a near 20 ft storm surge. Due to the difficulty in directly applying the storm surge gage data in Charleston to Savannah the data set was ratioed by ATM to create three synthetic storm surges with peaks of 5 ft, 10 ft, and 15 ft. These storm surge data sets were then added to the harmonic tide in Savannah to create a synthetic storm surge scenario. Six storm event scenarios were developed from the data set. Three had the 5 ft, 10 ft, and 15 ft peak surges occurring on top of the peak spring tidal condition. The fluctuation in water surface elevation in Savannah is so large that this peak-on-peak condition allowed evaluation of a worst case scenario. Three additional scenarios were also evaluated that had the 5 ft, 10 ft, and 15 ft peak storm surges occurring on the falling limb of the spring peak tide. The off-peak scenario would create a tidal surge that had a lower peak than the surge during the peak-on-peak scenario, but would have a longer duration. There are likely some areas where a longer duration storm would be a worst case scenario rather than a shorter peak surge.

***Model Limitations:***

The EFDC grid created for this study was not formed with emphasis on hurricane surge modeling. The shipping channel and smaller side channels including marsh areas are described in detail in the grid. However the higher banks and beaches are not accounted for in the model. These areas would likely be impacted during a hurricane and would have a direct effect on the propagation of a storm surge through the river system and navigation channel. The model is useful as a comparison tool to evaluate different deepening scenarios, however it should only be used for relative comparative purposes and not to describe where flooding would occur during a hurricane.

***Findings:***

The results from the hurricane surge modeling show that the change in water surface elevation due to the deepening is not significant. The existing depth is compared to the 48 ft deepening scenario (deepening an additional 6 ft) for all of the 6 storm events scenarios simulated. The maximum difference between the two water surface elevations, is 0.90 ft, which occurs during the 15 ft surge, coinciding peak simulations at the I-95 Bridge.

Table 1:

Comparison for 48 ft Deepening Scenario (All Simulated Events)

| | Ft. Jackson Difference in Water Surface Elevations | | I-95 Bridge Difference in Water Surface Elevations | |
|---|---|---|---|---|
| | Max – (High Tide) | Max + (Low Tide) | Max – (High Tide) | Max + (Low Tide) |
| 5 ft surge | | | | |
| Peak on peak | -0.095 m (-0.312 ft) | 0.093m (0.305 ft) | -0.204m (-0.669 ft) | 0.162m (0.531 ft) |
| Off set peaks | -0.090m (-0.295 ft) | 0.096m (0.315 ft) | -0.210m (-0.689 ft) | 0.136m (0.446 ft) |
| 10 ft surge | | | | |
| Peak on peak | -0.092m (-0.302 ft) | 0.097m (0.318 ft) | -0.234m (-0.768 ft) | 0.154m (0.505 ft) |
| Off set peaks | -0.093m (-0.305 ft) | 0.101m (0.331 ft) | -0.236m (-0.774 ft) | 0.142m (0.466 ft) |
| 15 ft surge | | | | |
| Peak on peak | -0.094m (-0.308 ft) | 0.119m (0.390 ft) | -0.275m (-0.902 ft) | 0.160m (0.525 ft) |
| Off set peaks | -0.099m (-0.325 ft) | 0.111m (0.364 ft) | -0.257m (-0.843 ft) | 0.165m (0.541 ft) |
| Overall | -0.099m (-0.325 ft) | 0.119m (0.390 ft) | -0.275m (-0.902 ft) | 0.165m (0.541 ft) |

* *The difference in water surface elevations were calculated as Difference = Existing – 48 ft Deepening.*

In addition to modeling the existing and 48 ft deepening scenarios, the other deepening scenarios (44, 45, 46, and 47 ft) were also modeled for the event that had the greatest difference in water surface elevation, the 15 ft surge during a peak on peak condition.

Table 2:
Comparison for Several Deepening Scenarios (15 ft Surge, Peak on Peak Conditions)

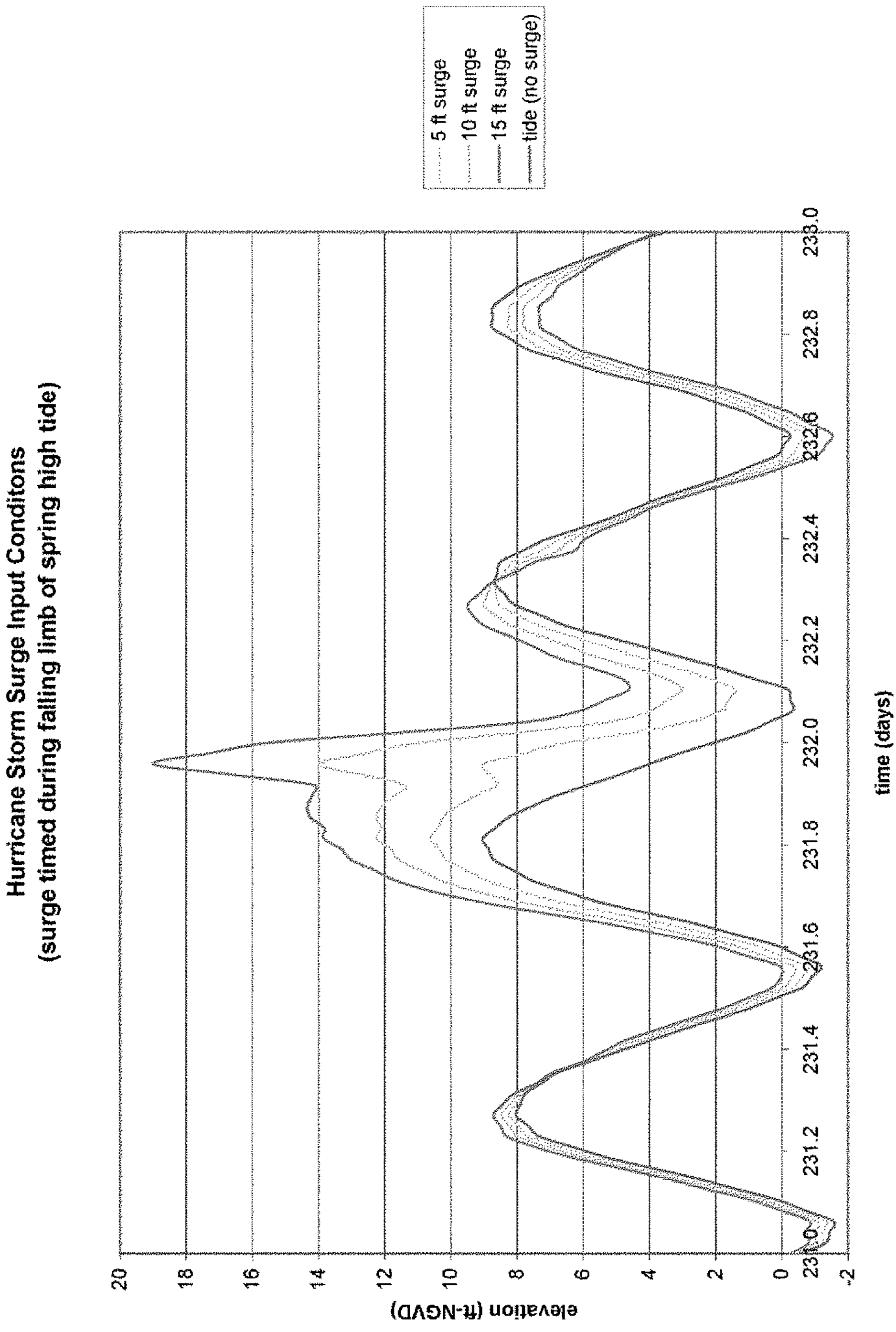
| | Ft. Jackson Difference in Water Surface Elevations | | I-95 Bridge Difference in Water Surface Elevations | |
|---|---|---|---|---|
| | Max – (High Tide) | Max + (Low Tide) | Max – (High Tide) | Max + (Low Tide) |
| 44 ft Deepening | -0.035m (-0.114 ft) | 0.040m (0.131 ft) | -0.091m (-0.298 ft) | 0.069m (0.226 ft) |
| 45 ft Deepening | -0.050m (-0.163 ft) | 0.069m (0.227 ft) | -0.143m (-0.468 ft) | 0.094m (0.307 ft) |
| 46 ft Deepening | -0.066m (-0.217 ft) | 0.081m (0.265 ft) | -0.181m (-0.595 ft) | 0.116m (0.379 ft) |
| 47 ft Deepening | -0.080m (-0.261 ft) | 0.099m (0.324 ft) | -0.232m (-0.760 ft) | 0.139m (0.455 ft) |
| 48 ft Deepening | -0.094m (-0.308 ft) | 0.119m (0.390 ft) | -0.275m (-0.902 ft) | 0.160m (0.525 ft) |

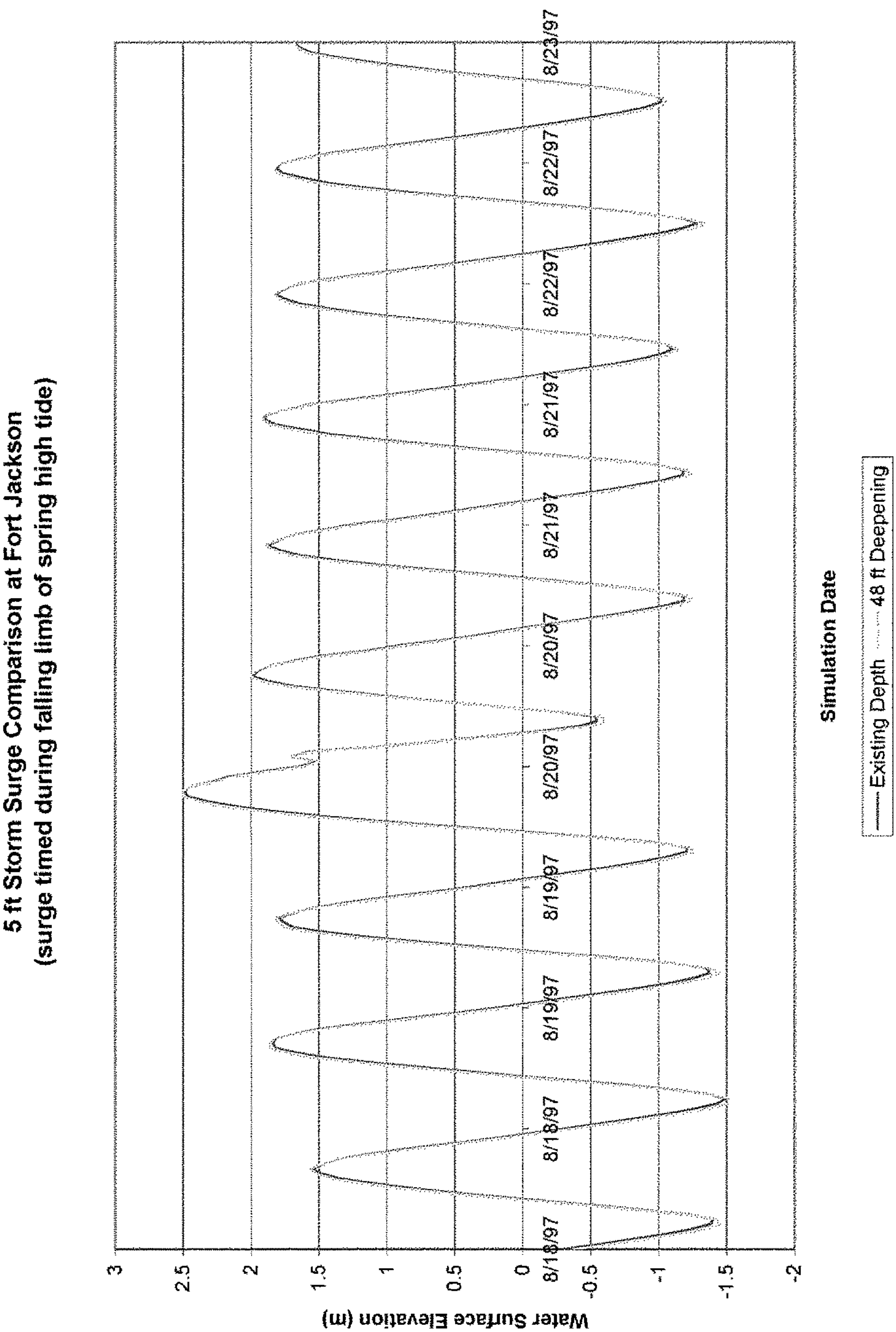
* *The difference in water surface elevations were calculated as Difference = Existing – Deepening.*

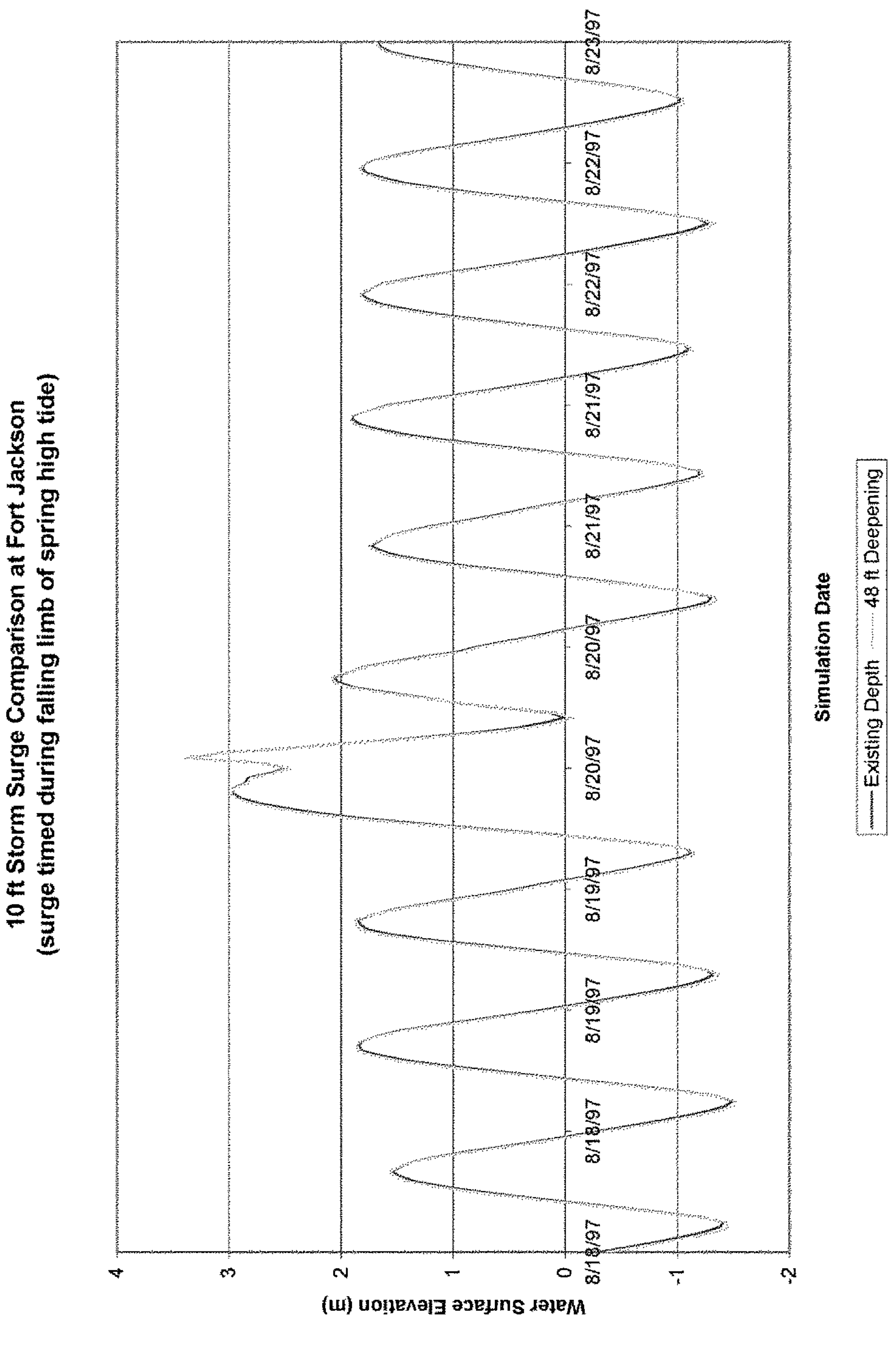
The high tide peaks are slightly higher for the deepened channel and the low tide lows are slightly lower for the deepened channel as compared to the existing depth condition. However, the difference is not significant. The minimal difference is due to the larger volumes of water being transported through the system during the tidal cycle and storm surge. These larger volumes cause a slight increase in peaks during high tide and surge and slight decrease in lows during low tide. In conclusion, the hurricane surge modeling shows no significant adverse impacts, due to harbor deepening, to a propagated storm surge as it travels upstream through the river system and navigation channel.

# Input & Output Data

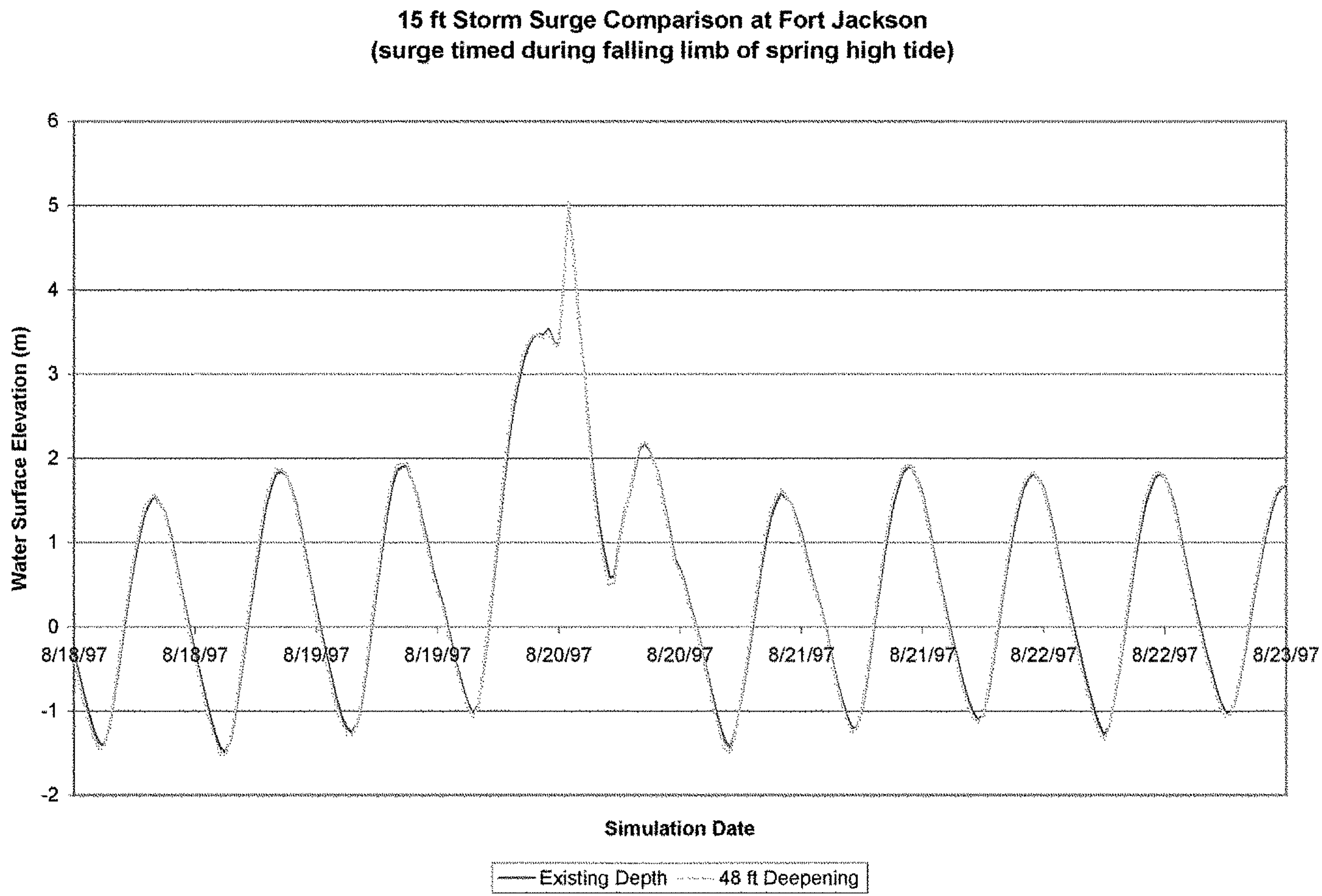
## Water Surface Elevations for Existing and 48 ft Deepening (surge timed during falling limb of spring high tide)

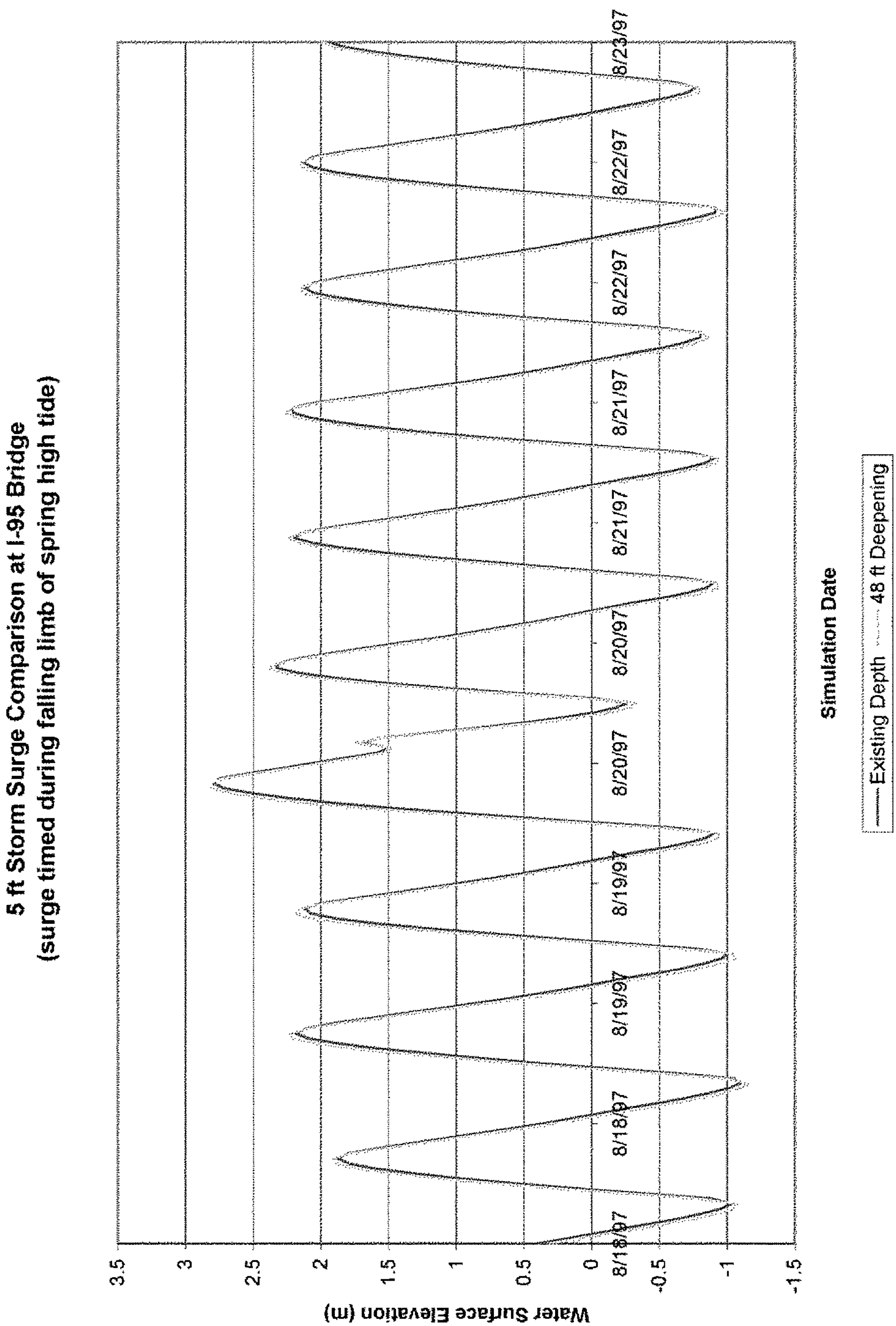

Hurricane Storm Surge Input Conditons
(surge timed during falling limb of spring high tide)
elevation (ft-NGVD)
20
18
16
14
12
10
8
6
4
2
0
-2
231.0
231.2
231.4
231.6
231.8
232.0
232.2
232.4
232.6
232.8
233.0
time (days)
5 ft surge
10 ft surge
15 ft surge
tide (no surge)

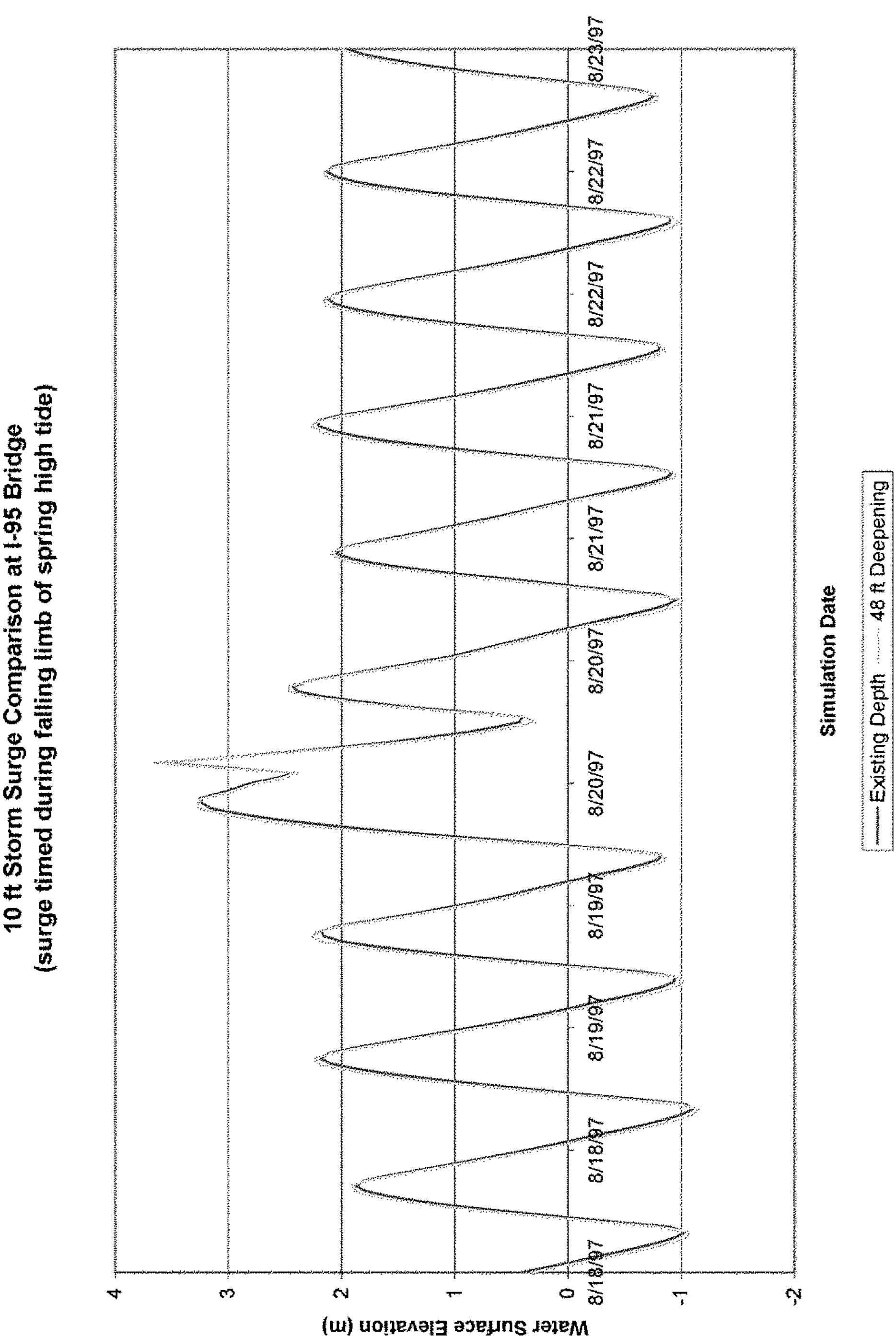

5 ft Storm Surge Comparison at Fort Jackson
(surge timed during falling limb of spring high tide)
Water Surface Elevation (m)
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
48 ft Deepening

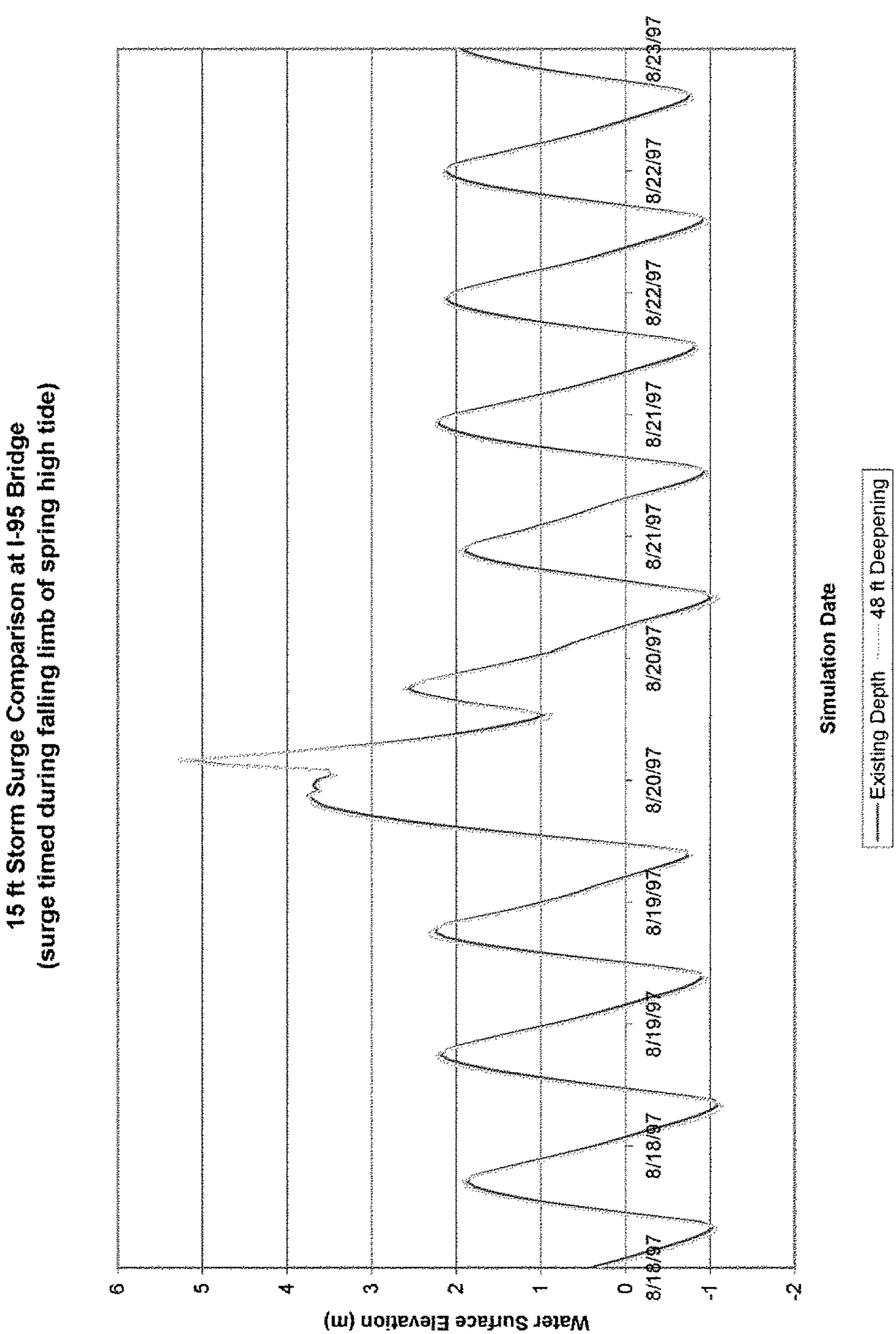


10 ft Storm Surge Comparison at Fort Jackson
(surge timed during falling limb of spring high tide)
Water Surface Elevation (m)
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
48 ft Deepening


15 ft Storm Surge Comparison at Fort Jackson
(surge timed during falling limb of spring high tide)
Water Surface Elevation (m)
6
5
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
48 ft Deepening

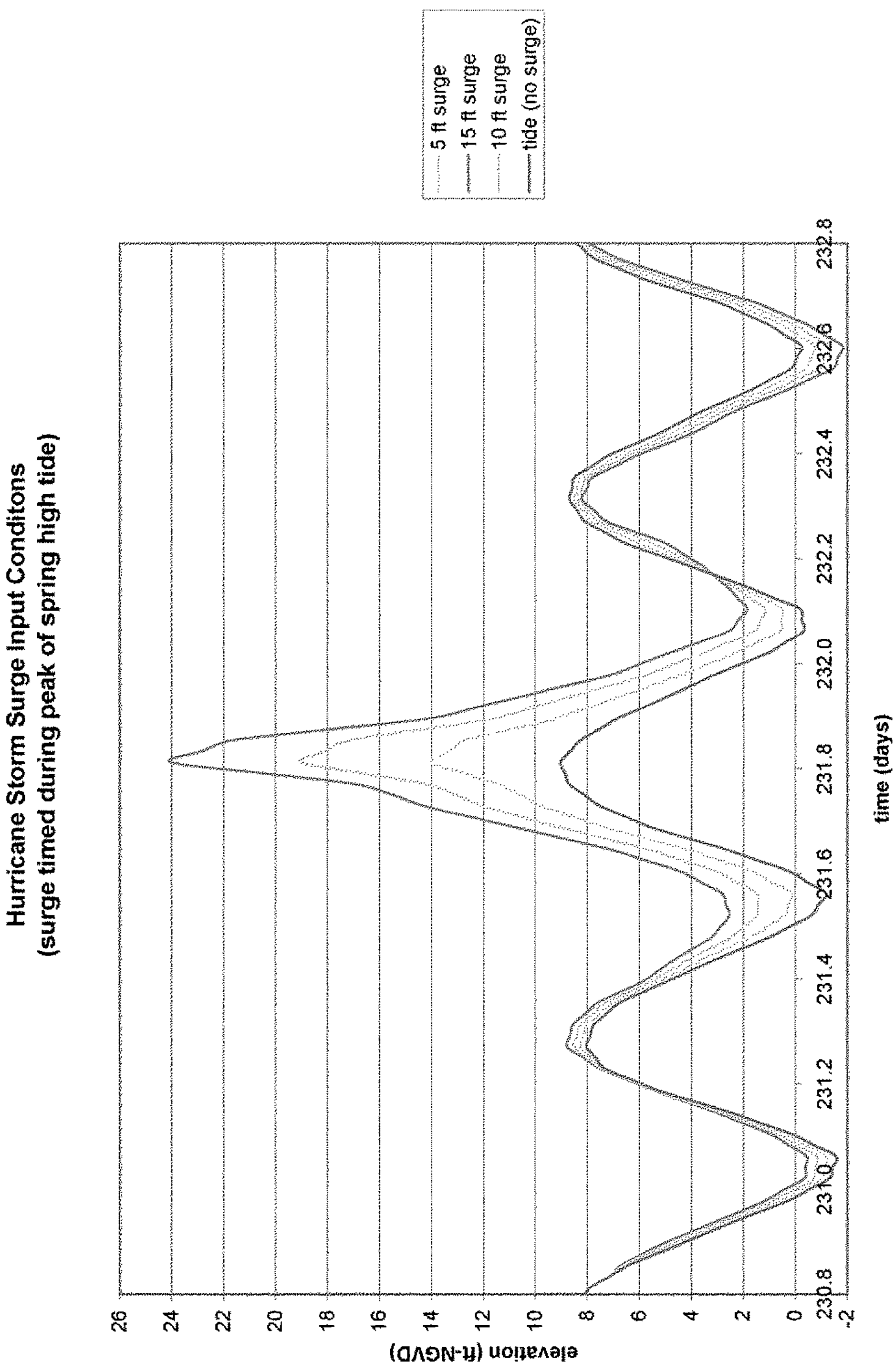

5 ft Storm Surge Comparison at I-95 Bridge
(surge timed during falling limb of spring high tide)
Water Surface Elevation (m)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
48 ft Deepening

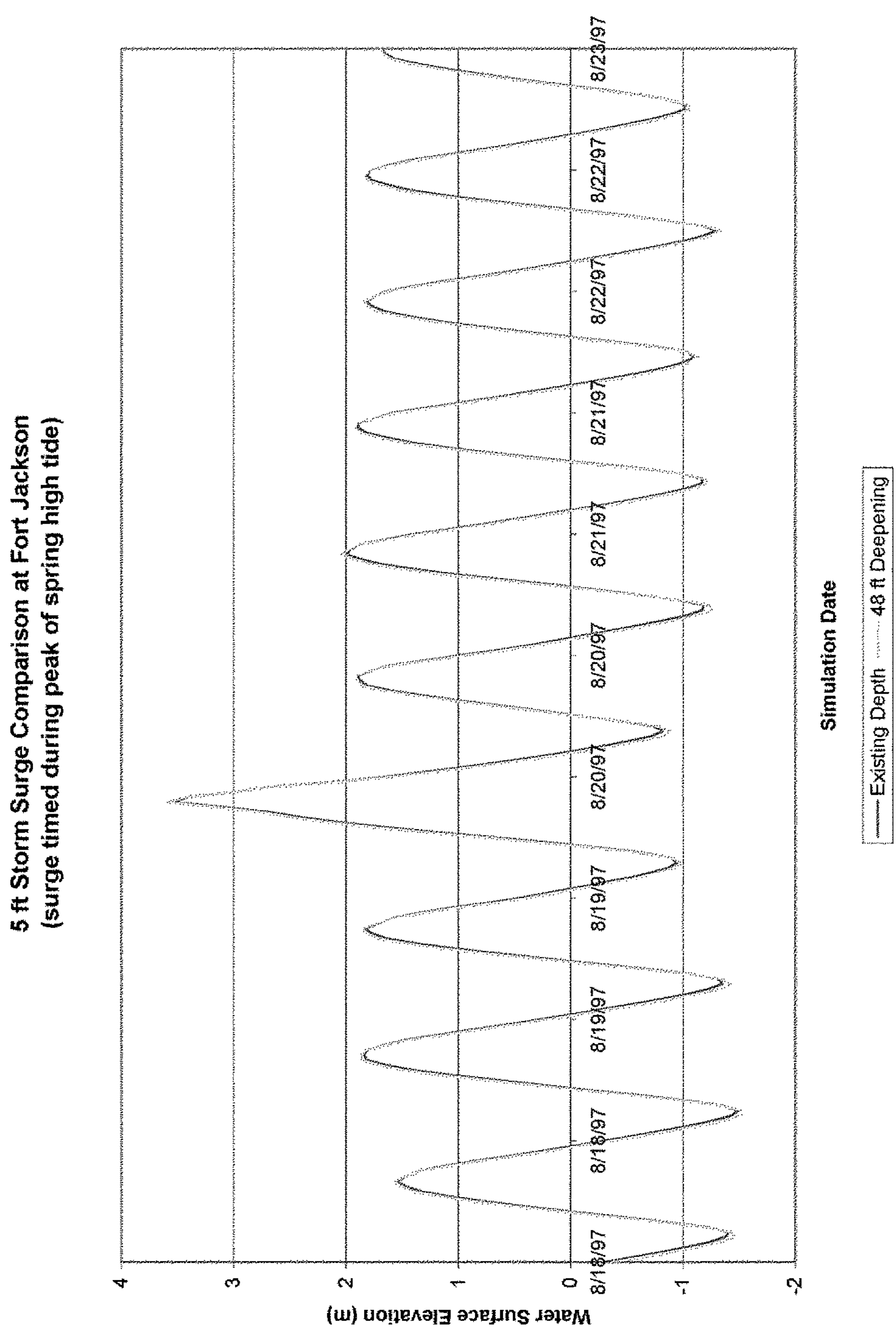

10 ft Storm Surge Comparison at I-95 Bridge
(surge timed during falling limb of spring high tide)
Water Surface Elevation (m)
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
48 ft Deepening

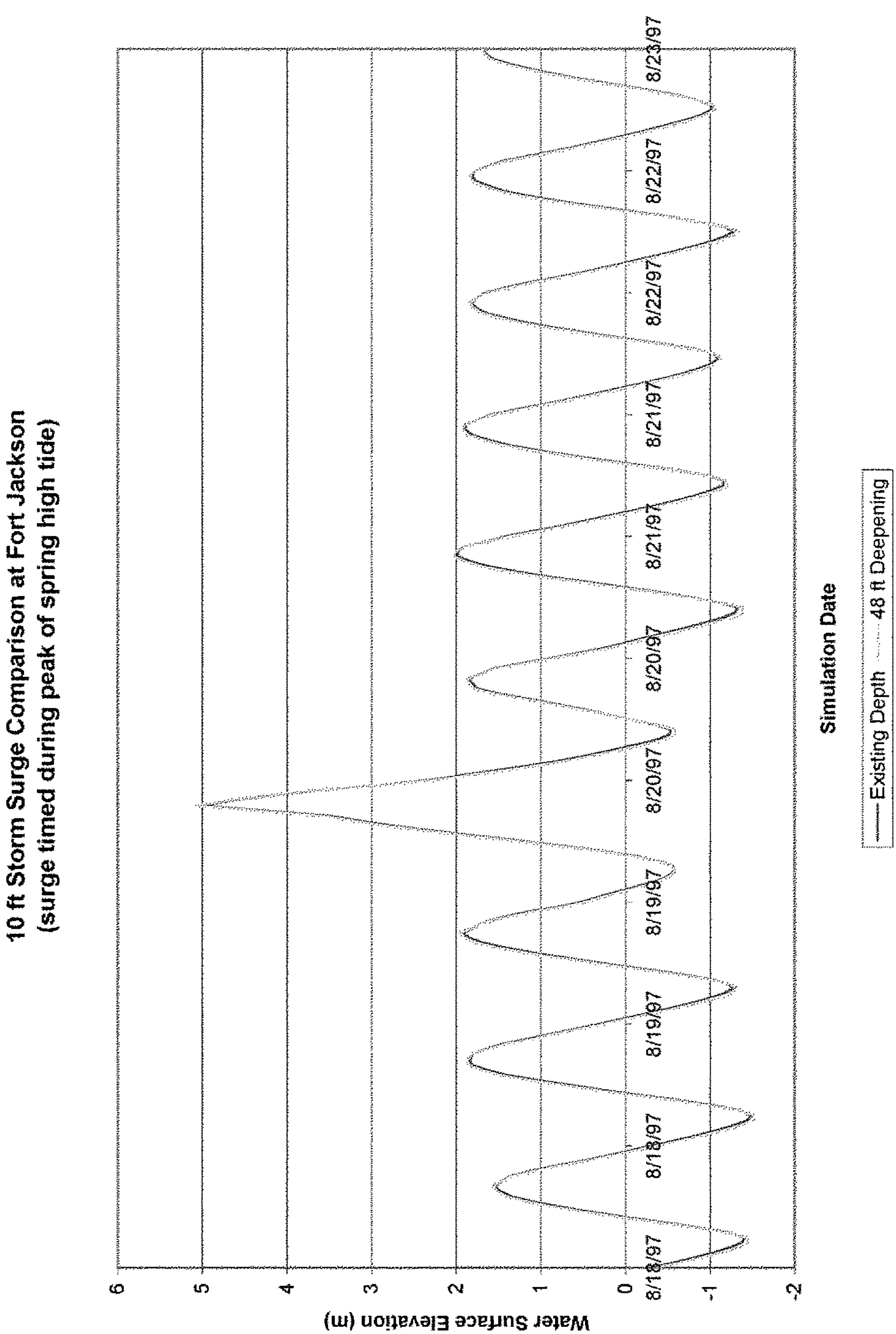

15 ft Storm Surge Comparison at I-95 Bridge
(surge timed during falling limb of spring high tide)
Water Surface Elevation (m)
6
5
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
48 ft Deepening

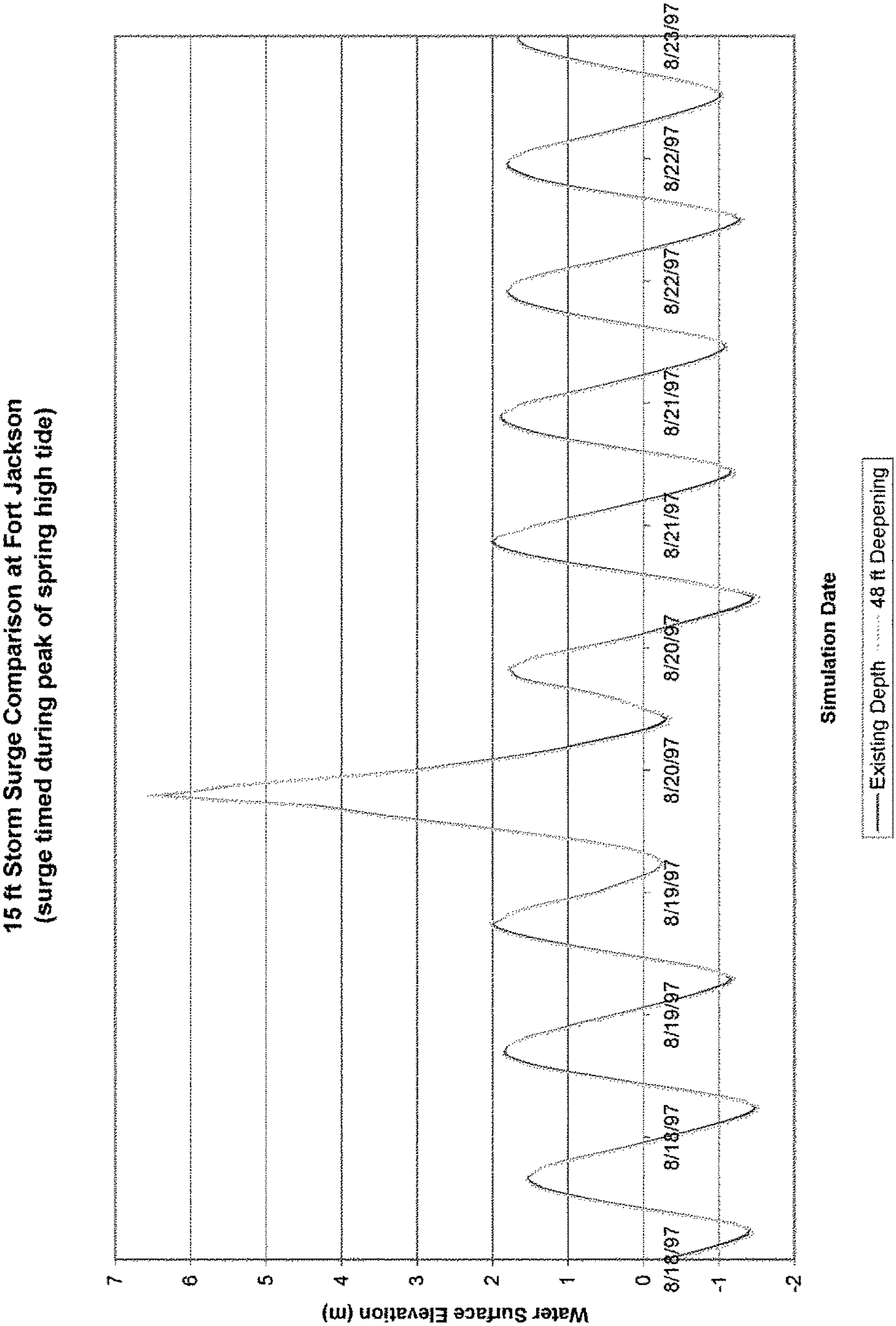
# Input & Output Data

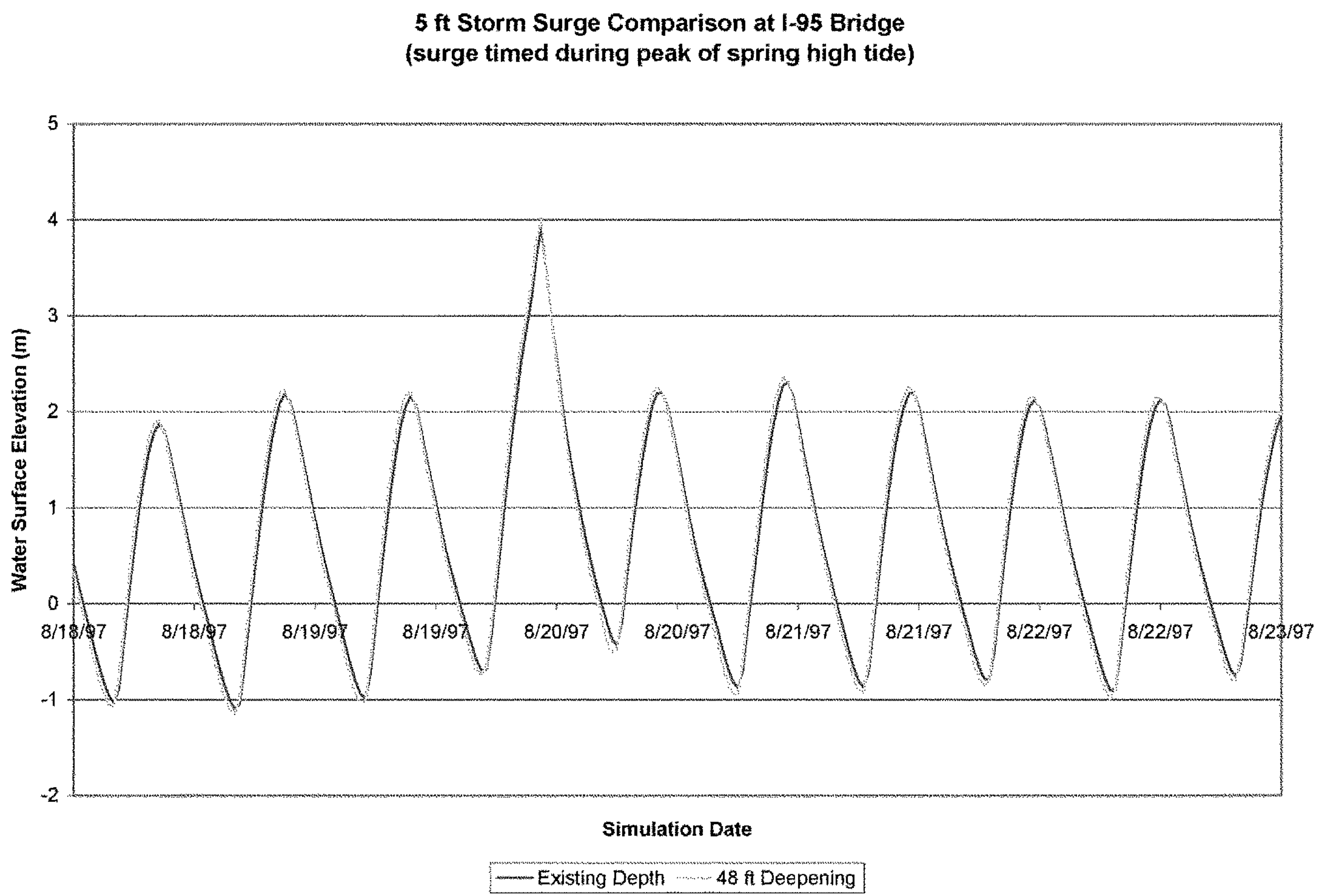
## Water Surface Elevations for Existing and 48 ft Deepening
## (surge timed during peak of spring high tide)

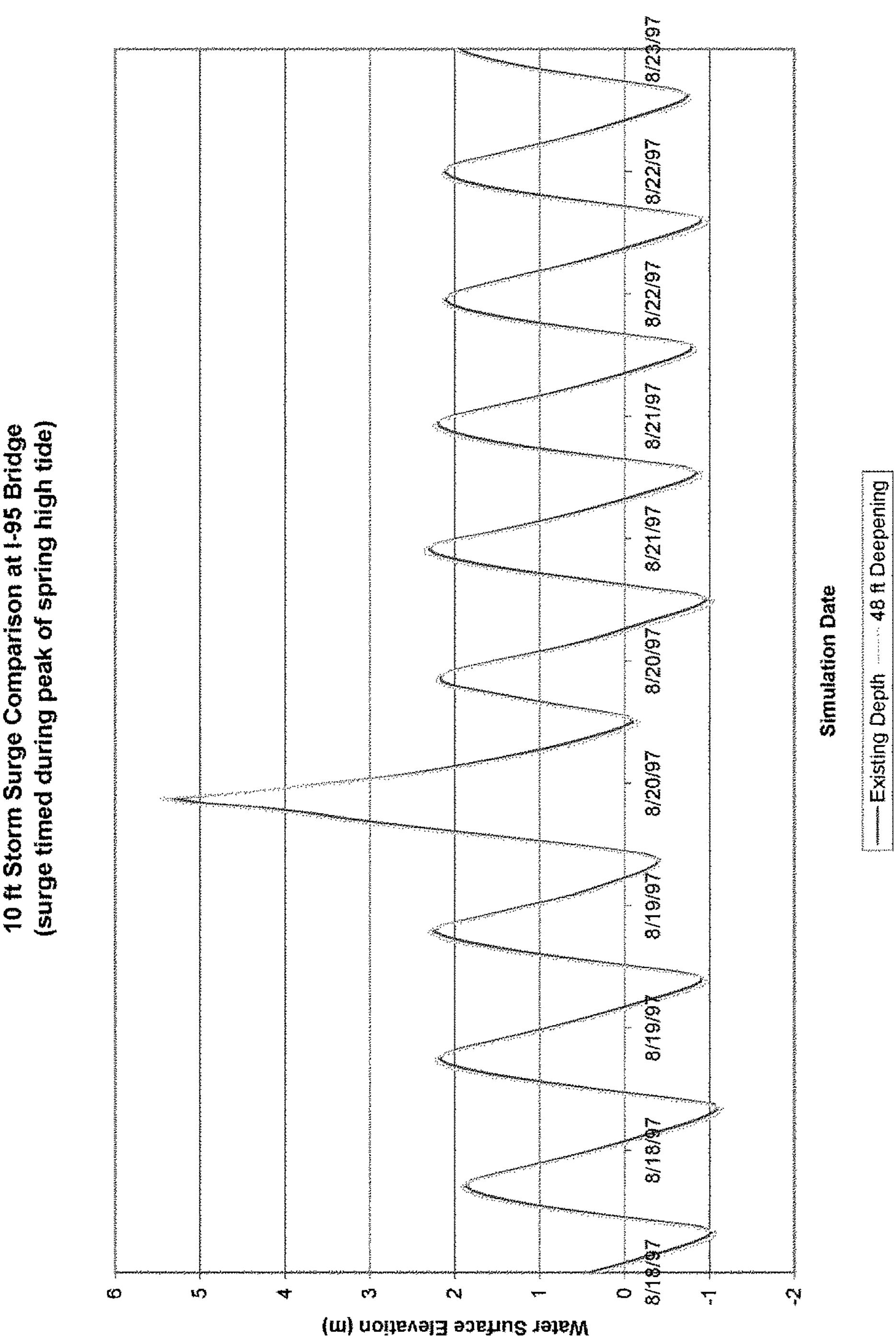

Hurricane Storm Surge Input Conditons
(surge timed during peak of spring high tide)
5 ft surge
15 ft surge
10 ft surge
tide (no surge)
elevation (ft-NGVD)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
230.8
231.0
231.2
231.4
231.6
231.8
232.0
232.2
232.4
232.6
232.8
time (days)

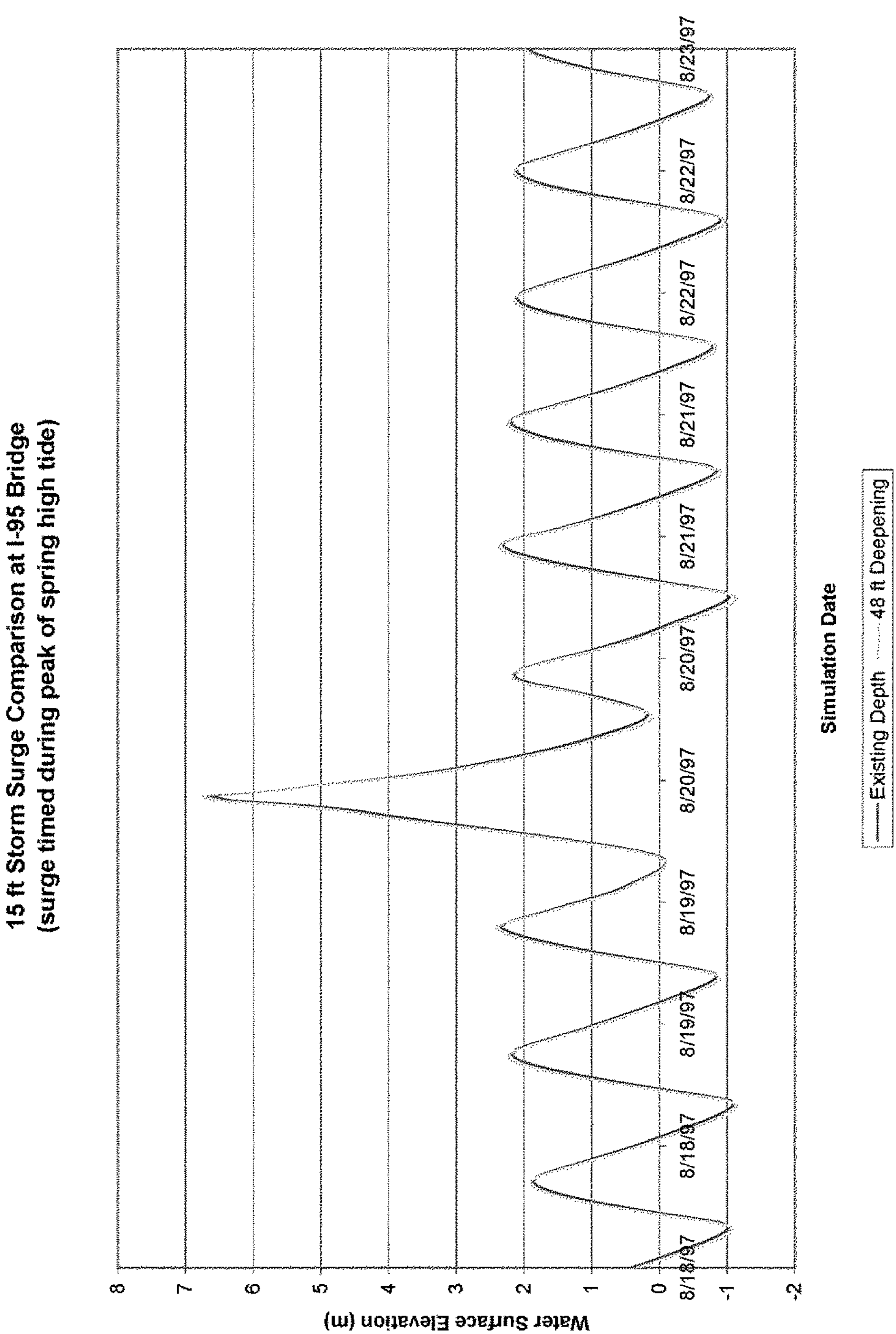

5 ft Storm Surge Comparison at Fort Jackson
(surge timed during peak of spring high tide)
Water Surface Elevation (m)
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
48 ft Deepening


10 ft Storm Surge Comparison at Fort Jackson
(surge timed during peak of spring high tide)
Water Surface Elevation (m)
6
5
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
48 ft Deepening


15 ft Storm Surge Comparison at Fort Jackson
(surge timed during peak of spring high tide)
Water Surface Elevation (m)
7
6
5
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
48 ft Deepening


5 ft Storm Surge Comparison at I-95 Bridge
(surge timed during peak of spring high tide)
Water Surface Elevation (m)
5
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
48 ft Deepening

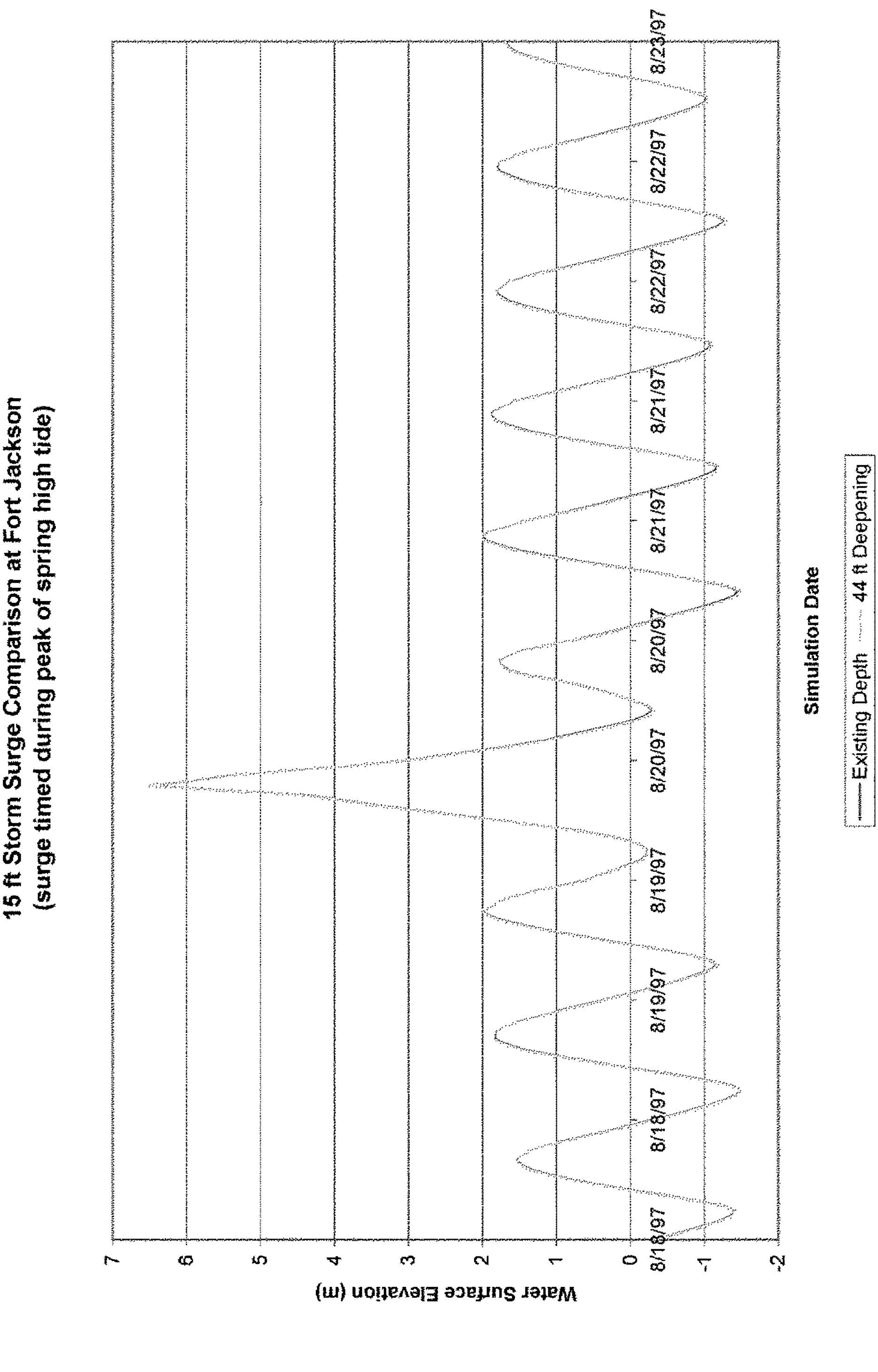

10 ft Storm Surge Comparison at I-95 Bridge
(surge timed during peak of spring high tide)
Water Surface Elevation (m)
6
5
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
48 ft Deepening



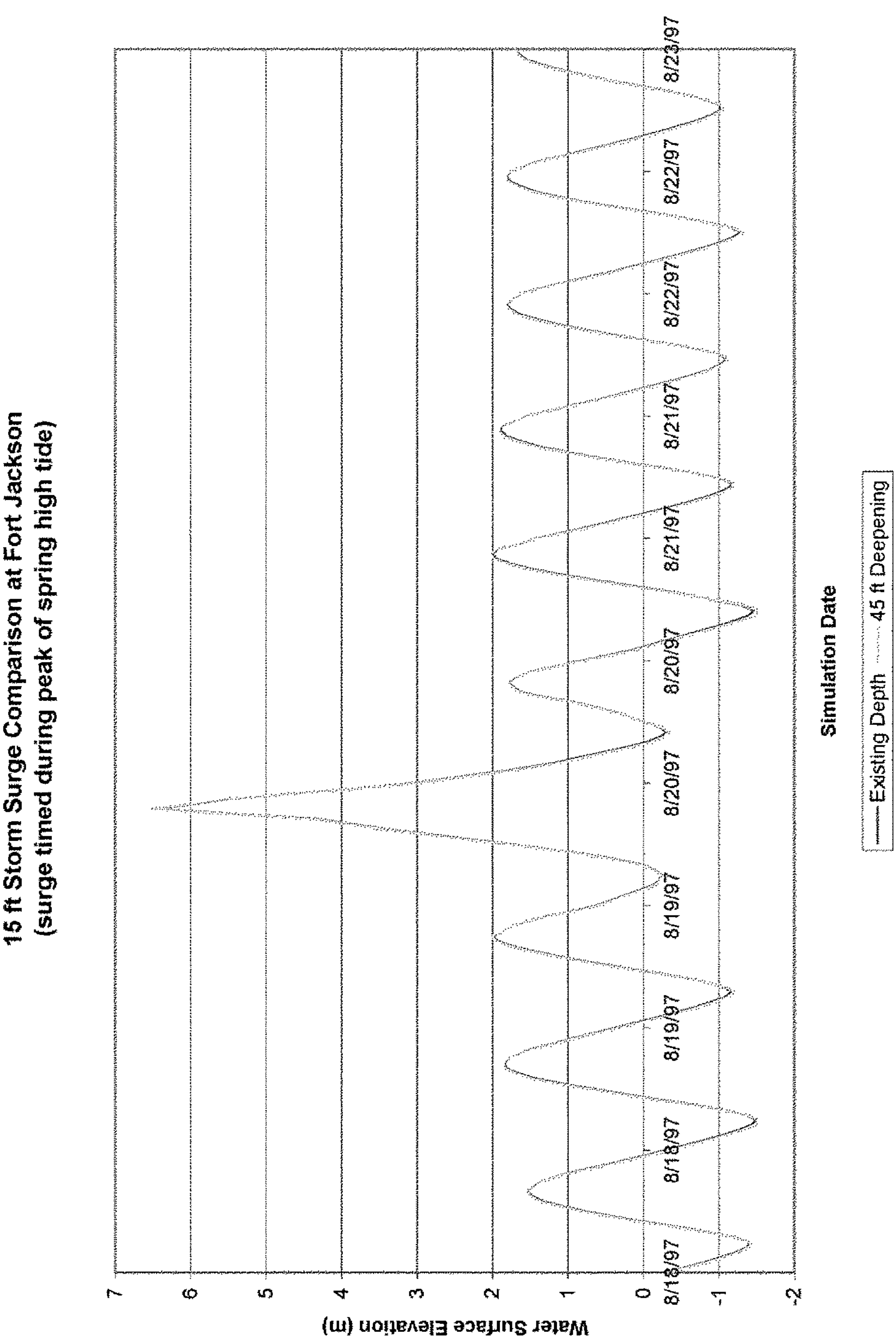
15 ft Storm Surge Comparison at I-95 Bridge
(surge timed during peak of spring high tide)
Water Surface Elevation (m)
8
7
6
5
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
48 ft Deepening

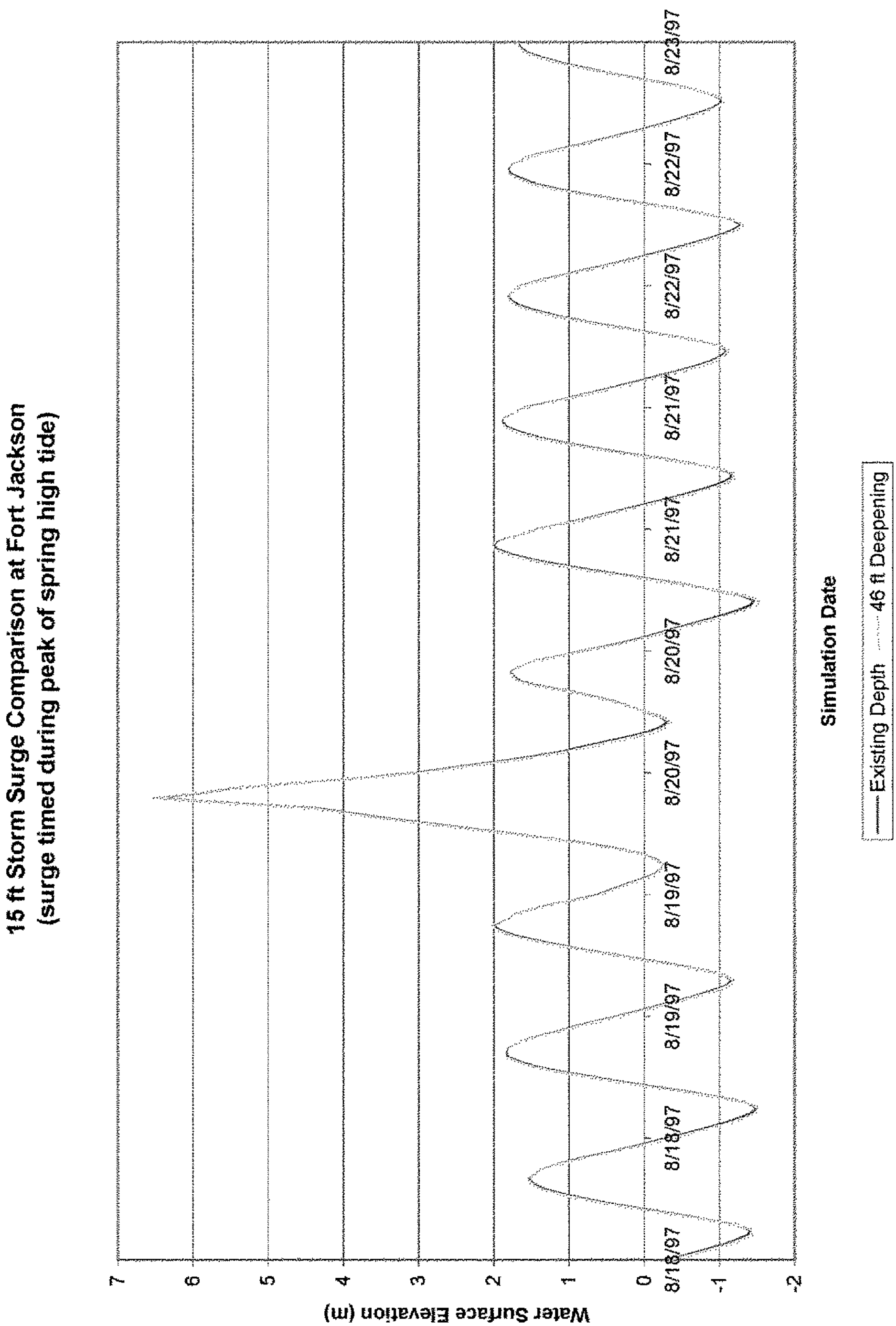
# Output Data

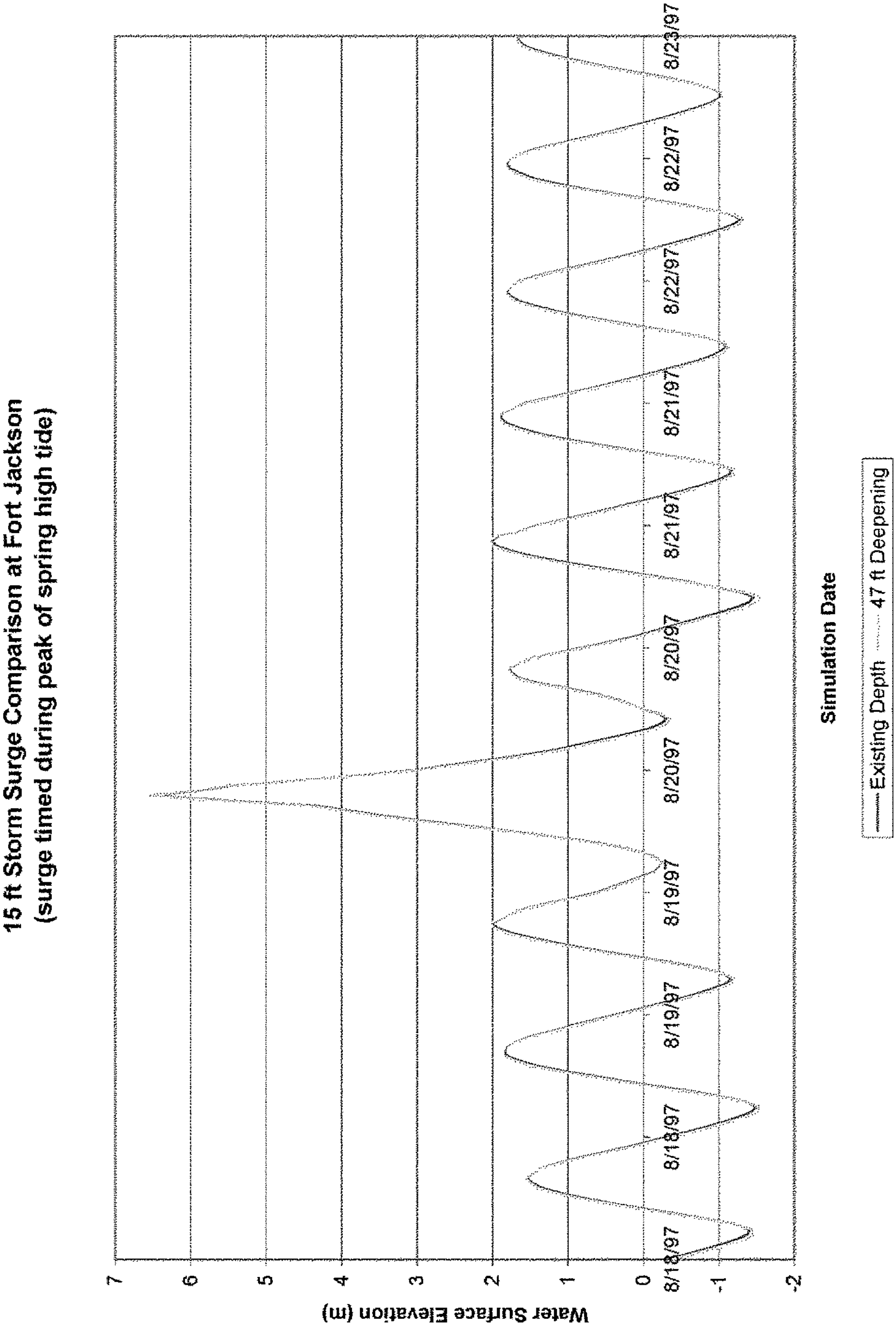
## Water surface Elevations for Existing and 47, 46, 45, and 44 ft Deepening (15 ft surge only, timed during peak of spring high tide)

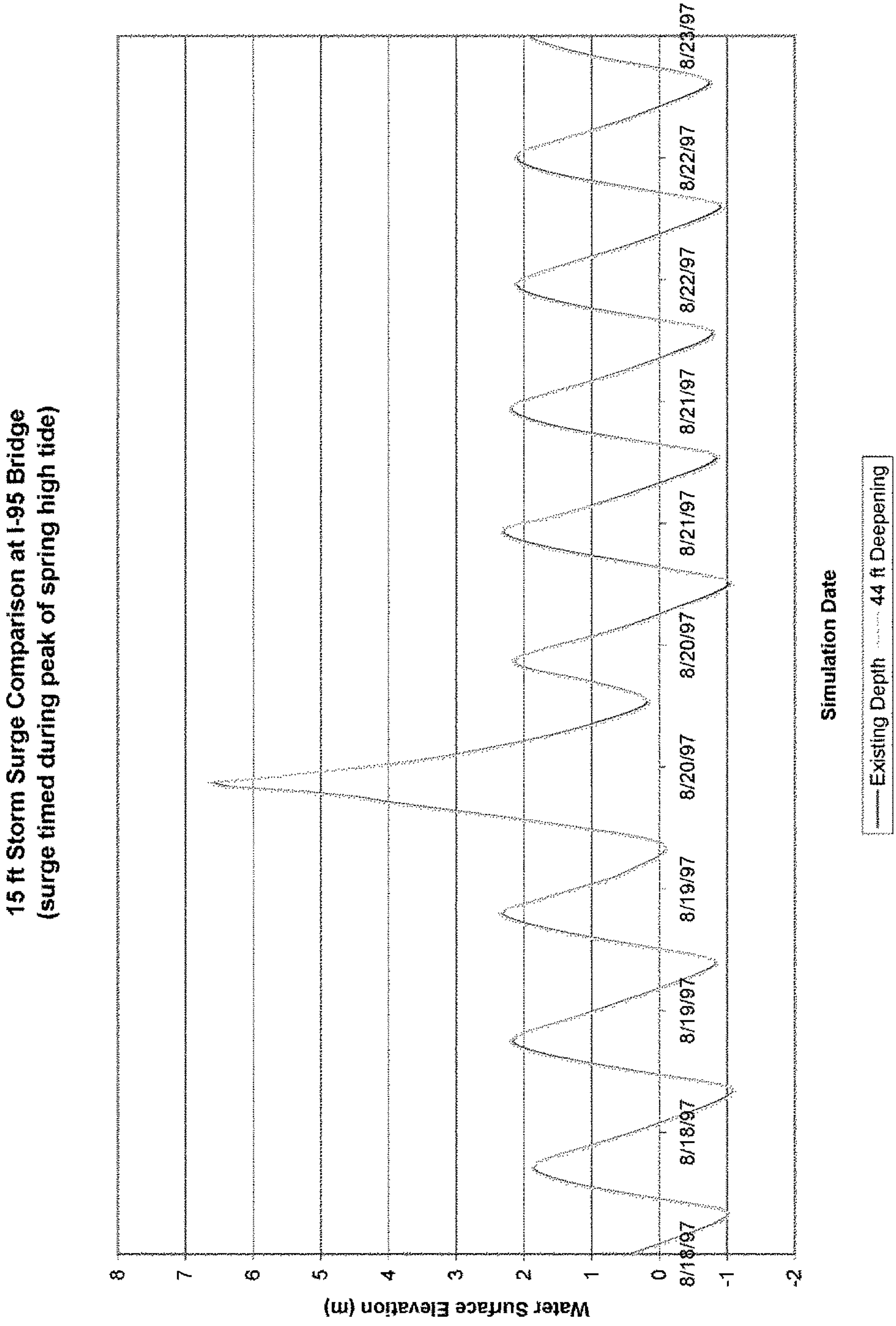


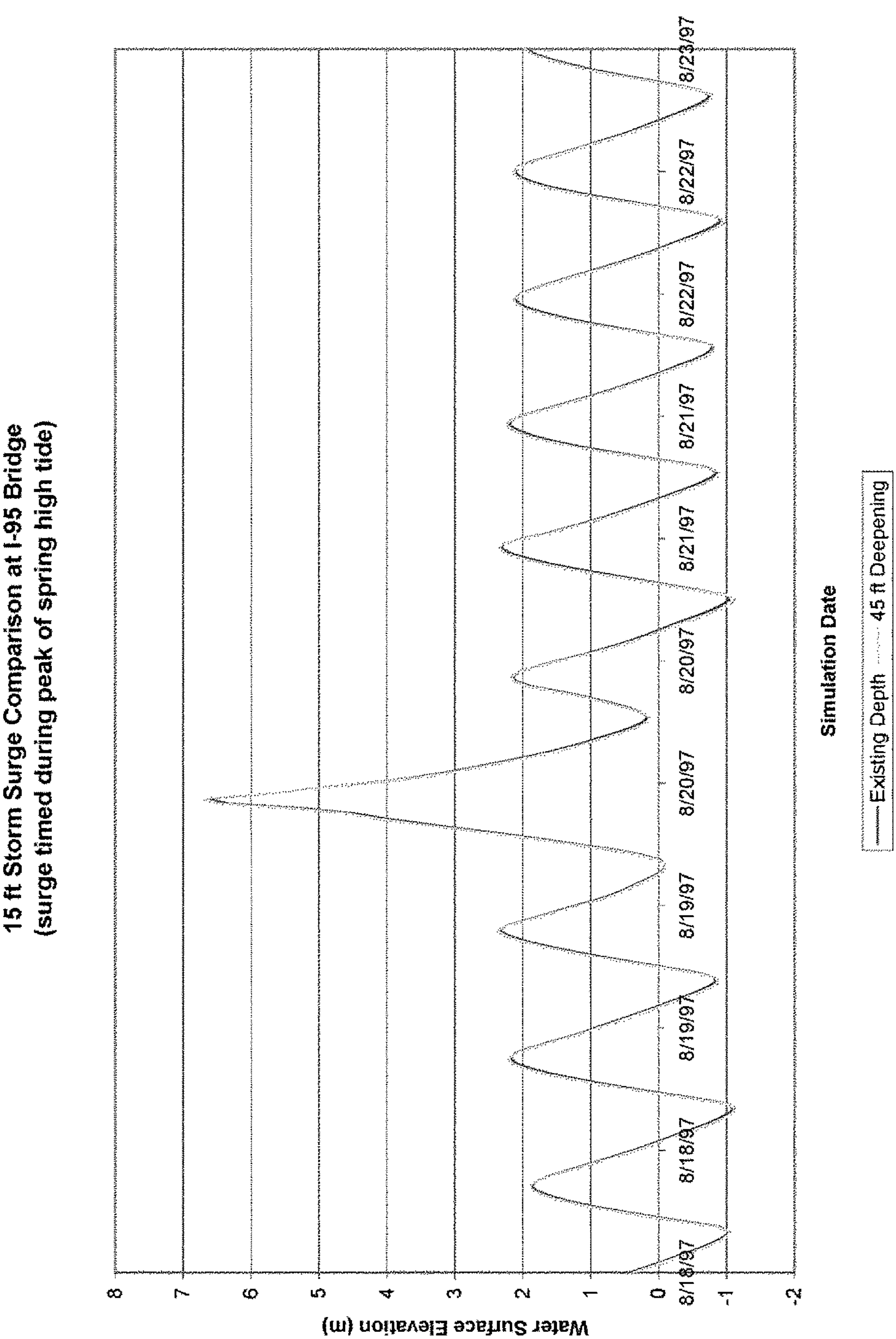
15 ft Storm Surge Comparison at Fort Jackson
(surge timed during peak of spring high tide)
Water Surface Elevation (m)
7
6
5
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
44 ft Deepening

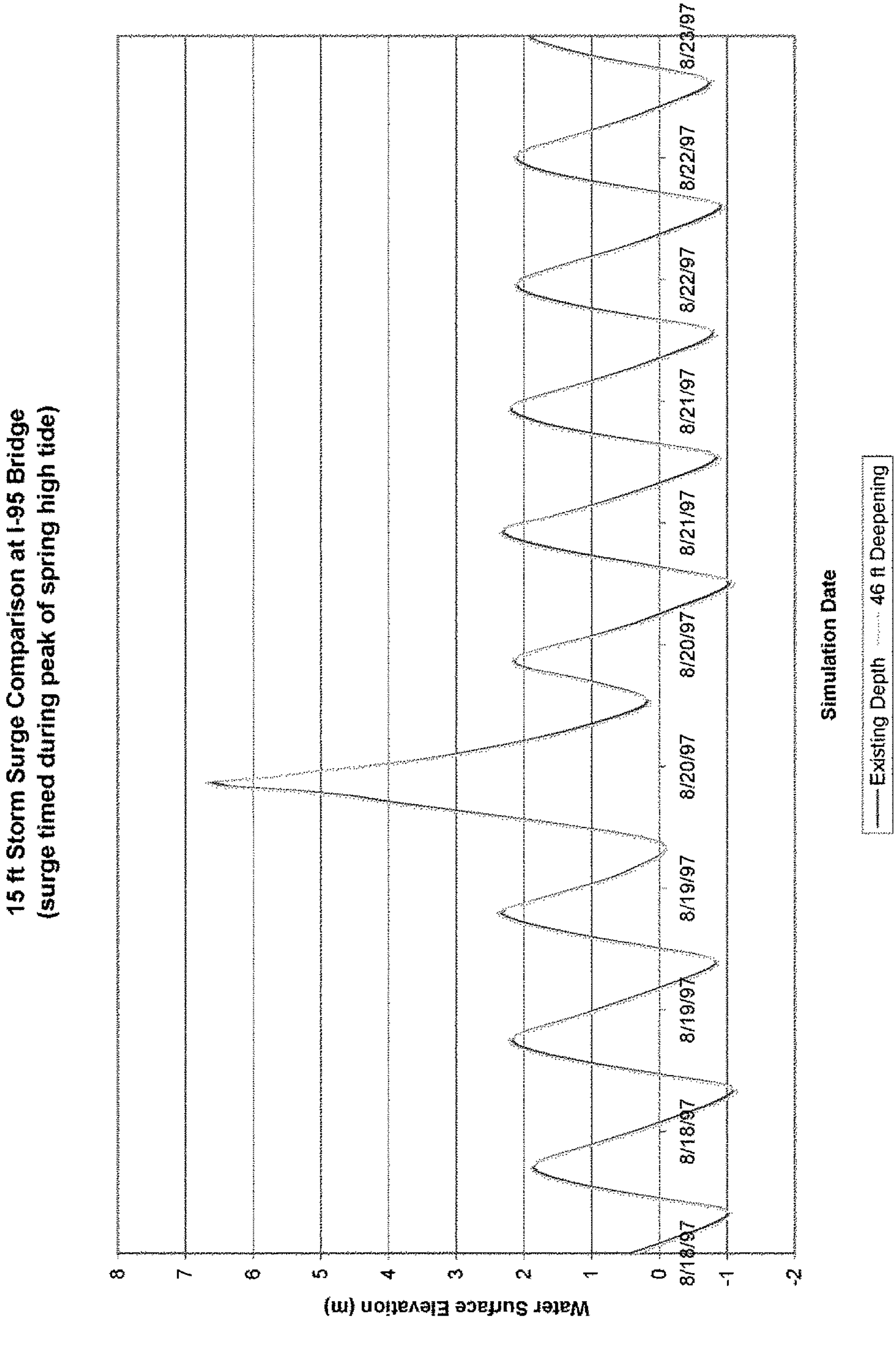

15 ft Storm Surge Comparison at Fort Jackson
(surge timed during peak of spring high tide)
Water Surface Elevation (m)
7
6
5
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
45 ft Deepening

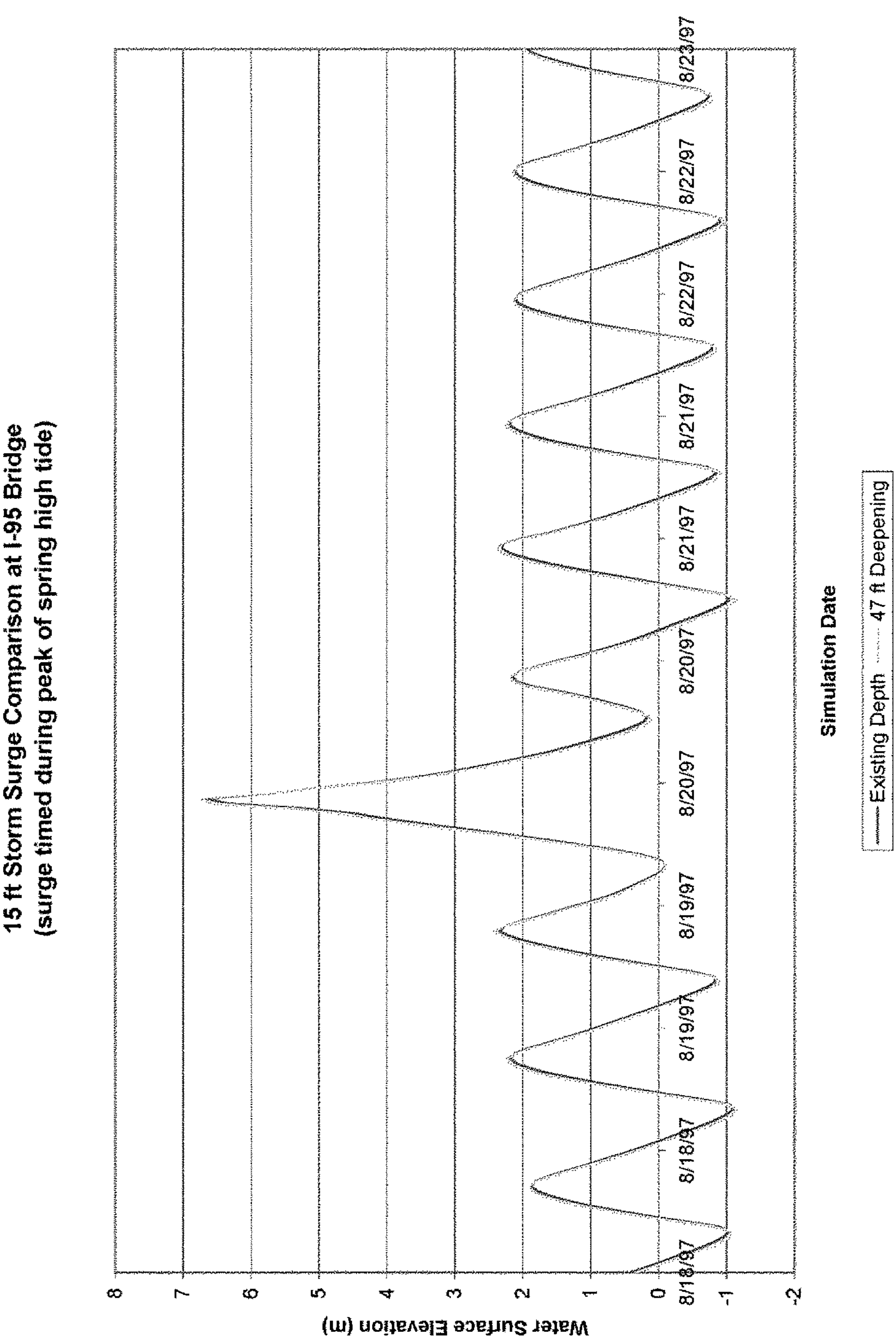

15 ft Storm Surge Comparison at Fort Jackson
(surge timed during peak of spring high tide)
Water Surface Elevation (m)
7
6
5
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
46 ft Deepening


15 ft Storm Surge Comparison at Fort Jackson
(surge timed during peak of spring high tide)
Water Surface Elevation (m)
7
6
5
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
47 ft Deepening


15 ft Storm Surge Comparison at I-95 Bridge
(surge timed during peak of spring high tide)
Water Surface Elevation (m)
8
7
6
5
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
44 ft Deepening


15 ft Storm Surge Comparison at I-95 Bridge
(surge timed during peak of spring high tide)
Water Surface Elevation (m)
8
7
6
5
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
45 ft Deepening


15 ft Storm Surge Comparison at I-95 Bridge
(surge timed during peak of spring high tide)
Water Surface Elevation (m)
8
7
6
5
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
46 ft Deepening


15 ft Storm Surge Comparison at I-95 Bridge
(surge timed during peak of spring high tide)
Water Surface Elevation (m)
8
7
6
5
4
3
2
1
0
-1
-2
8/18/97
8/18/97
8/19/97
8/19/97
8/20/97
8/20/97
8/21/97
8/21/97
8/22/97
8/22/97
8/23/97
Simulation Date
Existing Depth
47 ft Deepening

CESAS-EN-GG 6 August 2003

MEMORANDUM THRU

EN-GG
EN-G

FOR EN-HC (Seyle)

SUBJECT: Material fines for Savannah Harbor Sediments, Stations +103+000 thru –85+000 and KITB.

1. Attached is the subject material. This submittal supercedes previous submittals.

2. Range depths have been corrected for those evaluations between stations 24+000 and 70+000.

3. This submittal completes the request of 3 October 2002 Memorandum of Record.

4. Please call with any questions (5669).

Attachment

Matthew Delano, P.G.
Geology/Hydrogeology
and HTRW Design Section

# Savannah Harbor Expansion
## Percent Fines

| Station # | Final Depth (mlw) | Total Percent Fines |
|---|---|---|
| 0+000 to 10+000 | -52 | 14.139% |
| | -50 | 12.790% |
| | -48 | 12.679% |
| | -46 | 13.642% |
| 10+000 to 20+000 | -52 | 24.951% |
| | -50 | 23.621% |
| | -48 | 21.656% |
| | -46 | 15.992% |
| 20+000 to 24+000 | -52 | 59.561% |
| | -50 | 56.284% |
| | -48 | 48.588% |
| | -46 | 21.448% |
| 24+000 to 35+000 | -54 | 65.398% |
| | -52 | 64.337% |
| | -50 | 60.562% |
| | -48 | 54.025% |
| 35+000 to 37+000 | -56 | 67.195% |
| | -54 | 67.316% |
| | -52 | 67.526% |
| | -50 | 67.985% |
| 37+000 to 45+000 | -54 | 38.735% |
| | -52 | 36.925% |
| | -50 | 34.702% |
| | -48 | 31.977% |
| 45+000 to 55+000 | -54 | 40.270% |
| | -52 | 39.486% |
| | -50 | 38.579% |
| | -48 | 39.837% |
| 55+000 to 65+000 | -54 | 40.477% |
| | -52 | 40.352% |
| | -50 | 40.769% |
| | -48 | 42.268% |
| 65+000 to 70+000 | -54 | 14.947% |
| | -52 | 16.302% |
| | -50 | 20.719% |
| | -48 | 21.799% |

# Savannah Harbor Expansion
## Percent Fines

| Station # | Final Depth (mlw) | Total Percent Fines |
|---|---|---|
| 0+000 to -10+000 | -52 | 16.598% |
| | -50 | 14.946% |
| | -48 | 17.060% |
| | -46 | 20.745% |
| -10+000 to -20+000 | -52 | 29.403% |
| | -50 | 29.589% |
| | -48 | 30.599% |
| | -46 | 33.314% |
| -20+000 to -30+000 | -52 | 14.742% |
| | -50 | 15.933% |
| | -48 | 16.547% |
| | -46 | 17.830% |
| -30+000 to -40+000 | -52 | 28.571% |
| | -50 | 28.194% |
| | -48 | 28.589% |
| | -46 | 14.886% |
| -40+000 to -50+000 | -52 | 14.320% |
| | -50 | 14.725% |
| | -48 | 14.187% |
| | -46 | 9.808% |
| -50+000 to -60+000 | -52 | 11.595% |
| | -50 | 10.079% |
| | -48 | 10.706% |
| | -46 | 11.807% |
| -60+000 to -70+000 | -52 | 7.142% |
| | -50 | 8.656% |
| | -48 | N/A |
| | -46 | N/A |
| -70+000 to -80+000 | -52 | 3.443% |
| | -50 | 4.451% |
| | -48 | 5.200% |
| | -46 | N/A |
| -80+000 to -85+000 | -52 | 3.000% |
| | -50 | 3.000% |
| | -48 | N/A |
| | -46 | N/A |

## Savannah Harbor Expansion
## Percent Fines

| Station # | Final Depth (mlw) | Total Percent Fines |
|---|---|---|
| K I T B | -58 | 66.699% |
| | -56 | 67.760% |
| | -54 | 69.414% |
| | -52 | 72.348% |
| 70+000-80+000 | -52 | 29.610% |
| | -50 | 32.496% |
| | -48 | 34.275% |
| | -46 | 38.585% |
| 80+000-90+000 | -52 | 20.600% |
| | -50 | 17.742% |
| | -48 | 15.095% |
| | -46 | 13.232% |
| 90+000-102+000 | -52 | 57.961% |
| | -50 | 58.116% |
| | -48 | 59.147% |
| | -46 | 59.777% |
| 102+000-103+000 | -50 | 59.503% |
| | -48 | 51.478% |
| | -46 | 37.966% |
| | -44 | 17.740% |

CESAS-EN-GS

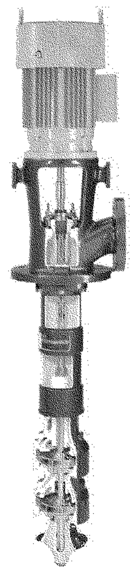
GEOTECHNICAL AND HTRW BRANCH
SOILS SECTION

US Army Corps
of Engineers®
Savannah District

**COST ESTIMATE**
**for**

# SUPPLEMENTAL WATER SUPPLY TO CITY OF SAVANNAH INTAKE AT ABERCORN CREEK

**April 15, 2011**



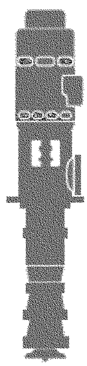
## SAVANNAH, GEORGIA

# Cost Estimate
## SUPPLEMENTAL WATER SUPPLY TO CITY OF SAVANNAH INTAKE AT ABERCORN CREEK

## Table of Contents

**Section** **Page**





# Cost Estimate
# SUPPLEMENTAL WATER SUPPLY TO CITY OF SAVANNAH INTAKE AT ABERCORN CREEK

## 1. Introduction

The City of Savannah expressed concerns that the Savannah Harbor Deepening Project may impact the salinity level at the Abercorn Creek intake structure. The Corps of Engineers (COE) is currently sampling and performing model studies to determine present chloride levels and the expected chloride levels at the Abercorn Creek Intake Site due to deepening of the Savannah River. In the event these studies indicate that deepening causes an unacceptable increase in chloride levels, various plans to mitigate for excess chlorides using supplemental water were investigated. The general requirements and costs contained herein are considered the best choice at a reasonable cost to accomplish a satisfactory reduction of chlorides in the present water system. Meetings were held with the City to determine their needs and a hardware list with associated costs was completed for various scenarios and water volumes. Actual design and pipe routes are not finalized and require additional work. This estimate provides a general overview of real estate impacts and costs for implementation. Finalization is expected to occur sometime after chloride studies are complete and a definite need established. Addressed herein are the latest planning level estimates prepared by HGBD for the City of Savannah and by USACE, Savannah District.

## 2. General Requirements

### 2.1 Summary of Major Components

A. Provide a new intake structure and Pump House at or near Plant McIntosh located about 10 miles upstream.

B. Provide a new guard house with sleeping quarters, a kitchen, and parking.

C. Provide an emergency power supply sufficient to power water supply pumps and ancillary devices.

D. Provide remote operational controls.

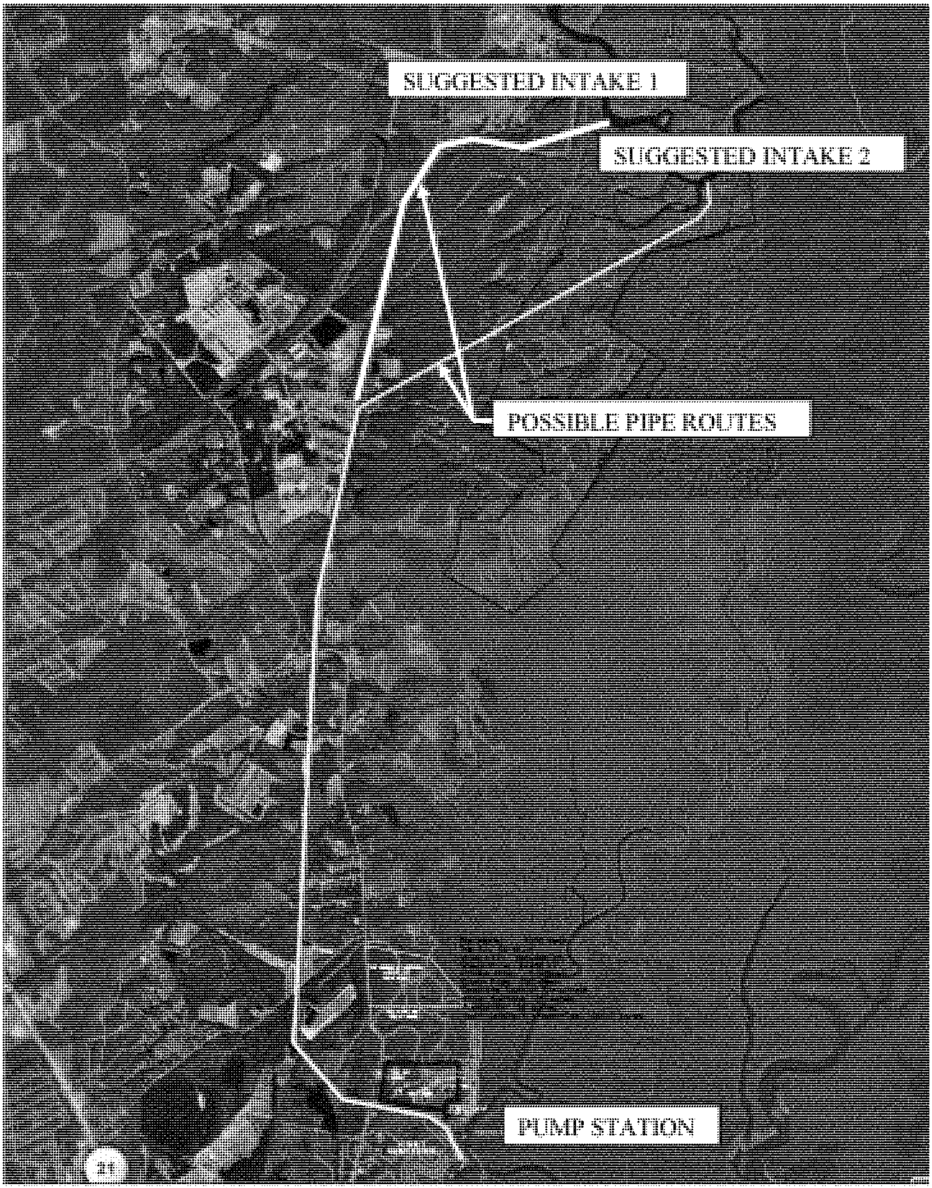
E. Provide redundant pump and supply pipe to ensure availability of water under all conditions.

F. Provide all related plumbing, valves, and hardware.

G. Acquire needed lands, easements, access roads, perform all required clearing and construction.

H. Provide required support utilities.

## 2.2 Pipeline Routing and Suggested Intake Locations -TBD



## 2.3 City of Savannah Cost Estimate (For Information Only)

Hussey, Gay, Bell, and DeYoung (HGBD) completed a cost estimate for the proposed work and furnished Mr. John Sawyer, City of Savannah a copy on January 20, 2009. The HGBD estimate is $38,532,238.

Jan 20 09 04:57p WATER AND SEWER DIRECTOR 9126513681 p.3
JAN-20-2009 09:22 HGBD 9123546754 P.02/03

SAVANNAH HARBOR EXPANSION PROJECT — MOST PROBABLE COST — 36" PIPE — April 11, 2008

| | | Quantity | UOM | Unit Price | Contract | Contingency | Total Cost | Unit |
|---|---|---|---|---|---|---|---|---|
| 01 | LANDS and Damages-Real Estate | 1 | JOB | | 1,180,000 | 295,000 | 1,475,000 | 1,475,000 |
| TOTAL QUANTITIES FOR WATER INTAKE AND PIPELINE | | | | | | | | |
| 1. | Hardware & Earthwork | | | | | | | |
| a. | Mob & DeMob | 1 | JOB | $605,000 | $605,000 | $151,000 | $756,000 | $756,000 |
| b. | 36" DIP Water Lines | 87,250 | LF | 315 ~~$400~~ | $27,483,750 | $549,700 | $28,033,450 | $321 |
| c. | 24" DIP Water Lines | 200 | LF | $272 | $54,400 | $20,000 | $74,400 | $372 |
| d. | 18" Water Lines | 200 | LF | $228 | $45,600 | $12,000 | $57,600 | $288 |
| e. | 12" Water Lines | 100 | LF | $184 | $18,400 | $6,000 | $24,400 | $244 |
| f. | 24" Gate Valves | 2 | LF | $17,000 | $34,000 | $6,800 | $40,800 | $20,400 |
| g. | 18" Gate Valves | 8 | EA | $17,400 | $139,200 | $27,840 | $167,040 | $20,880 |
| h. | 12" Gate Valves | 4 | EA | $4,500 | $18,000 | $3,600 | $21,600 | $5,400 |
| i. | 18" Check Valve | 4 | EA | $17,400 | $69,600 | $13,920 | $83,520 | $20,880 |
| j. | 12" Check Valve | 2 | EA | $4,500 | $9,000 | $1,800 | $10,800 | $5,400 |
| k. | Valve Pit | 1 | EA | $60,000 | $60,000 | $12,000 | $72,000 | $72,000 |
| l. | PPC Model 8x6M-V | 4 | EA | $58,000 | $232,000 | $46,400 | $278,400 | $69,600 |
| m. | Diesel Generator 350 kw | 1 | EA | $120,000 | $120,000 | $24,000 | $144,000 | $144,000 |
| n. | Intake structure | 1 | EA | $300,000 | $300,000 | $60,000 | $360,000 | $360,000 |
| j. | Power Requirement | 1 | LS | $1,000,000 | $1,000,000 | $20,000 | $1,020,000 | $1,020,000 |
| k. | 60x60x24 Tee | 1 | EA | $46,000 | $46,000 | $9,200 | $55,200 | $55,200 |
| l. | 48x48x24 Tee | 1 | EA | $29,440 | $29,440 | $5,888 | $35,328 | $35,328 |
| m. | Pump House | 600 | SF | $100 | $60,000 | $12,000 | $72,000 | $120 |
| n. | Guard House | 1,000 | SF | $100 | $100,000 | $20,000 | $120,000 | $120 |
| o. | Riprap GA Type I | 9,600 | TON | $88 | $844,800 | $168,960 | $1,013,760 | $106 |
| p. | Geotextile | 700 | SY | $30 | $21,000 | $4,200 | $25,200 | $36 |
| q. | Pipeline Access Road, 35 FT Width | 14,000 | LF | $24 | $336,000 | $67,200 | $403,200 | $29 |
| c. | Clear and Grub 10 MILES x 35 FT | 50 | ACR | $6,060 | $303,000 | $60,600 | $363,600 | $7,272 |
| s. | Remote Control to Plant | 1 | EA | $758,600 | $758,000 | $188,000 | $946,000 | $946,000 |
| | TOTAL LAND & HARDWARE | | | | $33,863,190 | $1,789,108 | $35,652,238 | |
| 30 | PLANNING, ENGINEERING AND DESIG | 1 | JOB | $1,300,000 | $1,300,000 | $260,000 | $1,560,000 | |
| 31 | SUPERVISION, ADMIN & CONST-MGM | 1 | JOB | $1,100,000 | $1,100,000 | $220,000 | $1,320,000 | |
| | TOTAL | | | | $36,263,190 | $2,269,108 | $38,532,238 | |

## 2.4 Corps of Engineers Cost Estimate

An estimate by the Corps of Engineers (COE) uses the same hardware and assumptions made by HGBD. Two exceptions between this estimate and the HGBD estimate are the contingency allowance, which the COE assumes as 25 percent, and the installed pipe costs, $351 vs. $221. A copy of the estimate is attached below: The COE estimate is $35,807,403.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | REAL ESTATE | | | | | Contingency 25% | | |
| 01 | Lands & Damages - Real Estate | 1 | JOB | $1,180,000 | $1,180,000 | $295,000 | $1,475,000 | |
| | QUANTITIES FOR WATER AND INTAKE AND PIPELINE | | Unit | | | | | |
| 1. | Description | Quantity | Measure | Unit Price | Contract | Contingency 25% | Total Cost | unit price with contingency |
| a | MOB & DEMOB | 1 | JOB | $605,000 | $605,000 | $151,250 | $756,250 | $756,250 |
| b | 36" Water Lines DIP | 87,250 | Lf | $221 | $19,282,250 | $4,820,563 | $24,102,813 | $276 |
| c | 24" Water Lines | 250 | Lf | $273 | $68,250 | $17,063 | $85,313 | $341 |
| d | 18" Water Lines | 250 | Lf | $229 | $57,303 | $14,326 | $71,628 | $287 |
| e | 12" Water Lines | 150 | Lf | $168 | $25,200 | $6,300 | $31,500 | $210 |
| f | 24" Gate Valves -ALL VALVES & TEES | 1 | LS | $574,774 | $574,774 | $143,694 | $718,468 | $718,468 |
| g | 18" Gate Valves | 8 | Ea | $0 | $0 | $0 | $0 | $0 |
| h | 12" Gate Valves | 4 | Ea | $0 | $0 | $0 | $0 | $0 |
| i | 18" Check Valve | 4 | Ea | $0 | $0 | $0 | $0 | $0 |
| j. | 12" Check Valve | 2 | Ea | $0 | $0 | $0 | $0 | $0 |
| k. | Valve Pit | 1 | | $90,800 | $90,800 | $22,700 | $113,500 | $113,500 |
| l. | PPC MODEL 8X6MI-V | 4 | Ea | $139,143 | $556,572 | $139,143 | $695,715 | $173,929 |
| m. | Diesel Backup Generator--350 kw | 1 | Ea | $120,000 | $120,000 | $30,000 | $150,000 | $150,000 |
| n. | Intake structure | 1 | Ea | $265,000 | $265,000 | $66,250 | $331,250 | $331,250 |
| j. | Power Requirement | 1 | Ea | $1,000,000 | $1,000,000 | $250,000 | $1,250,000 | $1,250,000 |
| k. | 60x60x24 Tee | 1 | Ea | $0 | $0 | $0 | $0 | $0 |
| l. | 48x48x24 Tee | 1 | Ea | $0 | $0 | $0 | $0 | $0 |
| m. | Pump House | 600 | SF | $100 | $60,000 | $15,000 | $75,000 | $125 |
| n. | Guard House | 1,000 | SF | $100 | $100,000 | $25,000 | $125,000 | $125 |
| o | Rip Rap-Ga Type 1 | 9,600 | TONS | $88 | $844,800 | $211,200 | $1,056,000 | $110 |
| p | Geotextile Fabric | 700 | SY | $30 | $21,000 | $5,250 | $26,250 | $38 |
| q | Pipeline Access Road, 35 FT Width | 14,000 | LF | $24 | $336,000 | $84,000 | $420,000 | $30 |
| r | Clear and Grub 10 miles x 35+ Width | 50 | ACR | $6,051 | $302,550 | $75,638 | $378,188 | $7,564 |
| s | Remote Control to Plant | 1 | LS | $756,424 | $756,424 | $189,106 | $945,530 | $945,530 |
| | CONSTRUCTION TOTAL | | | | $25,065,923 | $6,266,481 | $31,332,403 | |
| 30 | Planning, Engineering & Design | 1 | JOB | $1,300,000 | $1,300,000 | $325,000 | $1,625,000 | |
| 31 | Supervision, Admin & Const Mgt | 1 | JOB | $1,100,000 | $1,100,000 | $275,000 | $1,375,000 | |
| | TRUE AMOUNTS & PDF AMOUNTS THE SAME | | | | $28,645,923 | $7,161,481 | $35,807,403 | |

## 2.5 Cost Summary

COE costs are based on October 2010 prices and are considered good for today pricing.

| | |
|---|---|
| A. The City of Savannah Estimate | $38,532,238 |
| B. The COE Estimate | $35,807,403 |

## 3. Conclusions and Recommendations

The COE cost summarized in Item 2.5 B. is considered the minimum necessary to meet the City of Savannah requirements for supplemental water supply in the event supplemental water is required.

It is recommended that the COE estimate included herein be adopted into the project documents as the final estimate regarding supplemental water supply if deemed appropriate for the project to mitigate for chloride reduction.

CESAW-TS-EG

US Army Corps of Engineers®
Wilmington District

# SAVANNAH HARBOR EXPANSION BANK EROSION STUDY

ENVIRONMENTAL AND GEOTECHNICAL SECTION

## FORT PULASKI & NORTH TYBEE ISLAND GEORGIA

**02 November 2006**
**Amended per comments dated 29 July 2010**

# Savannah Harbor Expansion General Bank Erosion Study

## Table of Contents

## Appendices



## References

# SUMMARY
# SAVANNAH RIVER BANK EROSION STUDY
# SAVANNAH HARBOR EXPANSION PROJECT

## 1. Introduction

The Wilmington District Geotechnical Section (CESAW-TS-EG) has completed bank erosion studies for the shoreline at Fort Pulaski and North Tybee Island. Studies are based on available soils information, bathymetry, topographic surveys, aerial photographs, historical information, observation/review of channel side slopes resulting from previous harbor widening and deepening projects, and information from previous dredging works regarding channel side slope performance. Also included is information and data from the 'Ship Forces on the Shoreline of the Savannah Harbor Project' report recently completed by the US Army Engineer Research and Development Center (ERDC) and certain assumptions with regard to energies, erosion, and causal relationships. The ERDC Ship Forces Report originally included as Appendix A herein has been removed is now included as a separate document.

## 2. General

a. Channel side slopes historically average approximately 1 vertical on 3 horizontal (1V on 3H) for the Savannah River Inner Harbor and are generally considered the norm within the inner harbor. Channel side slopes for the Bar Channel are typically taken at 1V on 5H for dredging purposes; however, they will vary from 1V on 5H to flatter slopes. The shoreline for both the Fort Pulaski and North Tybee sites are well removed from the shipping channel and exist with much flatter side slopes that range from IV on 12H to 1V on 14H. The distance from the Fort Pulaski shoreline to the southernmost edge of the shipping channel varies from about 470 feet to 1,060 feet. The distance from the North Tybee Island shoreline to the shipping channel varies from just under to over one mile. The shoreline is separated from the shipping channel by the Cockspur Island Training Wall. A General Location Map is included as Appendix B.

Each is discussed separately in the following paragraphs. Areas that are not specifically addressed herein were also reviewed in detail using the proposed channel geometries and the most recent survey/sounding information, the results of which are addressed in other studies.

b. Addressed are the effects (or assumed effects) of time, tide, river currents, wind, rainfall, ship wakes, storms, channel configuration, aerial photography, structural enhancements, and other shoreline changes made from about 1957 to the present. Where actual measurements were obtained, they were considered in preparation of this report. Other information is based on known performance, bank materials, flow, area use, proximity of traffic, and other general assumptions made for each site.

c. Inspections were performed as a part of obtaining riverbank and structural information within the areas of concern. Field data obtained is described and discussed in ERDC's report Ship Forces on the Shoreline of the Savannah Harbor Project. A copy of the report is included as a separate document.

3. Subsurface Investigation

The U.S. Army Corps of Engineers (USACE) has performed a number of surface investigations and measurements within the Fort Pulaski and North Tybee Island areas. Soil borings were also made in the vicinity of the shipping channel. While these borings are not in the immediate vicinity of the shoreline, they describe typical soil types encountered nearby. The majority of these borings were drilled along the north side of the channel for the Savannah Harbor Widening and the Savannah Harbor Deepening projects. The investigations used a variety of methods to obtain subsurface data, including Vibracore, splitspooning, coring, cone penetration tests, and other methods. Standard penetration sampling using a split-barrel sampler was the method most often used. Using this method, a 1-3/8 inch inner diameter standard split barrel sampler was driven through the material using a 140-pound hammer with a 30-inch fall. The sampler was retrieved, and the material was described in accordance with the Unified Soil Classification System. Soil samples were obtained from borings and selected samples were tested for moisture content, plasticity, soil grain-size distribution, and strength characteristics.

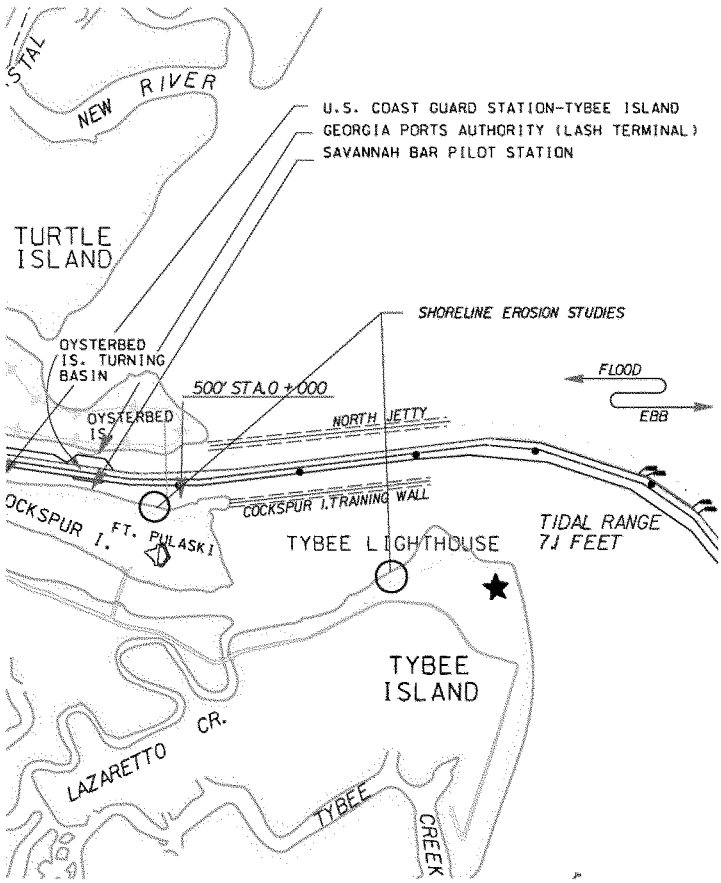
4. Analyses Overview

The analyses are intended to estimate the additional loss of shoreline due to ship wakes as a direct result of deepening the Savannah River shipping channel near the Fort Pulaski property and the northern beach of Tybee Island. The result was determined by taking the difference between the ship wakes of today versus the ship wakes of the future, after deepening. The total estimated shoreline erosion (due to all causes) is based on aerial photography from 1964 through 2003. While additional data is available, it doesn't appear to change the outcome with regard to shoreline recession. Other shoreline changes are discussed which include placement of dredged materials, armoring of adjacent shoreline, drainage features, and proximity of shoreline to the shipping channel.

5.. Fort Pulaski and North Tybee Descriptions

5.1 Fort Pulaski

The Fort Pulaski site is defined herein as the property along the shoreline from Georgia East NAD83 coordinates E 1049657.94, N 741683.76 (upstream) to E1052062.12, N 741085.54 (downstream); a distance of about 2,480 feet. The property is located at the entrance to the Savannah River from the Atlantic Ocean, directly adjacent to and on the outside bank of a 149 degree bend in (the river) real estate configuration. The general location is shown on the following Study Location Plan.




**STUDY LOCATION PLAN**

This shoreline is unprotected and lies immediately downstream from the protected shoreline utilized by the Savannah Pilots Association (SPA) and immediately upstream from the protected shoreline at the lower end of Cockspur Island. A circular erosion pattern exists immediately downstream from the SPA slope protection. The erosion for this area is apparently caused by eddy currents from tidal flows each day, the extent of which far exceeds other noted erosion anomalies. In addition, three prominent drainage features exist from upland areas to the shoreline spaced about 300 to 400 feet apart and located in the upstream half of the site.

The distance from the shoreline to shipping channel varies in a non-linear manner from about 790 feet to about 1,260 feet (Fort Pulaski), as determined from the shoreline visible on aerial photographs and measured to the shipping channel centerline, plotted and shown by coordinates (GA NAD 83).

Cross sections were plotted at 100-foot intervals along a baseline near the shore to cover the site and include the protected shoreline beyond the site at either end for a short distance. The plan view of the area indicating cross section locations is contained in Appendix C. Plans include the apparent shoreline taken from aerial photos for the years 1957 to 2003. Selected sections showing the range of variation are presented in Appendix D.

The proposed plan for deepening of the shipping channel calls for maintaining the existing shipping channel side slopes and allows for deepening by narrowing the channel bottom. Note that the shipping channel side slopes are separate and well removed from the shoreline or bank side slopes for both Fort Pulaski and North Tybee areas.

Review of the available information for Fort Pulaski and North Tybee indicates the proposed expansion with regard to the change or difference in ship wakes from 2005 through the year 2030 will not have a remarkable effect on either shoreline.

5.2 North Tybee

The North Tybee site is defined herein as the property along the shoreline from Georgia East NAD83 coordinates E 1060300.0, N 737576.0 (upstream) to E1062490.0, N 739000.0 (downstream); a distance of about 2,670 feet. The property is located near the entrance to the Savannah Front River from the Atlantic Ocean and behind a jetty located between the Front River and the Savannah River shipping channel. The general location is shown on the Study Location Plan.

The distance from the shoreline to shipping channel varies from less than one mile to almost one mile for North Tybee, as determined from the shoreline visible on aerial photographs and measured to the shipping channel centerline, plotted and shown by coordinates (GA NAD 83).

Immediately behind the Tybee shore and beach exists residential dwellings and various beach access structures.

6. Surface Investigations

The (unprotected) area of Fort Pulaski, North Tybee beach, City Front, and the north bight area has been investigated by several entities and methods. The City Front shows no adverse impacts due to deepening and will not be discussed herein. The bight area is being addressed as a separate issue and is currently programmed for repair and protection in the near future.

The unprotected river bank at Fort Pulaski has been the subject of several investigations.

(1) The Corps of Engineers, Savannah District has conducted an investigation of erosion using known soil properties composition, tide and flow patterns, aerial photographs from 1957 through 2006 showing the river's bank, and ship traffic through the shipping channel, now and predicted.

(2) The Engineer Research Development Center, Vicksburg, MS (formerly WES) was commissioned to conduct a study and has completed a 'Ship Forces on the Shoreline of the Savannah Harbor Project' Report which addresses the effect of ship wake(s) on the shoreline.

(3) The Skidaway Institute of Oceanography (SKIO) in Skidaway Island, GA has also conducted studies in and around the Fort Pulaski area under the direction of Dr. Alexander.

It appears that all of the studies, performed separately, have arrived at roughly the same conclusion with regard to 'the amount of shoreline recession' and 'where' erosion is taking place. There may some future discussion on exactly 'why' the (observed) erosion is taking place at any given point. Dr. Alexander has implied that the erosion at Fort Pulaski was due largely to ship traffic which is not supported by USACE studies.

Studies of the North Tybee area indicate some degree of erosion from various causes. However, correlations to ship traffic and the proposed deepening work do not appear to be supported. All indications suggest that the deepening of the shipping channel will reduce energies from ship wakes by approximately 2.3 to 5.9 percent. It is not believed that the deepening project will have any measurable effect on the North Tybee shore.

7. Fort Pulaski

The Fort Pulaski site identified in this study is the unprotected area previously described, it has three major drainage features, and one ongoing scour depression on the upstream side immediately adjacent to the end of the rock slope protection. Aerial photographs from 1955 through 2006 were used to estimate the average yearly bank erosion along about 4,100 feet of shoreline. Photos indicate that about 1.8 feet minimum each year is lost toward the approach and discharge ends. The maximum erosion occurs in the bend area of this site (about 148 degrees), and measurements indicate about 3 feet of shoreline per year are lost to erosion. Maps of the area are shown in Appendix C.

The early study was correlated with Dr. Alexander of the Skidaway Institute. His separate study indicated about 1 meter or a little over 1 meter for the same area; thus, with a good match on how much erosion is taking place for the area, additional refinements were not attempted.

The next step involved plotting of cross sections to determine channel configuration with respect to the shoreline; calculating the flow area; estimating the average velocity of flows, depths, radius, and other factors in an attempt to find the amount of scour and erosion that would take place on the bank (without ships), for the existing channel depth of 46 feet and the maximum proposed channel depth of 52 feet. Using the Zeller Bend Scour method from a paper and computation spreadsheet developed by David T. Williams, Ph.D. PE, and Leo R.

Kreymborg, PE, with input from Steve Maynord, ERDC and others, the erosion predicted for the Fort Pulaski bend site ranges from 1.6 feet to 3.2 feet. The model isn't perfect; it assumes that side slopes are uniform (not), bottom is uniform (not), crest contains smooth lines (not), and so forth.

Additional checks were performed using the CEDAS –ACES program. ACES is an interactive computer-based design and analysis system in the field of coastal engineering containing six functional areas: wave prediction, wave theory, wave transformation, structural design, wave runup, and littoral processes. This program looks at tides, velocities, shape and size of the entrance and discharge openings, and bend angle, among other parameters. The predicted erosion from this model ranged from 3.0 to 3.3 feet. Both models do not include ship traffic and/or ship wakes.

Consideration is given to the occasional storms, Northeastern'rs and long fetch waves on the Fort Pulaski site. However, this effort was limited to results from a single one hour event with a maximum wind of 45 mph. One such event yielded a 4.2 –foot wave height and a 4.2 -second wave period. A storm duration of the scope defined above is estimated to account for about 0.1 foot of shoreline loss each year/event.

Omitted are the eddy effects of the armor stone placed immediately upstream of this area, the three drainage features (ditches or severe roughness factors), and other shape factors that serve only to complicate erosion patterns beyond that actually measured on the ground.

Included are the results from ERDC's Ship Wake Study that notes: "Wave power, found by Kamphuis (1987) to correlate with shoreline recession, was calculated with equation 4. Bow and stern wave periods from the field study were 3-3.5 sec. The composite short period wave height increases of 1.5 to 4.4% result in wave power increases of 2.3 to 19%." The report is included as a separate document.

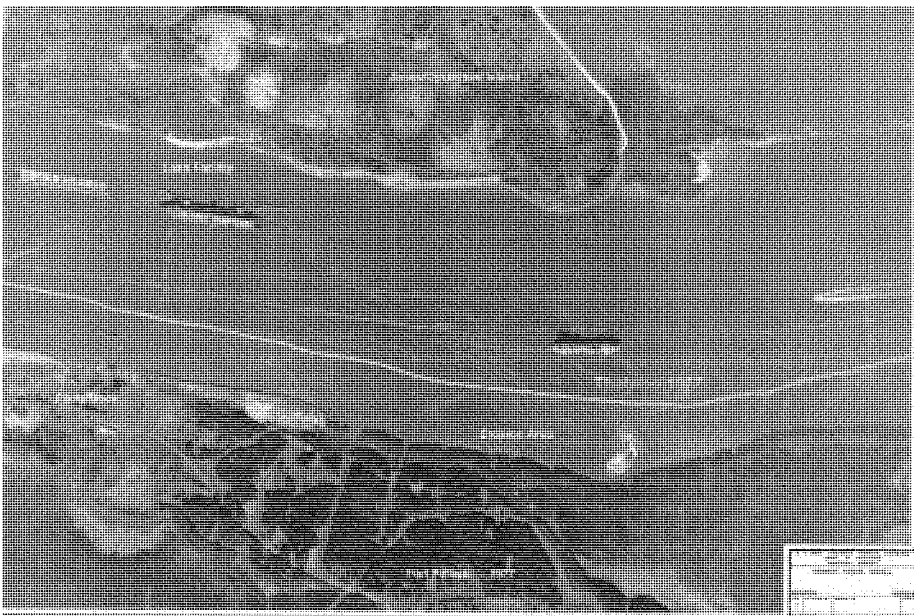
Also considered is the effect of the channel shape and appurtenances constructed which influence flow, thalwag configuration and direction, and the amount of time that a ship will spend contributing energy to the shore which could in turn contribute to erosion. The photo of the Fort Pulaski area (shown below) from 1977 is a good example of the ebb tide flow regime. It also shows the apparent magnitude of ship wake compared to normal ebb currents and waves.

The present ship traffic has been estimated from the ERDC study as shown in Table 4 of the early draft report (below):

Table 4. 2003 Containership Traffic for Savannah Harbor

| Vessel Type | Length, ft | Beam, ft | Design Draft, ft | # Calls | % of calls(*) |
|---|---|---|---|---|---|
| Post-Panamax | 1044 | 140 | 45.3 | 7 | 0.6(4.9) |
| Panamax | 951 | 106 | 40.7 | 872 | 70.0(48.0) |
| Sub-Panamax | 716.3 | 99.8 | 37.7 | 255 | 20.5(15.7) |
| Handysize | 579.1 | 85.1 | 31.8 | 105 | 8.4(17.6) |
| Feedermax | 427.5 | 67.7 | 25.2 | 5 | 0.4(8.8) |
| Feeder | 344.7 | 56.1 | 20.0 | 1 | 0.1(4.9) |

*%of ship transits in 2005 field study- based on 102 ship transits



FORT PULASKI - 1977

Based on the estimated number of ships in the ERDC study, approximately 1,245 calls were made to Savannah Harbor for the year 2003 (as estimated from the 2005 study). Georgia Ports, as of 2006, adjusted the 2003 port calls to 1,258. Ship traffic is quantified by number of calls with each call being equal to one inbound and one outbound transit. Ship speeds were measured from 9 to 14 knots (1 Foot per Second (fps) = 0.593124324324324 Knot) relative to the shore. Roughly translated, ship speeds varied between 15.2 and 23.6 feet per second, the average of which is about 19.4. At Fort Pulaski, ship speeds increased slightly, measured at 11.5 to 11.8 knots (19.4 to 19.9 fps) for an average of 19.6 fps. The average length of 98.9 percent of all ships calling was determined from the ERDC report to be 574 feet. The average time that any ship spent passing any given spot along the shore at Fort Pulaski was 574 / 19.6 or about 29 seconds. The duration of ship generated standing wave plus trailing waves incident upon the shore was approximately equal to the ship's speed. The effective time of ship generated wave activity incident upon the shore is estimated as 19.6 mph average. This is also a good match with field observations of incident waves on the shore from passing ships.

Summarizing, there is about (worst case) one meter or about 3.1 feet of shoreline lost to erosion each year due to all causes. Of the 3.1 feet, the flows, tides and normal wave activity accounts for between 3.0 +0.1 and 3.3 feet roughly determined from software model programs. For the purpose of this study, we have assumed that the values obtained with the erosion model do not exceed the observed erosion values.

For the year 2003: 1,258 calls * 2 (in and out) equals 2,516 passing events (at Fort Pulaski) of a duration approximately 19.6 seconds each which corresponds to about 49,314 seconds of impact at any given point during the year. Thus, the percent of time for ships is about 0.156 percent of the year 2003 at any given point.

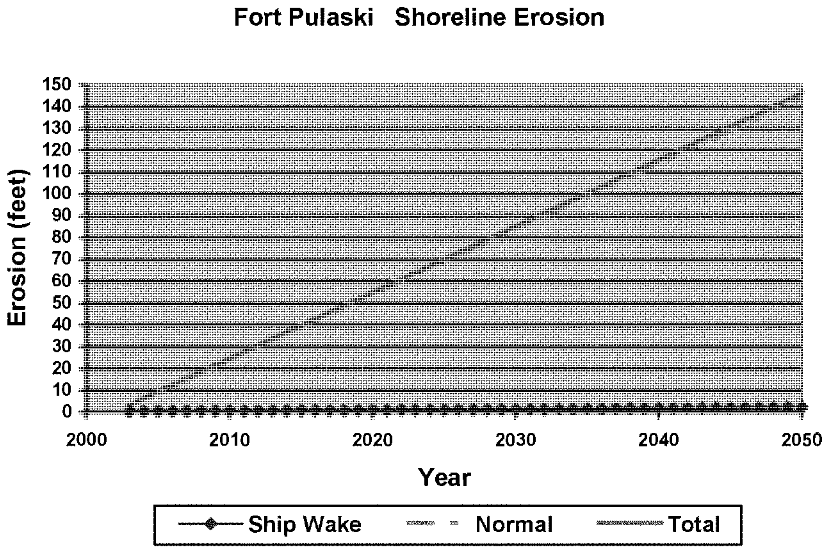
For the year 2030: 4,030 calls *2 (in and out) is 8,060 passing events (at Fort Pulaski), same duration, corresponds to about 157,976 seconds of impact at any given point during the year. Thus, the percent of time for ships is about 0.500 percent of the year 2030 at any given point.

For the year 2050: 7,801 calls *2 (in and out) is 15,602 passing events (at Fort Pulaski), same duration, corresponds to about 305,799 seconds of impact at any given point during the year. Thus, the percent of time for ships is about 0.970 percent of the year 2050 at any given point.

What is left (as a worst case) is the 3.1 feet (total) minus the 3.0 feet (predicted without traffic or other events) or 0.1 foot of erosion due to ship traffic and other causes. While 'other causes' were considered, detailed measurements were not made and could only be estimated. No doubt, the magnitude of each could be debated (until measurements are actually taken). Such events would include rain events, drainage events through the three drainage features, foot traffic, pleasure boat wakes, wind, the amount sedimentation contained or suspended in water flows, the GA Ports Lash Facility which serves to move the thalwag toward Fort Pulaski, etc., all of which will contribute to shoreline erosion of the unprotected slope. For the purpose of this study, the amount of erosion caused by 'other' events is estimated to operate more than 70 percent of the time each year with the ship traffic being responsible for the remaining possible 30 percent. Together, each is assumed to be responsible for the remaining 0.1 foot (1.2 inches) of erosion. Thus, it is estimated that 0.36 inch (about 3/8 inch maximum) of erosion could be attributed to all ship wakes during the year 2003. The existing range for erosion due to ship wakes then becomes an estimated negligible to 0.36 inch maximum.

Working with the maximum estimated erosion, predicting erosion for the years 2030 and 2050 becomes a function of ship numbers and size. Ships (of various size) have been predicted to call in about the same proportion as years earlier; thus, sizes were normalized and averaged. Therefore, if 1,258 ship calls were responsible for 0.36 inch of erosion at Fort Pulaski; then:

in the year 2030, 4,030 ship calls could be responsible for 3.2 * 0.36 or 1.15 inches, and in the year 2050, ship calls could be responsible for 6.2 * 0.36 or 2.23 inches of erosion, assuming the shoreline remains unprotected. The following chart graphically shows the predicted erosion due to ship wake(s), normal erosion, and the sum of the two (Total Erosion) over time.




The chart plots the erosion predicted from ship wakes (4.69) feet from 2003 through 2050. The chart also shows the expected normal erosion, without ship traffic or deepening, which is predicted to be 144 feet. It becomes obvious that if 148.69 feet (total) actually occurs over the next 47 years at this location, that amount of erosion would create a multitude of other problems. It is far more likely other events would prevent the full scope of the predicted erosion, i.e. slope protection might be installed.

8. North Tybee

As per the ERDC Ship Forces on the Shoreline of the Savannah Harbor Project Report, the Savannah Harbor Deepening will have no significant effect on North Tybee. The report concludes:

"At Tybee Island, the only significant ship effect reaching the shoreline is the long period drawdown or pressure wave. It is uncertain if the south jetty blocks ship effects at high tides because ship effects generated outside the jetties reach the TI shoreline. As shown in Tables 16-19, the composite drawdown in the channel between the jetties per ship is 2.3 to 5.9% less in the with project (deepened) channel. The actual drawdown at the TI shoreline will be about 1/3 of the drawdown in the channel between the jetties."

9. City Front

The average drawdown for all ship traffic measured was 0.355 foot. (See Table 21 of the ERDC Report.) Due to the reduced speed in the City Front area, drawdown and ship wake are predicted to remain unchanged. Deepening of the channel is predicted to reduce the effect of ship wake by approximately 4 percent.

10. Confined Disposal Facility

This area of the bight has been predicted to experience approximately the same effect as the Fort Pulaski Site. However, a separate project is currently in progress to armor the shoreline to protect the GA State owned property at the expense of the State of Georgia.

11. Bank Stability Review

A review of the Savannah Harbor Expansion Bank Stability Report dated May 2005 has been completed with respect to the ERDC Ship Wake Study. The May 2005 report addressed the shipping channel with special attention given to areas where the deepened and/or revised channel alignment would or could impact existing shore, involve real estate taking, or directly affect real property in any way. Nothing contained in the ERDC Ship Wake study directly impacts the previous study in a way that would require redesign or additional takings. Previously noted, the global or overall factor of safety (FS) against slope failure is 2.2 for the riverbank and dike. However, for the softer soils located generally within the tidal zone, the calculated factor of safety is approximately 1.1. While the lower FS does not necessarily indicate a local failure problem, the fact that soft soil material occurs in the tidal zone could indicate an ongoing erosion problem due mainly to tidal and wave action. The analyses also indicate that the calculated slope exposed to the river should remain stable on an approximate 1 vertical on 3.2 horizontal slope (1V on 3H). Erosion due to time and tide is not generally considered a concern in need of Federal intervention with regard to private property.

12. Summary

The effects of deepening the Savannah River channel will not impact either the City Front or the North Tybee Site to any measurable degree.

The Confined Disposal Facility Site while impacted is in the process of being protected with armor stone against future erosion from tides, flows, and ship traffic.

Unprotected portions of Fort Pulaski are subject to shoreline erosion measurable from 1.6 to 3.1 feet per year, depending on specific location. The majority of erosion is due to tide, flows, river mechanics, shape and other causes unrelated to ship traffic through channel. Ship traffic is estimated to have a minimal but measurable impact of about 0.36 inch (year 2003), 1.15 inch (year 2030), and 2.23 inch (year 2050) based on the predicted fleet mix and volume.

The total cumulative 47-year shoreline loss due to river environment without ships is estimated to be between 144 feet (maximum) and 75 feet (minimum).

The total cumulative 47-year shoreline loss due to ship traffic and predicted fleet mix is estimated to be between 4.69 feet (maximum) and 2.3 feet (minimum).

The total cumulative (predictable maximum) shoreline loss due to all causes, except for unforeseen and/or catastrophic events, is 144 + 4.69 or about 149 feet.

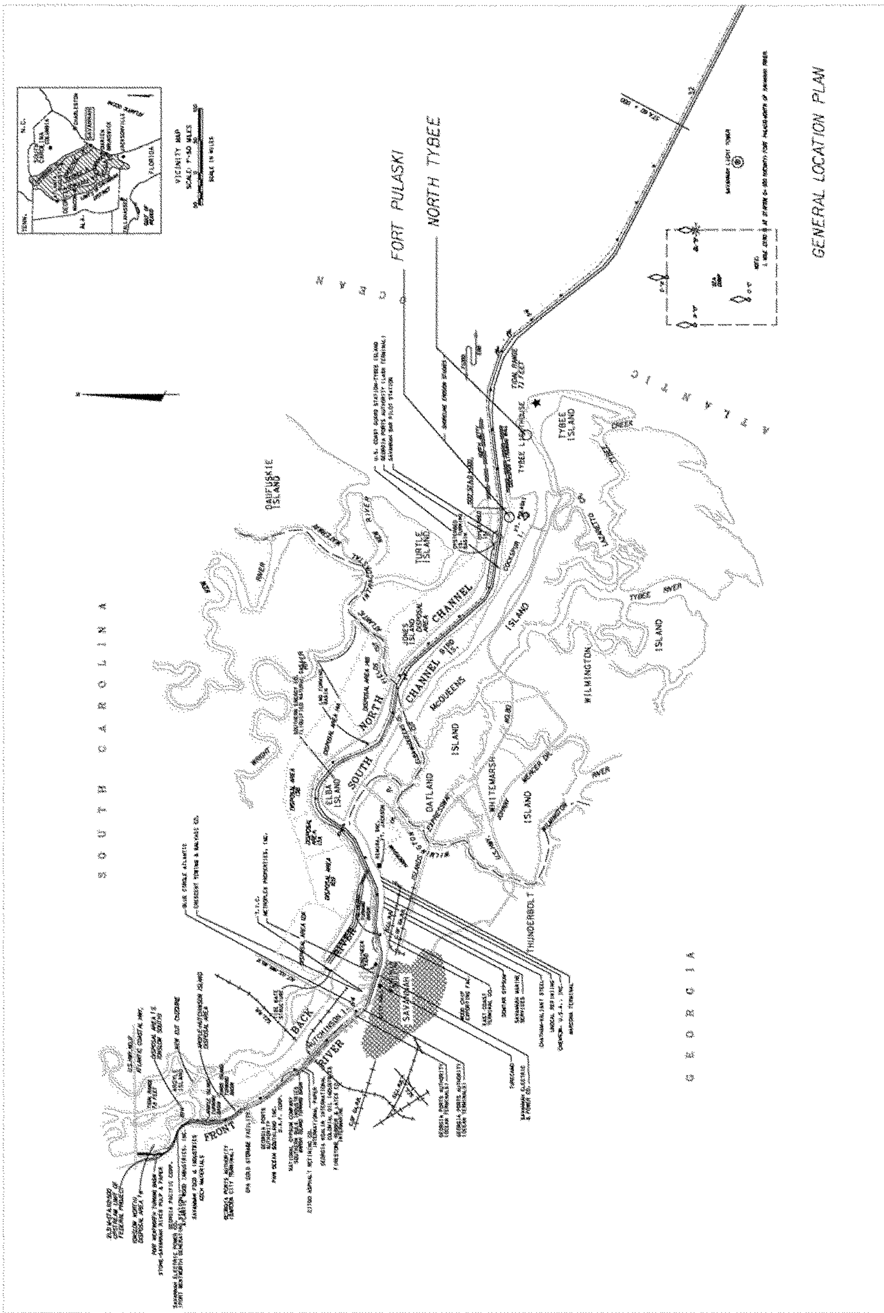
# APPENDIX A

# SHIP FORCES

**Removed from this report and included as a separate document.**

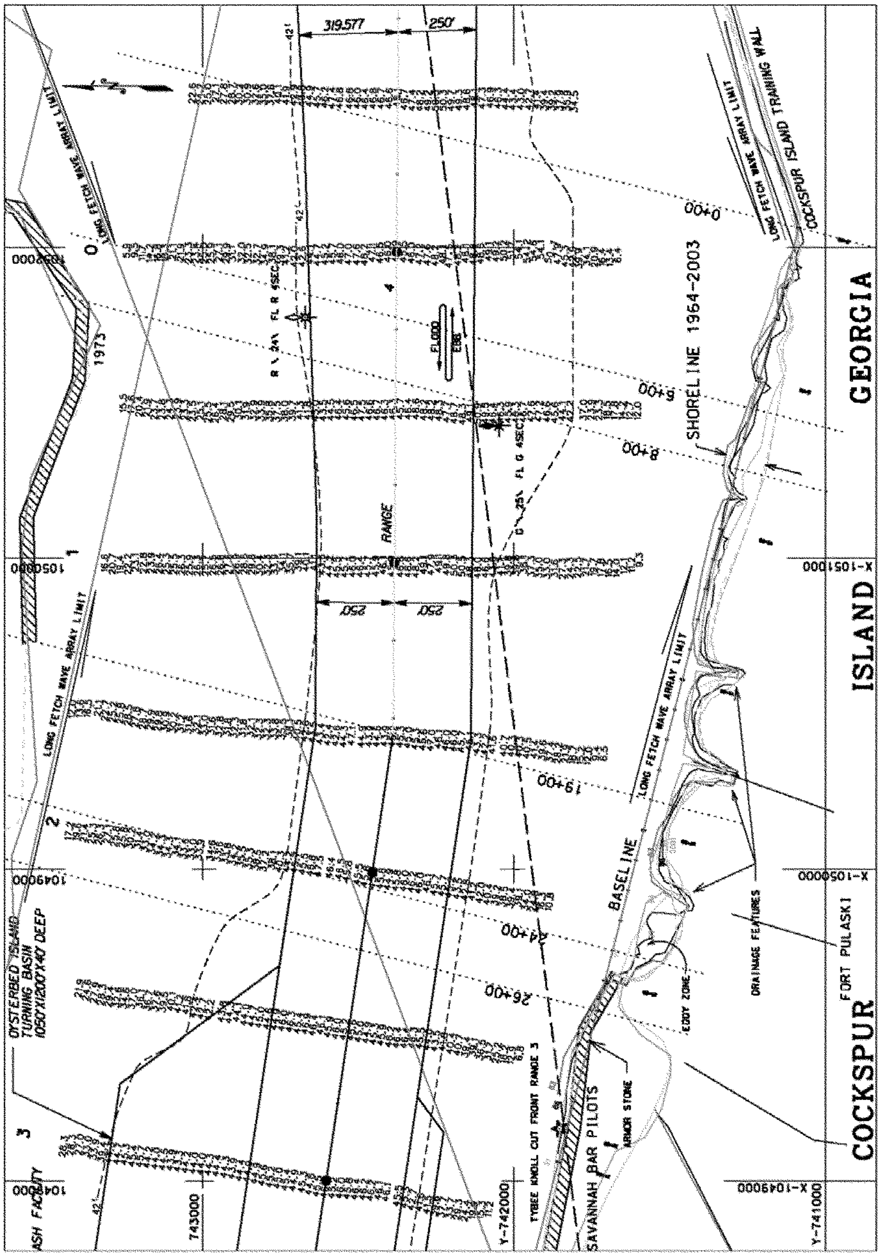
# APPENDIX B

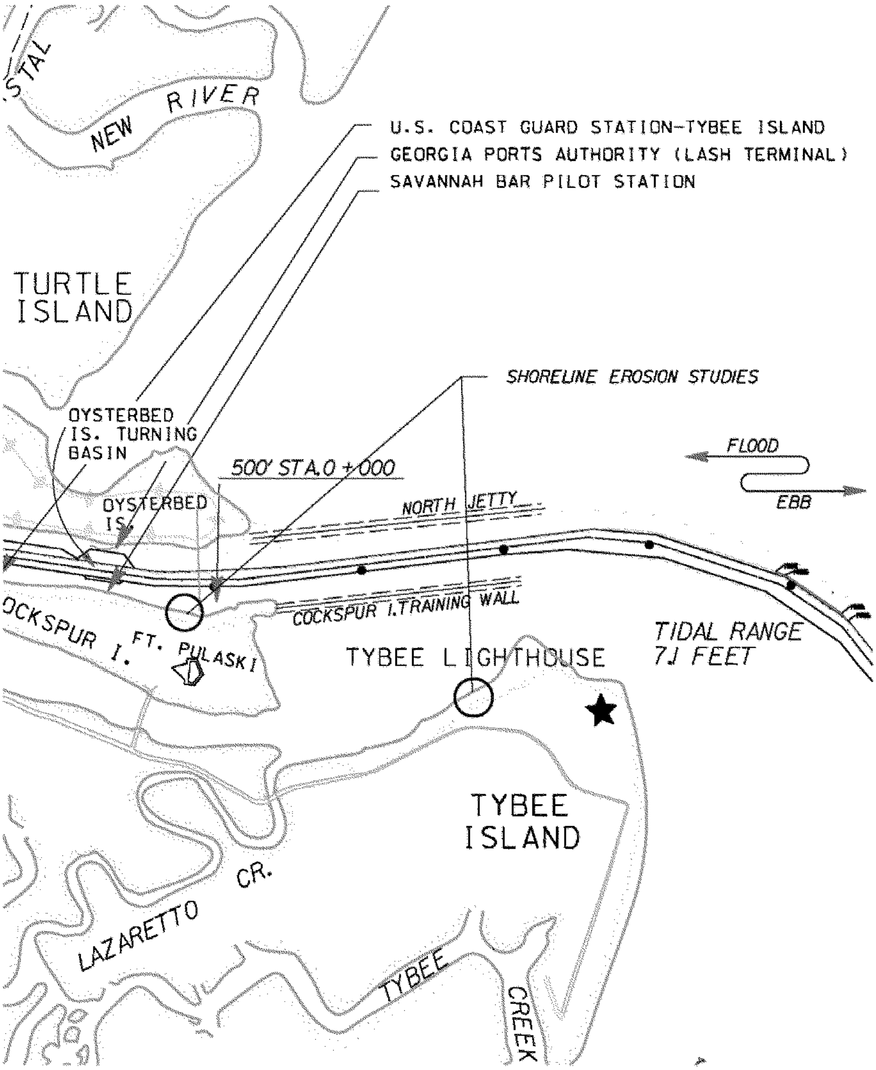
# GENERAL LOCATION MAP

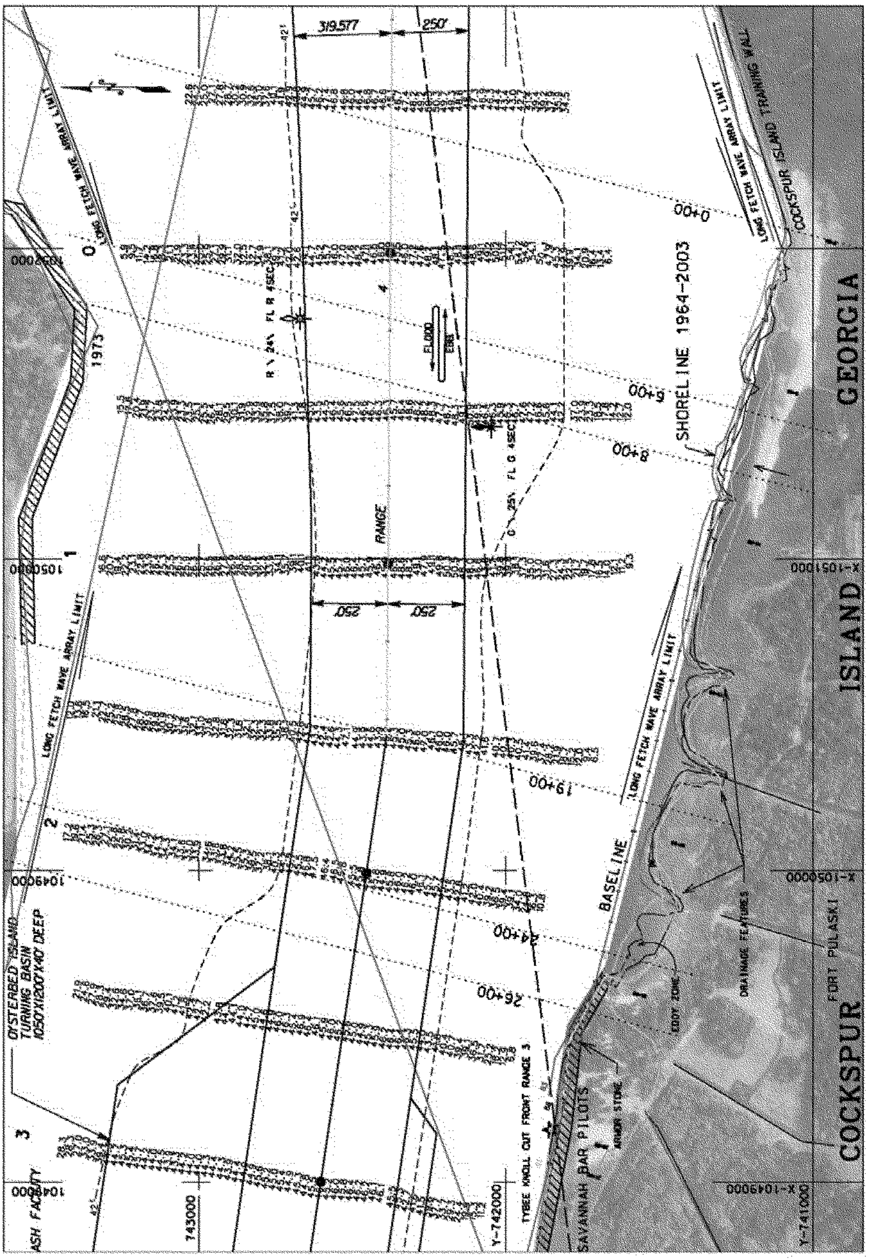

GENERAL LOCATION PLAN
FORT PULASKI
NORTH TYBEE
SOUTH CAROLINA
GEORGIA
DAUFUSKIE ISLAND
TURTLE ISLAND
TYBEE ISLAND
ELBA ISLAND
McQUEENS ISLAND
WILMINGTON ISLAND
WHITEMARSH ISLAND
OATLAND
SAVANNAH
THUNDERBOLT
NORTH CHANNEL
SOUTH CHANNEL
FRONT RIVER
BACK RIVER
TYBEE RIVER
VICINITY MAP

# APPENDIX C

# MAPS GENERAL


GEORGIA
ISLAND
COCKSPUR
SHORELINE 1964-2003
BASELINE
LONG FETCH WAVE ARRAY LIMIT
COCKSPUR ISLAND TRAINING WALL
DRAINAGE FEATURES
FORT PULASKI
EDDY ZONE
ARMOR STONE
SAVANNAH BAR PILOTS
TYBEE KNOLL CUT FRONT RANGE 3
OYSTERBED ISLAND TURNING BASIN 1050'X1200'X40' DEEP
RANGE
FLOOD
EBB
319.577
250'
1973

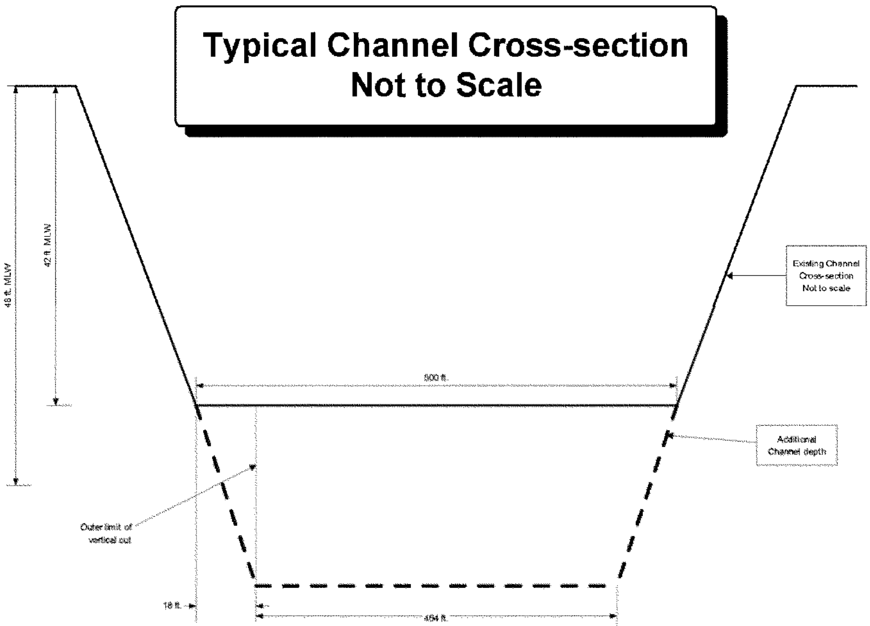

NEW RIVER
U.S. COAST GUARD STATION-TYBEE ISLAND
GEORGIA PORTS AUTHORITY (LASH TERMINAL)
SAVANNAH BAR PILOT STATION
TURTLE ISLAND
SHORELINE EROSION STUDIES
OYSTERBED IS. TURNING BASIN
FLOOD
EBB
500' STA.0 + 000
OYSTERBED IS.
NORTH JETTY
COCKSPUR I.TRAINING WALL
COCKSPUR I.
FT. PULASKI
TYBEE LIGHTHOUSE
TIDAL RANGE 7.1 FEET
TYBEE ISLAND
LAZARETTO CR.
TYBEE CREEK

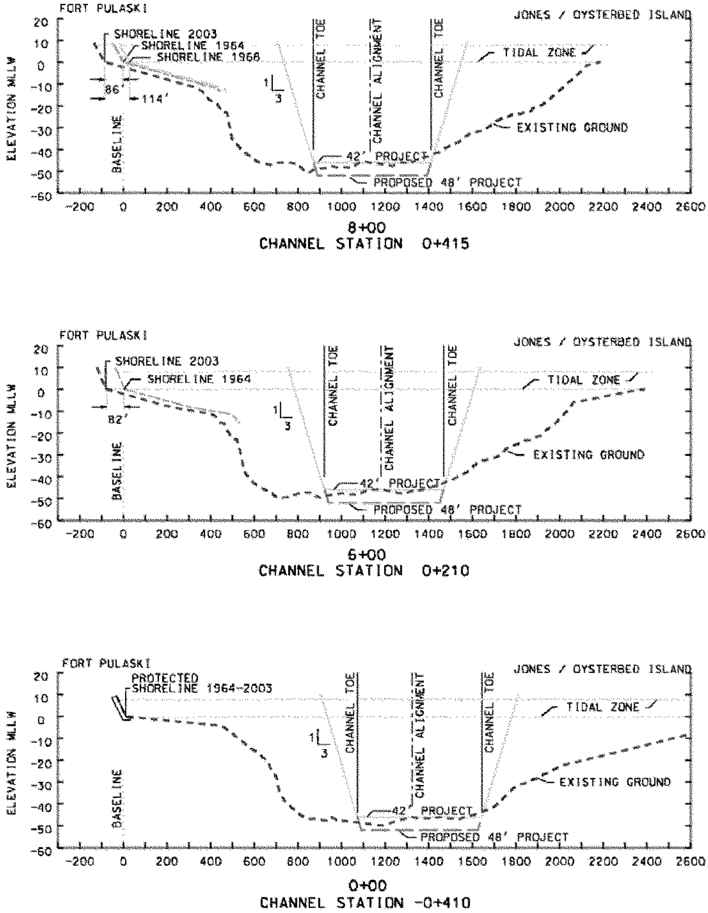

COCKSPUR ISLAND GEORGIA
FORT PULASKI
SHORELINE 1964-2003
BASELINE
LONG FETCH WAVE ARRAY LIMIT
COCKSPUR ISLAND TRAINING WALL
DRAINAGE FEATURES
EDDY ZONE
ARMOR STONE
SAVANNAH BAR PILOTS
TYBEE KNOLL CUT FRONT RANGE 3
OYSTERBED ISLAND TURNING BASIN 1050'X1200'X40' DEEP
RANGE
FLOOD
EBB
319.577
250'
0+00
6+00
8+00
19+00
24+00
26+00
1975

**Savannah River Entrance 2006**

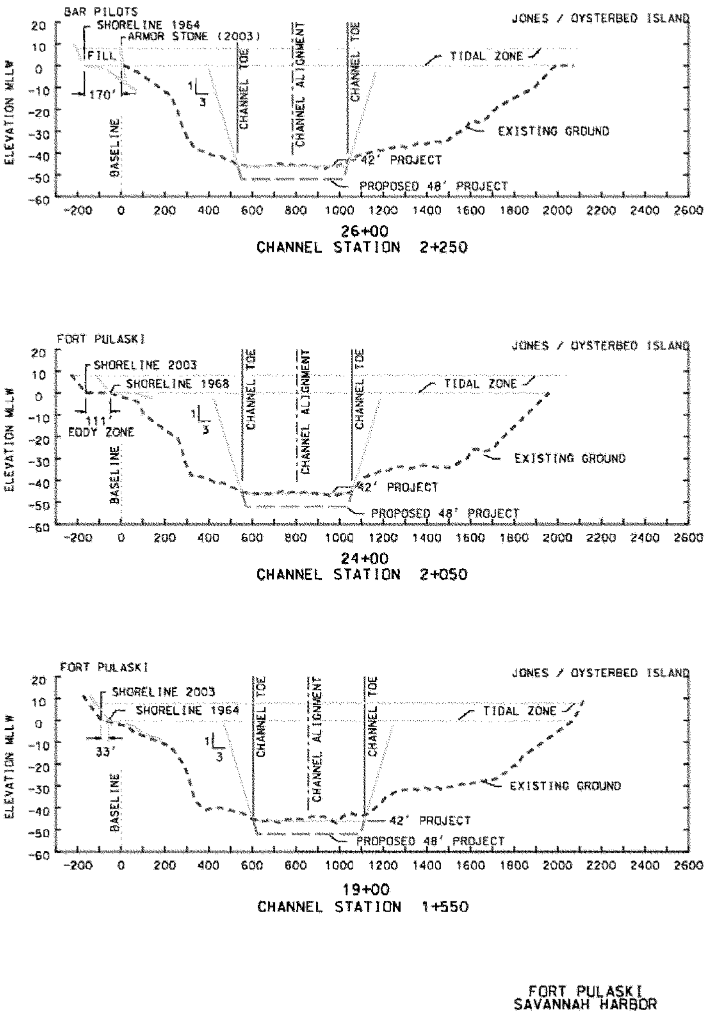
# APPENDIX D

# CROSS SECTION DRAWINGS


Typical Channel Cross-section
Not to Scale
48 ft. MLW
42 ft. MLW
Existing Channel
Cross-section
Not to scale
500 ft.
Additional
Channel depth
Outer limit of
vertical cut
18 ft.
464 ft.

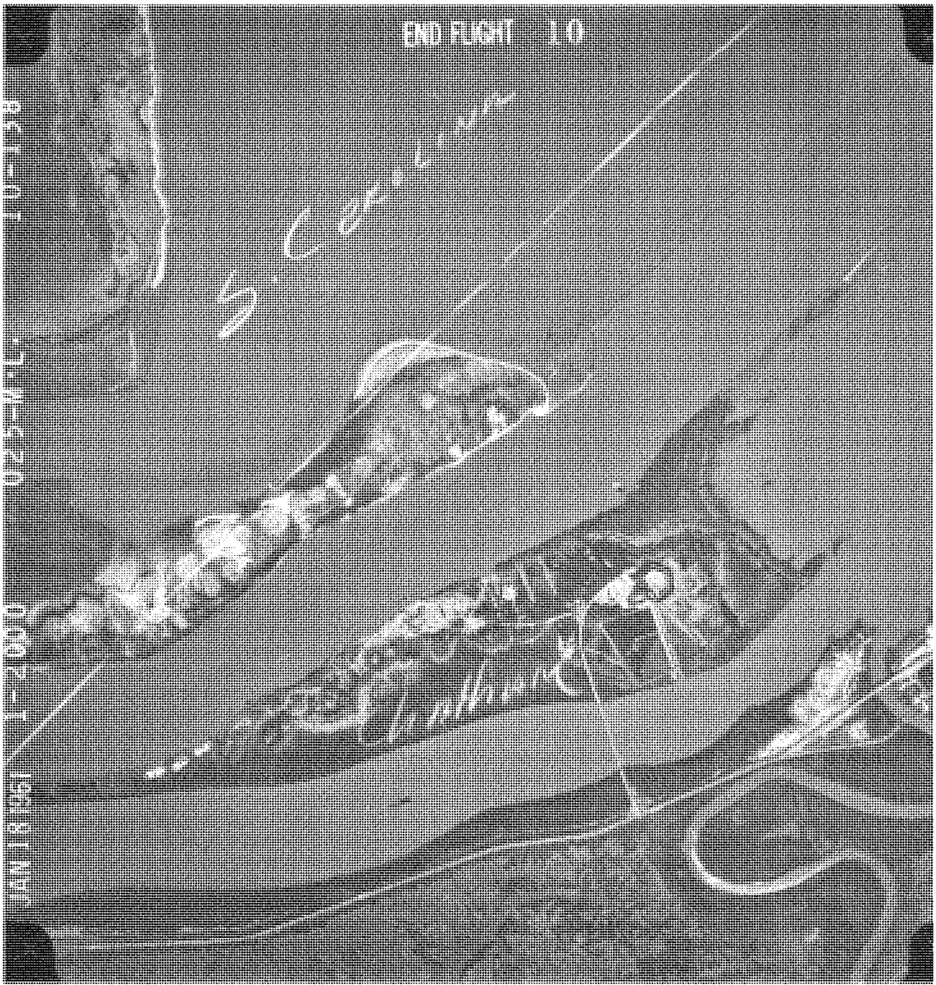



FORT PULASKI
SAVANNAH HARBOR


BAR PILOTS
SHORELINE 1964
ARMOR STONE (2003)
FILL
170'
JONES / OYSTERBED ISLAND
TIDAL ZONE
CHANNEL TOE
CHANNEL ALIGNMENT
CHANNEL TOE
EXISTING GROUND
42' PROJECT
PROPOSED 48' PROJECT
BASELINE
ELEVATION MLLW
26+00
CHANNEL STATION 2+250
FORT PULASKI
SHORELINE 2003
SHORELINE 1968
111'
EDDY ZONE
JONES / OYSTERBED ISLAND
TIDAL ZONE
EXISTING GROUND
42' PROJECT
PROPOSED 48' PROJECT
24+00
CHANNEL STATION 2+050
FORT PULASKI
SHORELINE 2003
SHORELINE 1964
33'
JONES / OYSTERBED ISLAND
TIDAL ZONE
EXISTING GROUND
42' PROJECT
PROPOSED 48' PROJECT
19+00
CHANNEL STATION 1+550
FORT PULASKI
SAVANNAH HARBOR

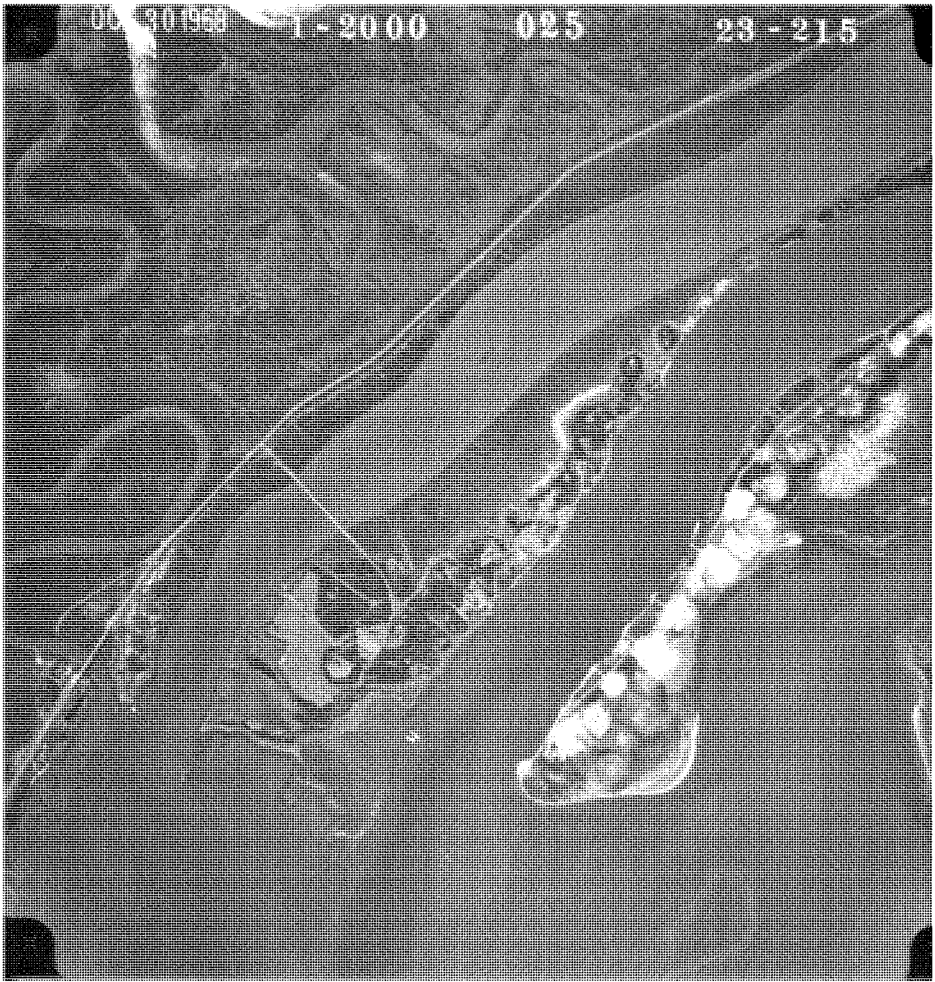
# APPENDIX E

# AERIAL PHOTOS



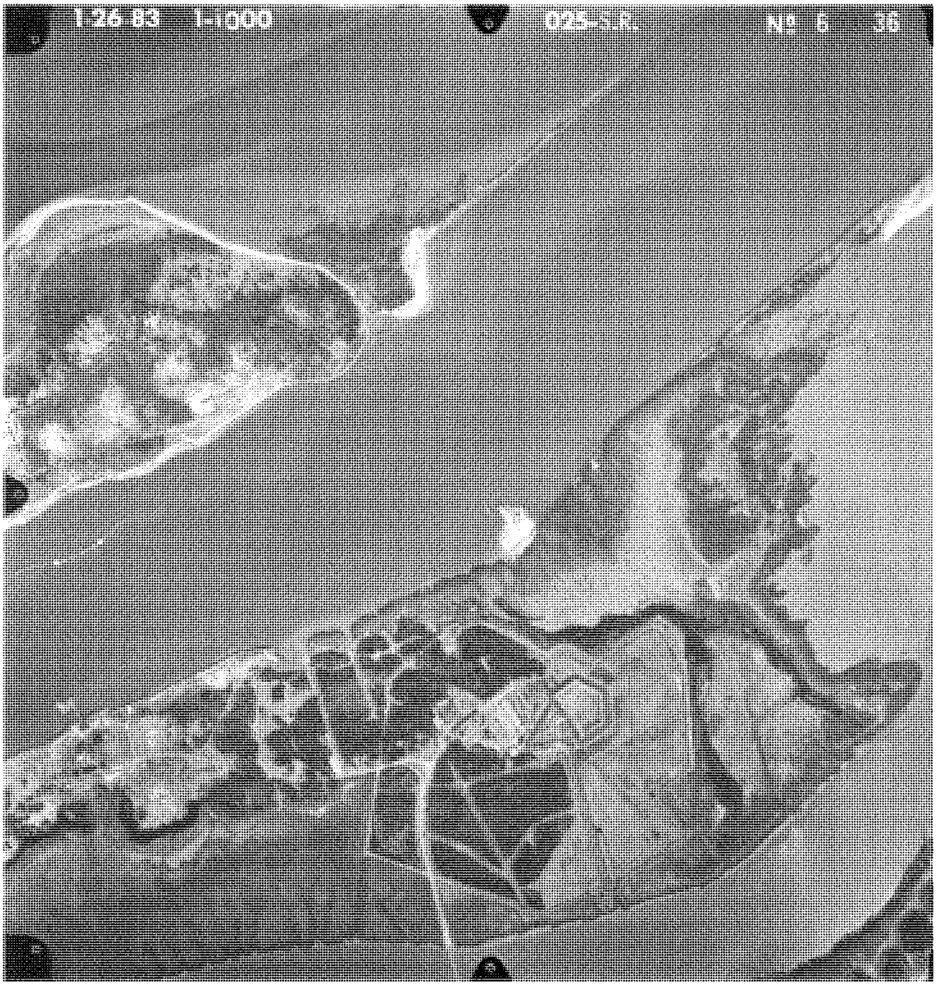

**Savannah Harbor Entrance 1961**

**Note: Absence of Lash Facility and apparent even flow regime**

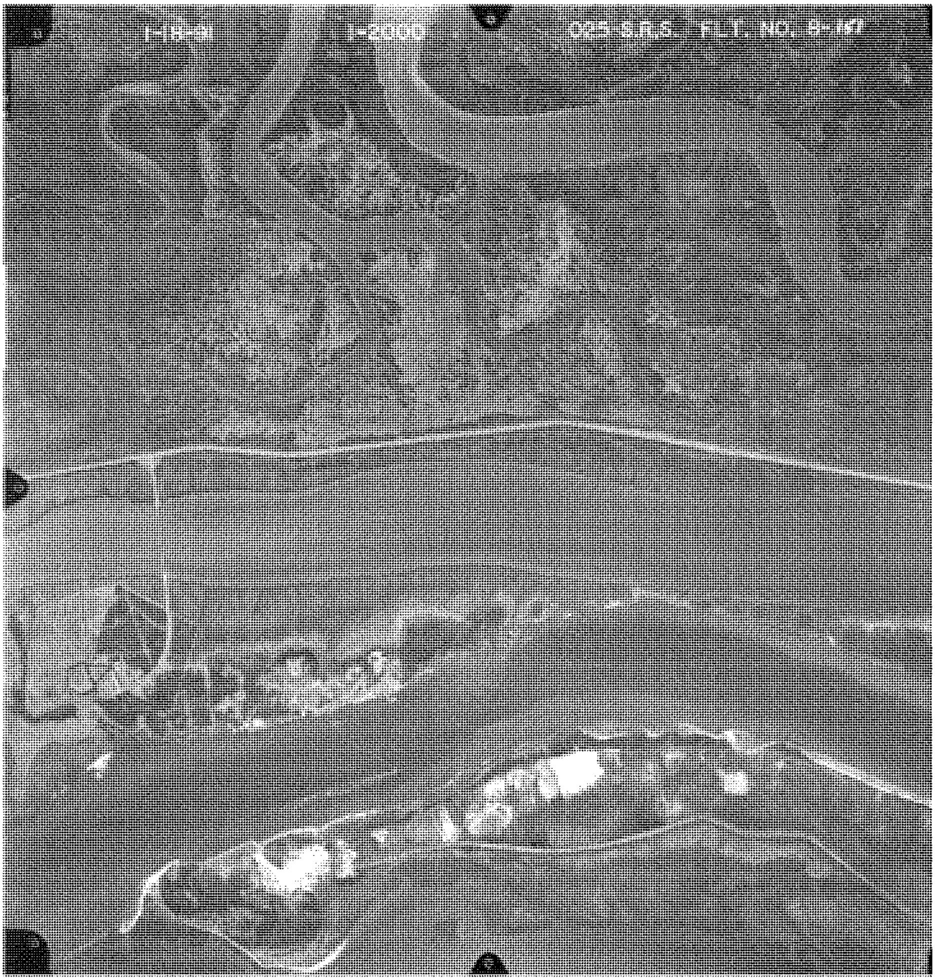



**Savannah Harbor Entrance 1968**

**Note: Thalwag generally away from Fort Pulaski side of river.**

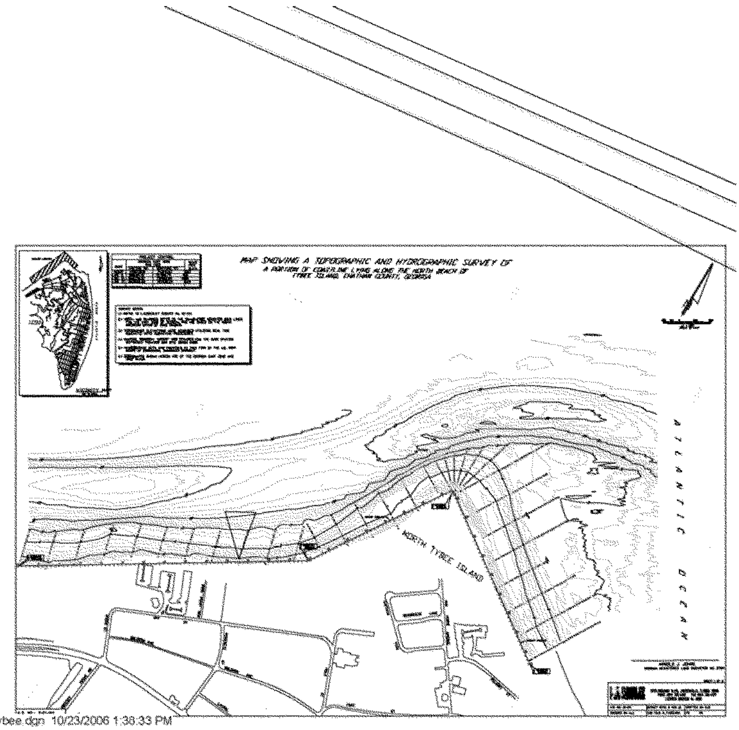



**Savannah River Entrance 1983**



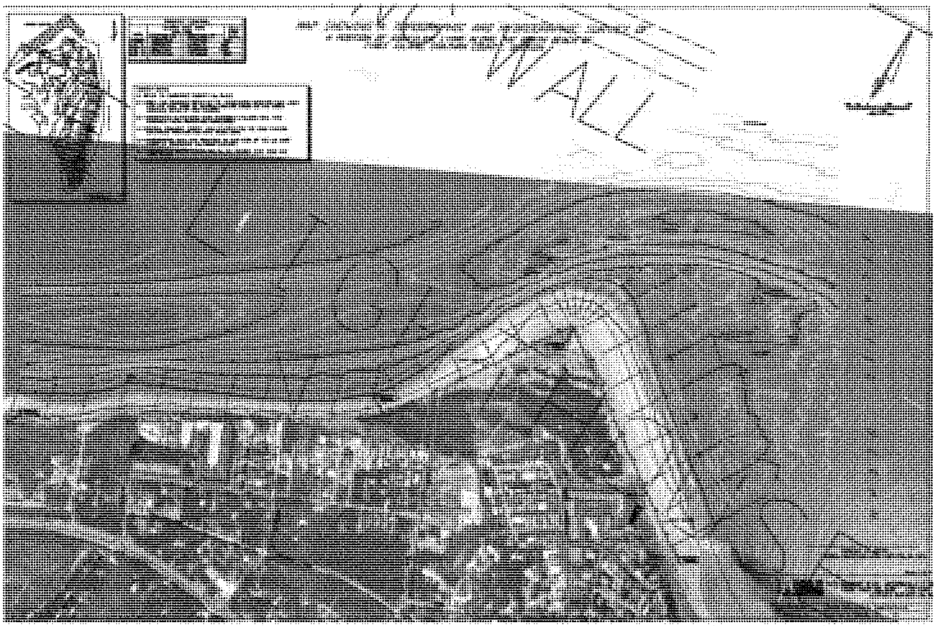

**Savannah River Entrance 1991**

**Savannah River Entrance / North Tybee 2006**




n tybee.dgn 10/23/2006 1:38:33 PM

**North Tybee w/respect to Savannah River Entrance Channel**


WALL

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George F. Oertel, Jimmy E. Fowler, Joan Pope (1985). “History of Erosion and Erosion Control Efforts at Tybee Island, Georgia”. Coastal Engineering Research Center, Department of the Army, Waterways Experiment Station, Corps of Engineers, Vicksburg, MS.

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Gerber, R. (2004). “Preliminary Restoration Plan (PRP) Bank Stabilization and Aquatic Restoration, Savannah Harbor Navigation Project”. Savannah District, Savannah, Georgia.

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Hudak, J. (2003). “Savannah Harbor Expansion Bank Stability Report”. Corps of Engineers, Savannah District, Savannah, Georgia.

# Sample Input Sheet for Scour Spreadsheet

PBS&J Scour Spreadsheet Version 1.1 August 30, 2006

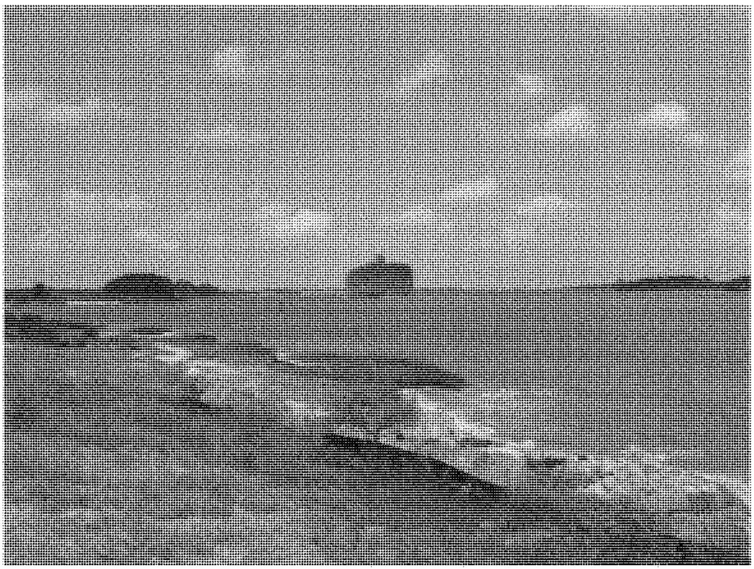
Instructions: Change values in colored cells only

| **Parameter** | **Value** |
|---|---|
| Design Discharge, Q | 320000 |
| Design Top Width, T (top width at design Q) | 2200 |
| Average / Hydraulic / Mean Depth | 46 |
| Hydraulic Radius | 2990 |
| Maximum Depth | 48 |
| Average Velocity | 4 |
| Bankfull Depth at Channel-Forming Discharge | 46 |
| Bankfull or Channel-Forming Discharge | 320000 |
| Bankfull Width at Channel-Forming Discharge | 2200 |
| Energy Slope | 0.0044 |
| Manning n-value | 0.043 |
| *Inputs for Bend Scour only:* | |
| Design Top Width, T | 1810 |
| Average / Hydraulic / Mean Depth | 8 |
| Maximum Depth | 12 |
| Bankfull Width | 1800 |
| Average Velocity | 2.3 |
| Energy Slope | 0.02 |
| Water Temperature | 72 |
| Bed form regime | dune |
| Dune scour fraction | 0.167 |
| Use Laceys Regime Equation For Mean Water Depth? | no |
| $D_{50}$ | 2.4 |
| $D_{90}$ | 30 |
| Neill Incised exponent | 0.7 |
| Bend Radius R in feet, at design Q | 200 |
| Degree of bend | severe |
| *Additional scour components* | |
| Low-flow incisement / thalweg scour | 0.5 |
| Calculated: | |
| R/T | 0.0909091 |

CESAS-EN-GS

US Army Corps
of Engineers®
Savannah District

# SAVANNAH HARBOR EXPANSION
# BANK EROSION STUDY UPDATE



## CITY FRONT, BIGHT SECTION,
## FORT PULASKI & NORTH TYBEE ISLAND
## GEORGIA

**23 June 2011**

GEOTECHNICAL AND HTRW BRANCH
SOILS SECTION

# Savannah Harbor Expansion Bank Erosion Study Update

## Table of Contents

## Appendices

| | |
|---|---|
| Appendix A | 2003 Fleet Forecast |
| Appendix B | 2011 Fleet Forecast |
| Appendix C | General Location Map |

## References

# SAVANNAH HARBOR EXPANSION BANK EROSION STUDY UPDATE

## 1. Introduction

The Savannah District Geotechnical Section (CESAS-EN-GS) has completed review of the bank erosion studies for the shoreline at City Front, Bight Section, Fort Pulaski and North Tybee Island. This report supersedes all previous bank erosion studies for Savannah River. Study Update is based on the revised Fleet Forecast received April 2011, and includes available soils information, bathymetry, topographic surveys, aerial photographs, historical information, observation/review of channel side slopes resulting from previous harbor widening and deepening projects, and information from previous dredging regarding channel side slope performance. Direct correlations were made using the recently updated 'Ship Forces on the Shoreline of the Savannah Harbor Project' report completed by the US Army Engineer Research and Development Center (ERDC) in May 2011. Waves generated by ships traffic begins with an initial wave of a maximum height with trailing waves of a much smaller energy level. The duration of ship wakes on the shore are compared to everyday wave events, tidal, flow, rainfall, and other influences normal to the river system without ship traffic.

## 2. Overview

This analysis estimates the loss of shoreline due to ship wakes as a direct result of deepening the Savannah River shipping channel near the City Front, Bight Section, Fort Pulaski property and the northern beach of Tybee Island, if any. This is taken as the difference between the ship wakes of today versus the ship wakes of the future, considering the without project condition compared with after deepening (with project). The total estimated shoreline erosion (due to all causes) is based on aerial photography from 1964 through 2003. While additional data is available, it doesn't appear to change the outcome with regard to shoreline recession. Other shoreline changes are considered which include placement of dredged materials, armoring of adjacent shoreline, drainage features, and proximity of shoreline to the shipping channel.

## 3. General

a. Original information available for the year 2003 and updated for 2010, the following without project forecast and calculations were completed for Containership + Tankers and General Cargo (GC) traffic: Information is presented for the total times (averaged) for any ship passing any given point of shoreline and thus causing waves that impact shoreline. Of the averaged event duration of 19.6 seconds for the estimated or given fleet, only three seconds maximum (approximately 15%) of the initial wave represents the highest energy level of consequence regardless of the ship size or speed. Smaller trailing waves are often less than wave activity normal to the shoreline at any given time without a ship passing event.

From information available for the year 2010: 3,205 calls * 2 (inbound and outbound) equals 6,410 passing events of duration approximately 19.6 seconds for each ship corresponds to 125,636 seconds of impact during the year. Thus, the percent of time for ships passing any point is about 0.398% (0.00398) of the year of which only about 15% can be considered as having an effective impact on adjacent shoreline. The result is 0.060% for the year 2010.

For the year 2017: 4,285 calls * 2 (inbound and outbound) equals 8,570 passing events, using same duration, corresponds to 167,972 seconds of impact during the year. Thus, the percent of time for ships passing a given point is about 0.532 % of the year and after applying the 15% impact correction, the result is 0.080% for the year 2017.

Predicted for the year 2030 and beyond: 7,204 calls *2 (inbound and outbound) equals 14,408 passing events of the same duration which corresponds to about 282,397 seconds of impact during the year. Thus, the percent of time for ships passing a check point is about 0.895 % of the year 2030 and applying 15% for impact correction, the result is 0.134%.

b. The latest Fleet Forecast from Economics, June 2011:

For the year 2017: 4,285 calls were counted for the existing 42-foot channel depth and 4,133 calls are predicted if the channel is deepened to 47 or 48-feet. This indicates a notable reduction (3.5%) of calls, the result of which will reduce total energies and impacts to adjacent shorelines.

For the year 2030 and beyond; 7,204 calls or 14,408 passing events are predicted for the without project (42') condition and 6,714 calls or 13,428 passing events predicted for the 47-foot to 48-foot depth condition. This represents about a 7 percent reduction of ship passing events which reduces erosion forces interacting with the banks of Savannah Harbor when compared to the without project condition.

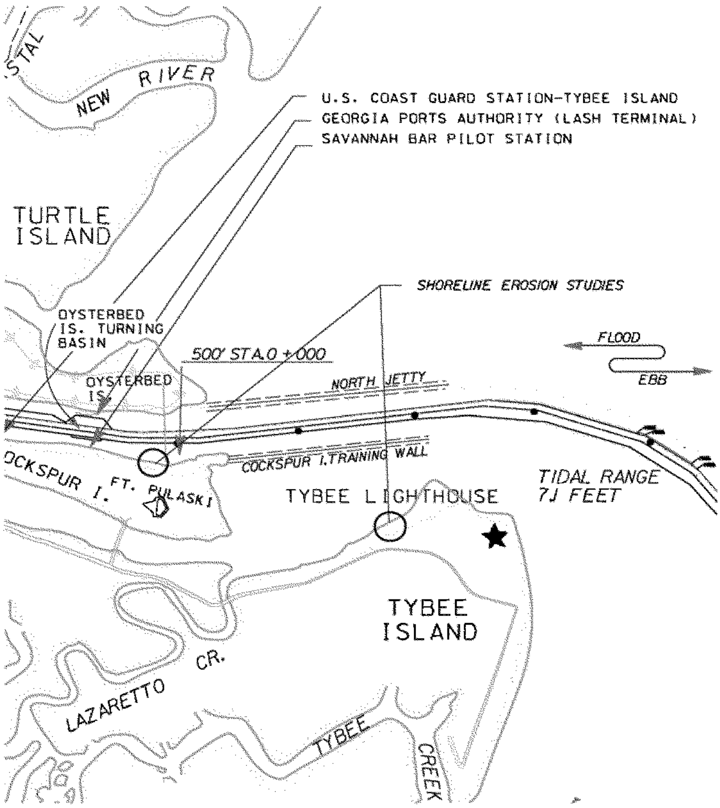
c. Ship length, beam, drafts, and speed were considered for the latest forecast. Evaluation of results yielded negligible adjustments to previous calculations. The results indicate that wave forces and passing events of predicted traffic within the deepened channel are reduced; therefore minor adjustments were not included.

d. Field measurements are presented in the revised report Ship Forces on the Shoreline of the Savannah Harbor Project. A copy of the report is available as a separate publication.

4. Fort Pulaski and North Tybee Descriptions

4.1 Fort Pulaski

The Fort Pulaski site is defined herein as the property along the shoreline from Georgia East NAD83 coordinates E 1049657.94, N 741683.76 (upstream) to E1052062.12, N 741085.54 (downstream); a distance of about 2,480 feet. The property is located at the entrance to the Savannah River from the Atlantic Ocean, directly adjacent to and on the outside bank of a 149 degree bend in the river. The general location is shown below.




**FORT PULASKI / TYBEE LOCATION PLAN**

The Fort Pulaski shoreline is unprotected and lies immediately downstream from the protected shoreline near the Savannah Pilots Association (SPA) and immediately upstream from the protected shoreline at the lower end of Cockspur Island. A circular erosion pattern exists immediately downstream from the SPA slope protection. The erosion in this area has been observed to be caused by eddy currents from tidal flows, the extent of which far exceeds other noted erosion anomalies. In addition, three prominent drainage features formerly existed from upland areas to the shoreline spaced about 300 to 400 feet apart and located in the upstream half of the site. The drainage features appear to have been removed/filled-in.

4.2 North Tybee

The North Tybee site is defined herein as the property along the shoreline from Georgia East NAD83 coordinates E 1060300.0, N 737576.0 (upstream) to E1062490.0, N 739000.0 (downstream); a distance of approximately 2,670 feet. The property is located near the entrance to the Savannah Front River from the Atlantic Ocean and behind a jetty located between the Front River and the Savannah River shipping channel. The general location is shown on the Study Location Plan.

The distance from the shoreline to shipping channel varies from less than one mile to almost one mile for North Tybee, as determined from the shoreline visible on aerial photographs and measured to the shipping channel centerline.

5. Fort Pulaski

Aerial photographs from 1955 through 2006 were used to estimate the average yearly bank erosion along about 4,100 feet of shoreline. Photos indicate that about 1.8 feet minimum each year is lost toward the approach and discharge ends. The maximum erosion occurs in the bend area of this site (about 149 degrees) and measurements indicate about 3 feet of shoreline per year are lost to erosion unrelated to predicted ship traffic. Maps of the area are shown in Appendix C.

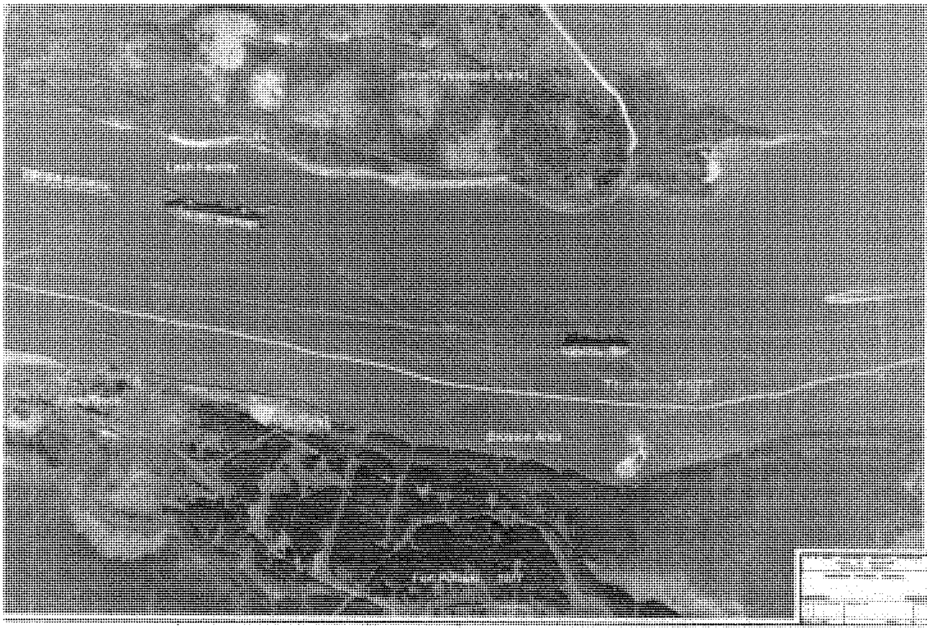
Cross sections were plotted to determine channel configuration with respect to the shoreline, calculating the flow area, estimating the average velocity of flows, depths, radius, and other factors in an attempt to find the amount of scour and erosion that would take place on the bank (without ship traffic), for the existing channel depth of 46 feet, and the maximum proposed channel depth of 52 feet, including over-depth and advance maintenance. The Zeller Bend Scour method developed by David T. Williams, Ph.D. PE, and Leo R. Kreymborg, PE, with input from the Ship Wake Study, the annual erosion predicted for the Fort Pulaski bend site ranges from 1.6 feet to 3.2 feet due to all causes, present day. The model assumes that side slopes are uniform, bottom is uniform, crest contains smooth lines, and ignoring minor variations which are not easily managed by the model.

Additional checks were performed using the CEDAS –ACES computer based program which considers six functional areas: wave prediction, wave theory, wave transformation, structural design, wave run-up, and littoral processes. The program includes input for tides, velocities, shape and size of the entrance and discharge openings, bend angle, among other parameters. The predicted erosion from this model ranged from 3.0 to 3.3 feet and do not include ship traffic and/or ship wakes.

Added was one Northeaster and associated long fetches waves on the Fort Pulaski site. This prediction was limited to a single one hour event with a maximum wind of 45 mph. The event yielded a 4.2 –foot wave height and a 4.2 -second wave period. The storm duration of the scope defined above is estimated to account for about 0.1 foot of shoreline loss each year/event.

Also considered is the effect of the channel shape and appurtenances constructed (Lash Facility) which influence flow, thalwag configuration and direction, and the amount of time that a ship will spend contributing energy to the shore which could in turn could contribute to erosion. The photo labeled FORT PULASKI – 1977 (below) is a good example showing the ebb tide flow regime. It also shows the apparent magnitude of ship wake compared to normal ebb currents and waves.

The present ship traffic has been estimated from the Fleet Forecast shown in Appendix B.



FORT PULASKI - 1977

From the Fleet Forecast predicted for Savannah Harbor before and after deepening, no additional erosion can be attributed to ship traffic.

Study indicates about one meter of shoreline lost to erosion each year due to all causes and zero erosion due to ship traffic associated with deepening of the river.

6. North Tybee

From the Fleet Forecast predicted for Savannah Harbor before and after deepening, no additional erosion can be attributed to ship traffic.

7. City Front

Due to the reduced speed in the City Front area, drawdown and ship wake are predicted to remain unchanged. Deepening of the channel is predicted to reduce the effect of ship wake by approximately 10 percent. From the Fleet Forecast predicted for Savannah Harbor before and after deepening, no additional erosion can be attributed to ship traffic.

8. Confined Disposal Facility (Bight Section)

This area of the bight has been predicted to experience approximately the same effect as the Fort Pulaski Site due to normal causes. However, this reach is or will be very soon armored against further erosion. After the planned dike protection has been completed, erosion from all causes is expected to be reduced to negligible. Based on the Fleet Forecast predicted for Savannah Harbor before and after deepening, no additional erosion can be attributed to ship traffic.

9. Bank Stability Review

A June 2011 review of the Savannah Harbor Expansion Bank Stability Report dated April 2003 has been completed with respect to the revised Ship Wake Study, April 2011. The April 2003 report addressed the shipping channel with special attention given to areas where the deepened and/or revised channel alignment would or could impact existing shore, involve real estate taking, or directly affect real property in any way. There is nothing contained in the Ship Wake study that directly impacts the Bank Stability study in a way that would require redesign or additional takings.

10. Summary

Given the current traffic predictions and forecasts, no bank erosion impact(s) can be directly attributed to the deepening project.

# APPENDIX A

## 2003 Fleet Forecast

**Table 6. Containership Traffic for Savannah Harbor. Numbers are for both without and with project values in 0 and % total calls.**

| Vessel Type | GEC | | 10% Increase | | 20% Increase | | 30% Increase | |
|---|---|---|---|---|---|---|---|---|
| | **2030** | **2050** | **2030** | **2050** | **2030** | **2050** | **2030** | **2050** |
| **Post-Panamax** | 211 (5.2) | 291 (3.7) | 565 (14.0) | 992 (12.7) | 920 (22.8) | 1693 (21.7) | 1274 (31.6) | 2394 (30.7) |
| **Panamax** | 3333 (82.7) | 6718 (86.1) | 2979 (73.9) | 6017 (77.1) | 2624 (65.1) | 5316 (68.1) | 2270 (56.3) | 4615 (59.2) |
| **Sub-Panamax** | 252 (6.3) | 458 (5.9) | 252 (6.3) | 458 (5.9) | 252 (6.3) | 458 (5.9) | 252 (6.3) | 458 (5.9) |
| **Handysize** | 215 (5.3) | 315 (4.0) | 215 (5.3) | 315 (4.0) | 215 (5.3) | 315 (4.0) | 215 (5.3) | 315 (4.0) |
| **Feedermax** | 18 (0.4) | 18 (0.2) | 18 (0.4) | 18 (0.2) | 18 (0.4) | 18 (0.2) | 18 (0.4) | 18 (0.2) |
| **Feeder** | 1 (0.0) | 1 (0.0) | 1 (0.0) | 1 (0.0) | 1 (0.0) | 1 (0.0) | 1 (0.0) | 1 (0.0) |
| **Total Calls** | 4030 | 7801 | 4030 | 7801 | 4030 | 7801 | 4030 | 7801 |

# APPENDIX B

# REVISED FLEET FORECAST

**Forecast Vessel Calls by Vessel Size Class, Channel Depth, and Year – June 23, 2011**

| 42-Foot Depth | 2010 | 2017 | 2020 | 2025 | 2030 | 2062 |
|---|---|---|---|---|---|---|
| SPX | 348 | 497 | 593 | 758 | 947 | 947 |
| PX | 1,124 | 1,196 | 778 | 1,122 | 1,196 | 1,196 |
| PPX1 | 203 | 479 | 866 | 1,006 | 1,421 | 1,421 |
| PPX2 | 2 | 120 | 271 | 382 | 527 | 527 |
| *Gen + LNG* | *1,528* | *1,993* | *2,204* | *2,619* | *3,113* | *3,113* |
| *All Vessel Calls Total* | *3,205* | *4,285* | *4,712* | *5,887* | *7,204* | *7,204* |

| 44-Foot Depth | 2010 | 2017 | 2020 | 2025 | 2030 | 2062 |
|---|---|---|---|---|---|---|
| SPX | 348 | 497 | 593 | 758 | 947 | 947 |
| PX | 1,096 | 1,135 | 700 | 992 | 1,067 | 1,067 |
| PPX1 | 200 | 312 | 478 | 471 | 672 | 672 |
| PPX2 | 5 | 239 | 533 | 761 | 1,035 | 1,035 |
| *Gen + LNG* | *1,528* | *1,993* | *2,204* | *2,619* | *3,113* | *3,113* |
| *All Vessel Calls Total* | *3,177* | *4,176* | *4,508* | *5,601* | *6,834* | *6,834* |

| 45-Foot Depth | 2010 | 2017 | 2020 | 2025 | 2030 | 2062 |
|---|---|---|---|---|---|---|
| SPX | 348 | 497 | 593 | 758 | 947 | 947 |
| PX | 1,085 | 1,109 | 671 | 952 | 1,007 | 1,007 |
| PPX1 | 200 | 312 | 474 | 467 | 666 | 666 |
| PPX2 | 5 | 239 | 527 | 753 | 1,027 | 1,027 |
| *Gen + LNG* | *1,528* | *1,993* | *2,204* | *2,619* | *3,113* | *3,113* |
| *All Vessel Calls Total* | *3,166* | *4,150* | *4,469* | *5,549* | *6,760* | *6,760* |

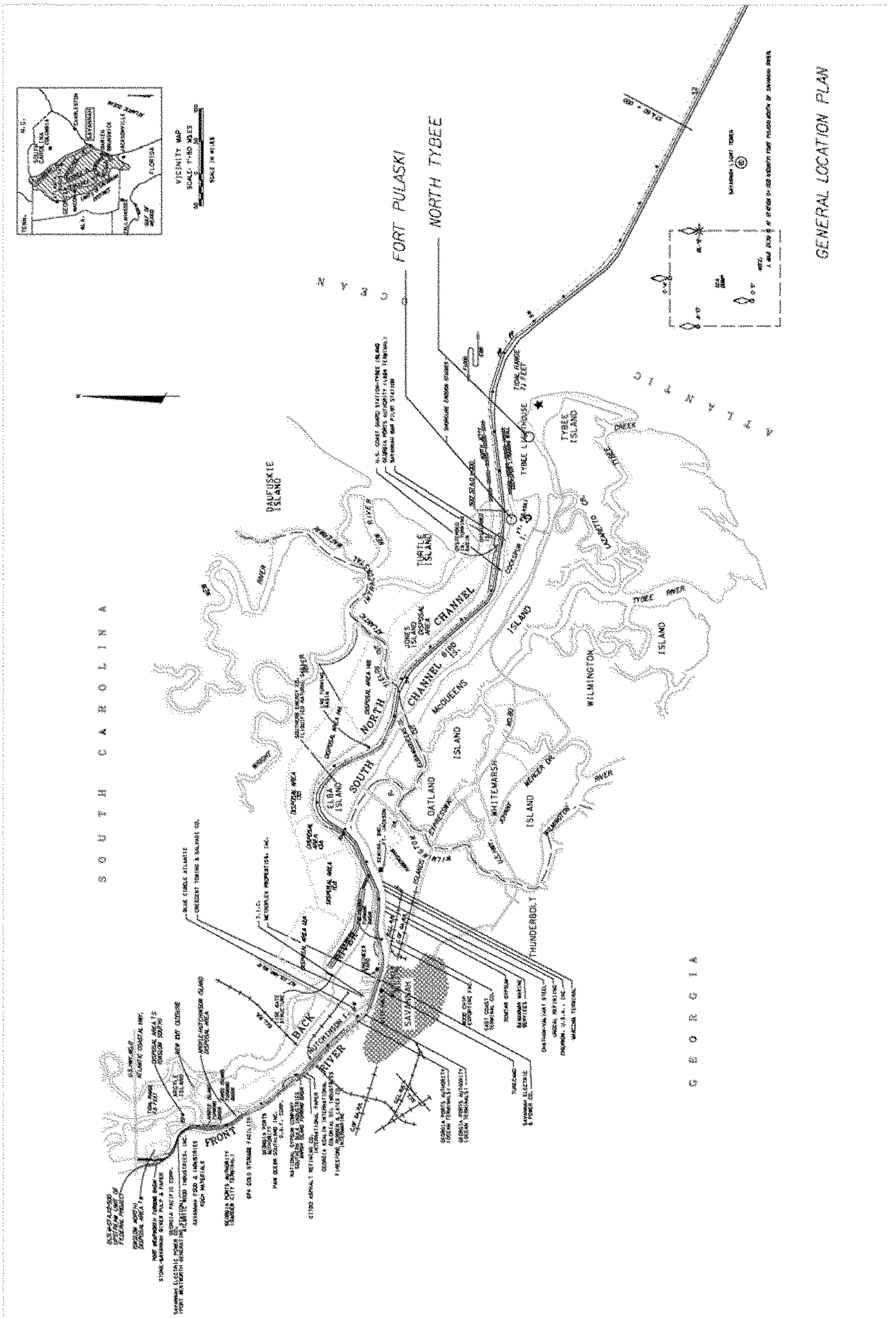
| 46-Foot Depth | 2010 | 2017 | 2020 | 2025 | 2030 | 2062 |
|---|---|---|---|---|---|---|
| SPX | 348 | 497 | 593 | 758 | 947 | 947 |
| PX | 1,084 | 1,096 | 658 | 932 | 982 | 982 |
| PPX1 | 200 | 312 | 471 | 465 | 662 | 662 |
| PPX2 | 5 | 239 | 524 | 749 | 1,021 | 1,021 |
| *Gen + LNG* | *1,528* | *1,993* | *2,204* | *2,619* | *3,113* | *3,113* |
| *All Vessel Calls Total* | *3,165* | *4,137* | *4,450* | *5,523* | *6,725* | *6,725* |

| 47-Foot Depth | 2010 | 2017 | 2020 | 2025 | 2030 | 2062 |
|---|---|---|---|---|---|---|
| SPX | 348 | 497 | 593 | 758 | 947 | 947 |
| PX | 1,084 | 1,092 | 649 | 924 | 975 | 975 |
| PPX1 | 200 | 312 | 471 | 462 | 661 | 661 |
| PPX2 | 5 | 239 | 524 | 749 | 1,018 | 1,018 |
| *Gen + LNG* | *1,528* | *1,993* | *2,204* | *2,619* | *3,113* | *3,113* |
| *All Vessel Calls Total* | *3,165* | *4,133* | *4,441* | *5,512* | *6,714* | *6,714* |

| 48-Foot Depth | 2010 | 2017 | 2020 | 2025 | 2030 | 2062 |
|---|---|---|---|---|---|---|
| SPX | 348 | 497 | 593 | 758 | 947 | 947 |
| PX | 1,084 | 1,092 | 649 | 924 | 975 | 975 |
| PPX1 | 200 | 312 | 471 | 462 | 661 | 661 |
| PPX2 | 5 | 239 | 524 | 749 | 1,018 | 1,018 |
| *Gen + LNG* | *1,528* | *1,993* | *2,204* | *2,619* | *3,113* | *3,113* |
| *All Vessel Calls Total* | *3,165* | *4,133* | *4,441* | *5,512* | *6,714* | *6,714* |

# APPENDIX C

# GENERAL LOCATION MAP


GENERAL LOCATION PLAN
FORT PULASKI
NORTH TYBEE
S O U T H C A R O L I N A
G E O R G I A
DAUFUSKIE ISLAND
TURTLE ISLAND
JONES ISLAND
ELBA ISLAND
McQUEENS ISLAND
OATLAND ISLAND
WHITEMARSH ISLAND
WILMINGTON ISLAND
TYBEE ISLAND
TYBEE LIGHTHOUSE
THUNDERBOLT
SAVANNAH
NORTH CHANNEL
SOUTH CHANNEL
BACK RIVER
FRONT RIVER
TYBEE RIVER
HUTCHINSON ISLAND
VICINITY MAP

## References

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# SAVANNAH HARBOR EXPANSION BANK STABILITY REPORT

# ANALYSES & REEVALUATION SUMMARY

**w/Updates and Comments**

**28 July 2010**

# Savannah Harbor Expansion General Bank Stability Report

## Table of Contents

## Appendices

CESAS-EN-GS

15 APRIL 2003
W/Comments 28 JULY 2010

# SUMMARY
# SAVANNAH RIVER SIDE SLOPE STABILITIES
# SAVANNAH HARBOR EXPANSION PROJECT

## 1. Introduction

The Savannah District Soils Section (EN-GS) has completed computations, sketches and preliminary drawings regarding channel side slopes for use in preparation of plans and specifications. Computations are based on drilling data, test results from soil samples taken at drilling locations, the 2002 Annual Survey data, hill survey data as requested for specific locations, observation/review of channel side slopes resulting from previous harbor widening and deepening projects, and other information from previous dredging works regarding channel side slope performance. NOTE: References to mean low water (mlw) used herein have since been revised to mean lower low water reference (mllw) for later work. The difference is minor, 0.2 tenths of an inch. Such references have not been changed herein to maintain consistency between drilling logs, survey data, and other information used during analyses.

## 2..General

a. Channel side slopes historically average approximately 1 vertical on 3 horizontal (1V on 3H) for the Savannah River Inner Harbor and are generally considered the norm within the inner harbor. Areas where possible exceptions might occur have been identified by borings taken during the subsurface investigation program. Other areas of concern have been identified by the Savannah District Planning Division. Addressed in these analyses are the known locations or reaches of problem areas regarding channel side slopes, sloughing of materials, and/or real estate acquisition requirements. Each is discussed separately in the following paragraphs. Areas that are not specifically addressed herein were also reviewed in detail using the proposed channel geometries and the most recent survey/sounding information. Review of these areas indicates the proposed expansion will not have a direct effect on lands above mean low water (mlw) and/or structures located on the river.

b. Specifically not addressed are the effects of time, tide, erosion, wind, rain, ships wake, earthquake, structural deterioration, or any other natural or unnatural forces not directly related to the removal of material by dredging as proposed. Exceptions to this occur only at Federally owned facilities, i.e. the Corps of Engineers (COE) Engineer Yard or other Federally recognized areas or facilities of historical interest. With regard to time, tide, erosion, etc. as stated above, all other real estate properties are considered the responsibility of respective owners, which historically has always been the case.

c. Inspections were performed as a part of obtaining riverbank and structural information within the limits of this project. The data obtained is described and discussed in the trip report written as a Memorandum for Record and dated 06 December 2001. A copy of the report, photographs, and descriptions are included as Appendix G, Inspection Summary.

3. Subsurface Investigation

The U.S. Army Corps of Engineers, Savannah District, has performed a number of subsurface investigations within the project area. Recently, borings have also been performed using contract drillers. Several hundred borings have been drilled within and adjacent to the Savannah Harbor. The majority of these borings were drilled along the north side of the channel for the Savannah Harbor Widening and the Savannah Harbor Deepening projects. These borings were drilled to obtain information necessary for evaluating the in-situ materials within specific areas of the channel for harbor modification projects. The majority of the borings were water-borne. The land-based borings were completed to identify soil materials within the channel side slopes to help determine the most probable channel side slopes resulting for each proposed harbor modification. The investigations have used a variety of methods to obtain subsurface data, including Vibracore, splitspooning, coring, cone penetration tests, and other methods. Standard penetration sampling using a split-barrel sampler was the method most often used. Using this method, a 1-3/8 inch inner diameter standard split barrel sampler was driven through the material using a 140-pound hammer with a 30-inch fall. The sampler was retrieved and the material was described in accordance with the Unified Soil Classification System. Subsurface investigations were performed at selected locations based on the early-proposed revisions to the channel limits. Drilling Logs are located in Appendix A. Standard penetration test borings were performed at the locations indicated on the included maps. See Appendix F. Soil samples were obtained from each boring and selected samples were tested for moisture content, plasticity, soil grain-size distribution, and strength characteristics.

4. Analyses Overview

All slope analyses for the turning basin were performed using the Modified Slope Stability Package with Kansas City Analysis (DGSLOPE) and the computer program UTEXAS3. Both programs were used for original analyses and for the checking and verification of results. Final input data sets and the results are provided separately. Illustrations of cross-sections, slip circles and/or wedge location(s) are provided separately.

5.0. Channel Summaries by Stations

5.1. Channel Stations 101+250 through 102+000 (Argyle Island).

Review and analysis indicate that side slopes after widening should closely match side slopes before dredging. The cross-section sketches indicate expected side slopes after the dredging has been performed. See Appendix C for Maps and Appendix D for Cross Section Drawings. Indications are that the proposed widening will result in the existing top of slope being relocated landward. Specifically, approximately 2.5 acres is expected to be taken above the mean low water (mlw) line. Of the 2.5 acres, approximately 0.3 acre occurs above elevation plus 8.0 mlw. Coordinates of the line that describe the taking limit are shown on the map and do not include any provision for rights-of-way or construction limits. The maps and cross-sections have been reviewed by Coastal Hydraulics Section and appropriate areas were provided to Real Estate for acquisition purposes. Coastal Hydraulics Section can also use for planning and computation of dredge volumes.

5.2 Channel Stations 97+500 through 101+250 (Kings Island Turning Basin).

a. Existing Conditions. Analysis indicates a global or overall factor of safety (FS) against slope failure of 2.2 for the riverbank and dike adjacent to Kings Island Turning Basin. However, for the softer soils located generally within the tidal zone, the calculated factor of safety is approximately 1.1. While the lower FS does not necessarily indicate a local failure problem, the fact that soft soil material occurs in the tidal zone could indicate an ongoing erosion problem due mainly to tidal and wave action. The analyses also indicate that the calculated slope exposed to the river should remain stable on an approximate 1 vertical on 3.2 horizontal slope (1V on 3H). The measured distance from the top of the riverbank to the toe of the Disposal Area 2A dike is approximately 110 feet.

b. Proposed Conditions. In accordance with the proposed widening studies, analyses were performed assuming a new bottom depth for the turning basin of -55 mlw. Assuming the final side slope would be 1V on 3H, the analysis indicates results similar to existing conditions. The overall FS against slope and dike failure was calculated at 1.9. The local factor of safety for the soft area within the tidal zone was calculated at 1.1. The calculated distance remaining from the top of the riverbank measured to the toe of the existing dike is approximately 45 feet. Please note that depending on how the turning basin is dredged and whether or not the slopes are dredged, the bank side slopes could stand somewhat steeper for a short time. However, any materials remaining steeper than the 1V on 3H will likely collapse and fall into the turning basin. Erosion within the tidal zone (soft marsh material) will likely involve the loss of approximately 20 additional feet of riverbank within a short time. Such erosion would leave approximately 25 feet between the top of slope and the toe of the existing disposal area dike.

c. Summary. Calculations indicate that dredging within the Kings Island Turning Basin to an elevation of -60 mlw will not adversely affect the embankment stability nor the stability of the Disposal Area 2A dike. The material within a 1V on 3H slope measured from the bottom of the turning basin limits should be included in dredge quantities. Approximately 60 to 80 feet of channel bank measured landward from the top of the existing river slope will likely be lost as a result of dredging to -60 mlw. Coordinates of the line that describe the taking limit are shown on the map and do not include any provision for rights-of-way or construction limits. The map should be reviewed and provided to Real Estate for acquisition purposes prior to beginning the proposed work. Cross-sections will be provided to Coastal Hydraulics Section for their use in planning and computation of dredge volumes.

5.3 Channel Stations 92+500 through 97+500.

The sketch for Station 96+500 indicates a recommended side slope of 1V on 3H. The recommendation is based on review of previously obtained subsurface data, existing side slopes, test results, and comparison with similar channel soil profiles for which DGSLOPE was performed. Cross Section 96+500 was chosen to represent the worst case for the reach suspected as a possible problem area with regard to sloughing of materials. The currently proposed expansion maintains the existing side slope to the new depths to elevation -58 mlw. Provided over-swing of the dredge cutterhead (beyond the channel toe) can be tightly controlled, real estate acquisition should not be required.

5.4 Channel Stations 89+500 through 91+500. Georgia Side Only.

Analysis indicates that a normal channel side slope of 1V on 3H should be used for the reach between 89+500 through 91+500. The currently proposed expansion maintains the existing side slope to the new proposed depth. Provided over-swing of the dredge cutterhead (beyond the channel toe) can be tightly controlled, real estate acquisition should not be required.

5.5 Channel Stations 87+250 through 88+750.

Analysis indicates that a channel side slope of 1V on 3H should be used from the channel bottom to approximately elevation 0 mlw. Above 0 mlw, a side slope of 1V on 4H should be used. The currently proposed expansion maintains the existing channel toe to the new proposed depth. The estimated top of slope occurs at approximately 0 mlw. However, variations in the shoreline may require real estate acquisition. Coordinates for the estimated top of slope are given on the map for this reach.

5.6 Channel Stations 86+000 through 87+500.

Analysis indicates that a channel side slope of 1V on 3H should be used for the reach between 86+000 through 87+500. The currently proposed expansion maintains the existing side slope the to new depths of study defined as elevations -44, -45, -46, -47, and -48 and considers 2 feet of overdepth and 2 feet of squat for each depth. Provided over-swing of the dredge cutterhead (beyond the channel toe) can be tightly controlled, real estate should not be directly impacted. However, variations in the shoreline may require real estate acquisition. Coordinates for the estimated top of slope are given on the map for this reach.

5.7 Channel Stations 77+500 through 79+000, Northeast Side.

Review and analysis indicate that side slopes after deepening should closely match side slopes before dredging. The cross-section sketches indicate expected side slopes after the expansion dredging has been performed. See Appendix D, Cross Section Drawings for sketches. This area was previously within a proposed widener, which was deleted from the WES channel model. However, subsurface information was obtained and a cross-section was setup for analysis if needed, as may be decided later. If a widener does occur in this reach, preliminary analysis indicates the existing Savannah Marine bulkhead may be at risk.

5.8 Channel Stations 75+000 through 76+200.

Review and analysis indicate that side slopes after deepening should closely match side slopes before dredging. The cross-section sketch indicates expected side slope after the expansion dredging has been performed. This area was previously within a proposed widener, which was deleted from the WES channel model. However, subsurface information was obtained and a cross-section was setup for analysis if needed, as may be decided later. If a widener does occur in this reach, preliminary analysis indicates the existing T.I.C. bulkhead may be at risk.

5.9 Channel Stations 72+750 through 73+750, Upstream of the COE Engineer Yard.

Review and analysis indicate that side slopes after deepening should closely match side slopes before dredging. The cross-section sketch indicates expected side slope after the expansion dredging has been performed. This area is not within a proposed widener, however the bank materials are known to contain artifacts of historical interest. Over-swinging of the proposed channel toe could expose such artifacts. Caution is advised through this particular reach with regard to dredging operations.

5.10 Channel Stations 69+700 through 71+200, North Side.

Review and analysis indicate that side slopes after deepening should closely match side slopes before dredging. The cross-section sketch indicates expected side slope after the expansion dredging has been performed. This area was previously within a proposed widener, which was deleted from the WES channel model. However, subsurface information was obtained and a cross-section was setup for analysis if needed, as may be decided later. If a widener does occur in this reach, preliminary analysis indicates a real estate taking of approximately 1.5 acres above 0 mlw, of which 0.7 acre is located above elevation +8.0 mlw. An access easement of approximately 30 feet in width may also be required.

5.11 Channel Stations 58+000 to 59+000 (Fort Jackson / CSS Georgia location.)

a. This reach has typically been excluded from dredging over the past several years to avoid either (1) disturbing the CSS Georgia and/or (2) affecting the structure located at Old Fort Jackson. A review of previous and present channel soundings indicates that where a short section is left higher than the adjacent bottom depths, the higher area will eventually scour to the elevation of the adjacent depths at either end. The CSS Georgia appears to be 'perched' on a stiff layer located near the north toe of the river channel. Disposition of the CSS Georgia is currently being addressed by Planning Division.

b. Plans have been completed for the extended protection of Old Fort Jackson. However, at the present time, protection of Old Fort Jackson is considered an issue separate from the Savannah Harbor Expansion project.

5.12 Channel Stations 49+500 through 52+800, South Channel Training Wall & Southern LNG Pipe Crossing.

a. The proposed widener and new channel toe through this reach is approximately 156 feet southeast of the existing channel toe. It is expected that dredging operations will encounter both rock and timber and/or remnants of the rock and timber cribbing placed during construction of the South Channel Training Wall. Dredging in this area may require special consideration with regard to equipment, i.e. clamshell dredging may be more appropriate than hydraulic cutterhead methods.

b. The LNG pipeline crossing the river bottom at approximate Station 51+000 will need to be addressed before dredging begins. Location will need to be established and relocation may be required.

5.13 Channel Stations 34+500 through 41+900, LNG Turning Basin.

A review of the proposed expansion through the recently completed LNG turning basin indicates minimal impact. Top of slope occurs generally between -42 and -46 mlw elevations and well within the turning basin boundaries.

5.14 Channel Stations 34+500 through -85+500 (all below 34+500).

Top of slope occurs at elevations well below mlw and away from real estate and shorelines. By inspection, taking will not be required.

6. Additional Geotechnical Requirements.

Changes in channel geometry due to deepening, widening, realignment, slope stability, or feature avoidance require re-evaluation of existing data. As channel geometry continues to change, older geotechnical data is no longer adequate to evaluate these changes for a number a reasons. One concern is that there may be an insufficient number of borings located in areas that involve real estate taking or acquisition. Another concern is that older borings, drilled for a much shallower project, were completed at depths that are shallower than proposed project depths. Also, as channels become deeper to accommodate larger vessels, bend wideners are often added in areas that have not been previously investigated. These concerns were considered prior to the performance of the investigations conducted for the re-evaluation of this project. However, as additional changes in channel geometry are identified, these concerns will be re-evaluated and additional subsurface investigations will be required.

# APPENDIX A

# BORING LOGS

# BORING LOGS

**CS-7**
**SH-34**
**SH-102**
**SH-112**
**SH-122**
**SH-127**
**SH-128**
**SH-138**
**SH-149**
**SH-150**
**SH-218**
**SH-373**
**SH-374**
**SH-384**
**SH-385**
**SH-386**
**SH-400**
**SH-401**
**SH-402**
**SH-403**
**SH-404**
**SH-405**
**SH-406**
**SH-406-UD**
**SH-407**
**SH-407-UD**
**SH-408**
**SH-410**
**SH-410A**
**SH-411**
**SH-412**

Hole No. CS-7

| DRILLING LOG | DIVISION: SOUTH ATLANTIC | INSTALLATION: SAVANNAH R. & HARBOR | SHEET 1 OF 2 SHEETS |
|---|---|---|---|

1. PROJECT: KINGS ISLAND TURNING BASIN
2. LOCATION (Coordinates or Station): SEE PLAN — OPPOSITE STA. 93+500 AT WATERS EDGE
3. DRILLING AGENCY: SAVANNAH DISTRICT
4. HOLE NO. (As shown on drawing title and file number): CS 7
5. NAME OF DRILLER: J. McDONALD
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE: 45.5' BELOW MLW
10. SIZE AND TYPE OF BIT: 1 3/8" ID SPLITSPOON
11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MLW
12. MANUFACTURER'S DESIGNATION OF DRILL: FAILING 314
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 5 | UNDISTURBED 0
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE: STARTED 27 APRIL 1973 | COMPLETED 27 APRIL 1973
17. ELEVATION TOP OF HOLE: 0.0' = MLW
18. TOTAL CORE RECOVERY FOR BORING
19. SIGNATURE OF INSPECTOR: Charles D. Griffin

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. JAR | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g BLOWS |
|---|---|---|---|---|---|---|
| -0.8 | | | WATER DEPTH 0.8' AT MLW | | | |
| | | | ML - GRAY INORGANIC SILT W/SILTY SAND LAYERS | | 1 | 0, 1, 1, 1, 1, 1, 1, 1 |
| | 5 | | | | | |
| | 10 | | | | | |
| | | | CH - GRAY FAT CLAY W/GRAVEL | | 2 | 7, 8 |
| | 15 | | SM - GRAY SILTY FINE MEDIUM SAND. | | 3 | 13, 12, 19, 32, 34, 36, 41, 44, 46 |
| | 20 | | | | | |
| | 25 | | | | | |
| | 30 | | GREEN, SLIGHTLY MICACEOUS | | 4 | 49 |

CONTINUED ON SHEET NO 2

DRILLING LOG (Cont Sheet) ELEVATION TOP OF HOLE O.B. BELOW MLW — Hole No. CS 7

PROJECT: KINGS ISLAND TURNING BASIN — INSTALLATION: SAVANNAH RIVER HARBOR — SHEET 2 OF 2 SHEETS

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g BLOWS |
|---|---|---|---|---|---|---|
| | 30 | | | | | 51 |
| | | | | | | 54 |
| | | | SM- GREEN SILTY FINE SAND, SLIGHTLY MICACEOUS | | | 62 |
| | 35 | | | | | 64 |
| | | | | | | 59 |
| | | | | | | 61 |
| | 40 | | | | | 62 |
| | | | | | | 60 |
| | | | | | | 58 |
| -45.5 | 45 | | | | 5 | 51 |
| | | | NOTE: Soils field classified in accordance with the Unified Soil Classification System. | | | BLOWS PER FOOT: Number required to drive 1⅜" ID splitspoon w/140 lb hammer falling 30". |

Hole No. SH-34

| DRILLING LOG | DIVISIO South Atlantic | INSTALLATION Savannah, GA | SHEET 1 OF 2 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT Savannah Harbor | 10. SIZE AND TYPE OF BIT 1 3/8" ID splitspoon |
| 2. LOCATION (Coordinates or Station) Sta 70+000N, R="26" (X-838665 Y-758100) | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLW |
| 3. DRILLING AGENCY Savannah District | 12. MANUFACTURER'S DESIGNATION OF DRILL Sprague and Henwood |
| 4. HOLE NO. (As shown on drawing title and file number) SH-34 | 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 11; UNDISTURBED 0 |
| 5. NAME OF DRILLER Perry Rountree | 14. TOTAL NUMBER CORE BOXES |
| 6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT. | 15. ELEVATION GROUND WATER |
| | 16. DATE HOLE: STARTED 31 Oct 77; COMPLETED 2 Nov 77 |
| 7. THICKNESS OF OVERBURDEN 55.0 | 17. ELEVATION TOP OF HOLE 0.0 MLW |
| 8. DEPTH DRILLED INTO ROCK 0.0' | 18. TOTAL CORE RECOVERY FOR BORING % |
| 9. TOTAL DEPTH OF HOLE -55.0' MLW | 19. SIGNATURE OF INSPECTOR CHARLES D. GRIFFIN |

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g |
|---|---|---|---|---|---|---|
| 0.0 MLW | 0 | | Water | | | |
| -4.0 | | | Bottom of river -4.0' | | JAR | BLOWS |
| | 5' | | SM - Gray silty fine sand | | 1 | 7 |
| | | | | | | 5 |
| -8.5 | | | | | | 7 |
| | 10' | | MH - Gray soft clayey silt | | 2 | 1 |
| -10.5 | | | SM - Gray silty fine and medium sand | | | 4 |
| | | | | | 3 | 8 |
| | | | | | | 15 |
| | 15' | | With some soft silt pockets | | 4 | 35 |
| | | | | | | 30 |
| | | | Gray and brown | | | 33 |
| | 20' | | | | | 31 |
| | | | | | | 31 |
| | | | | | | 25 |
| | 25' | | Gray fine silty sand | | 5 | 21 |
| | | | | | | 20 |
| | | | | | | 24 |
| | | | Gray fine sand with soft silt pockets | | 6 | |

**DRILLING LOG (Cont Sheet)** ELEVATION TOP OF HOLE 0.0 MLW **Hole No.** SH-34

PROJECT Savannah Harbor | INSTALLATION Savannah, GA | SHEET 2 OF 2 SHEETS

| ELEVATION a | DEPTH 38' b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. JAR f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g |
|---|---|---|---|---|---|---|
| | 35' | | SM - Gray fine silty sand with soft silt pockets | | | |
| -38.5 | 40' | | SP - Light tan poorly graded sand | | 7 | |
| -41.5 | | | MH - Dark gray soft clayey silt | | 8 | |
| -45.0 | 45' | | SP - Tan poorly graded sand | | 9 | |
| -48.0 | 50' | | SM - Dark green very fine cemented silty sand, hard slightly clayey | | 10<br>11 | |
| -55.0 | 55' | | Bottom of hole -55.0' MLW | | | |

BLOWS: 19, 18, 12, 20, 28, 34, 30, 18, 3, 5, 19, 20, 68, 87, 79, 93, 90

Hole No. SH-102

| DRILLING LOG | DIVISION South Atlantic | INSTALLATION Savannah, GA | SHEET 1 OF 2 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT: Savannah Harbor Widening | 10. SIZE AND TYPE OF BIT: 1 3/8" ID splitspoon |
| 2. LOCATION (Coordinates or Station): X-838175 Y-758052 | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MLW |
| 3. DRILLING AGENCY: Savannah District | 12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 314 |
| 4. HOLE NO. (As shown on drawing title and file number): SH-102 | 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 11; UNDISTURBED 0 |
| 5. NAME OF DRILLER: E. Maulden | 14. TOTAL NUMBER CORE BOXES: 0 |
| 6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT. | 15. ELEVATION GROUND WATER: 0.0 MLW |
| | 16. DATE HOLE: STARTED 30 Sep 83; COMPLETED 30 Sep 83 |
| 7. THICKNESS OF OVERBURDEN: 50.0' includes water | 17. ELEVATION TOP OF HOLE: 0.0 MLW |
| 8. DEPTH DRILLED INTO ROCK: 0.0' | 18. TOTAL CORE RECOVERY FOR BORING: N/A % |
| 9. TOTAL DEPTH OF HOLE: 50.0' | 19. SIGNATURE OF INSPECTOR: James E. Bolen, Geologist |

| ELEVATION 0.0 | DEPTH 0 (b) | LEGEND (c) | CLASSIFICATION OF MATERIALS (Description) (d) | % CORE RECOVERY (e) | BOX OR SAMPLE NO. JAR | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) (g) | Blows |
|---|---|---|---|---|---|---|---|
| | | | Sea Water 0.0'-2.0' Bottom of Harbor 2.0' | | | | |
| -2.0 | 5 | | MH-Dark gray fat clayey silt with 15% medium grained sand | | 1 | Note: Weight of tools 2.0'-7.4' | |
| | | | | | | Note: At 10.4' cleaned ou to 10.5' Next drive was 10.5'-12.0. | 7 |
| -7.4 | 10 | | SM-Gray silty coarse medium sand, moderate silt content | | 2 | | |
| | | | | | 3 | At 13.5' set 6" diameter steel casing to 13.5' | 34 |
| | | | | | | | 9 |
| | | | | | | Weight of tools 16.5'-17.2' | 15 |
| | 15 | | | | 4 | Next drive 17.2'-18.7' | 9 |
| | | | | | | Weight of tools 19.0-20.0' | 9 |
| | 20 | | | | | Weight of tools 24.5'-26.5' | 33 |
| | | | With lenses of clay 10% | | 5 | | W/T |
| | | | | | | | 32 |
| | | | | | | | 17 |
| -24.5 | 25 | | SC-Alternating layers of fat clay and gray silty medium fine sand | | 6 | | 11 |
| -26.5 | | | CH-Dark gray silty fat clay with some black wood chips | | 7 | | W/T |
| | | | | | | Weight of tools 28.0'-29.1' | 7 |
| -30.0 | 30 | | | | | | W/T |

Sample Lab

| No. | Class | LL | PL | PI |
|---|---|---|---|---|
| 1 | CH | 86 | 34 | 52 |
| 4 | SP-SM | NP | NP | NP |
| 6 | SM | NP | NP | NP |
| 7 | MH | 80 | 40 | 40 |
| 9 | MH | 70 | 35 | 35 |
| 10 | SP-SM | NP | NP | NP |

Continued on Sheet 2

Note: Soils field classified in accordance with the Unified Soil Classification System.

Blows Per Foot: Number required to drive 1 3/8 ID splitpoon w/140 lb. hammer falling 30".

Note: W/T=Weight of tool.

**DRILLING LOG (Cont Sheet)** | ELEVATION TOP OF HOLE: 0.0 MLW | Hole No.

PROJECT: Savannah Harbor Widening | INSTALLATION: Savannah, GA | SHEET 2 OF 2 SHEETS

| ELEVATION | DEPTH | LEGEND | CLASSIFICATION OF MATERIALS (Description) | % CORE RECOVERY | BOX OR SAMPLE NO. JAR | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) | Blows |
|---|---|---|---|---|---|---|---|
| -30.0 | 30 | c | d | e | | g | |
| | | | CH-Dark gray silty fat clay with some black wood chips | | 8 | Weight of tool 29.1'-30.6'. | 6, W/T |
| | 35 | | | | 9 | Weight of tool 30.5'-31.7'. | 5 |
| | | | | | | Weight of tool 33.2'-35.7' | W/T |
| -37.7 | | | | | | Weight of tool 37.2'-37.7'. | 18, W/T |
| | 40 | | SM-Gray silty coarse, medium sand with some small clay lenses (moderate silt content) | | 10 | Note: At 40.7' cleaned out to 41.0' Next drive is 41.0'-42.5'. | 28, 36, 36 |
| | 45 | | | | 11 | | 60, 40, 51, 77, 97 |
| -50.0 | 50 | | Bottom of Hole: 50.0' | | | Note: 6" diameter casing must be advanced 1.5' after every drive. Note: W/T = Weight of tools including 140 lb. hammer. | |

**Hole No.** SH-112

| DRILLING LOG | DIVISION: South Atlantic | INSTALLATION: Savannah District | SHEET 1 OF 1 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT: Savannah Harbor Widening | 10. SIZE AND TYPE OF BIT: 1 3/8" ID Splitspoon |
| 2. LOCATION (Coordinates or Station): X-824512, Y-767695 | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MLW |
| 3. DRILLING AGENCY: Savannah District | 12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 314 |
| 4. HOLE NO. (As shown on drawing title and file number): SH-112 | 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 8; UNDISTURBED 0 |
| 5. NAME OF DRILLER: Tommy Scott | 14. TOTAL NUMBER CORE BOXES: 0 |
| 6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT. | 15. ELEVATION GROUND WATER: N/A |
| | 16. DATE HOLE: STARTED 31 Oct 83; COMPLETED 31 Oct 83 |
| 7. THICKNESS OF OVERBURDEN: 27.0' | 17. ELEVATION TOP OF HOLE: 0.0 MLW |
| 8. DEPTH DRILLED INTO ROCK: 0.0' | 18. TOTAL CORE RECOVERY FOR BORING: N/A % |
| 9. TOTAL DEPTH OF HOLE: 48.0' | 19. SIGNATURE OF INSPECTOR: Ted Zielonka *Ted Zielonka* |

| ELEVATION (a) | DEPTH (b) | LEGEND (c) | CLASSIFICATION OF MATERIALS (Description) (d) | % CORE RECOVERY (e) | BOX OR SAMPLE NO. JAR (f) | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) (g) Blows |
|---|---|---|---|---|---|---|
| 0.0 | 0 | | River Water 0.0' to 21.0' | | | Note: Scale change at 20.0'. |
| -21.0 | 20 | | Bottom of Harbor 21.0' | | | |
| | | | SM-Tan fine to medium grained silty sand. Color change to gray at 22.2' | | 1 | 16 |
| | | | | | 2 | 17 |
| | 25 | | Contains organic material from 22.2' to 24.0'. | | | 18 |
| | | | | | | 55 |
| -28.5 | | | Color change to dark gray at 28.0'. 28.5' | | 3 | 36 |
| | 30 | | No Recovery 31.5' | | | 100/0.9 |
| -31.5 | | | | | | Note: 28.5' to 31.5' cuttings appear to be from gray fine to medium silty sand. Tried new plastic spring and plastic in spoon. 72 |
| -33.0 | | | SC-Dark gray fine to medium grained clayey sand. 33.0' | | 4 | 23 |
| | | | | | 5 | 20 |
| | 35 | | SM-Gray fine to medium grained silty sand. | | | 20 |
| | | | Fine to coarse grained with gravel below 37.5'. | | | 20 |
| | | | | | | Note: 40.5' to 43.5' Cuttings appear to be from gray fine to coarse silty sand. 23 |
| -40.5 | 40 | | 40.5' | | 6 | 60 |
| | | | | | | 29 |
| -43.5 | | | No Recovery. 43.5' | | | 32 |
| | 45 | | SP-Tan fine to coarse grained poorly graded sand with gravel. | | 7 | 40 |
| | | | Gravel absent below 46.5'. | | | 39 |
| -48.0 | | | | | 8 | 40 |
| | | | Bottom of boring at 48.0' | | | |

SAMPLE LAB

| No. | Class | LL | PL | PI |
|---|---|---|---|---|
| 2 | SP | NP | NP | NP |
| 4 | SM | - | - | - |
| 7 | SP | NP | NP | NP |

Note: Soils field classified in accordance with the Unified Soil Classification System

BLOWS PER FOOT
Number required to drive 1 3/8" ID splitspoon w/140 hammer falling 30".

**Hole No.** SH-122

**DRILLING LOG**

| | |
|---|---|
| DIVISION | South Atlantic |
| INSTALLATION | Savannah District |
| SHEET | 1 OF 2 SHEETS |
| 1. PROJECT | Savannah Harbor Widening |
| 2. LOCATION (Coordinates or Station) | X-835410 Y-758830 |
| 3. DRILLING AGENCY | Savannah District |
| 4. HOLE NO. (As shown on drawing title and file number) | SH-122 |
| 5. NAME OF DRILLER | P. Rountree |
| 6. DIRECTION OF HOLE | [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT. |
| 7. THICKNESS OF OVERBURDEN | 65.0 |
| 8. DEPTH DRILLED INTO ROCK | 0.0 |
| 9. TOTAL DEPTH OF HOLE | 65.0 |
| 10. SIZE AND TYPE OF BIT | 1 3/8" ID Splitspoon |
| 11. DATUM FOR ELEVATION SHOWN (TBM or MSL) | MLW |
| 12. MANUFACTURER'S DESIGNATION OF DRILL | CME 550 |
| 13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN | DISTURBED 16 / UNDISTURBED 0 |
| 14. TOTAL NUMBER CORE BOXES | N/A |
| 15. ELEVATION GROUND WATER | N/A |
| 16. DATE HOLE | STARTED 2 Nov 83 / COMPLETED 3 Nov 83 |
| 17. ELEVATION TOP OF HOLE | 15.1 |
| 18. TOTAL CORE RECOVERY FOR BORING | N/A % |
| 19. SIGNATURE OF INSPECTOR | James E. Bolen (signed) |

| ELEVATION (a) | DEPTH (b) | CLASSIFICATION OF MATERIALS (Description) (d) | % CORE RECOVERY (e) | BOX OR SAMPLE NO. JAR (f) | BLOWS |
|---|---|---|---|---|---|
| 15.1 | 0 | CL-Dark brown lean clay with some silt and fine sand. | | 1 | 21 |
| 12.1 | | 3.0' | | - | 10 |
| | | SM-Dark brown silty medium fine sand with some clay. | | 2 | 10 |
| | 5 | | | 3 | 11 |
| | | | | | 11 |
| 6.1 | | 9.0' | | | 4 |
| | 10 | SC-Gray clayey coarse-medium sand. | | 4 | 4 |
| | | | | | 6 |
| | | With wood chips and fibers. | | | 6 |
| 0.1 | 15 | 15.0' | | 5 | 2 |
| | | MH- Dark green fat clayey silt with a trace of wood chips and fibers. | | | W/T |
| -3.9 | | 19.0' | | 6 | |
| | 20 | SM-Dark green silty coarse medium sand. (moderate silt content). | | 7 | 16 |
| | | | | | 13 |
| -8.4 | | 23.5' | | | 11 |
| | 25 | SC-Alternating layers of dark green fat clay and medium grained silty sand. | | | 11 |
| | | MH- Dark green fat clayey silt with 25% medium sand. | | 8 | 14 |
| -13.4 | | | | . | 14 |
| -14.9 | 30 | | | 9 | 11 |

Continued on sheet 2

Note: Soils field classified in accordance with the Unified Soil Classification System.

**REMARKS** (Drilling time, water loss, depth of weathering, etc., if significant) (g)

W.T. 7.0'
Date 2 Nov. 83
Depth to water during drilling

W.T. 6.3'
Water table reading 24 hrs. after hole completed.

Note: Fill material 0.0'-4.0'. Mixed mud at 7.5'.

Note: W/T=Weight of Tools.

SAMPLE LAB

| No | Class | LL | PL | PI |
|---|---|---|---|---|
| 1 | CL | 37 | 18 | 19 |
| 4 | SC-H | 56 | 25 | 31 |
| 6 | MH | 93 | 44 | 49 |
| 8 | SM-H | 58 | 31 | 27 |
| 9 | CH | 130 | 44 | 86 |
| 11 | SP-SM | NP | NP | NP |
| 13 | SP-SM | NP | NP | NP |

BLOWS PER FOOT:
Number required to drive 1 3/8" ID splitspoon w/140 lb. hammer falling 30".

**DRILLING LOG (Cont Sheet)** ELEVATION TOP OF HOLE 15.1' | Hole No. SH-122

PROJECT: Savannah Harbor Widening | INSTALLATION: Savannah District | SHEET 2 OF 2 SHEETS

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. JAR | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g | BLOWS |
|---|---|---|---|---|---|---|---|
| -14.9 | 30 | | MH- Dark green fat clayey silt with 25% medium sand. | | 9 | | 5, 7 |
| -18.9 | | | 34.0' | | | | 24 |
| | 35 | | SM- Gray/green silty medium fine sand. (Moderate silt content). | | 10 | | 27, 21, 20 |
| | 40 | | | | 11 | | 19, 20, 20 |
| | 45 | | Silty coarse-medium sand. | | 12 | | 21, 37, 34 |
| | 50 | | | | 13 | | 42, 44, 50, 59 |
| | 55 | | Gray/brown silty coarse medium sand. | | 14 | | 94, 74, 25 |
| | 60 | | | | 15 | | 47, 65, 60, 66 |
| -50.4 | 65 | | | | 16 | | 97 |
| | | | Bottom of Boring 65.5' | | | | |
| | | | Note: Soils field classified in accordance with the Unified Soil Classification System. | | | BLOWS PER FOOT: Number required to drive 1 3/8" ID splitspoon w/140 lb. hammer falling 30". | |

Hole No. SH-127

| DRILLING LOG | DIVISION South Atlantic | INSTALLATION Savannah River | SHEET 1 OF 2 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT Savannah Harbor Widening | 10. SIZE AND TYPE OF BIT 1 3/8" splitspoon & 5 1/2" fishtail |
| 2. LOCATION (Coordinates or Station) X-324881 Y-767364 | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLW |
| 3. DRILLING AGENCY Savannah District | 12. MANUFACTURER'S DESIGNATION OF DRILL CME-550 |
| 4. HOLE NO. (As shown on drawing title and file number) SH-127 | 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 14; UNDISTURBED 0 |
| 5. NAME OF DRILLER P. Rountree | 14. TOTAL NUMBER CORE BOXES 0 |
| 6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT. | 15. ELEVATION GROUND WATER |
| | 16. DATE HOLE: STARTED 5-13-84; COMPLETED 5-14-84 |
| 7. THICKNESS OF OVERBURDEN 58.5' | 17. ELEVATION TOP OF HOLE 8.4 |
| 8. DEPTH DRILLED INTO ROCK 0.0' | 18. TOTAL CORE RECOVERY FOR BORING N/A % |
| 9. TOTAL DEPTH OF HOLE 58.5' | 19. SIGNATURE OF INSPECTOR Larry Benjamin |

| ELEVATION a 8.4 | DEPTH b 0' | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. JAR | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g | BLOWS |
|---|---|---|---|---|---|---|---|
| | 0 | | SM-Black & white fine silty sand. | | 1 | | 5 |
| | | | Brown | | 2 | | 4 |
| 5.4 | 3 | | MH-Grey fine silty fat clay w/roots. | | 3 | | 1 |
| | 5 | | | | | W.T. 2.5' Date 5-13-84 Depth to water during drilling. | 2 |
| | | | | | | | weight of hammer |
| | | | | | | | 2 |
| -0.6 | 9 | | SP-Grey med. to coarse poorly graded sand. | | 4 | W.T. 2.0' Water table reading 24 hrs. after hole completed. | 5 |
| | 10 | | | | | | 13 |
| | | | Coarse grained | | | | 13 |
| | | | | | 5 | | 10 |
| | 15 | | | | | | 14 |
| | | | | | | | 13 |
| | | | | | | At 9.0' mixed zeogel mud & continuously drove 1.5'(18") & fishtailed 1.5'(18") to a depth of 58.5'. | 16 |
| | 20 | | | | 6 | | 15 |
| | | | | | | | 15 |
| | | | | | | | 15 |
| | 25 | | | | 7 | | 22 |
| | | | | | | | 25 |
| | | | | | | | 25 |
| | | | | | | | 23 |
| -21.6 | 30 | | | | | | |

Continued on sht 2

NOTE Soils field classified in accordance with the Unified Soil Classification System.

BLOWS PER FOOT:

Number required to drive 1 3/8"ID splitspoon w/ 140 lb. hammer falling 30".

**DRILLING LOG (Cont Sheet)** — ELEVATION TOP OF HOLE: 8.4' — **Hole No.** SH-127

PROJECT: Savannah Harbor Widening — INSTALLATION: Savannah River — SHEET 2 OF 2 SHEETS

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. f (JAR) | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g | BLOWS |
|---|---|---|---|---|---|---|---|
| -21.6' | 30 | | SP-Grey coarse poorly graded sand. | | 8 | | 27 |
| | | | | | | | 31 |
| | | | | | | | 29 |
| | 35 | | | | 9 | | 26 |
| | | | | | | | 24 |
| | | | | | | | 23 |
| | 40 | | | | 10 | | 23 |
| | | | | | | | 27 |
| | | | | | | | 28 |
| | | | | | 11 | | 27 |
| | 45 | | Trace of coarse river gravel. | | | | 29 |
| | | | | | | | 30 |
| | | | | | | | 28 |
| | 50 | | Tan no river gravel. | | 12 | | 26 |
| | | | | | | | 32 |
| | | | Trace of clay | | 13 | | 37 |
| | 55 | | No clay. | | | | 34 |
| | | | | | | | 30 |
| -50.1 | | | | | 14 | | 29 |
| | | | Bottom of Boring 58.5' | | | | |
| | | | NOTE: Soils field classified in accordance with the Unified Soil Classification System | | | BLOWS PER FOOT: Number required to drive 1 3/8"ID splitspoon w/ 140 lb. hammer falling 30". | |

| DRILLING LOG | DIVISION South Atlantic | INSTALLATION Savannah River | SHEET 1 OF 2 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT Savannah Harbor Widening | 10. SIZE AND TYPE OF BIT 1 3/8" splitsspoon |
| 2. LOCATION (Coordinates or Station) X-831931 Y-760221 | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLW |
| 3. DRILLING AGENCY Savannah District | 12. MANUFACTURER'S DESIGNATION OF DRILL Failing 314 |
| 4. HOLE NO. (As shown on drawing title and file number) SH-128 | 13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN: DISTURBED 16, UNDISTURBED 0 |
| 5. NAME OF DRILLER C.D. Justiss | 14. TOTAL NUMBER CORE BOXES |
| 6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT. | 15. ELEVATION GROUND WATER |
| | 16. DATE HOLE: STARTED 15 May 1984; COMPLETED 17 May 1984 |
| 7. THICKNESS OF OVERBURDEN 64.5' | 17. ELEVATION TOP OF HOLE 12.6' |
| 8. DEPTH DRILLED INTO ROCK 0.0' | 18. TOTAL CORE RECOVERY FOR BORING % |
| 9. TOTAL DEPTH OF HOLE 64.5' | 19. SIGNATURE OF INSPECTOR Lou Archambault |

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g |
|---|---|---|---|---|---|---|
| 12.6' | 0' | | | | JAR | BLOWS |
| | | | SM-Tan & brown, fine to med. grained, dry, silty sand w/scattered gravel, twigs & grasses. | | 1 | 28, 9, 7, 5 |
| 6.6' | 5 | | Brown with shell fragments. | | 2 | W.T. 6' Date 15 May 1984 Depth to water during drilling. W.T. 6' Water table reading 72 hrs. after hole completed. 2, 1, 0, 0, 8 |
| -0.9' | 10 | | CH-Grey fat clay w/organics. | | 3 | 3 |
| -3.4' | 15 | | SP-SM-Grey, green med.-poorly graded silty sand w/scattered mica. | | 4, 5 | 14, 32, 40, 20, 23, 17, 10, 16, 10 |
| -15.9' | 20, 25 | | SW-SM-Grey green fine to coarse grained silty sand w/mica. | | 6 | 27 |
| | 30 | | (Con't. on sht. 2) | | | |

NOTE: Soils field classified in in accordance with the Unified Soil Classification System.

BLOWS PER FOOT: Number required to drive 1 3/8" ID splitspoon w/140 lb. hammer falling 30".

**DRILLING LOG (Cont Sheet)** ELEVATION TOP OF HOLE 12.6' **Hole No.** SH-128

PROJECT: Savannah Harbor Widening | INSTALLATION: Savannah River | SHEET 2 OF 2 SHEETS

| ELEVATION a | DEPTH b | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. JAR | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g BLOWS |
|---|---|---|---|---|---|
| | 30 | W/wood fragments | | | 16, 22 |
| -20.4' | | SP-SM-Grey green med. grained, silty sand w/mica throughout. | | 7 | 35 |
| -21.9' | 35 | SW-SM-fine to med.grained silty sand w/mica. | | | 33, 31 |
| | | Occassional gravel. | | 8 | 37 |
| | 40 | | | | 22, 20 |
| | | | | 9 | 37, 25 |
| | 45 | | | | 27 |
| | | Tan coarse - med. | | 10 | 37, 44 |
| -36.9' | 50 | SP-SM-Light grey coarse grained silty sand. | | 11 | 40, 26, 21 |
| | 55 | Tan | | 12 | 37, 43 |
| | | Medium grained. | | | 31, 36 |
| -47.4' | 60 | SW-SM-Grey green well graded silty sand. | | 13 | 10 |
| -48.9' | | CH-Grey fat clay. | | 14 | 1 |
| -50.4' | | SW-SM-Grey green well graded silty sand. | | 15 | 31 |
| -51.4' | | CH-Green fat clay. | | 16 | |
| -51.9' | 65 | Bottom of Hole 64.5' | | | |

Hole No. SH-138

**DRILLING LOG**

| | |
|---|---|
| DIVISION | South Atlantic |
| INSTALLATION | Savannah, Ga. |
| SHEET 1 OF 2 SHEETS | |
| 1. PROJECT | Savannah Harbor Widening |
| 2. LOCATION (Coordinates or Station) | X=831848 Y=760405 |
| 3. DRILLING AGENCY | Savannah District |
| 4. HOLE NO. (As shown on drawing title and file number) | SH-138 |
| 5. NAME OF DRILLER | J. Butts |
| 6. DIRECTION OF HOLE | [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT. |
| 7. THICKNESS OF OVERBURDEN | 63.0' |
| 8. DEPTH DRILLED INTO ROCK | 0.0' |
| 9. TOTAL DEPTH OF HOLE | 63.0' |
| 10. SIZE AND TYPE OF BIT | 1 3/8"splitspoon,6" spiral auger & fishtail |
| 11. DATUM FOR ELEVATION SHOWN (TBM or MSL) | MLW |
| 12. MANUFACTURER'S DESIGNATION OF DRILL | Failing 314 |
| 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN | DISTURBED 18 / UNDISTURBED 1 |
| 14. TOTAL NUMBER CORE BOXES | 0 |
| 15. ELEVATION GROUND WATER | See Remarks |
| 16. DATE HOLE | STARTED 12 Mar 1987 / COMPLETED 14 Mar 1987 |
| 17. ELEVATION TOP OF HOLE | 13.0' |
| 18. TOTAL CORE RECOVERY FOR BORING | N/A % |
| 19. SIGNATURE OF INSPECTOR | T. Nicholson(0-24')/J. Arthur(24-63') |

ELEVATION (a): 13.0' — DEPTH (b): 0 — LEGEND (c) — CLASSIFICATION OF MATERIALS (Description) (d) — % CORE RECOVERY (e) — BOX OR SAMPLE NO. (f): JAR — REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) (g) — BLOWS

Elevations: 9.5', 8.5', 7.0', 5.5', 4.0', 2.5', 1.0', -0.5', -2.0', -3.5', -6.5', -11.0', -12.5', -15.5', -17.0'

Depth: 0, 5, 10, 15, 20, 25, 30

Classification of materials:

- CH-Dark brown fat clay,some roots,brick fragments & sand, dry.
- SP-Tan poorly graded fine sand,some brick fragments, dry.
- Dark brown,fine to med. grained,trace of clay,damp.
- Trace of roots & fine gravel, wet.
- CH-Brown fat clay,trace of fine to coarse gravel & roots,wet.
- Some roots,no gravel.
- Greenish grey,no roots,3" piece of wood @ 11.0'.
- Trace of fine to med.sand.
- Trace of fine to coarse gravel.
- SM-Greyish green silty fine sand,trace of fine to coarse gravel,wet.
- Some fine to coarse gravel, trace of clay in thin layers.
- No clay.
- CH-Greenish grey fat clay, trace of fine to coarse gravel,fine sand & mica, damp.
- SC-Greenish grey clayey fine to med.sand,trace of mica, wet.
- SM-Greenish grey silty fine to med. sand,trace of mica, wet.

Continued on sht 2

Sample No. (Jar): 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Blows: 3, 10, 11, 5, 13, 5, 2, 2, 2, 11, 16, 7, 3, 14, 25, 9, 4, 10, 15, 21

Remarks:

Water level 4.8' depth to water during drilling.

No 24 hour water level taken. Backfilled hole/w grout aftet completion of boring.

12.0'-Began using Revert mud.

Undisturbed sample taken from 24.0' to 26.0' w/5"shelby tube.Recovered 1.8'. Jar sample from 24.0' to 24.1' & 25.7' to 25.8' from shelby tube.

LAB CLASSIFICATION

| No. | Class | LL | PL | PI |
|---|---|---|---|---|
| 1 | SM | NP | NP | NP |
| 6 | SP-SM | NP | NP | NP |
| 8 | CH | 126 | 37 | 39 |
| 9 | SC | 40 | 24 | 16 |
| 11 | SP | NP | NP | NP |
| 14 | SP | NP | NP | NP |
| 16 | SW | NP | NP | NP |

BLOWS PER FOOT: Number required to drive 1 3/8" ID splitspoon w/140 lb. hammer falling 30".

NOTE: Soils visually field classified in accordance with the Unified Soil Classification System.

**DRILLING LOG (Cont Sheet)** | ELEVATION TOP OF HOLE: 13.0' MLW | **Hole No.** SH-138

PROJECT: Savannah Harbor Widening | INSTALLATION: Savannah, Ga. | SHEET 2 OF 2 SHEETS

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. f (JAR) | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g (BLOWS) |
|---|---|---|---|---|---|---|
| -17.0' | 30' | | | | | |
| -20.0' | | | SM-Greenish grey silty fine to med.sand, trace of mica, wet. | | | 24, 19 |
| -21.5' | 35 | | Med. to coarse grained. | | 11 | 28 |
| | | | Fine to med. grained. | | 12 | 28, 31, 29 |
| | 40 | | Grey, some light brown & tan streaks. | | | 30 |
| -29.0' | | | SP-Greyish brown poorly graded med.to coarse sand, trace of silt & mica, wet. | | 13 | 25 |
| -30.5' | | | | | 14 | 33 |
| -32.0' | 45 | | Light brown, few grayish brown streaks. | | | 21 |
| -33.5' | | | | | | 26 |
| -35.0' | | | Very thin layer of decayed wood at approx. 47.0'. | | | 21 |
| -36.5' | 50 | | Few grey streaks, trace of fine gravel. | | 15 | 26 |
| -38.0' | | | No gravel. | | | 38 |
| -39.5' | | | Light greyish tan, fine to med.grained, trace of fine gravel. | | 16 | 32 |
| -41.0' | 55 | | | | | 24, 22 |
| -44.0' | | | Greyish tan, med.to coarse grained. | | | 25 |
| -45.5' | | | Coarse grained. | | 17 | 17 |
| | 60 | | Some fine gravel. | | | 20 |
| -50.0' | | | Few thin grey silty layers. | | 18 | 20, 22 |
| | | | Bottom of Boring 63.0' | | | |
| | 65 | | | | | |

Hole No. SH-149

| DRILLING LOG | DIVISION: SOUTH ATLANTIC | INSTALLATION: SAVANNAH, GA. | SHEET 1 OF 2 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT: SAVANNAH HARBOR DEEPENING | 10. SIZE AND TYPE OF BIT: 1 3/8" I.D. SPLITSPOON, 4" SPIRAL AUGER, 5½" FISHTAIL |
| 2. LOCATION (Coordinates or Station): X= 817840 ; Y= 778530 (GA EAST) | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MLW |
| 3. DRILLING AGENCY: SAVANNAH DISTRICT | 12. MANUFACTURER'S DESIGNATION OF DRILL: FAILING 314 |
| 4. HOLE NO. (As shown on drawing title and file number): SH-149 | 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 15; UNDISTURBED 0 |
| 5. NAME OF DRILLER: D. JUSTISS | 14. TOTAL NUMBER CORE BOXES: 0 |
| 6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ____ DEG. FROM VERT. | 15. ELEVATION GROUND WATER: SEE REMARKS |
| | 16. DATE HOLE: STARTED 18 OCT 91; COMPLETED 18 OCT 91 |
| 7. THICKNESS OF OVERBURDEN: 60.0' | 17. ELEVATION TOP OF HOLE: |
| 8. DEPTH DRILLED INTO ROCK: 0.0' | 18. TOTAL CORE RECOVERY FOR BORING: N/A % |
| 9. TOTAL DEPTH OF HOLE: 60.0' | 19. SIGNATURE OF INSPECTOR: J. [signature], P.G. |

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. (JAR) f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g | Blows |
|---|---|---|---|---|---|---|---|
| | 0 | | (SM) BROWN, SILTY FINE TO MEDIUM SAND, TRACE OF ROOTS, SLIGHTLY DAMP. | | 1 | CLEANED OUT HOLE WITH 4" SPIRAL AUGER FROM 1.5' TO 4.5' & 6.0' TO 9.0'. | 7 |
| | | | (SP) LIGHT BROWN TO TAN, POORLY GRADED FINE TO MEDIUM SAND, TRACE OF SILT, SLIGHTLY DAMP. | | 2 | JAR SAMPLE #2 TAKEN FROM AUGER FROM 1.5' TO 4.5'. | |
| | 5 | | (SM) BROWN, SILTY, FINE TO MEDIUM SAND, DAMP. | | 3 | BEGAN USING 5½" FISHTAIL & ZEOGEL DRILLING MUD AT 10.5'. | 15 |
| | | | MEDIUM SAND, WET. | | | | |
| | 10 | | MEDIUM TO COARSE SAND, SOME FINE TO MEDIUM SAND FROM 10.3' TO 10.5'. | | 4 | SPLITSPOON DRIVES TAKEN AT 4.5' INTERVALS. | 4 |
| | | | WASH | | | | |
| | | | (SC) GREENISH GRAY, CLAYEY, FINE TO MEDIUM SAND, SOME SILT, TRACE OF MICA, WET. | | 5 | WATER LEVEL 6.5' DEPTH TO WATER DURING DRILLING. | 4 |
| | 15 | | WASH | | | WATER LEVEL NOT ENCOUNTERED 21 OCT 91. TAPED HOLE TO 5.0'. | |
| | | | (SM) TANNISH GRAY, SILTY, MEDIUM TO COARSE SAND, TRACE OF CLAY, WET. | | 6 | | 18 |
| | 20 | | WASH | | | | |
| | | | (SP) TANNISH GRAY, POORLY GRADED MEDIUM TO COARSE SAND, TRACE OF SILT, WET. | | 7 | | 15 |
| | 25 | | WASH | | | | |
| | | | SAME AS 22.5' TO 24.0'. | | 8 | | 13 |
| | | | WASH | | | | |
| | 30 | | CONTINUED ON SHEET #2 | | | | |
| | | | NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM. | | | BLOWS PER FOOT: NUMBER REQUIRED TO DRIVE 1 3/8" I.D. SPLIT-SPOON WITH 140 lb. HAMMER FALLING 30". | |

| DRILLING LOG (Cont. Sheet) | ELEVATION TOP OF HOLE | Hole No. SH-149 | |
|---|---|---|---|
| PROJECT SAVANNAH HARBOR DEEPENING | INSTALLATION SAVANNAH, GA. | SHEET 2 OF 2 SHEETS | |

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. JAR | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g BLOWS |
|---|---|---|---|---|---|---|
| | 30 | | Wash. | | | |
| | | | (SM) Grey, fine to med. silty SAND. Trace of mica, wet. | | 9 | 24 |
| | 35 | | Wash. | | | |
| | | | (SP) Grey, med. to coarse, poorly graded SAND. Trace of silt & mica, wet. | | 10 | 39 |
| | 40 | | Wash. | | | |
| | | | Same as 36.0' to 37.5' but coarse sand. Trace of fine gravel. | | 11 | 46 |
| | 45 | | Wash. | | | |
| | | | Same as 40.5' to 42.0'. | | 12 | 33 |
| | | | Wash. | | | |
| | 50 | | (GP) Greenish-grey, fine, poorly graded GRAVEL. Trace of silt & coarse sand, wet. | | 13 | 17 |
| | | | Wash. NOTE: Wash return contained same sand and clay. | | | |
| | 55 | | (CL) Greyish-green, silty, lean CLAY. Trace of mica & fine sand, slightly damp. | | 14 | 36 |
| | | | Wash | | | |
| | 60 | | Same as 54.0' to 55.5' but dry. | | 15 | 45 |
| | | | Bottom of Boring 60.0' | | | |

Hole No. SH-150

| | | | |
|---|---|---|---|
| DRILLING LOG | DIVISION SOUTH ATLANTIC | INSTALLATION SAVANNAH, GA. | SHEET 1 OF 2 SHEETS |

| | |
|---|---|
| 1. PROJECT SAVANNAH HARBOR DEEPENING | 10. SIZE AND TYPE OF BIT 1⅜" splitspoon, 4" spiral auger, 5½" fishtail |
| 2. LOCATION (Coordinates or Station) X-817555 Y-779145 GA. EAST | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLW |
| 3. DRILLING AGENCY SAVANNAH DISTRICT | 12. MANUFACTURER'S DESIGNATION OF DRILL FAILING 314 |
| 4. HOLE NO. (As shown on drawing title and file number) SH-150 | 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED 18; UNDISTURBED 0 |
| 5. NAME OF DRILLER DAVID JUSTISS | 14. TOTAL NUMBER CORE BOXES 0 |
| 6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT. | 15. ELEVATION GROUND WATER SEE REMARKS |
| | 16. DATE HOLE — STARTED 16 OCT 91; COMPLETED 17 OCT 91 |
| 7. THICKNESS OF OVERBURDEN 64.5' | 17. ELEVATION TOP OF HOLE |
| 8. DEPTH DRILLED INTO ROCK 0.0' | 18. TOTAL CORE RECOVERY FOR BORING N/A % |
| 9. TOTAL DEPTH OF HOLE 64.5' | 19. SIGNATURE OF INSPECTOR JAMES ARTHUR, P.G. |

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. JAR f | REMARKS (Drilling time, water loss, depth of weathering, etc. if significant) g | BLOWS |
|---|---|---|---|---|---|---|---|
| | 0 | | (SP) Tan, coarse, poorly graded SAND. Damp. | | 1 | | 4 |
| | | | (SC) Olive, fine clayey SAND. Some silt, damp. | | 2 | Cleaned out hole with spiral auger to 4.5'. Jar #2 taken from auger from 1.5' to 4.5'. Splitspoon drive taken at each 4.5' interval to 55.5'. Began using 5½" fishtail & Zeogel drilling mud at 6.0'. | |
| | 5 | | Fine to med. sand, trace of fine gravel, wet. | | 3 | Water level 2.0' depth to water during drilling. | 0 |
| | | | Wash. NOTE: Wash return contained large amount of clay. | | | Water level 1.7' depth to water on 21 Oct 91. Taped hole to 19.8' depth. | |
| | 10 | | Same as 4.5' to 6.0'. | | 4 | | 15 |
| | | | Wash | | | | |
| | 15 | | (SP) Olive grey, med., poorly graded SAND. Trace of silt, wet. | | 5 | | 30 |
| | | | Wash. | | | | |
| | | | (SM) Olive-grey, med., silty SAND, wet. | | 6 | | 21 |
| | 20 | | Wash. Note: Traces of wood in wash. | | | | |
| | | | (SP) Light brown, med. to coarse, poorly graded SAND. Trace of silt, wet. | | 7 | | 16 |
| | 25 | | Wash. | | | | |
| | | | Same as 22.5' to 24.0', but with traces of fine gravel. | | 8 | | 26 |
| | | | Wash. | | | | |
| | 30 | | Continued on sheet #2 NOTE: Soils visually field classified in accordance with the Unified Soil Classification System. | | | BLOWS PER FOOT: Number required to drive 1⅜" I.D. splitspoon w/140 lb. hammer falling 30". | |

**DRILLING LOG (Cont.Sheet)** | ELEVATION TOP OF HOLE | Hole No. SH-150

PROJECT: SAVANNAH HARBOR DEEPENING | INSTALLATION: SAVANNAH, GA. | SHEET 2 OF 2 SHEETS

| ELEVATION | DEPTH | CLASSIFICATION OF MATERIALS (Description) | % CORE RECOVERY | BOX OR SAMPLE NO. JAR | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) | BLOWS |
|---|---|---|---|---|---|---|
| | 30 | Wash. | | | | |
| | | (SP) Light brown, fine to med poorly graded SAND. Trace of silt, wet. | | 9 | | 33 |
| | 35 | Wash. | | | | |
| | | Same as 31.5' to 33.0' but med. to coarse sand. | | 10 | | 30 |
| | 40 | Wash. | | | | |
| | | Same as 36.0' to 37.5' but with some wood. | | 11 | | 26 |
| | | Wash. | | | | |
| | 45 | (SP) Greyish-brown, coarse, poorly graded SAND. Trace of fine gravel & silt, wet. | | 12 | | 27 |
| | | Wash. | | | | |
| | 50 | (CL) Greyish-green, silty lean CLAY. Trace of Mica & fine sand, dry. | | 13 | | 31 |
| | | Wash | | | | |
| | 55 | Same as 49.5' to 51.0' but greyish-green. | | 14 | | 54 |
| | | Wash. | | | Began continuous splitspoon drives at 58.5'. | |
| | 60 | (SM) Grey & greenish-grey, fine silty SAND. Trace of Mica, dry. | | 15 | | 10D/0.8 |
| | | | | 16 | | 78 |
| | | (SC) Greyish-green, fine clayey SAND. Some silt, dry. | | 17 | | 42 |
| | | | | 18 | | 43 |
| | 65 | Bottom of Boring 64.5' | | | | |

Hole No. SH-218

| DRILLING LOG | DIVISION SOUTH ATLANTIC | INSTALLATION SAVANNAH, GA. | SHEET 1 OF 1 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT SAVANNAH HARBOR DEEPENING | 10. SIZE AND TYPE OF BIT 1⅜" SPLITSPOON, 5½" FISHTAIL |
| 2. LOCATION (Coordinates or Station) X=843032 Y=758229 GA. EAST | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLW |
| 3. DRILLING AGENCY SAVANNAH DISTRICT | 12. MANUFACTURER'S DESIGNATION OF DRILL Failing 314 |
| 4. HOLE NO. (As shown on drawing title and file number) SH-218 | 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 6; UNDISTURBED 0 |
| 5. NAME OF DRILLER DAVID JUSTISS | 14. TOTAL NUMBER CORE BOXES 0 |
| 6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT. | 15. ELEVATION GROUND WATER N/A |
| 7. THICKNESS OF OVERBURDEN 50.0' (Water 41.0') | 16. DATE HOLE: STARTED 16 JAN 92; COMPLETED 16 JAN 92 |
| 8. DEPTH DRILLED INTO ROCK 0.0' | 17. ELEVATION TOP OF HOLE 0.0' |
| 9. TOTAL DEPTH OF HOLE 50.0' | 18. TOTAL CORE RECOVERY FOR BORING N/A % |
| | 19. SIGNATURE OF INSPECTOR JAMES ARTHUR, P.G. |

| ELEVATION 0.0 | DEPTH 0 (b) | LEGEND (c) | CLASSIFICATION OF MATERIALS (Description) (d) | % CORE RECOVERY (e) | BOX OR SAMPLE NO. JAR | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) (g) | BLOWS |
|---|---|---|---|---|---|---|---|
| | | | Water | | | Scale change at 40.0'. Set 6" diameter casing by own weight to 44.4'. | |
| | 40 | | Bottom of Harbor ~~42.8'~~ 41.0 | | | | |
| -41.0' | | | (MH) Dark grey to black clayey SILT. | | 1 | | 0 |
| -42.5' | | | (SM) Dark grey to black, medium to coarse silty SAND. Some clay. | | 2 | | 4 |
| -44.0' | | | (SC) Dark grey to black, medium to coarse clayey SAND. Some silt. | | 3 | | |
| -45.0' | 45 | | (SM) Dark grey, fine to medium, silty SAND. Some clay. | | 4 | | 15 |
| -45.5' | | | | | 5 | | 16 |
| | | | (SP) Tannish-light grey, coarse, poorly graded SAND. Trace of silt. | | 6 | | 22 |
| | | | With some fine gravel. | | | | 56 |
| -50.0' | 50 | | Bottom of Boring 50.0' | | | | |

BLOWS PER FOOT:
Number required to drive 1⅜" I.D. SPLITSPOON W/140 LB HAMMER FALLING 30". FOR THE LAST FOOT OF EACH DRIVE

NOTE: Soils visually field classified in accordance with the Unified Soil Classification System.

splitspoon w/140 lb. hammer falling 30".

Hole No. SH- 373

| DRILLING LOG | DIVISION South Atlantic | INSTALLATION Savannah, Ga. | SHEET 1 OF 1 SHEETS |
|---|---|---|---|
| 1. PROJECT Savannah Harbor Deepening | | 10. SIZE AND TYPE OF BIT 1 3/8" I.D. Splitspoon | |
| 2. LOCATION (Coordinates or Station) UTM, X- 523009.46, Y- 3538226.61 | | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLW 5½ "Fishtail | |
| 3. DRILLING AGENCY Savannah District | | 12. MANUFACTURER'S DESIGNATION OF DRILL Failing-314 | |
| 4. HOLE NO. (As shown on drawing title and file number) SH- 373 | | 13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN | DISTURBED 6 / UNDISTURBED 0 |
| 5. NAME OF DRILLER D. Justiss | | 14. TOTAL NUMBER CORE BOXES 0 | |
| 6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ___ DEG. FROM VERT. | | 15. ELEVATION GROUND WATER N/A | |
| 7. THICKNESS OF OVERBURDEN 60.8' (Water 44.3') | | 16. DATE HOLE | STARTED MAR 7 1992 / COMPLETED MAR 7 1992 |
| 8. DEPTH DRILLED INTO ROCK 0.0' | | 17. ELEVATION TOP OF HOLE 0.0' | |
| 9. TOTAL DEPTH OF HOLE 60.8' | | 18. TOTAL CORE RECOVERY FOR BORING N/A % | |
| | | 19. SIGNATURE OF INSPECTOR P.G. J. ARTHUR | |

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g | Blows |
|---|---|---|---|---|---|---|---|
| | | | WATER | | | SCALE CHANGE AT 40.0'. SET 6" DIAMETER CASING BY OWN WEIGHT TO 47.1. | |
| | 40 | | | | | | |
| -44.3' | | | BOTTOM OF HARBOR 44.3' | | JARS | | |
| -45.8' | 45 | | (SP) GRAYISH BROWN MEDIUM TO COARSE POORLY GRADED SAND, SOME SMALL SHELL FRAGMENTS, TRACE OF FINE GRAVEL & SILT. | | 1 | WEIGHT OF RODS DROVE SPLITSPOON FROM 44.3' TO 44.8'. | 6 |
| | | | | | 2 | BEGAN USING ZEOGEL DRILLING MUD AT 47.3'. | 38 |
| -48.8' | | | (SM) DARK GRAY FINE TO MEDIUM SILTY SAND, TRACE OF SMALL SHELL FRAGMENTS. | | | | 24 |
| -51.8' | 50 | | (GP) GRAY FINE POORLY GRADED QUARTZ GRAVEL, SHELLY, SOME FINE TO COARSE SAND, TRACE OF SILT. | | 3 | NO SPLITSPOON RECOVERY ON FIRST DRIVE FROM 48.8 TO 50.3', RE-DROVE TO 50.3' THEN CONT'D WITH DRIVE TO 51.8'. JAR SAMPLE #3 FROM 48.8 TO 51.8'. | 11 |
| | | | | | | | 13 |
| | | | (CH) GRAY FAT CLAY. | | 4 | | 31 |
| | 55 | | | | | | 13 |
| | | | | | 5 | | 16 |
| | | | | | | | 14 |
| -59.3' | | | (SC) OLIVE FINE CLAYEY SAND, SOME SILT. | | | | 14 |
| -60.8' | 60 | | | | 6 | | 15 |
| | | | BOTTOM OF BORING 60.8' | | | | |

NOTE: Soils field classified in accordance with the Unified Soil Classification System

BLOWS PER FOOT: Number required to drive 1 3/8" ID splitspoon w/140 lb hammer falling 30".

Hole No. SH-374

| DRILLING LOG | DIVISION: SOUTH ATLANTIC | INSTALLATION: SAVANNAH, GA. | SHEET 1 OF 1 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT: SAVANNAH HARBOR DEEPENING | 10. SIZE AND TYPE OF BIT: 1⅜" SPLITSPOON, 5½" FISHTAIL |
| 2. LOCATION (Coordinates or Station): X-938464 Y-723217 GA. EAST | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MLW |
| 3. DRILLING AGENCY: SAVANNAH DISTRICT | 12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 314 |
| 4. HOLE NO. (As shown on drawing title and file number): SH-374 | 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 6; UNDISTURBED 0 |
| 5. NAME OF DRILLER: DAVID JUSTISS | 14. TOTAL NUMBER CORE BOXES: 0 |
| 6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT. | 15. ELEVATION GROUND WATER: N/A |
| 7. THICKNESS OF OVERBURDEN: 60.7' (Water 42.7') | 16. DATE HOLE: STARTED 20 FEB 92; COMPLETED 20 FEB 92 |
| 8. DEPTH DRILLED INTO ROCK: 0.0' | 17. ELEVATION TOP OF HOLE: 0.0' |
| 9. TOTAL DEPTH OF HOLE: 60.7' | 18. TOTAL CORE RECOVERY FOR BORING: N/A % |
| | 19. SIGNATURE OF INSPECTOR: JAMES ARTHUR, P.G. |

| ELEVATION 0.0 | DEPTH 0 | LEGEND | CLASSIFICATION OF MATERIALS (Description) | % CORE RECOVERY | BOX OR SAMPLE NO. JAR | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) | BLOWS |
|---|---|---|---|---|---|---|---|
| | 40 | | Water | | | Scale change at 40.0'. Set 6" diameter casing by own weight to 43.7'. | |
| -42.7' | | | Bottom of Harbor 42.7' | | | | |
| | 45 | | (SM) Dark grey, fine, silty SAND. | | 1 | No recovery on first splitspoon drive. Redrove first drive to 44.2' then continued drive to 45.7'. | 11 |
| -45.7' | | | Fine to medium sand, trace of small to large shell fragments. | | | | 12 |
| -47.2' | | | (GP) Grey, fine poorly graded GRAVEL. Trace of silt, fine sand & small to large shell fragments. | | 2 | | 19 |
| -48.7' | 50 | | (SM) Grey, fine to medium, silty SAND. Trace of small shell fragments. | | 3 | | 8 |
| | | | | | | | 25 |
| -51.7' | | | (CH) Dark grey, fat CLAY. Trace of silt. | | 4 | | 6 |
| | | | | | | | 27 |
| | 55 | | | | 5 | | 13 |
| | | | | | | | 14 |
| | | | | | | | 15 |
| | 60 | | | | 6 | | 19 |
| -60.7' | | | Bottom of Boring 60.7' | | | | 17 |
| | | | NOTE: Soils visually field classified in accordance with the Unified Soil Classification System. | | | BLOWS PER FOOT: Number required to drive 1⅜" I.D. splitspoon w/140 lb. hammer falling 30". | |

Hole No. SH-384

| DRILLING LOG | DIVISION SOUTH ATLANTIC | INSTALLATION SAVANNAH, GA. | SHEET 1 OF 1 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT SAVANNAH HARBOR DEEPENING | 10. SIZE AND TYPE OF BIT 1⅜"splitspoon,5½"fishtail |
| 2. LOCATION *(Coordinates or Station)* x-849850 Y-759106 GA. EAST | 11. DATUM FOR ELEVATION SHOWN *(TBM or MSL)* MLW |
| 3. DRILLING AGENCY SAVANNAH DISTRICT | 12. MANUFACTURER'S DESIGNATION OF DRILL FAILING 314 |
| 4. HOLE NO. *(As shown on drawing title and file number)* SH-384 | 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED 9 — UNDISTURBED 0 |
| 5. NAME OF DRILLER DAVID JUSTISS | 14. TOTAL NUMBER CORE BOXES 0 |
| 6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT. | 15. ELEVATION GROUND WATER N/A |
| | 16. DATE HOLE — STARTED 26 NOV 91 — COMPLETED 26 NOV 91 |
| 7. THICKNESS OF OVERBURDEN 60.0' (WATER 30.4') | 17. ELEVATION TOP OF HOLE 0.0' |
| 8. DEPTH DRILLED INTO ROCK 0.0' | 18. TOTAL CORE RECOVERY FOR BORING N/A % |
| 9. TOTAL DEPTH OF HOLE 60.0' | 19. SIGNATURE OF INSPECTOR JAMES ARTHUR, P.G. |

| ELEVATION 0.0 (a) | DEPTH 0 (b) | LEGEND (c) | CLASSIFICATION OF MATERIALS *(Description)* (d) | % CORE RECOVERY JAR (e) | BOX OR SAMPLE NO. (f) | REMARKS *(Drilling time, water loss, depth of weathering, etc., if significant)* (g) | BLOWS |
|---|---|---|---|---|---|---|---|
| | | | Water | | | Scale change at 30.0'. Set 6"diameter casing by own weight to 35.4'. | |
| | 30 | | Bottom of Harbor 30.4' | | | | |
| -30.4' | | | (CH) Dark olive grey, fat CLAY. Very soft & wet. | | 1 | | 0 |
| -34.5' | 35 | | Dark grey, some coarse sand, wood particles & glass fragment at 35.8'. | | | | 1 |
| -36.0' | | | (SC) Dark grey, coarse clayey SAND. Trace of glass fragments. | | 2 | | 3 |
| -37.5' | | | (SP) Greyish-tan, coarse, poorly graded SAND. Some fine to coarse gravel, glass & rock fragments. | | 3 | Weight of rods drove splitspoon from 30.4' to 34.5'. | 18 |
| -39.0' | 40 | | | | | | 15 |
| | | | Tan, some fine gravel, trace of glass fragments. | | | | 13 |
| -43.5' | | | No glass. | | | | 18 |
| -45.0' | 45 | | Trace of silt & glass fragments. | | 4 | | 20 |
| -46.5' | | | (SM) Olive-grey, fine silty SAND. | | 5 | | 26 |
| -48.0' | | | (CL) Olive-grey, silty, lean CLAY. Some fine sand. | | 6 | | 25 |
| | 50 | | | | | | 17 |
| | | | | | | | 20 |
| -52.5' | | | (SC) Olive-grey, fine clayey SAND. Some silt. | | 7 | | 19 |
| | 55 | | | | | | 26 |
| | | | | | 8 | | 31 |
| | | | | | | | 11 |
| | | | | | | | 26 |
| -60.0' | 60 | | | | 9 | | 17 |
| | | | Bottom of Boring 60.0' | | | BLOWS PER FOOT: | |
| | | | NOTE: Soils visualy field classified in accordance with the Unified Soil Classification System. | | | Number required to drive 1⅜" I.D. splitspoon w/140 lb. hammer falling 30". | |

Hole No. SH-385

| DRILLING LOG | DIVISION SOUTH ATLANTIC | INSTALLATION .VANNAH, GA. | SHEET 1 OF 1 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT SAVANNAH HARBOR DEEPENING | 10. SIZE AND TYPE OF BIT 1⅜"SPLITSPOON, 5½" FISHTAIL |
| 2. LOCATION (Coordinates or Station) X-849451 Y-759522 GA. EAST | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLW |
| 3. DRILLING AGENCY SAVANNAH DISTRICT | 12. MANUFACTURER'S DESIGNATION OF DRILL Failing 314 |
| 4. HOLE NO. (As shown on drawing title and file number) SH-385 | 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 8 6; UNDISTURBED 0 |
| 5. NAME OF DRILLER DAVID JUSTISS | 14. TOTAL NUMBER CORE BOXES 0 |
| 6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT. | 15. ELEVATION GROUND WATER N/A |
| | 16. DATE HOLE: STARTED 18 DEC 91; COMPLETED 18 DEC 91 |
| 7. THICKNESS OF OVERBURDEN 60.8' (Water 42.8') | 17. ELEVATION TOP OF HOLE 0.0' |
| 8. DEPTH DRILLED INTO ROCK 0.0' | 18. TOTAL CORE RECOVERY FOR BORING N/A % |
| 9. TOTAL DEPTH OF HOLE 60.8' | 19. SIGNATURE OF INSPECTOR JAMES ARTHUR, P.G. |

| ELEVATION 0.0 | DEPTH 0 | LEGEND | CLASSIFICATION OF MATERIALS (Description) | % CORE RECOVERY | BOX OR SAMPLE NO. JAR | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) BLOWS |
|---|---|---|---|---|---|---|
| | | | Water | | | Scale change at 40.0'. Set 6" diameter casing by own weight to 44.9'. |
| | 40 | | Bottom of Harbor 42.8' | | -- | |
| -42.8' | | | (SP) Tan, coarse poorly graded SAND. | | 1 | 3 |
| -44.3' | 45 | | (CL) Olive, silty lean CLAY. Trace of fine sand. | | 2 | 30 |
| -45.8' | | | (SC) Olive, fine clayey SAND. | | 3 | 100/0.6' |
| | | | | | | 58 |
| | 50 | | | | | 70 |
| | | | | | 4 | 33 |
| | | | | | | 32 |
| | | | | | | 24 |
| | 55 | | | | 5 | 26 |
| | | | | | | 25 |
| | | | | | | 26 |
| | 60 | | | | 6 | 22 |
| -60.8' | | | Bottom of Boring 60.8' | | | |
| | | | NOTE: Soils visually field classified in accordance with the Unified Soil Classification System. | | | BLOWS PER FOOT: Number required to drive 1⅜" I.D. splitspoon w/140 lb. hammer falling 30". |

HOLE NO. SH-386

| DRILLING LOG | DIVISION SOUTH ATLANTIC | INSTALLATION SAVANNAH, GA. | SHEET 1 OF 2 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT SAVANNAH HARBOR DEEPENING | 10. SIZE AND TYPE OF BIT 1⅜" splitspoon, 5½" fishtail |
| 2. LOCATION (Coordinates or Station) X-849665 Y-759846 GA. EAST | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLW |
| 3. DRILLING AGENCY SAVANNAH DISTRICT | 12. MANUFACTURER'S DESIGNATION OF DRILL Failing 314 |
| 4. HOLE NO. (As shown on drawing title and file number) SH-386 | 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED 10; UNDISTURBED 0 |
| 5. NAME OF DRILLER DAVID JUSTISS | 14. TOTAL NUMBER CORE BOXES 0 |
| 6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT. | 15. ELEVATION GROUND WATER N/A |
| | 16. DATE HOLE — STARTED 17 DEC 91; COMPLETED 17 DEC 91 |
| 7. THICKNESS OF OVERBURDEN 60.8' (Water 29.3') | 17. ELEVATION TOP OF HOLE 0.0' |
| 8. DEPTH DRILLED INTO ROCK 0.0' | 18. TOTAL CORE RECOVERY FOR BORING N/A % |
| 9. TOTAL DEPTH OF HOLE 60.8' | 19. SIGNATURE OF INSPECTOR JAMES ARTHUR, P.G. |

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. JAR f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g | BLOWS |
|---|---|---|---|---|---|---|---|
| | 25 | | Water | | | Scale change at 25.0'. Set 6" diameter casing by own weight to 29.5'. | |
| -29.3' | | | Bottom of Harbor 29.3' | | | | |
| | 30 | | (SM) Olive grey, fine silty SAND. Some clay, trace of shell fragments & mica | | 1 | Weight of rods drove splitspoon to 30.5', cont'd. drive to 30.8' with four blows. | 4 |
| -30.8' | | | No shell fragments. | | 2 | | 46, 52, 43, 57 |
| -36.8' | 35 | | (SC) Olive-grey, fine clayey SAND. Some silt, trace of mica. | | 3, 4 | | 52, 52, 49, 52, 36 |
| -44.3' | 40, 45 | | (SM) Olive, fine silty SAND. Trace of clay. | | 5, 6 | | 67, 71, 100/0.8' |
| -50.3' | 50 | | (SC) Olive-grey, fine clayey SAND. Some silt, trace of mica. | | 7 | | 79, 32 |
| -51.8' | | | (CL) Olive-grey, silty lean CLAY. Some fine sand, trace of mica. | | 8 | | 44, 25 |
| -55.0' | 55 | | Continued on sheet #2 | | | BLOWS PER FOOT: | |
| | | | NOTE: Soils visually field classified in accordance with the Unified Soil Classification System. | | | Number required to drive 1⅜" I.D. splitspoon w/140 lb. hammer falling 30". | |

| DRILLING LOG (Cont Sheet) | ELEVATION TOP OF HOLE 0.0' MLW | | Hole No. SH-386 |
|---|---|---|---|
| PROJECT SAVANNAH HARBOR DEEPENING | | INSTALLATION SAVANNAH, GA. | SHEET 2 OF 2 SHEETS |

| ELEVATION -55.0' (a) | DEPTH 55 (b) | LEGEND (c) | CLASSIFICATION OF MATERIALS (Description) (d) | % CORE RECOVERY (e) | BOX OR SAMPLE NO. JAR | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) (g) | |
|---|---|---|---|---|---|---|---|
| | | | (CL) Olive grey, silty lean CLAY. Some fine sand, trace of mica. | | | | 34 |
| | | | | | 9 | | 27 |
| | | | | | | | 24 |
| | 60 | | | | 10 | | 21 |
| -60.8' | | | Bottom of Boring 60.8' | | | | |

Hole No. SH-400

**DRILLING LOG**

| Field | Value |
|---|---|
| DIVISION | SOUTH ATLANTIC |
| INSTALLATION | SAVANNAH, GA. |
| SHEET | 1 OF 1 SHEETS |
| 1. PROJECT | SAVANNAH HARBOR DEEPENING FEASIBILITY STUDY |
| 2. LOCATION (Coordinates or Station) | LAT: 31°57'44.2169", LON. 80°42'41.0623" |
| 3. DRILLING AGENCY | SAVANNAH DISTRICT |
| 4. HOLE NO. (As shown on drawing title and file number) | SH-400 |
| 5. NAME OF DRILLER | P. ROUNTREE |
| 6. DIRECTION OF HOLE | [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT. |
| 7. THICKNESS OF OVERBURDEN | 60.4' (INCL. 52.9' WATER) |
| 8. DEPTH DRILLED INTO ROCK | 0.0' |
| 9. TOTAL DEPTH OF HOLE | 60.4' |
| 10. SIZE AND TYPE OF BIT | 1 3/8" I.D. SPLITSPOON, 5 1/2" FISHTAIL |
| 11. DATUM FOR ELEVATION SHOWN (TBM or MSL) | MLW |
| 12. MANUFACTURER'S DESIGNATION OF DRILL | FAILING 314 |
| 13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN | DISTURBED 6 / UNDISTURBED 0 |
| 14. TOTAL NUMBER CORE BOXES | 0 |
| 15. ELEVATION GROUND WATER | N/A |
| 16. DATE HOLE | STARTED 30 SEP 97 / COMPLETED 30 SEP 97 |
| 17. ELEVATION TOP OF HOLE | 0.0' MLW |
| 18. TOTAL CORE RECOVERY FOR BORING | N/A % |
| 19. SIGNATURE OF INSPECTOR | [signature], P.G. |

| ELEVATION MLW (a) | DEPTH (b) | LEGEND (c) | CLASSIFICATION OF MATERIALS (Description) (d) | % CORE RECOVERY (e) | SAMPLE NO. JAR | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) (g) | Blows |
|---|---|---|---|---|---|---|---|
| | 0 | | WATER | | | SCALE CHANGE AT 50.0' | |
| | 50 | | BOTTOM OF OCEAN 52.9' | | | SET 6" DIAMETER STEEL CASING TO 56.6'. | |
| -52.9' | | | (SP) GRAY FINE POORLY GRADED QUARTZ SAND, TRACE OF FINE TO COARSE SAND SIZE SHELL FRAGMENTS CALCAREOUS. (SEE REMARKS) 54.4' | | 1 | NO RECOVERY ON FIRST DRIVE, REDRIVE 52.9' TO 54.4' THEN CONT'D DRIVE TO 55.9'. RECOVERED BOTH DRIVES. | 3 / 2 |
| -54.4' | 55 | | (SM) GRAY FINE TO MEDIUM SILTY QUARTZ SAND, 15% FINE TO COARSE SAND SIZE SHELL FRAGMENTS, TRACE OF FINE GRAVEL SIZE SHELL FRAGMENTS, CALCAREOUS 55.9' | | 2 | | 1 / 8 / 11 |
| -55.9' | | | (SP) GRAY COARSE POORLY GRADED QUARTZ SAND, 40% FINE GRAVEL SIZE SHELL FRAGMENTS, CALCAREOUS. 57.0' | | 3 | | 9 / 12 / 12 |
| -57.0' | | | (SM) OLIVE GRAY FINE SILTY QUARTZ SAND, SLIGHTLY CALCAREOUS. 58.9' | | 4 | | |
| -58.9' | | | DARK OLIVE GRAY, TRACE OF CLAY. | | 5 | BEGAN USING ZOOGEL DRILLING MUD AT 55.9'. | 10 / 11 / 14 |
| -60.4' | 60 | | BOTTOM OF BORING 60.4' | | 6 | | 11 / 15 / 15 |

NOTE: Soils field classified in accordance with the Unified Soil Classification System.

BLOWS PER 1/2 FOOT

NUMBER REQUIRED TO DRIVE 1 3/8" I.D. SPLITSPOON w/140 lb HAMMER FALLING 30".

STA -65+000 R300

N 716 730.2 E 1107 482.0

Hole No. SH-401

**DRILLING LOG** — DIVISION: SOUTH ATLANTIC — INSTALLATION: SAVANNAH, GA — SHEET 1 OF 1 SHEETS

1. PROJECT: SAVANNAH HARBOR DEEPENING FEASIBILITY STUDY
2. LOCATION (Coordinates or Station): LAT: 31°57'15.2135", LON: 80°41'57.4161"
3. DRILLING AGENCY: SAVANNAH DISTRICT
4. HOLE NO. (As shown on drawing title and file number): SH-401
5. NAME OF DRILLER: P. ROUNTREE
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 60.4' (INCL. 49.9' WATER)
8. DEPTH DRILLED INTO ROCK: 0.0'
9. TOTAL DEPTH OF HOLE: 60.4'
10. SIZE AND TYPE OF BIT: 1 3/8" I.D. SPLIT-SPOON, 5 1/2" FISHTAIL
11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MLW
12. MANUFACTURER'S DESIGNATION OF DRILL: FAILING 314
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 7; UNDISTURBED 0
14. TOTAL NUMBER CORE BOXES: 0
15. ELEVATION GROUND WATER: N/A
16. DATE HOLE: STARTED 30 SEP 97; COMPLETED 30 SEP 97
17. ELEVATION TOP OF HOLE: 0.0' MLW
18. TOTAL CORE RECOVERY FOR BORING: N/A %
19. SIGNATURE OF INSPECTOR: [signature], P.G.

| ELEVATION (MLW) a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | SAMPLE NO. f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g | Blows |
|---|---|---|---|---|---|---|---|
| | | | WATER | | | SCALE CHANGE AT 45.0'. | |
| | 45 | | BOTTOM OF OCEAN 49.9' | | | SET 6" DIAMETER STEEL CASING TO 53.2'. | |
| | | | (SP) GRAY MEDIUM TO COARSE POORLY GRADED QUARTZ SAND, TRACE OF FINE QUARTZ GRAVEL, 20% SHELL FRAGMENTS, CALCAREOUS. | | | BEGAN USING ZEOGEL DRILLING MUD AT 49.9'. | |
| -49.9' | 50 | | 51.4 | | | | |
| -51.4' | | | FINE TO MEDIUM GRAINED, TRACE OF SHELL FRAGMENTS. 52.9' | | 1 | CASING BEGAN DROPPING WITH CLEANOUT BEGINNING AT 57.4'. | 2, 7, 10 |
| -52.9' | | | NO GRAVEL. 54.4' | | 2 | | 15, 20, 34 |
| -54.4' | | | FINE GRAINED. 55.9' | | 3 | | 14, 34, 21 |
| -55.9' | 55 | | COARSE GRAINED, SOME FINE QUARTZ GRAVEL AND SHELL FRAGMENTS. 58.9' | | 4 | | 19, 16, 36 |
| | | | | | 5 | | 5, 10, 15 |
| -58.9' | | | (SC) VERY DARK OLIVE GRAY FINE CLAYEY SAND, SOME SILT, SLIGHTLY CALCAREOUS. | | 6 | | 33, 39, 29 |
| -60.4' | 60 | | BOTTOM OF BORING 60.4' | | 7 | | 13, 12, 9 |
| | 65 | | | | | | |

STA-69+965, L-05   E: 1 111 794.8   N: 714170.3

NOTE: Soils field classified in accordance with the Unified Soil Classification System.

BLOWS PER 1/2 FOOT: NUMBER REQUIRED TO DRIVE 1 3/8" I.D. SPLITSPOON W/140 LB HAMMER FALLING 30".

Hole No. SH-402

| DRILLING LOG | DIVISION: SOUTH ATLANTIC | INSTALLATION: SAVANNAH, GA. | SHEET 1 OF 1 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT: SAVANNAH HARBOR DEEPENING FEASIBILITY STUDY | 10. SIZE AND TYPE OF BIT: 1 3/8" I.D. SPLITSPOON 5' 6" FISHTAIL |
| 2. LOCATION (Coordinates or Station): LAT: 31° 56' 52.4257" LON: 80° 41' 1.9911" | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MLW |
| 3. DRILLING AGENCY: SAVANNAH DISTRICT | 12. MANUFACTURER'S DESIGNATION OF DRILL: FAILING 314 |
| 4. HOLE NO. (As shown on drawing title and file number): SH-402 | 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 8; UNDISTURBED 0 |
| 5. NAME OF DRILLER: C. ROBBINS | 14. TOTAL NUMBER CORE BOXES: 0 |
| 6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT. | 15. ELEVATION GROUND WATER: N/A |
| | 16. DATE HOLE: STARTED 6 OCT 97; COMPLETED 6 OCT 97 |
| 7. THICKNESS OF OVERBURDEN: 60.3' (INCL. 48.3' WATER) | 17. ELEVATION TOP OF HOLE: 0.0' MLW |
| 8. DEPTH DRILLED INTO ROCK: 0.0 | 18. TOTAL CORE RECOVERY FOR BORING: N/A % |
| 9. TOTAL DEPTH OF HOLE: 60.3' | 19. SIGNATURE OF INSPECTOR: P.G. |

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g | Blows |
|---|---|---|---|---|---|---|---|
| | 0 | | WATER | | | SCALE CHANGE AT 45.0'. SET 6" DIAMETER STEEL CASING TO 53.1'. BEGAN USING ZEOGEL DRILLING MUD AT 51.3. | |
| | 45 | | BOTTOM OF OCEAN 48.3' | | | | |
| -48.3' | | | (SP) GRAY MEDIUM TO COARSE POORLY GRADED SAND, TRACE OF FINE QUARTZ GRAVEL AND SHELL FRAGMENTS, SLIGHTLY CALCAREOUS. 49.8' | | 1 | | 0 5 6 |
| -49.8' | 50 | | GRAY TO LIGHT GRAY, FINE TO MEDIUM GRAINED, NO GRAVEL, CALCAREOUS. 52.8' | | 2 | | 10 13 23 |
| -51.3' | | | | | 3 | | 12 36 55 |
| -52.8' | | | LIGHT GRAY, MEDIUM GRAINED SLIGHTLY CALCAREOUS. 54.3' | | 4 | NO SPLITSPOON RECOVERY ON FIRST ATTEMPT FROM 54.3' TO 55.5'. RE-DROVE TO 55.5' THEN CONT'D DRIVE TO 57.3'. CHANGE OF MATERIAL AT 57.1'. | 12 16 13 |
| -54.3' | 55 | | GRAY, MEDIUM TO COARSE GRAINED, TRACE OF FINE QUARTZ GRAVEL. 57.1' | | 5 | | 10 13 9 |
| | | | | | 6 | | 6 18 22 |
| -57.1' | | | (SC) DARK OLIVE GRAY FINE CLAYEY SAND, SLIGHTLY CALCAREOUS. | | 7 | | 8 10 11 |
| -60.3' | 60 | | | | 8 | | 6 9 11 |
| | | | BOTTOM OF BORING 60.3' | | | | |
| | 65 | | | | | | |

NOTE: Soils field classified in accordance with the Unified Soil Classification System.

BLOWS PER 1/2 FOOT
NUMBER REQUIRED TO DRIVE 1 3/8" I.D. SPLITSPOON W/140 lb HAMMER FALLING 30".

N: 711,612.0 E 1,116,089.2 STA -74+980.0

Hole No. SH-403

| DRILLING LOG | DIVISION: SOUTH ATLANTIC | INSTALLATION: SAVANNAH, GA. | SHEET 1 OF 1 SHEETS |
|---|---|---|---|

1. PROJECT: SAVANNAH HARBOR DEEPENING FEASIBILITY STUDY
2. LOCATION (Coordinates or Station): LAT: 31°56'31.6649" LON: 80°40'8.9228"
3. DRILLING AGENCY: SAVANNAH DISTRICT
4. HOLE NO. (As shown on drawing title and file number): SH-403
5. NAME OF DRILLER: C. ROBBINS
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 60.1' (INCL 49.6' WATER)
8. DEPTH DRILLED INTO ROCK: 0.0'
9. TOTAL DEPTH OF HOLE: 60.1'
10. SIZE AND TYPE OF BIT: 1 3/8" I.D. SPLITSPOON, 5/2" FISHTAIL
11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MLW
12. MANUFACTURER'S DESIGNATION OF DRILL: FAILING 314
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 7 | UNDISTURBED 0
14. TOTAL NUMBER CORE BOXES: 0
15. ELEVATION GROUND WATER: N/A
16. DATE HOLE: STARTED 14 OCT 97 | COMPLETED 14 OCT 97
17. ELEVATION TOP OF HOLE: 0.0' MLW
18. TOTAL CORE RECOVERY FOR BORING: N/A %
19. SIGNATURE OF INSPECTOR: [signature] P.G.

N: 709,576.9 E 1,120,691.0 STA -80+005, ℄

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | ~~BOX OR~~ SAMPLE NO. JAR f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g | BLOWS |
|---|---|---|---|---|---|---|---|
| | | | WATER | | | SCALE CHANGE AT 45.0'. | |
| | 45 | | | | | SET 6" DIAMETER STEEL CASING TO 53.6'. | |
| -49.6' | | | BOTTOM OF OCEAN 49.6' (SP) BROWN MEDIUM TO COARSE POORLY GRADED SAND, TRACE OF SHELL FRAGMENTS AND FINE QUARTZ GRAVEL, CALCAREOUS. | | | | |
| -51.1' | 50 | | 51.1' | | 1 | NO RECOVERY ON FIRST DRIVE. REDROVE 49.6' TO 51.1' THEN | 3 6 10 |
| | | | GRAY, FINE TO MEDIUM GRAINED, TRACE OF SILT, NO GRAVEL. | | 2 | CONTINUED DRIVE TO 52.6'. RECOVERED BOTH DRIVES. | 20 28 50 |
| -54.1' | | | 54.1' | | 3 | | 30 29 29 |
| -55.6' | 55 | | TRACE OF FINE QUARTZ GRAVEL, NO SILT, SLIGHTLY CALCAREOUS. 55.6' | | 4 | BEGAN USING ZEOGEL DRILLING MUD AT 52.6'. | 4 5 8 |
| | | | COARSE GRAINED. 58.6' | | 5 | | 6 9 8 |
| -58.6' | | | (CL) DARK OLIVE GRAY SILTY LEAN CLAY, SOME FINE QUARTZ SAND, SLIGHTLY CALCAREOUS. | | 6 | | 12 11 18 |
| -60.1' | 60 | | | | 7 | | 6 9 12 |
| | | | BOTTOM OF BORING 60.1' | | | | |
| | 65 | | | | | | |

NOTE: Soils field classified in accordance with the Unified Soil Classification System.

BLOWS PER ½ FOOT
Number required to drive 1 3/8" ID Splitspoon w/140lb hammer falling 30".

Hole No. SH-404

| DRILLING LOG | DIVISION: SOUTH ATLANTIC | INSTALLATION: SAVANNAH, GA. | SHEET 1 OF 2 SHEETS |
|---|---|---|---|

1. PROJECT: SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY
2. LOCATION (Coordinates or Station): SEE REMARKS X 973 878 Y 779 250
3. DRILLING AGENCY: SAVANNAH DISTRICT
4. HOLE NO. (As shown on drawing title and file number): SH-404
5. NAME OF DRILLER: C. ROBBINS
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 64.5'
8. DEPTH DRILLED INTO ROCK: 0.0'
9. TOTAL DEPTH OF HOLE: 64.5'
10. SIZE AND TYPE OF BIT: 1 3/8" I.D. SPLITSPOON 5 7/8" FISHTAIL, 3" DIAMETER SHELBY TUBE
11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MLW
12. MANUFACTURER'S DESIGNATION OF DRILL: CME-550
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 20; UNDISTURBED 1
14. TOTAL NUMBER CORE BOXES: 0
15. ELEVATION GROUND WATER: N/A
16. DATE HOLE: STARTED 20 NOV 97; COMPLETED 21 NOV 97
17. ELEVATION TOP OF HOLE: 10.4' MLW
18. TOTAL CORE RECOVERY FOR BORING: N/A %
19. SIGNATURE OF INSPECTOR: [signature], P.G.

| ELEVATION MLW (a) 10.4' | DEPTH FT. (b) 0 | LEGEND (c) | CLASSIFICATION OF MATERIALS (Description) (d) | % CORE RECOVERY (e) | BOX OR SAMPLE NO. JAR (f) | BLOWS |
|---|---|---|---|---|---|---|
| 8.9' | | | (SM) BROWN AND GRAY FINE TO MEDIUM SILTY QUARTZ SAND, SOME ROOTS. 1.5' | | 1 | 1, 2, 2 |
| 7.4' | | | WASH 3.0' | | | |
| 5.9' | 5 | | (SP) LIGHT BROWN FINE TO MEDIUM POORLY GRADED QUARTZ SAND. 4.5' | | 2 | 2, 3, 4 |
| 4.4' | | | WASH 6.0' | | | |
| 1.4' | | | (SC) GRAY MEDIUM TO COARSE CLAYEY QUARTZ SAND. 9.0' | | 3 | 1, 1, 0 / 1, 2, 6 |
| -0.1' | 10 | | (SP) LIGHT BROWN MEDIUM TO COARSE POORLY GRADED QUARTZ SAND, TRACE OF SILT. 10.5' | | 4 | 4, 4, 6 |
| -1.6' | | | WASH 12.0' | | | |
| -3.1' | | | (SM) GRAY FINE TO MEDIUM SILTY QUARTZ SAND. 13.5' | | 5 | 4, 12, 13 |
| -4.6' | 15 | | WASH 15.0' | | | |
| -6.1' | | | (SM) SAME AS 12.0'-13.5' BUT WITH TRACE OF CLAY. 16.5' | | 6 | 2, 8, 6 |
| -7.6' | | | WASH 18.0' | | | |
| -9.1' | | | (SP) GRAY MEDIUM TO COARSE POORLY GRADED QUARTZ SAND, TRACE OF WOOD. 19.5' | | 7 | 6, 10, 5 |
| -10.6' | 20 | | WASH 21.0' | | | |
| -12.1' | | | (SP) GRAY FINE TO MEDIUM POORLY GRADED QUARTZ SAND, TRACE OF SILT. 22.5' | | 8 | 17, 13, 15 |
| -13.6' | | | WASH 24.0' | | | |
| -15.1' | 25 | | (SP) GRAY MEDIUM TO COARSE POORLY GRADED QUARTZ SAND, TRACE OF WOOD. 25.5' | | 9 | 9, 6, 7 |
| -16.6' | | | WASH 27.0' | | | |
| -18.1' | | | (SP) SAME AS 24.0'-25.5' BUT WITH TRACE OF FINE QUARTZ GRAVEL. 28.5' | | 10 | 5, 8, 11 |
| -19.6' | 30 | | WASH | | | |

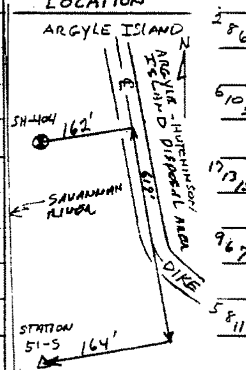
CONTINUED ON SHEET #2

REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) (g):

BEGAN USING DRILLING MUD AT 0.0'.
SPLITSPOONED ON 3' CENTERS.
NOTE: NO RECOVERY ON FIRST ATTEMPT FROM 6.0' TO 7.5', REDROVE TO 7.5' THEN CONTINUED DRIVE TO 9.0'. JAR SAMPLE #3 FROM 6.0' TO 9.0'.

UNDISTURBED UD-1, 6.0'-7.8'

LOCATION




Blows per 1/2 FOOT
NUMBER REQUIRED TO DRIVE 1 3/8" I.D. SPLITSPOON W/140 Lb HAMMER FALLING 30"

NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

**DRILLING LOG (Cont Sheet)** | ELEVATION TOP OF HOLE: 10.4' MLW | **Hole No.** SH-404

PROJECT: SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY | INSTALLATION: SAVANNAH, GEORGIA | SHEET 2 OF 2 SHEETS

| ELEVATION MLW a | DEPTH FT. b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g |
|---|---|---|---|---|---|---|
| 19.6' | 30 | | | | | |
| -21.1' | | | (SP) GRAY FINE TO MEDIUM POORLY GRADED QUARTZ SAND, TRACE OF SILT AND FINE QUARTZ GRAVEL. 31.5' | | 11 | 6, 13, 13 |
| -22.6' | | | WASH 33.0' | | | |
| -24.1' | | | (SP) LIGHT GRAY MEDIUM TO COARSE POORLY GRADED QUARTZ SAND, TRACE OF FINE QUARTZ GRAVEL. 34.5' | | 12 | 5, 6, 8 |
| -25.6' | 35 | | WASH 36.0' | | | |
| -27.1' | | | (SM) GRAY AND BROWN FINE TO MEDIUM SILTY QUARTZ SAND. 37.5' | | 13 | 12, 13, 12 |
| -28.6' | | | WASH 39.0' | | | |
| -30.1' | 40 | | (SP) GRAY FINE TO MEDIUM POORLY GRADED QUARTZ SAND, TRACE OF SILT. 40.5' | | 14 | 9, 19, 18 |
| -31.6' | | | WASH 42.0' | | | |
| -33.1' | | | (SP) SAME AS 39.0'-40.5' BUT WITH SOME WOOD. 43.5' | | 15 | 8, 5, 6 |
| -34.6' | 45 | | WASH 45.0' | | | |
| -36.1' | | | (CH) GRAY FAT CLAY, TRACE OF MEDIUM TO COARSE QUARTZ SAND AND WOOD. 46.5' | | 16 | 0, 2, 5 |
| -37.6' | | | WASH 48.0' | | | |
| -39.1' | | | (SP) LIGHT GRAY MEDIUM TO COARSE POORLY GRADED QUARTZ SAND. 49.5' | | 17 | BEGAN 5' CENTERS AT 49.5'. 16, 24, 25 |
| | 50 | | WASH 53.0' | | | |
| -42.6' | | | | | | |
| -44.1' | 55 | | (CL) OLIVE GRAY SILTY LEAN CLAY, SOME FINE QUARTZ SAND, TRACE OF MICA. 54.5' | | 18 | 15, 22, 27 |
| | | | WASH 58.0' | | | |
| -47.6' | | | | | | |
| -49.1' | 60 | | (CL) SAME AS 53.0'-54.5' BUT WITH TRACE OF SAND AND MICA. 59.5' | | 19 | 14, 22, 28 |
| | | | WASH 63.0' | | | |
| -52.6' | | | | | | |
| -54.1' | 65 | | (CL) SAME AS 58.0'-59.5'. | | 20 | 15, 27, 36 |
| | | | BOTTOM OF BORING 64.5' | | | |

Hole No. SH-405

**DRILLING LOG**

| DIVISION | INSTALLATION | SHEET |
|---|---|---|
| SOUTH ATLANTIC | SAVANNAH, GA. | SHEET 1 OF 2 SHEETS |

1. PROJECT SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY
2. LOCATION (Coordinates or Station) X 975641 Y 477213
3. DRILLING AGENCY SAVANNAH DISTRICT
4. HOLE NO. (As shown on drawing title and file number) SH-405
5. NAME OF DRILLER C. ROBBINS
6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN 75.5'
8. DEPTH DRILLED INTO ROCK 0.0'
9. TOTAL DEPTH OF HOLE 75.5'
10. SIZE AND TYPE OF BIT 1 3/8" I.D. SPLITSPOON 5/8" FISHTAIL, 3" SHELBY TUBE
11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLW
12. MANUFACTURER'S DESIGNATION OF DRILL CME-550
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED 21, UNDISTURBED 2
14. TOTAL NUMBER CORE BOXES 0
15. ELEVATION GROUND WATER N/A
16. DATE HOLE — STARTED 22NOV97, COMPLETED 24NOV97
17. ELEVATION TOP OF HOLE 18.3' MLW
18. TOTAL CORE RECOVERY FOR BORING N/A %
19. SIGNATURE OF INSPECTOR [signature], P.G.

| ELEVATION MLW (a) | DEPTH FT. (b) | LEGEND (c) | CLASSIFICATION OF MATERIALS (Description) (d) | % CORE RECOVERY (e) | SAMPLE NO. JAR (f) | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) (g) Blows | |
|---|---|---|---|---|---|---|---|
| 16.8' | 0 | SM | (SM) BROWN FINE TO MEDIUM SILTY QUARTZ SAND, TRACE OF GRASS ROOTS. 1.5' | | 1 | 2 5 8 | 13 |
| 15.3' | | | WASH 3.0' | | | | |
| 13.8' | | SP | (SP) LIGHT BROWN FINE TO MEDIUM POORLY GRADED QUARTZ SAND. 4.5' | | 2 | 2 5 4 | 9 |
| 12.3 | 5 | | WASH 6.0' | | | | |
| 10.8' | | SP | (SP) SAME AS 3.0'-4.5' 7.5' | | 3 | 10 13 12 | 25 |
| 9.3' | | | WASH 9.0' | | | | |
| 7.8' | 10 | SP | (SP) SAME AS 6.0'-7.5' BUT LIGHT BROWN AND ORANGE, TRACE OF SILT. 10.5' | | 4 | 4 6 7 | 13 |
| 6.3' | | | WASH 12.0' | | | | |
| 4.8 | | SM | (SM) GRAY FINE TO MEDIUM SILTY QUARTZ SAND, TRACE OF WOOD. 13.5' | | 5 | 2 3 3 | 6 |
| 3.3' | 15 | | WASH 15.0' | | | | |
| 1.8 | | CH | (CH) GRAY FAT CLAY, TRACE OF SILT, ROOTS AND ORGANIC FIBERS. 16.5' | | 6 | 2 1 1 | 2 |
| 0.3 | | | WASH 18.0' | | | | |
| -1.2 | | CH | (CH) SAME AS 15.0'-16.5'. 19.5' | | 7 | 0 1 1 | 2 |
| -2.7' | 20 | | WASH 21.0' | | | | |
| -4.2' | | SC | (SC) GRAY FINE TO MEDIUM CLAYEY QUARTZ SAND, SOME SAND AND SILT LAYERS 22.5' | | 8 | 2 9 13 | 22 |
| -5.7' | | | WASH 24.0' | | | | |
| -7.2' | 25 | SP | (SP) GRAY FINE TO MEDIUM POORLY GRADED QUARTZ SAND, TRACE OF CLAYEY LAYERS 25.5' | | 9 | 3 7 9 | 16 |
| -8.7' | | | WASH 27.0' | | | | |
| -10.2' | | SP | (SP) SAME AS 24.0'-25.5' BUT MEDIUM TO COARSE GRAINED. 28.5' | | 10 | 9 7 9 | 16 |
| -11.7' | 30 | | WASH | | | | |

CONTINUED ON SHEET #2

REMARKS:

BEGAN USING DRILLING MUD AT 0.0'.

SPLITSPOONED ON 3' CENTERS

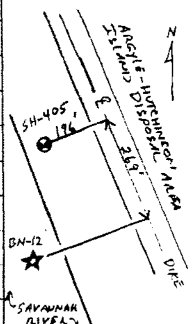
UNDISTURBED

UD-1, 15.0'-16.8'

UD-2, 17.0'-18.7'

LOCATION

ARGYLE ISLAND




BLOWS PER 1/2 FOOT

NUMBER REQUIRED TO DRIVE 1 3/8" I.D. SPLITSPOON W/140 lb HAMMER FALLING 30".

NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

**DRILLING LOG (Cont Sheet)** ELEVATION TOP OF HOLE 18.3' MLW — Hole No. SH-405

PROJECT SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY — INSTALLATION SAVANNAH, GA. — SHEET 2 OF 2 SHEETS

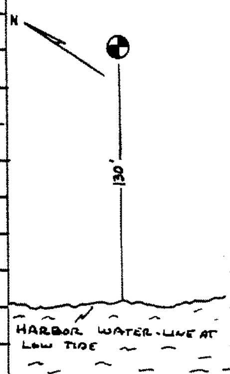
| ELEVATION MLW (a) | DEPTH FT. (b) | LEGEND (c) | CLASSIFICATION OF MATERIALS (Description) (d) | % CORE RECOVERY (e) | SAMPLE NO. (f) | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) (g) | Blows |
|---|---|---|---|---|---|---|---|
| 11.7 / 13.2' | 30 | | (SP) GRAY FINE TO MEDIUM POORLY GRADED QUARTZ SAND, TRACE OF WOOD. 31.5' | | 11 | | 6 13 14 — 27 |
| 14.7' | | | WASH 33.0' | | | | |
| 16.2' | | | (SP) SAME AS 30.0' - 31.5' BUT NO WOOD. 34.5' | | 12 | | 13 23 23 — 46 |
| 17.7' | 35 | | WASH 36.0' | | | | |
| 19.2' | | | (SP) SAME AS 33.0 - 34.5' 37.5' | | 13 | | 12 17 19 — 36 |
| 20.7' | | | WASH 39.0' | | | | |
| 22.2' | 40 | | (SP) SAME AS 33.0' - 34.5' BUT WITH TRACE OF SILT. 40.5' | | 14 | | 9 10 16 — 26 |
| 25.7' | | | WASH 44.0' | | | BEGAN 5' CENTERS AT 40.5'. | |
| 27.2' | 45 | | (SP) GRAY MEDIUM POORLY GRADED QTZ SAND. 45.5' | | 15 | | 13 20 21 — 41 |
| 30.7' | | | WASH 49.0' | | | | |
| 32.2' | 50 | | (SP) SAME AS 44.0' - 45.5' BUT WITH TRACE OF SILT. 50.5' | | 16 | | 8 16 19 — 35 |
| 35.7' | | | WASH 54.0' | | | | |
| 37.2' | 55 | | (SM) DARK GRAY MEDIUM TO COARSE SILTY QUARTZ SAND, TRACE OF FINE QUARTZ GRAVEL. 55.5' | | 17 | | 7 5 5 — 10 |
| 40.7' | | | WASH 59.0' | | | | |
| 42.2' | 60 | | (CL) OLIVE GRAY LEAN CLAY, TRACE OF FINE QUARTZ SAND AND MICA. 60.5' | | 18 | | 8 14 18 — 32 |
| 45.7' | | | WASH 64.0' | | | | |
| 47.2' | 65 | | (CL) SAME AS 59.0' BUT WITH SOME SILT AND FINE QUARTZ SAND. 65.5' | | 19 | | 13 31 27 — 58 |
| 50.7' | | | WASH 69.0' | | | | |
| 52.2' | 70 | | (CL) OLIVE GRAY SANDY LEAN CLAY, FINE GRAINED QUARTZ AND MICA. 70.5' | | 20 | | 14 25 24 — 49 |
| 55.7' | | | WASH 74.0' | | | | |
| 57.2 | 75 | | (CL) SAME AS 69.0' - 70.5' | | 21 | | 19 30 45 — 75 |
| | | | BOTTOM OF BORING 75.5' | | | | |

Hole No. SH-406

| DRILLING LOG | DIVISION: SOUTH ATLANTIC | INSTALLATION: HUTCHINSON ISLAND | SHEET 1 OF 2 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT: SAVANNAH HARBOR EXPANSION, SLOPE STABILITY | 10. SIZE AND TYPE OF BIT: 1 3/8" ID SPLITSPOON, 6" FISH- |
| 2. LOCATION (Coordinates or Station) | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MLW |
| 3. DRILLING AGENCY: SAVANNAH DISTRICT | 12. MANUFACTURER'S DESIGNATION OF DRILL: FAILING 1500 |
| 4. HOLE NO. (As shown on drawing title and file number): SH-406 | 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 21; UNDISTURBED 2 |
| 5. NAME OF DRILLER: P. ROUNTREE | 14. TOTAL NUMBER CORE BOXES: NONE |
| 6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ___ DEG. FROM VERT. | 15. ELEVATION GROUND WATER: NOT DETERMINED |
| | 16. DATE HOLE: STARTED 24 NOV 97; COMPLETED 25 NOV 97 |
| 7. THICKNESS OF OVERBURDEN: >71.5' | 17. ELEVATION TOP OF HOLE: 9.94 |
| 8. DEPTH DRILLED INTO ROCK: — | 18. TOTAL CORE RECOVERY FOR BORING: N/A % |
| 9. TOTAL DEPTH OF HOLE: 71.5' | 19. SIGNATURE OF INSPECTOR: G. ANDERSON / James Biddle GEOLOGIST |

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g | BLOWS/FT |
|---|---|---|---|---|---|---|---|
| 9.9 | 0' | | BROWN (SM) FINE TO MEDIUM SILTY SAND W/ SOME ROOTLETS/WOOD | | 1 | WATER LEVEL NOT DETERMINED DURING DRILLING. ZEOGEL DRILLING FLUID USED FROM SURFACE. 24 HOUR WATER LEVEL WAS NOT DETERMINED | 12 |
| | | | LOG, WOOD | | | | |
| | | | TAN, GREEN, GRAY, TRACE OF GRAVEL | | 2 | SEE COMPANION LOG SH-406-UD FOR UNDISTURBED SAMPLE DESCRIPTIONS, LOCATIONS | 8 |
| | 5' | | GREEN AND GRAY W/ LAYERS OF HARD SILT | | 3 | | 6 |
| 0.9 | 9' | | | | | | |
| | 10' | | (MH) GREEN AND GRAY, HIGH LIQUID LIMIT SILT | | 4 | | 3 |
| -2.1 | 12' | | (SM) TAN FINE TO MEDIUM SILTY SAND | | 5 | | 5 |
| | 15' | | GRAY WITH LARGE PIECE OF GRAVEL | | 6 | | 19 |
| | | | | | 7 | | 13 |
| | 20' | | | | 8 | | 21 |
| | 25' | | | | 9 | | 23 |
| | | | GRAY, FINE TO MEDIUM WITH A TRACE OF GRAVEL | | 10 | | 6 |
| -20.1 | 30' | | | | | | |




CONTINUED ON SHEET No. 2

NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

**DRILLING LOG (Cont Sheet)** | ELEVATION TOP OF HOLE: 9.94 MLW | **Hole No.** SH-406

PROJECT: SAVANNAH HARBOR EXPANSION, SLOPE STABILITY | INSTALLATION: HUTCHINSON ISLAND, SAVANNAH, GA | SHEET 2 OF 2 SHEETS

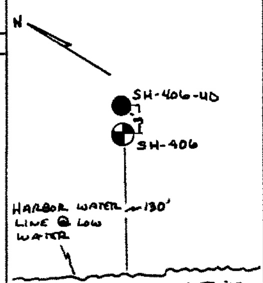
| ELEVATION | DEPTH | LEGEND | CLASSIFICATION OF MATERIALS (Description) | % CORE RECOVERY | BOX OR SAMPLE NO. | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) | |
|---|---|---|---|---|---|---|---|
| -20.1 | 30' b | c | d | e | f | g | |
| | | | (ML) GRAY, LOW LIQUID LIMIT SILT, MICACEOUS TRACE OF WOOD | | 11 | WEIGHT OF HAMMER PUSHED TOOLS FROM 30.0' TO 31.0' | 1 |
| -24.1 | 34' | | | | 12 | WEIGHT OF HAMMER PUSHED TOOLS FROM 33.0' TO 33.5' | 8 |
| | 35' | | (SM) GRAY, FINE TO MEDIUM SILTY SAND, MICACEOUS | | 13 | | 20 |
| -28.1 | 39' | | | | | | |
| | 40' | | (SP) GRAY, FINE, POORLY GRADED SAND WITH A TRACE OF MICA | | 14 | | 32 |
| -32.1 | 42' | | (SM) GRAY, FINE, SILTY SAND WITH A TRACE OF MICA. | | 15 | | 24 |
| -35.1 | 45' | | (SP) GRAY AND TAN, FINE TO MEDIUM POORLY GRADED SAND WITH ONE COARSE PIECE OF GRAVEL | | 16 | | 35 |
| | | | WITH FINE GRAVEL | | 17 | | 35 |
| | 50' | | | | | | |
| | | | FINE TO COARSE, WITH SOME SILT | | 18 | | 15 |
| | 55' | | | | | | |
| | | | FINE TO MEDIUM, POORLY GRADED SAND | | 19 | | 36 |
| | 60' | | | | | | |
| | | | (ML) GREEN, LOW LIQUID LIMIT SILT, VERY DENSE, FINE | | 20 | | 79 |
| | 65' | | | | | | |
| -58.8 | | | | | 21 | | 100/0.7' |
| | | | BOTTOM OF BORING: 68.7' | | | | |

Hole No. SH-406-UD

| DRILLING LOG | DIVISION: SOUTH ATLANTIC | INSTALLATION: HUTCHINSON ISLAND, GA | SHEET 1 OF 1 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT: SAVANNAH HARBOR EXPANSION, SLOPE STABILITY | 10. SIZE AND TYPE OF BIT: 3" ID SHELBY TUBE, 6½" FISH-TAIL |
| 2. LOCATION (Coordinates or Station): See Boring Plan, SH-406, REMARKS. | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MLW |
| 3. DRILLING AGENCY: SAVANNAH DISTRICT | 12. MANUFACTURER'S DESIGNATION OF DRILL: FAILING 1500 |
| 4. HOLE NO. (As shown on drawing title and file number): SH-406-UD | 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED NONE; UNDISTURBED 2 |
| 5. NAME OF DRILLER: D. ROUNTREE | 14. TOTAL NUMBER CORE BOXES: NONE |
| 6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT. | 15. ELEVATION GROUND WATER: NOT DETERMINED |
| | 16. DATE HOLE: STARTED 24 NOV 97; COMPLETED 24 NOV 97 |
| 7. THICKNESS OF OVERBURDEN: >32.5' | 17. ELEVATION TOP OF HOLE: 9.94 |
| 8. DEPTH DRILLED INTO ROCK: — | 18. TOTAL CORE RECOVERY FOR BORING: N/A % |
| 9. TOTAL DEPTH OF HOLE: 32.5' | 19. SIGNATURE OF INSPECTOR: James A. Biddle, GEOLOGIST |

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g |
|---|---|---|---|---|---|---|
| | | | | | | WAITED 15 MINUTES AFTER EACH PUSH BEFORE REMOVING TUBE. |
| | 10' | | GREEN & GRAY HIGH LIQUID LIMIT SILT. FINE | | UD-1 | |
| | 20' | | | | | |
| | 30' | | GRAY, LOW LIQUID LIMIT SILT, FINE, MICACEOUS. | | UD-2 | COMPANION LOG TO SH-406 |
| | | | BOTTOM OF BORING: 32.5' | | | |



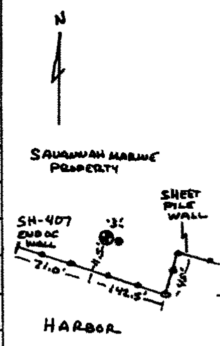

NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

Hole No. SH-407

| DRILLING LOG | DIVISION: SOUTH ATLANTIC | INSTALLATION: HUTCHINSON ISLAND | SHEET 1 OF 2 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT | SAVANNAH HARBOR EXPANSION, SLOPE STABILITY |
| 2. LOCATION (Coordinates or Station) | SEE BORING PLAN, REMARKS |
| 3. DRILLING AGENCY | SAVANNAH DISTRICT |
| 4. HOLE NO. (As shown on drawing title and file number) | SH-407 |
| 5. NAME OF DRILLER | P. ROUNTREE |
| 6. DIRECTION OF HOLE | ☒ VERTICAL ☐ INCLINED ____ DEG. FROM VERT. |
| 7. THICKNESS OF OVERBURDEN | 71.5 |
| 8. DEPTH DRILLED INTO ROCK | – |
| 9. TOTAL DEPTH OF HOLE | 71.5' |
| 10. SIZE AND TYPE OF BIT | 1 3/8" ID SPLITSPOON, 6 1/2" FISH- |
| 11. DATUM FOR ELEVATION SHOWN (TBM or MSL) | MLW |
| 12. MANUFACTURER'S DESIGNATION OF DRILL | FAILING 1500 |
| 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN | DISTURBED 21 ; UNDISTURBED 3 |
| 14. TOTAL NUMBER CORE BOXES | NONE |
| 15. ELEVATION GROUND WATER | NOT DETERMINED |
| 16. DATE HOLE | STARTED 24 NOV 97 ; COMPLETED 25 NOV 97 |
| 17. ELEVATION TOP OF HOLE | 14.8 |
| 18. TOTAL CORE RECOVERY FOR BORING | NA % |
| 19. SIGNATURE OF INSPECTOR | James A Biddle, GEOLOGIST |

| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g | BLOWS/FT |
|---|---|---|---|---|---|---|---|
| 14.8 | 0' | | (SC) DARK GREENISH-GRAY AND REDDISH-BROWN FINE TO MEDIUM CLAYEY SAND, TRACE OF COARSE SAND | | 1 | ZEOGEL-DRILLING FLUID USED FROM SURFACE. NOT POSSIBLE TO DETERMINE WATER LEVEL DURING DRILLING. 24 HOUR WATER LEVEL WAS NOT DETERMINED DUE TO REQUIREMENT OF PROPERTY OWNER TO BACKFILL HOLES ON COMPLETION OF BORING | 14 |
| | | | | | 2 | | 20 |
| | 4.2' / 5' | | (SP) BROWNISH-TAN, FINE TO MEDIUM POORLY GRADED SAND | | | | |
| | | | (SP/SC) POORLY GRADED SAND ABOVE W/ GRAY, FINE TO MEDIUM CLAYEY SAND | | 3 | SEE COMPANION LOG SH-407-40 FOR LOG OF UNDISTURBED SAMPLES | 4 |
| | 9.0' / 10' | | (SC) GRAYISH-BROWN, FINE, CLAYEY SAND W/ FINE GRAVEL | | 4 | | 2 |
| | | | LOST SAMPLE, TRACES OF FINE TO COARSE SATURATED SAND AND FINE GRAVEL | | 5 | | 2 |
| -0.2 | 13.5' / 15' | | (CL) GRAYISH-GREEN SANDY LEAN CLAY WITH FINE TO COARSE GRAVEL, SOFT SLIGHTLY ORGANIC APPEARANCE AND FEEL | | | | 5 |
| | | | (MH) DARK GRAYISH-GREEN, HIGH LIQUID LIMIT SILT WITH FINE GRAVEL AND ORGANIC MATERIAL | | 6 | | 2 |
| | | | W/ 20% FINE SAND | | 7 | | 2 |
| | 20' / 21.9' | | (SP) LIGHT GREENISH-GRAY FINE TO MEDIUM, POORLY GRADED SAND | | 8 | | 12 |
| | 25' | | WITH 15% CLAY | | 9 | | 14 |
| | | | TRACES OF SATURATED FINE SAND IN SPLIT SPOON | | 10 | LOST SAMPLE | 6 |
| -15.2 | 30' | | | | | NO SAMPLE RECOVERY | 2 |




CONTINUED ON SHEET NO. 2

NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

BLOWS PER FOOT

NUMBER REQUIRED TO DRIVE 1 3/8" ID SPLITSPOON w/ 140 Lb HAMMER FALLING 30" FOR THE LAST 12" OF EACH DRIVE

**DRILLING LOG (Cont Sheet)** ELEVATION TOP OF HOLE 14.8 MLW — Hole No. SH-407

PROJECT: SAVANNAH HARBOR EXPANSION, SLOPE STABILITY — INSTALLATION: SAVANNAH HARBOR, HUTCHINSON ISLAND, GA — SHEET 2 OF 2 SHEETS

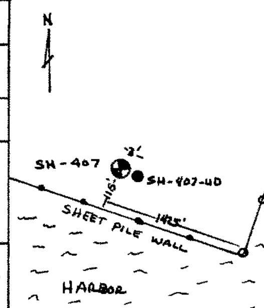
| ELEVATION a | DEPTH b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | BOX OR SAMPLE NO. f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g Blows/FT |
|---|---|---|---|---|---|---|
| -15.2 | 30' | | (SP) CONTINUED FROM SHEET No. 1 OLIVE GREEN, FINE TO MEDIUM POORLY GRADED SAND | | 11 | 24 |
| | | | FINE TO 33.8' | | | |
| | | | CLAY LAYERS | | 12 | 25 |
| | 35' | | FINE TO MEDIUM, NO CLAY | | 13 | 34 |
| | 40' | | SLIGHT SULFUR ODOR | | 14 | 18 |
| | | | ONE FINE GRAVEL SIZED PIECE OF LIMESTONE | | 15 | 30 |
| | 45' | | TRACE OF COARSE SAND | | 16 | 26 |
| | 50' | | FINE TO COARSE | | 17 | 37 |
| | 55' | | TRACE OF FINE GRAVEL | | 18 | 44 |
| | 60' | | FINE TO COARSE W/15% SILT, NO GRAVEL | | 19 | 22 |
| | 65' | | | | 20 | 30 |
| -51.2 | 66' | | (ML) DARK GRAYISH-GREEN ORGANIC SILT, HARD, DENSE | | | |
| | 70' | | | | 21 | 58 |
| -56.8 | | | BOTTOM OF BORING: 71.5' | | | |

Hole No. SH-407-UD

| DRILLING LOG | DIVISION: SOUTH ATLANTIC | INSTALLATION: HUTCHINSON ISLAND | SHEET 1 OF 1 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT: SAVANNAH HARBOR EXPANSION | 10. SIZE AND TYPE OF BIT: 3" ID SHELBY TUBE, 6½" FISH-TAIL |
| 2. LOCATION (Coordinates or Station): SEE BORING PLAN, SH-407, REMARKS | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MLW |
| 3. DRILLING AGENCY: SAVANNAH DISTRICT | 12. MANUFACTURER'S DESIGNATION OF DRILL: FAILING 1500 |
| 4. HOLE NO. (As shown on drawing title and file number): SH 407-UD | 13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED: NONE; UNDISTURBED: 2 |
| 5. NAME OF DRILLER: P. ROUNTREE | 14. TOTAL NUMBER CORE BOXES: NONE |
| 6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT. | 15. ELEVATION GROUND WATER: NOT DETERMINED |
| | 16. DATE HOLE: STARTED 24 NOV 97; COMPLETED 24 NOV 97 |
| 7. THICKNESS OF OVERBURDEN: > 20.9 | 17. ELEVATION TOP OF HOLE: 14.8 |
| 8. DEPTH DRILLED INTO ROCK: — | 18. TOTAL CORE RECOVERY FOR BORING: N/A % |
| 9. TOTAL DEPTH OF HOLE: 20.9 | 19. SIGNATURE OF INSPECTOR: James A Biddle GEOLOGIST |

| ELEVATION (a) | DEPTH (b) | LEGEND (c) | CLASSIFICATION OF MATERIALS (Description) (d) | % CORE RECOVERY (e) | BOX OR SAMPLE NO. (f) | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) (g) |
|---|---|---|---|---|---|---|
| 14.8 | 0' | | | | | COMPANION LOG TO SH-407. SAMPLES ALLOWED TO SIT 30 MINUTES AFTER EACH PUSH BEFORE PULLING TUBE. ATTEMPTED SAMPLES FROM 14.0-15.8 AND 16.0-17.9. LOST BOTH SAMPLES AT SURFACE WHEN PULLING TUBES |
| | 5' | | | | | |
| 6.8 | 8' | | (SC) GRAYISH-GREENISH BROWN FINE TO MEDIUM CLAYEY SAND WITH GRAVEL | | UD-1 | |
| 5.0 | 10' | | | | | |
| 2.8 | 12' | | (SP/SC) FINE TO COARSE SATURATED SAND AND FINE GRAVEL, SOME CLAY WITH GRAYISH-BROWN FINE CLAYEY SAND | | UD-2 | |
| 1.0 | 13.8 | | | | | |
| | 15' | | | | | |
| -3.0 | 18' | | (ML) DARK GREENISH-GRAY, LOW LIQUID LIMIT SILT WITH SOME CLAY, SAND | | UD-3 | |
| -6.1 | 20' | | | | | |
| | | | BOTTOM OF BORING: 20.9' | | | |




NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

Hole No. SH-408

**DRILLING LOG** | DIVISION: SOUTH ATLANTIC | INSTALLATION: SAVANNAH, GA. | SHEET 1 OF 2 SHEETS

1. PROJECT: SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY
2. LOCATION (Coordinates or Station): X 975329 Y 777666
3. DRILLING AGENCY: SAVANNAH DISTRICT
4. HOLE NO. (As shown on drawing title and file number): SH-408
5. NAME OF DRILLER: C. ROBBINS
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 55.5'
8. DEPTH DRILLED INTO ROCK: 0.0'
9. TOTAL DEPTH OF HOLE: 55.5'
10. SIZE AND TYPE OF BIT: 1 3/8" I.D. SPLITSPOON, 5 1/2" FISHTAIL, 3" SHELBY TUBE
11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MLW
12. MANUFACTURER'S DESIGNATION OF DRILL: CME-550
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 17; UNDISTURBED 2
14. TOTAL NUMBER CORE BOXES: 0
15. ELEVATION GROUND WATER: N/A
16. DATE HOLE: STARTED 25 NOV 97; COMPLETED 26 NOV 97
17. ELEVATION TOP OF HOLE: 15.7' MLW
18. TOTAL CORE RECOVERY FOR BORING: N/A %
19. SIGNATURE OF INSPECTOR: [signature] P.G.

| ELEVATION MLW (a) | DEPTH FT. (b) | LEGEND (c) | CLASSIFICATION OF MATERIALS (Description) (d) | % CORE RECOVERY (e) | BOX OR SAMPLE NO. SPT (f) | BLOWS (g) |
|---|---|---|---|---|---|---|
| 15.7' | 0 | | | | | |
| 14.2' | | | (SM) LIGHT BROWN FINE TO MEDIUM SILTY QUARTZ SAND. 1.5' | | 1 | 1 4 6 (10) |
| 12.7' | | | WASH 3.0' | | | |
| 11.2' | | | (SP) LIGHT GRAY FINE TO MEDIUM POORLY GRADED QUARTZ SAND, TRACE OF FINE GRAVEL. 4.5' | | 2 | 3 9 9 (18) |
| 9.7' | 5 | | WASH 6.0' | | | |
| 8.2' | | | (SC) GRAY MEDIUM TO COARSE CLAYEY QUARTZ SAND, SOME FINE QUARTZ GRAVEL. 7.5' | | 3 | 4 4 4 (8) |
| 6.7' | | | WASH – SEE REMARKS 9.0' | | | |
| 5.2' | 10 | | (SM) GRAY FINE TO MEDIUM SILTY QUARTZ SAND, SOME CLAY. 10.5' | | 4 | 1 1 1 (2) |
| 3.7' | | | WASH 12.0' | | | |
| 2.2' | | | (SC) GRAY FINE TO MEDIUM CLAYEY QUARTZ SAND. 13.5' | | 5 | 1 2 3 (5) |
| 0.7' | | | WASH 15.0' | | | |
| -0.8' | 15 | | (CH) GRAY AND BROWN FAT CLAY, TRACE OF DECAYED WOOD AND FINE TO MEDIUM QUARTZ SAND. 16.5' | | 6 | 1 1 1 (2) |
| -2.3' | | | WASH 18.0' | | | |
| -3.8' | | | (SP) LIGHT GRAY FINE POORLY GRADED QUARTZ SAND. 19.5' | | 7 | 8 12 14 (26) |
| -5.3' | 20 | | WASH 21.0' | | | |
| -6.8' | | | (SP) SAME AS 18.0'-19.5' BUT FINE TO MEDIUM GRAINED 22.5' | | 8 | 14 17 18 (35) |
| -8.3' | | | WASH 24.0' | | | |
| -9.8' | 25 | | (SP) SAME AS 21.0'-22.5'. 25.5' | | 9 | 9 6 4 (10) |
| -11.3' | | | WASH 27.0 | | | |
| -12.8' | | | (SP) SAME AS 21.0'-22.5'. 28.5' | | 10 | 10 14 11 (25) |
| -14.3' | 30 | | WASH | | | |

CONTINUED ON SHEET #2

NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

**REMARKS** (Drilling time, water loss, depth of weathering, etc., if significant)

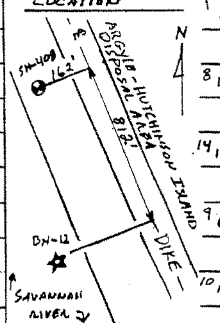
BEGAN USING DRILLING MUD AT 0.0'.

SPLITSPOON ON 3' CENTERS.

NOTE: WASH RETURN FROM 7.5' TO 9.0' CONTAINED LARGE PIECES OF WOOD, FISHTAIL HAD LARGE AMOUNT OF FAT CLAY, COBBLE AND GRAVEL.

UNDISTURBED
UD-1, 12.0'-13.8'
UD-2, 14.7'-16.5'

LOCATION




BLOWS PER 1/2 FOOT
NUMBER REQUIRED TO DRIVE 1 3/8" I.D. SPLITSPOON W/140 Lb HAMMER FALLING 30".

**DRILLING LOG (Cont Sheet)** ELEVATION TOP OF HOLE: 15.7' MLW — **Hole No.** SH-408

PROJECT: SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY — INSTALLATION: SAVANNAH, GA. — SHEET 2 OF 2 SHEETS

| ELEVATION MLW a | DEPTH FT. b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | % CORE RECOVERY e | ~~BOX OR~~ SAMPLE NO. JAR f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g | Blows | |
|---|---|---|---|---|---|---|---|---|
| 14.3' | 30 | | | | | | | |
| -15.8' | | | (SP) LIGHT GRAY FINE TO MEDIUM POORLY GRADED QUARTZ SAND. 31.5' | | 11 | | 8 17 18 | 35 |
| -17.3' | | | WASH 33.0' | | | | | |
| -18.8' | | | (SM) GRAY MEDIUM SILTY QUARTZ SAND. 34.5' | | 12 | | 7 14 16 | 30 |
| -20.3' | 35 | | WASH 36.0' | | | | | |
| -21.8' | | | (SP) LIGHT GRAY FINE TO MEDIUM POORLY GRADED QUARTZ SAND. 37.5' | | 13 | NOTE: INADVERTENTLY WASHED FROM 39.0' TO 41.0'. | 12 12 15 | 27 |
| -25.3' | 40 | | WASH (SEE REMARKS) 41.0' | | | | | |
| -26.8' | | | (SP) SAME AS 36.0'-37.5'. 42.5' | | 14 | | 10 5 10 | 15 |
| -28.3' | | | WASH 44.0' | | | | | |
| -29.8' | 45 | | (SP) SAME AS 36.0'-37.5' BUT WITH TRACE OF SILT. 45.5' | | 15 | BEGAN 5' CENTERS AT 45.5'. | 15 19 21 | 40 |
| -33.3' | | | WASH 49.0' | | | | | |
| -34.8' | 50 | | (SP) GRAY MEDIUM TO COARSE POORLY GRADED QUARTZ SAND. 50.5' | | 16 | | 13 26 26 | 52 |
| -38.3' | | | WASH 54.0' | | | | | |
| -39.8' | 55 | | (SP) GRAY COARSE POORLY GRADED QUARTZ SAND. PIECE OF WOOD FROM 55.2' TO 55.5'. | | 17 | | 14 17 13 | 26 |
| | | | BOTTOM OF BORING 55.5' | | | | | |
| | 60 | | | | | | | |

Hole No. SH-410

| DRILLING LOG | DIVISION SOUTH ATLANTIC | INSTALLATION SAVANNAH, GEORGIA | SHEET 1 OF 1 SHEETS |
|---|---|---|---|
| 1. PROJECT SAVANNAH HARBOR EXPANSION, SAVANNAH HARBOR | | 10. SIZE AND TYPE OF BIT 4" AUGER, 5¾" ROCK BIT, 5.5" FISHTAIL | |
| 2. LOCATION GA NAD83 E 989278.56 N 759851.67 | | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLW | |
| 3. DRILLING AGENCY SAVANNAH DISTRICT | | 12. MANUFACTURER'S DESIGNATION OF DRILL PETERBUILT - FAILING 1500 | |
| 4. HOLE NO. (As shown on drawing title and file number) | SH-410 | 13. TOTAL NUMBER OF OVERBURDEN SAMPLES TAKEN: DISTURBED 2 | UNDISTURBED 0 |
| 5. NAME OF DRILLER H. FULCHER | | 14. TOTAL NUMBER OF CORE BOXES 0 | |
| 6. DIRECTION OF HOLE ☒VERTICAL ☐INCLINED ____ DEGREES FROM VERTICAL | | 15. ELEVATION GROUNDWATER SEE REMARKS | |
| 7. THICKNESS OF OVERBURDEN > 7.0' | | 16. DATE HOLE: STARTED 21 AUG 2002 | COMPLETED 22 AUG 2002 |
| 8. DEPTH DRILLED INTO ROCK 0.0 | | 17. ELEVATION TOP OF HOLE 12.0' | |
| 9. TOTAL DEPTH OF HOLE 7.0' | | 18. TOTAL CORE RECOVERY FOR BORING N/A % | |
| | | 19. SIGNATURE OF INSPECTOR DANA POLACSEK | |

| ELEVATION (FEET) a | DEPTH (FEET) b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | MOISTURE CONTENT (%) e | JAR OR SAMPLE NO. f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) BLOWS/1/2 INCHES g | "N" VALUE |
|---|---|---|---|---|---|---|---|
| | 0 | | (SM) SILTY SAND, DK BROWN, FINE W/5-10% ROCK FRAGMENTS & FINE TO COARSE GRAVEL, & OCCASIONAL ASPHALT PIECES TO 1" ACROSS (FILL) WOOD AT 2.5 FEET. | | | HAND AUGERED TO 3.0 FEET | |
| | | | | | 1 | 4" O.D. AUGER, LARGE ROCK AT 3', 5¾" ROCK BIT TO ABOUT 3.5', LOST MUD | |
| | | | LT. GRAY | | | SET 10' CASING TO DEPTH OF 9 FT BELOW GROUND SURFACE | |
| | 5 | | YELLOWISH RED W/CLAYEY ZONES AND LITTLE MED SAND, OCCASIONAL SHELLS TO ¾", WOOD FRAGMENTS. | | 2 | 4/3/3 | 6 |
| | | | BORING TERMINATED AT 7 FEET DUE TO CONTINUED WATER LOSS | | | WATER LEVEL NOT ENCOUNTERED | |
| | 10 | | | | | | |
| | 15 | | | | | | |
| | 20 | | | | | | |
| | 25 | | | | | | |
| | 30 | | | | | | |

Hole No. SH-410A

| DRILLING LOG | DIVISION: SOUTH ATLANTIC | INSTALLATION: SAVANNAH, GEORGIA | SHEET 1 OF 2 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT: SAVANNAH HARBOR EXPANSION, SAVANNAH HARBOR | 10. SIZE AND TYPE OF BIT: 4" SPIRAL AUGER, 5.5" FISHTAIL |
| 2. LOCATION: GA NAD83 E 989247.95 N 759814.98 | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MLW |
| 3. DRILLING AGENCY: SAVANNAH DISTRICT | 12. MANUFACTURER'S DESIGNATION OF DRILL: PETERBUILT - FAILING 1500 |
| 4. HOLE NO. (As shown on drawing title and file number): SH-410A | 13. TOTAL NUMBER OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 17, UNDISTURBED 0 |
| 5. NAME OF DRILLER: H. FULCHER | 14. TOTAL NUMBER OF CORE BOXES: 0 |
| 6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ____ DEGREES FROM VERTICAL | 15. ELEVATION GROUNDWATER: 5.2' |
| 7. THICKNESS OF OVERBURDEN: >73.0' | 16. DATE HOLE: STARTED 22 AUG 2002, COMPLETED 28 AUG 2002 |
| 8. DEPTH DRILLED INTO ROCK: 0.0 | 17. ELEVATION TOP OF HOLE: 12.0' |
| 9. TOTAL DEPTH OF HOLE: 73.0' | 18. TOTAL CORE RECOVERY FOR BORING: N/A % |
| | 19. SIGNATURE OF INSPECTOR: DANA POLACSEK |

| ELEVATION (FEET) a | DEPTH (FEET) b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | MOISTURE CONTENT (%) e | JAR OR SAMPLE NO. f | REMARKS (Drilling time, water loss, etc.) BLOWS/18 INCHES g | "N" VALUE |
|---|---|---|---|---|---|---|---|
| 12.0 | 0 | | (SM) SILTY SAND, BROWN & GRAY, FINE, W/5-10% COARSE SAND & FINE GRAVEL, OCCAS. ROCK FRAGMENTS, ASPHALT FRAGMENTS, TRACE IRON STAINING (FILL) | | | 4" SPIRAL AUGER | |
| | | | | | 1 | 51/100-8"/STOP | 100 |
| | | | | | | WATER MEASURED AT 5.2' DEPTH @ 0920, 25 AUG 02. | |
| | 5 | | AT 4.5' - PLASTIC SHEETING<br>4.5-6.0' - DK BRN TO DK GRAY W/TRACE ROCK FRAGMENTS TO 1 CM DIAM. BRICK FRAGMENTS, OCCAS. SILTY ZONES & COARSE GRAVEL, SLIGHTLY MOIST. | | 2 | 6/5/4 | 9 |
| | | | | | | WATER LEVEL TAGGED @ 5.9' DEPTH @ 1245 ON 29 AUG 02. | |
| | | | 6.0-8.0', CLAYEY ZONES IN CUTTINGS, WET AT 7.0' | | 3 | 7/15/5 | 20 |
| | 10 | | 8.0-9.5', DK GRAY TO GRAY, FINE TO MED W/10-15% SILT AND COARSE SAND TO 8.5', TRACE SHELL FRAGMENTS, OCCAS. FINE GRAVEL AND WOOD FRAGMENTS. | | | MIX MUD, SWITCH TO FISHTAIL | |
| | | | | | 4 | 1/1/1 | 2 |
| | | | (CL) LEAN CLAY, OLIVE GRAY W/ TRACE SILT & OCCAS. ROCK FRAGS. TO ½" DIAM. | | | | |
| | 15 | | (SM) SILTY SAND, DK GRAY, FINE, W/FREQUENT FINE LAMINATED CLAY LENSES, MOIST | | 5 | 1/1/2 | 3 |
| | | | (CL) LEAN CLAY, OLIVE GRAY, SOFT | | 6 | 1/7/11<br>OILY SHEEN ON DRILLING FLUID | 18 |
| | 20 | | (SM) SILTY SAND, FINE TO MED, W/SILT, MOIST TO WET | | | | |
| | | | (CL) LEAN CLAY, OLIVE GRAY, W/ TRACE SILT, SOFT, WET | | 7 | WR/WR/1 | 1 |
| | 25 | | BECOMMING MORE STIFF W/OCCAS. PARTING OF FINE TO MED SAND | | 8 | 4/6/9 | 15 |
| | | | (SP) POORLY GRADED SAND, GRAY TO LT BRN, FINE, W/TRACE SILT | | | | |
| | 30 | | GRAY, MOSTLY FINE SAND, LAMINATED W/DK GRAY FINE SAND, W/TRACE MICA | | 9 | 6/8/10 | 19 |
| | | | 2-3MM LENSES AND LAMINATIONS OF CLAY AT 33-33.5', W/OCCAS. ROCK & SHELL FRAGS TO 1.5 CM DIAM. | | 10 | 10/15/16 | 31 |
| | 35 | | | | | | |

CONTINUED ON SHEET #2

| DRILLING LOG (Cont Sheet) | ELEVATION TOP OF HOLE 12.0' | Hole No. SH-410A |
|---|---|---|
| PROJECT SAVANNAH HARBOR EXPANSION, SAVANNAH HARBOR | INSTALLATION SAVANNAH, GEORGIA | SHEET 2 OF 2 SHEETS |

| ELEVATION (FEET) a | DEPTH (FEET) b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | MOISTURE CONTENT (%) e | JAR OR SAMPLE NO. f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) BLOWS/18 INCHES g | "N" VALUE |
|---|---|---|---|---|---|---|---|
| 2.07 | 35 | | (SP) POORLY GRADED SAND, GRAY | | | CAVING 37'-39', THICKEN MUD | |
| | | | WOOD FRAGMENTS IN DRILLING MUD | | 11 | WOOD FRAGMENTS | |
| | | | (NR) NO RECOVERY | | NR | 10/8/2 | 10 |
| | 40 | | (SC) CLAYEY SAND, OLIVE GRAY, FINE TO MED SAND, SOFT, MOIST, W/FREQ (3-4%) WOOD FRAGMENTS TO 1.5" LONG & 1" THICK. | | 12 | WR/1/4 | 5 |
| | | | | | | WOOD FRAGMENTS IN CUTTINGS | |
| | 45 | | (SM) SILTY SAND, OLIVE GRAY, FINE, W/LITTLE TO SOME CLAY, MOIST TO WET, W/FREQ ZONES OF CLAY TO CLAYEY SAND AND WOOD FRAGMENTS TO 1" THICK. | | 13 | 2/3/4 | 7 |
| | 50 | | | | 14 | 2/20/20 | 40 |
| | 55 | | (SP) POORLY GRADED SAND, GRAY TO LT GRAY, MED, W/LITTLE TO SOME SILT, CLAY DECREASING TO FREQ PARTINGS/SEAMS, MOIST, MICAEOUS. | | | | |
| | 60 | | W/TRACE TO LITTLE FINE SAND AND TRACE COARSE SAND TO FINE GRAVEL FRAGMENTS, ANGULAR | | 15 | 22/19/23 | 42 |
| | | | (CH) FAT CLAY, OLIVE GRAY, W/1" LAYER OF FINE GRAVEL FRAGMENTS | | | | |
| | 65 | | (ML) CLAYEY SILT, OLIVE GRAY, DAMP, FINELY LAMINATED, MIOCENE | | 16 | 8/12/17 | 29 |
| | 70 | | GREENISH GRAY, W/TRACE CLAY, FREQ SEAMS & LAYERS OF SILTY SAND IN UPPER 0.5', W/OCCAS FINE GRAVEL FRAGS, ALSO IN UPPER 0.5', SLIGHTLY MOIST MIOCENE | | 17 | 12/16/23 | 39 |
| | 75 | | BOTTOM OF BORING AT 73.0' | | | | |

Hole No. SH-411

| DRILLING LOG | DIVISION SOUTH ATLANTIC | INSTALLATION SAVANNAH, GEORGIA | SHEET 1 OF 2 SHEETS |
|---|---|---|---|
| 1. PROJECT SAVANNAH HARBOR EXPANSION, SAVANNAH HARBOR | | 10. SIZE AND TYPE OF BIT 4" ROTARY ROCK BIT | |
| 2. LOCATION GA NAD83 E 998735.3 N 758126.7 | | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLW | |
| 3. DRILLING AGENCY SAVANNAH DISTRICT | | 12. MANUFACTURER'S DESIGNATION OF DRILL CME 55, USING AUTOMATIC HAMMER | |
| 4. HOLE NO. (As shown on drawing title and file number) | SH-411 | 13. TOTAL NUMBER OF OVER-BURDEN SAMPLES TAKEN | DISTURBED 16 / UNDISTURBED 0 |
| 5. NAME OF DRILLER JOEY W. & NICK A. - GEC | | 14. TOTAL NUMBER OF CORE BOXES 0 | |
| 6. DIRECTION OF HOLE ☒VERTICAL ☐INCLINED ____ DEGREES FROM VERTICAL | | 15. ELEVATION GROUNDWATER APPROX. 5' | |
| | | 16. DATE HOLE | STARTED 22 OCT 2002 / COMPLETED 28 OCT 2002 |
| 7. THICKNESS OF OVERBURDEN >73.0' | | 17. ELEVATION TOP OF HOLE 12.0' | |
| 8. DEPTH DRILLED INTO ROCK 0.0 | | 18. TOTAL CORE RECOVERY FOR BORING N/A % | |
| 9. TOTAL DEPTH OF HOLE 73.0' | | 19. SIGNATURE OF INSPECTOR JOEY W. | |

| ELEVATION (FEET) a | DEPTH (FEET) b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | MOISTURE CONTENT (%) e | JAR OR SAMPLE NO. f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) BLOWS/18 INCHES g | "N" VALUE |
|---|---|---|---|---|---|---|---|
| 12.0 | 0 | | (SM) SILTY SAND, BLACK, FINE, W/ORGANICS | | | MIX & USING MUD | |
| | | | | | 1 | 2/2/2 | 4 |
| | | | | | | WATER LEVEL ESTIMATED AT 5' DEPTH DURING DRILLING | |
| | 5 | | | | 2 | 1/2/2 | 4 |
| | | | BROWN, VERY LOOSE | | | WOOD FRAGMENTS | |
| | | | (CL) LEAN CLAY, GRAY, TRACE FINE SILT WITH ORGANICS | | 3 | 1/0/1 | 1 |
| | 10 | | | | | | |
| | | | | | 4 | WEIGHT OF HAMMER | 0 |
| | 15 | | | | 5 | WEIGHT OF HAMMER | 0 |
| | | | GRAY, VERY SOFT, WET | | 6 | WEIGHT OF HAMMER | 0 |
| | 20 | | | | | | |
| | | | GRAY, W/TRACE SILT, SOFT, WET, WITH ORGANICS | | 7 | 1/1/1 | 2 |
| | 25 | | | | 8 | WEIGHT OF HAMMER | 0 |
| | 30 | | | | 9 | WEIGHT OF HAMMER | 0 |
| | | | | | 10 | WEIGHT OF HAMMER | 0 |
| | 35 | | | | | | |

CONTINUED ON SHEET #2

| DRILLING LOG (Cont Sheet) | ELEVATION TOP OF HOLE 12.0' | Hole No. SH-411 |
|---|---|---|
| PROJECT SAVANNAH HARBOR EXPANSION, SAVANNAH HARBOR | INSTALLATION SAVANNAH, GEORGIA | SHEET 2 OF 2 SHEETS |

| ELEVATION (FEET) a | DEPTH (FEET) b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | MOISTURE CONTENT (%) e | JAR OR SAMPLE NO. f | REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) BLOWS/18 INCHES g | 'N' VALUE |
|---|---|---|---|---|---|---|---|
| -22.0 | 35 | | (CL) LEAN CLAY, GRAY, TRACE FINE SILT WITH ORGANICS | | | WOOD FRAGMENTS | |
| | 40 | | (NR) NO RECOVERY | | 11 | WEIGHT OF HAMMER | 0 |
| | | | (SC) CLAYEY SAND, OLIVE GRAY, FINE TO MED SAND, SOFT, MOIST, W/FREQ (3-4%) WOOD FRAGMENTS TO 1.5" LONG & 1" THICK. | | | WOOD FRAGMENTS IN CUTTINGS | |
| | 45 | | (SM) SILTY SAND, OLIVE GRAY, FINE, W/LITTLE TO SOME CLAY, MOIST TO WET, W/FREQ ZONES OF CLAY TO CLAYEY SAND AND WOOD FRAGMENTS TO 1" THICK. | | 12 | WEIGHT OF HAMMER | 0 |
| | 50 | | | | | | |
| | | | (SP) POORLY GRADED SAND, GRAY TO LT GRAY, MED, W/LITTLE TO SOME SILT, CLAY DECREASING TO FREQ PARTINGS/SEAMS, MOIST, MICAEOUS. | | 13 | 6/9/10 | 19 |
| | 55 | | | | | | |
| | 60 | | | | 14 | 4/7/7 | 14 |
| | 65 | | | | 15 | 4/7/9 | 16 |
| | 70 | | | | 16 | 6/7/9 | 16 |
| | 75 | | BOTTOM OF BORING AT 73.0' | | | | |

Hole No. SH-412

| DRILLING LOG | DIVISION: SOUTH ATLANTIC | INSTALLATION: SAVANNAH, GEORGIA | SHEET 1 OF 2 SHEETS |
|---|---|---|---|

| | |
|---|---|
| 1. PROJECT: SAVANNAH HARBOR EXPANSION, SAVANNAH HARBOR | 10. SIZE AND TYPE OF BIT: 4" SPIRAL AUGER, 5.5" & 7.5" FISHTAIL, 9" ROCK BIT |
| 2. LOCATION: GA NAD83 E 991671.84 N 759038.80 | 11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MLW |
| 3. DRILLING AGENCY: SAVANNAH DISTRICT | 12. MANUFACTURER'S DESIGNATION OF DRILL: FAILING 1500 |
| 4. HOLE NO. (As shown on drawing title and file number): SH-412 | 13. TOTAL NUMBER OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 16; UNDISTURBED 1 |
| 5. NAME OF DRILLER: H. FULCHER | 14. TOTAL NUMBER OF CORE BOXES: 0 |
| 6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ____ DEGREES FROM VERTICAL | 15. ELEVATION GROUNDWATER: SEE REMARKS |
| 7. THICKNESS OF OVERBURDEN: >73.0 FT | 16. DATE HOLE: STARTED 29 AUG 2002; COMPLETED 06 SEP 2002 |
| 8. DEPTH DRILLED INTO ROCK: 0.0 | 17. ELEVATION TOP OF HOLE: 12.0' |
| 9. TOTAL DEPTH OF HOLE: 73.0 FT | 18. TOTAL CORE RECOVERY FOR BORING: N/A % |
| | 19. SIGNATURE OF INSPECTOR: DANA POLACSEK |

| ELEVATION (FEET) a | DEPTH (FEET) b | LEGEND c | CLASSIFICATION OF MATERIALS (Description) d | MOISTURE CONTENT (%) e | JAR OR SAMPLE NO. f | REMARKS (Drilling time, water loss, etc.) BLOWS/18 INCHES g | 'N' VALUE |
|---|---|---|---|---|---|---|---|
| 19.39 | 0 | | (SM) SILTY SAND, FINE W/5-10% MED SAND & SILT, DK BRN TO BRN, W/TRACE COARSE SAND, OCCAS. CLAYEY/SILTY NODULES, DRY TO DAMP | | | 4" SPIRAL AUGER | |
| | | | | | 1 | 4/12/17 | 29 |
| | | | | | | WATER ENCOUNTERED AT 4.55' DURING DRILLING | |
| | 5 | | SLIGHT INCREASE IN SILT & MED SAND, CLAY/SILT NODULES BECOME SEAMS OF DARK GRAY CLAY | | 2 | 2/2/2 | 4 |
| | | | (SP) POORLY GRADED SAND, OLIVE GRAY W/TRACE SILT, TRACE COARSE SAND & ROCK FRAGS OF COARSE SAND SIZE TO OCCAS. FINE GRAVEL SIZE, WET | | 3 | 1/1/1 | 2 |
| 9.39 | 10 | | | | | MIX MUD - SWITCHED TO 5.5" FISHTAIL | |
| | | | (CH) FAT CLAY, OLIVE GRAY W/ TRACE SILT, OCCAS. PARTING OF SILTY FINE SAND, VERY SOFT, WET | | 4 | UD-1 UNDISTURBED 1/1/1 | 2 |
| | 15 | | W/FINE SAND, FINELY LAMINATED IN LAYERS, W/WOOD FRAGMENTS IN SHOE & CORE BARREL LIKE A CORE ADJACENT TO CLAY | | 5 | 1/2/2 | 4 |
| | | | NO RECOVERY - WOOD IN SHOE | | 6 | WOOD IN SHOE 2/15/3 | 18 |
| | 20 | | | | | | |
| | | | (SP) POORLY GRADED SAND, OLIVE GRAY, FINE TO MED, W/TRACE OF SILT, WET, MICAEOUS | | 7 | SWITCH TO 7.5" FISHTAIL 4/5/4 | 9 |
| | 25 | | | | | USING 9" ROCK BIT | |
| | | | DK GRAY, W/OCCAS. ZONES W/TRACE CLAY, WOOD FRAGMENTS & TRACE MICA | | 8 | 2/3/7 | 10 |
| | | | | | | USING 7.5" FISHTAIL | |
| | 30 | | | | 9 | 4/6/12 PUMP/RODS CLOGGED WITH SAND & WOOD, CLEAN OUT PUMP, MIX NEW MUD | 18 |
| | | | TRACE COARSE SAND, FINE GRAVEL, OCCAS, ROCK FRAGMENTS, ROUNDED, UP TO 1 CM DIAMETER | | 10 | 3/17/26 | 43 |
| | 35 | | | | | | |

CONTINUED ON SHEET #2

| DRILLING LOG (Cont Sheet) | ELEVATION TOP OF HOLE 12.0' | Hole No. SH-412 |
|---|---|---|
| PROJECT SAVANNAH HARBOR EXPANSION, SAVANNAH HARBOR | INSTALLATION SAVANNAH, GEORGIA | SHEET 2 OF 2 SHEETS |

| ELEVATION (FEET) a | DEPTH (FEET) b | LEGEND c | CLASSIFICATION OF MATERIALS d | MOISTURE CONTENT (%) e | JAR OR SAMPLE NO. f | REMARKS BLOWS/18 INCHES g | "N" VALUE |
|---|---|---|---|---|---|---|---|
| | 35 | | (SP) POORLY GRADED SAND, OLIVE GRAY, FINE TO MED, W/TRACE OF SILT, WET, MICAEOUS | | | | |
| | 40 | | FINELY LAMINATED W/CLAYEY ZONES, FINE GRAVEL, ROCK FRAGMENTS, WOOD, DECREASING | | 11 | 9/17/19 | 36 |
| | 45 | | LAMINATIONS ABSENT, W/FEW SEAMS OF DARK GRAY TO BLACK SILT | | 12 | 7/14/13 | 27 |
| | 50 | | GRAY TO LT GRAY W/DARK GRAY CLAY LAYER ABOUT 0.4 FT THICK FROM 52.0 TO 52.4 FT | | 13 | 10/15/15 | 30 |
| | 55 | | | | | | |
| | 60 | | BROWN & GRAY, MOSTLY COARSE SAND, TRACE FINE TO MED SAND & FINE GRAVEL, W/LAYER OF FINE LAMINATED GRAY FINE TO MED SAND ABOUT 59.0 TO 59.5 AND TRACE SILT, WOOD ABSENT | | 14 | 12/23/28 | 51 |
| | | | 63' TO 64' DRILLER REPORTS SOFT SOIL BASED ON DRILLING RESPONSE | | | | |
| | 65 | | (ML) LEAN SILT, GREENISH GRAY, W/TRACE FINE SAND, VERY STIFF, DRY TO SLIGHTLY MOIST, MIOCENE | | 15 | 15/25/40 | 65 |
| | 70 | | W/LITTLE FINE SAND, BECOMING OLIVE GRAY TO DK GRAY W/TRACE TO NO FINE SAND FROM 72.5 TO 73', VERY FINELY LAMINATED | | 16 | 6/14/18 | 32 |
| | | | BOTTOM OF BORING AT 73.0' | | | | |
| | 75 | | | | | | |

# APPENDIX B

# LABORATORY DATA

**(Click for Test Results)**

# LABORATORY DATA

**Liquid and Plastic Limits**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SH 410A | Sample 4 | Depth | 11.5 | to | 13.0 | CH | |
| SH 410A | Sample 4 | Depth | 11.5 | to | 13.0 | CH | Lab Work Sheet |
| SH 410A | Sample 6 | Depth | 18.5 | to | 20.0 | SC | |
| SH 410A | Sample 16 | Depth | 65.0 | to | 66.5 | GM | |
| SH 411 | Sample 2 | Depth | 4.5 | to | 6.0 | SM | |
| SH 411 | Sample 5 | Depth | 15.0 | to | 16.5 | CH | |
| SH 411 | Sample 8 | Depth | 25.5 | to | 27.0 | MH | |
| SH 411 | Sample 12 | Depth | 45.5 | to | 47.0 | CH | |
| SH 412 | Sample 5 | Depth | 15.0 | to | 16.5 | CH | |

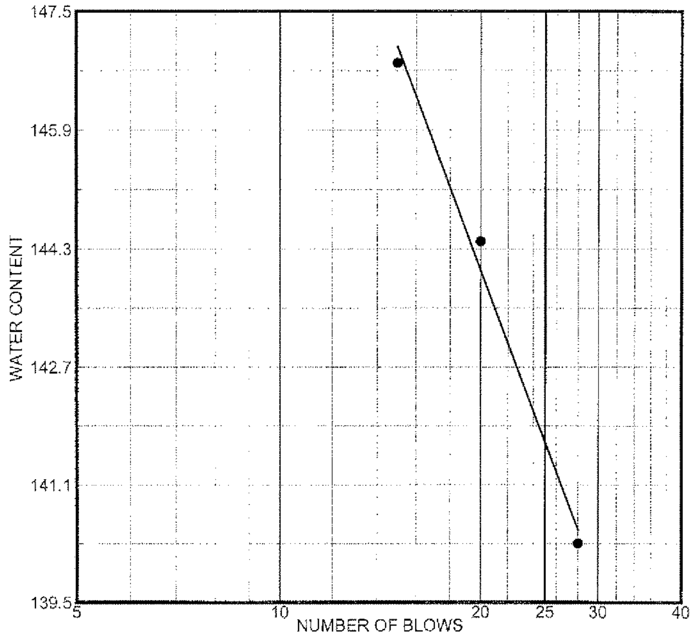
**Grain Size Distribution**

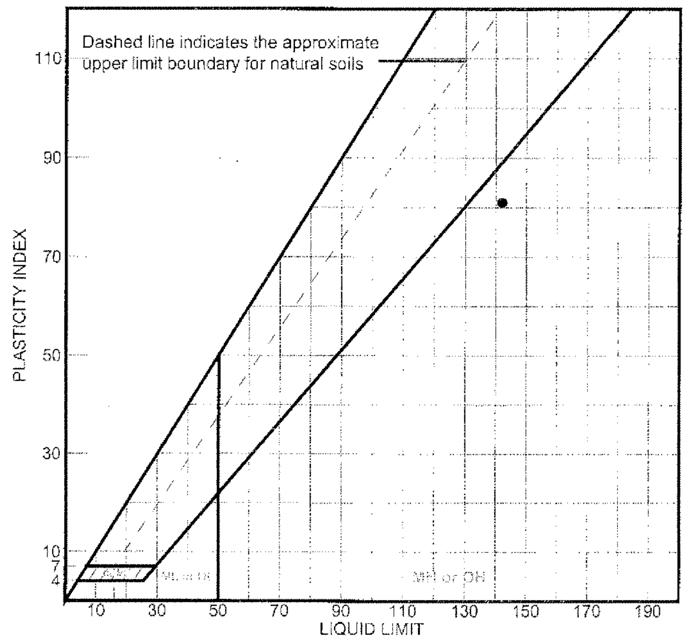
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SH 410 | Sample 2 | Depth | 4.5 | to | 6.0 | SC | |
| SH 410 | Sample 2 | Depth | 4.5 | to | 6.0 | SC | Lab Work Sheet |
| SH 410A | Sample 3 | Depth | 8.0 | to | 9.5 | SM | |
| SH 410A | Sample 3 | Depth | 8.0 | to | 9.5 | SM | Lab Work Sheet |
| SH 410A | Sample 4 | Depth | 11.5 | to | 13.0 | CH | |
| SH 410A | Sample 4 | Depth | 11.5 | to | 13.0 | CH | Lab Work Sheet |
| SH 410A | Sample 6 | Depth | 18.0 | to | 20.0 | SC | |
| SH 410A | Sample 6 | Depth | 18.0 | to | 20.0 | SC | Lab Work Sheet |
| SH 410A | Sample 6 | Depth | 18.0 | to | 20.0 | SC | |
| SH 410A | Sample 6 | Depth | 18.0 | to | 20.0 | SC | Lab Work Sheet |
| SH 411 | Sample 2 | Depth | 4.5 | to | 6.0 | SM | |
| SH 411 | Sample 2 | Depth | 4.5 | to | 6.0 | SM | Lab Work Sheet |
| SH 411 | Sample 5 | Depth | 15.0 | to | 16.5 | CH | |
| SH 411 | Sample 8 | Depth | 25.5 | to | 27.0 | MH | |
| SH 411 | Sample 12 | Depth | 45.5 | to | 47.0 | CH | |
| SH 411 | Sample 14 | Depth | 58.5 | to | 60.0 | SM | |
| SH 412 | Sample 5 | Depth | 15.0 | to | 16.5 | CH | |

**Triaxial Shear Test**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SH 412 | Sample UD1 | Depth | 11.5 | to | 13.3 | CH | R w/pore pressures |
| SH 412 | Sample Jar | Depth | 11.5 | to | 11.7 | SM | |
| SH 412 | Sample UD1 | Depth | 11.5 | to | 13.3 | CH | Sieve Analysis |
| SH 412 | Sample UD1 | Depth | 11.5 | to | 13.3 | CH | Atterberg Limits |

**Moisture Contents Summary** **Table 410, 411 & 412**



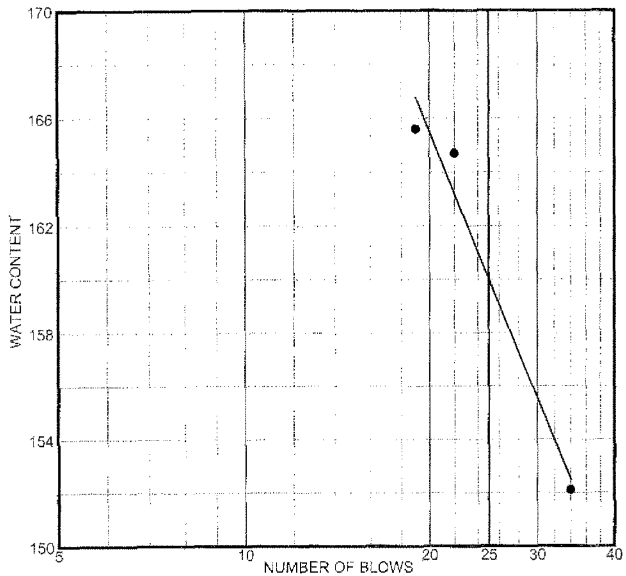



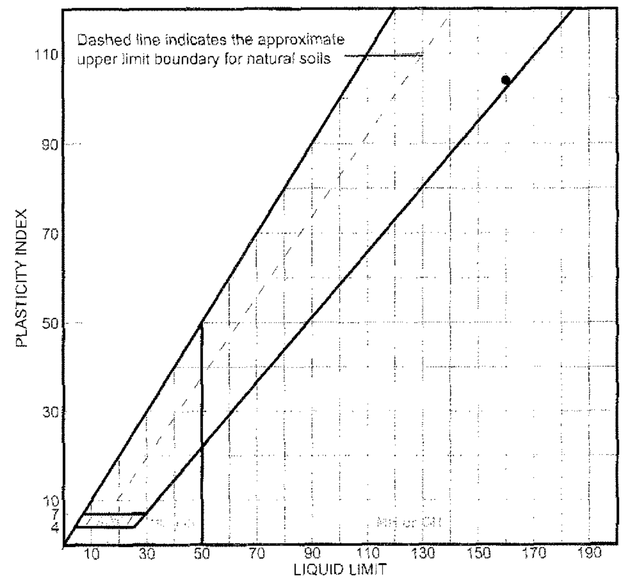

| | SOURCE | SAMPLE # | DEPTH/ELEV. | DATE SAMPLED | USCS | MATERIAL DESCRIPTION | NM % | LL | PI |
|---|---|---|---|---|---|---|---|---|---|
| ● | Boring No. SH-410A | 16 | 65.0'- 66.5' | | GM | Olive-Brown Very Silty Fine SAND w/ rock fragments | 34.7 | 142 | 81 |

Client US Army Corps of Engineers
Project Savannah Harbor Expansion
Project No. 1452-01-40

**WOLF TECHNOLOGIES, INC.**

# LIQUID AND PLASTIC LIMITS TEST REPORT




| | SOURCE | SAMPLE # | DEPTH/ELEV. | DATE SAMPLED | USCS | MATERIAL DESCRIPTION | NM % | LL | PI |
|---|---|---|---|---|---|---|---|---|---|
| ● | Boring No. SH-410A | 4 | 11.5'- 13.0' | | CH | Brown Sandy CLAY w/ some rock fragments | 107.3 | 160 | 104 |

Client US Army Corps of Engineers

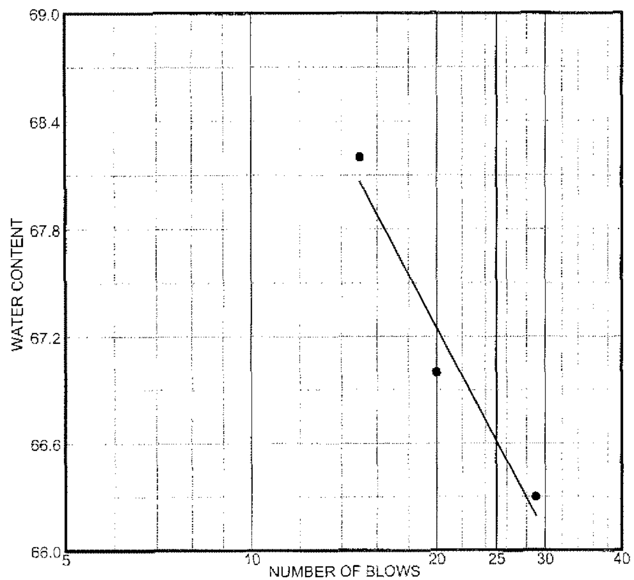
Project Savannah Harbor Expansion

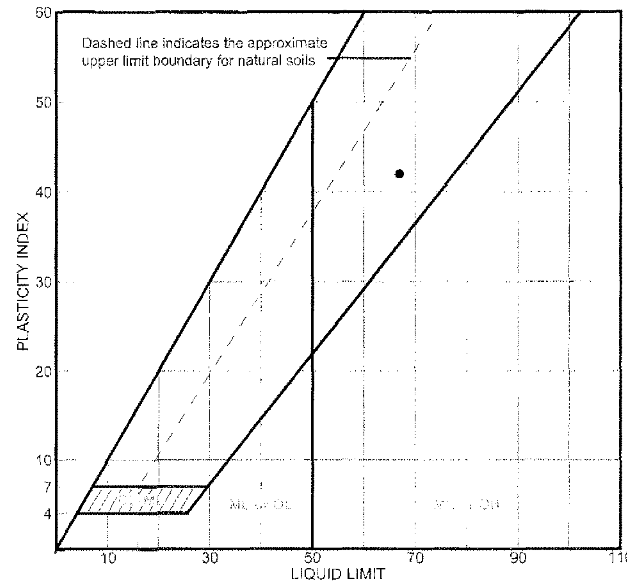
Project No. 1452-01-40

**WOLF TECHNOLOGIES, INC.**

●

# LIQUID AND PLASTIC LIMITS TEST REPORT




| | SOURCE | SAMPLE # | DEPTH/ELEV. | DATE SAMPLED | USCS | MATERIAL DESCRIPTION | NM % | LL | PI |
|---|---|---|---|---|---|---|---|---|---|
| ● | Boring No. SH-410A | 6 | 18.5'- 20.0' | | SC | Brown Clayey Fine SAND w/ some rock fragments and organics | 52.5 | 67 | 42 |

Client US Army Corps of Engineers
Project Savannah Harbor Expansion
Project No. 1452-01-40

**WOLF TECHNOLOGIES, INC.**

●

## LIQUID AND PLASTIC LIMIT TEST DATA

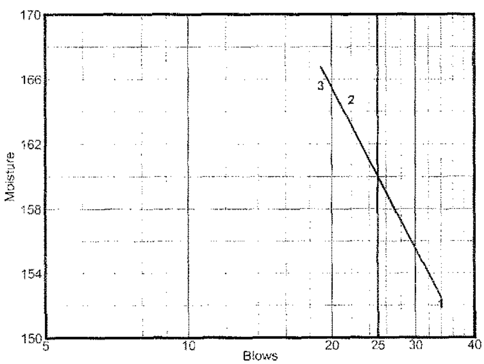
**Client:** US Army Corps of Engineers
**Project:** Savannah Harbor Expansion
**Project Number:** 1452-01-40

### Sample Data

**Source:** Boring No. SH-410A
**Sample No.:** 4
**Elev. or Depth:** 11.5'- 13.0' **Sample Length (in./cm.):**
**Location:**
**Description:** Brown Sandy CLAY w/ some rock fragments
**Date:** **Natural Moisture:** 107.3
**USCS Class.:** CH **AASHTO Class.:** A-7-5(101)
**Testing Remarks:**

### Liquid Limit Data

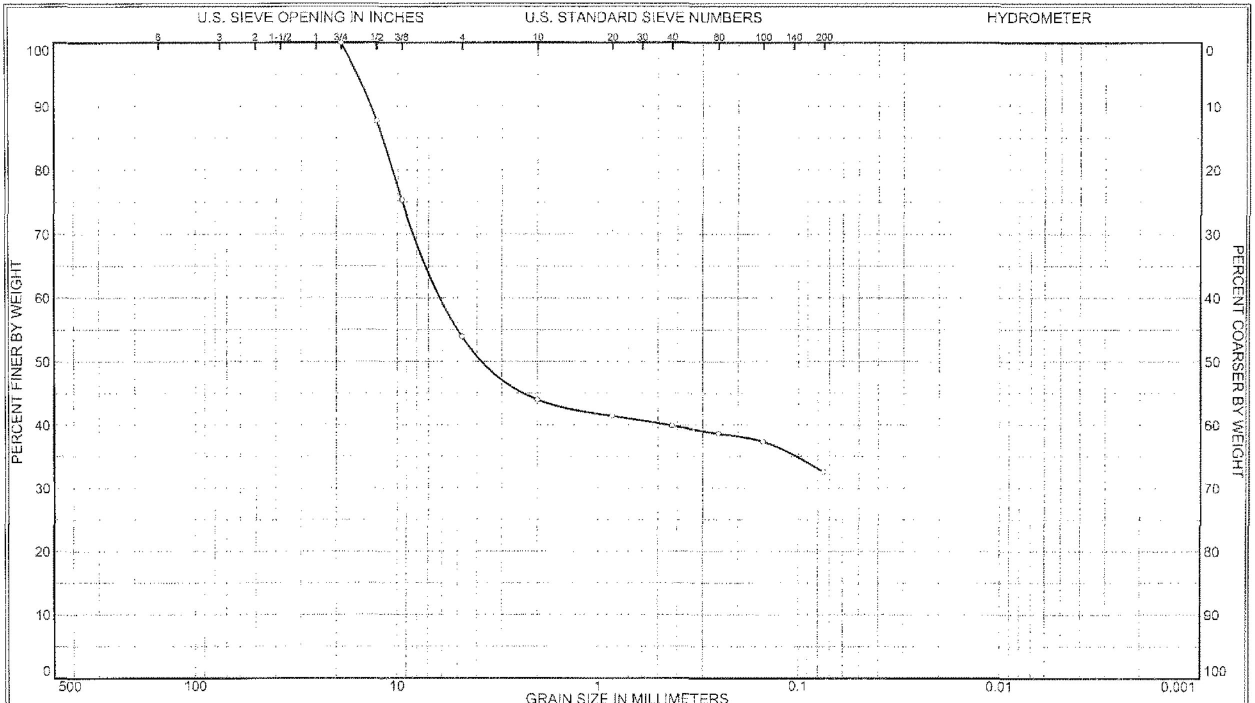
| Run No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Wet+Tare | 35.26 | 35.56 | 34.95 | | | |
| Dry+Tare | 32.31 | 32.48 | 32.40 | | | |
| Tare | 30.37 | 30.61 | 30.86 | | | |
| # Blows | 34 | 22 | 19 | | | |
| Moisture | 152.1 | 164.7 | 165.6 | | | |




**Liquid Limit=** 160
**Plastic Limit=** 56
**Plasticity Index=** 104

### Plastic Limit Data

| Run No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Wet+Tare | 9.65 | | | |
| Dry+Tare | 7.48 | | | |
| Tare | 3.61 | | | |
| Moisture | 56.1 | | | |




| COBBLES | GRAVEL | SAND | SILT | CLAY |
|---|---|---|---|---|

| Sample No. | Elev or Depth | Classification | Nat w% | LL | PL | PI |
|---|---|---|---|---|---|---|
| 16 | 65.0'- 66.5' | Olive-Brown Very Silty Fine SAND w/ rock fragments | 34.7 | 142 | 61 | 81 |

**Project** Savannah Harbor Expansion

**Area**

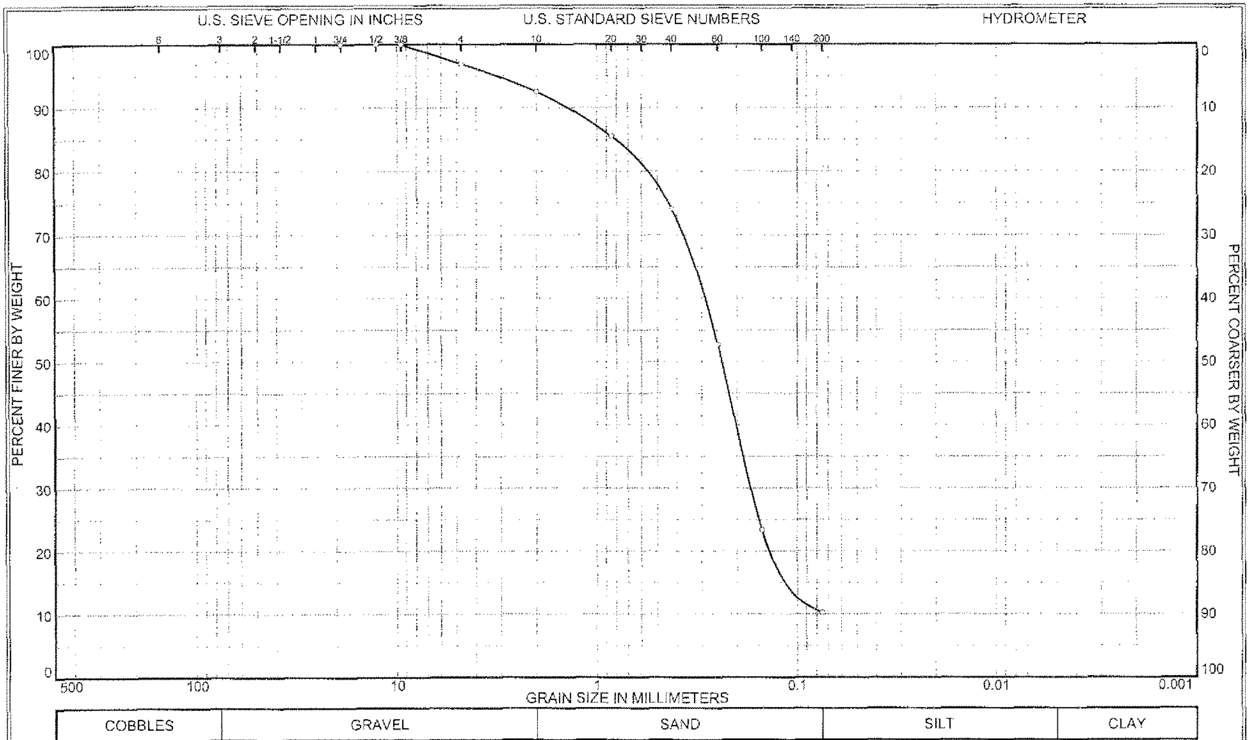
**Boring No.** Boring No. SH-410A

**Date:** 1/17/2003

**WOLF TECHNOLOGIES, INC.**

Grain Size Distribution Report

ENG FORM 1 MAY 63 2087




| Sample No. | Elev or Depth | Classification | Nat w% | LL | PL | PI |
|---|---|---|---|---|---|---|
| 3 | 8.0'- 9.5' | Gray Slightly Silty Fine SAND w/ rock fragments | 23.8 | | NP | NP |

**Project** Savannah Harbor Expansion

**Area**

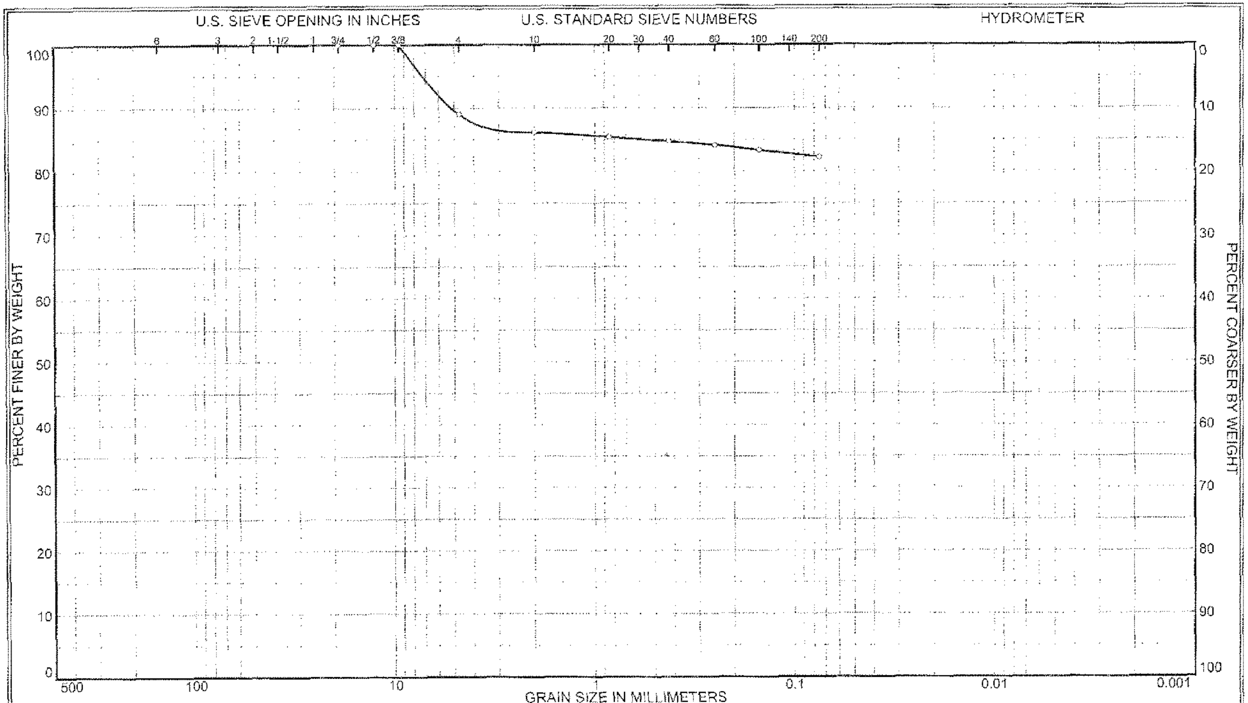
**Boring No.** Boring No. SH-410A

**Date:** 1/17/2003

**WOLF TECHNOLOGIES, INC.**

Grain Size Distribution Report

**ENG** FORM 1 MAY 63 **2087**




| COBBLES | GRAVEL | SAND | SILT | CLAY |
|---|---|---|---|---|

| Sample No. | Elev or Depth | Classification | Nat w% | LL | PL | PI |
|---|---|---|---|---|---|---|
| 4 | 11.5'- 13.0' | Brown Sandy CLAY w/ some rock fragments | 107.3 | 160 | 56 | 104 |

Project Savannah Harbor Expansion

Area

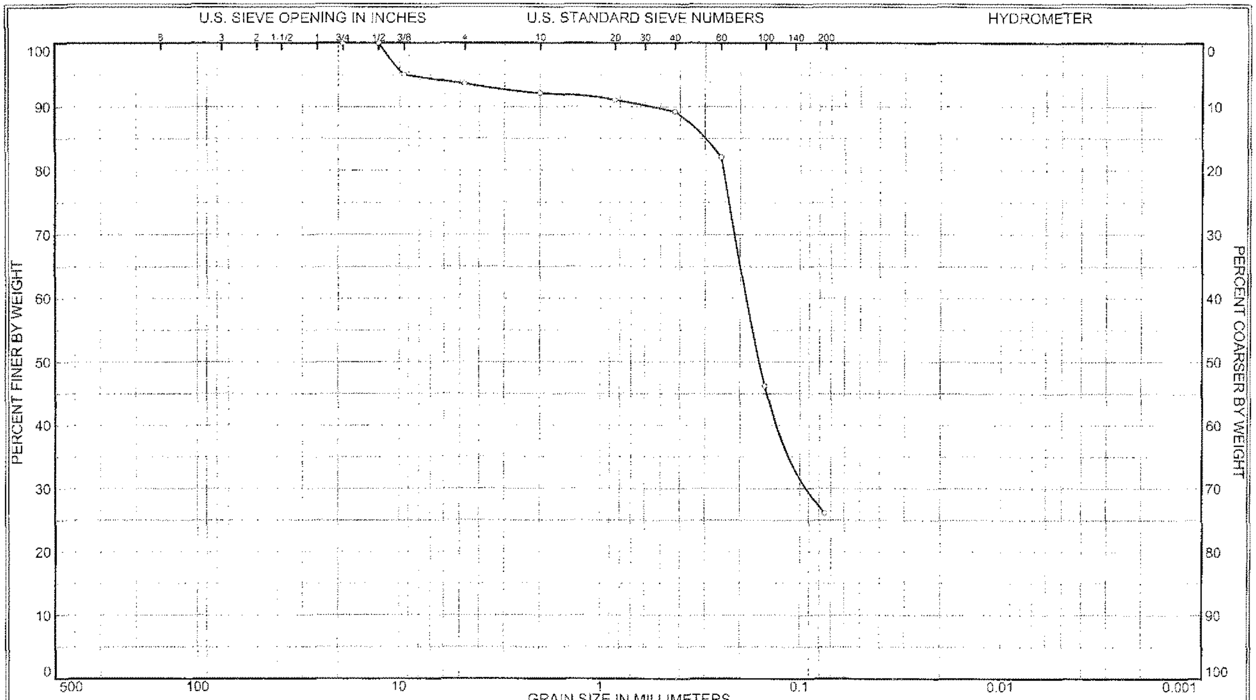
Boring No. Boring No. SH-410A

Date: 1/17/2003

**WOLF TECHNOLOGIES, INC.**

Grain Size Distribution Report

ENG FORM 1 MAY 63 2087




| COBBLES | GRAVEL | SAND | SILT | CLAY |
|---|---|---|---|---|

| Sample No. | Elev or Depth | Classification | Nat w% | LL | PL | PI |
|---|---|---|---|---|---|---|
| 6 | 18.5'- 20.0' | Brown Clayey Fine SAND w/ some rock fragments and organics | 52.5 | 67 | 25 | 42 |

**Project** Savannah Harbor Expansion

**Area**

**Boring No.** Boring No. SH-410A

**Date:** 1/17/2003

**WOLF TECHNOLOGIES, INC.**

Grain Size Distribution Report

**ENG** FORM 1 MAY 63 **2087**

## GRAIN SIZE DISTRIBUTION TEST DATA

**Project:** Savannah Harbor Expansion

### Sample Data

**Source:** Boring No. SH-410A
**Sample No.:** 16
**Elev. or Depth:** 65.0'- 66.5' **Sample Length (in./cm.):**
**Location:**
**Description:** Olive-Brown Very Silty Fine SAND w/ rock fragments
**PL:** 61 **LL:** 142
**PI:** 81 **Nat W.%:** 34.7

### Mechanical Analysis Data

| | Initial | After wash |
|---|---|---|
| **Dry sample and tare=** | 109.77 | 90.48 |
| **Tare =** | 50.06 | 50.06 |
| **Dry sample weight =** | 59.71 | 40.42 |
| **Minus #200 from wash=** | 32.3 % | |

**Tare for cumulative weight retained=** .00

| Sieve | Cumul. Wt. retained | Percent finer |
|---|---|---|
| .75 inch | 0.00 | 100.0 |
| .50 inch | 7.32 | 87.7 |
| .375 inch | 14.75 | 75.3 |
| # 4 | 27.53 | 53.9 |
| # 10 | 33.46 | 44.0 |
| # 20 | 35.01 | 41.4 |
| # 40 | 35.91 | 39.9 |
| # 60 | 36.64 | 38.6 |
| # 100 | 37.45 | 37.3 |
| # 200 | 40.32 | 32.5 |

### Fractional Components

**Gravel/Sand based on** #10
**Sand/Fines based on** #200
% **COBBLES** = % **GRAVEL** = 56.0 % **SAND** = 11.5
% **FINES** = 32.5

$D_{85}$= 11.88 $D_{60}$= 6.14 $D_{50}$= 3.80

## GRAIN SIZE DISTRIBUTION TEST DATA

**Project:** Savannah Harbor Expansion

### Sample Data

**Source:** Boring No. SH-410A
**Sample No.:** 3
**Elev. or Depth:** 8.0'- 9.5' **Sample Length (in./cm.):**
**Location:**
**Description:** Gray Slightly Silty Fine SAND w/ rock fragments
**PL:** NP **LL:**
**PI:** NP **Nat W.%:** 23.8

### Mechanical Analysis Data

| | Initial | After wash |
|---|---|---|
| Dry sample and tare= | 142.84 | 134.01 |
| Tare = | 49.94 | 49.94 |
| Dry sample weight = | 92.90 | 84.07 |

**Minus #200 from wash=** 9.5 %
**Tare for cumulative weight retained=** .00

| Sieve | Cumul. Wt. retained | Percent finer |
|---|---|---|
| .75 inch | 0.00 | 100.0 |
| .50 inch | 0.00 | 100.0 |
| .375 inch | 0.00 | 100.0 |
| # 4 | 2.90 | 96.9 |
| # 10 | 6.98 | 92.5 |
| # 20 | 13.50 | 85.5 |
| # 40 | 24.11 | 74.1 |
| # 60 | 43.92 | 52.7 |
| # 100 | 71.23 | 23.3 |
| # 200 | 83.40 | 10.2 |

### Fractional Components

**Gravel/Sand based on** #10
**Sand/Fines based on** #200
% **COBBLES** = % **GRAVEL** = 7.5 % **SAND** = 82.3
% **FINES** = 10.2

$D_{85}$= 0.81 $D_{60}$= 0.29 $D_{50}$= 0.24
$D_{30}$= 0.17 $D_{15}$= 0.12

## GRAIN SIZE DISTRIBUTION TEST DATA

**Project:** Savannah Harbor Expansion

### Sample Data

**Source:** Boring No. SH-410A
**Sample No.:** 4
**Elev. or Depth:** 11.5'- 13.0' **Sample Length (in./cm.):**
**Location:**
**Description:** Brown Sandy CLAY w/ some rock fragments
**PL:** 56 **LL:** 160
**PI:** 104 **Nat W.%:** 107.3

### Mechanical Analysis Data

| | Initial | After wash |
|---|---|---|
| Dry sample and tare= | 90.23 | 57.49 |
| Tare = | 50.52 | 50.52 |
| Dry sample weight = | 39.71 | 6.97 |
| Minus #200 from wash= | 82.4 % | |

**Tare for cumulative weight retained=** .00

| Sieve | Cumul. Wt. retained | Percent finer |
|---|---|---|
| .75 inch | 0.00 | 100.0 |
| .50 inch | 0.00 | 100.0 |
| .375 inch | 0.00 | 100.0 |
| # 4 | 4.36 | 89.0 |
| # 10 | 5.53 | 86.1 |
| # 20 | 5.80 | 85.4 |
| # 40 | 6.07 | 84.7 |
| # 60 | 6.31 | 84.1 |
| # 100 | 6.63 | 83.3 |
| # 200 | 7.06 | 82.2 |

### Fractional Components

**Gravel/Sand based on** #10
**Sand/Fines based on** #200
% **COBBLES** = % **GRAVEL** = 13.9 % **SAND** = 3.9
% **FINES** = 82.2

$D_{85}$= 0.57

**Wolf Technologies, Inc.**

## GRAIN SIZE DISTRIBUTION TEST DATA

**Project:** Savannah Harbor Expansion

### Sample Data

**Source:** Boring No. SH-410A
**Sample No.:** 6
**Elev. or Depth:** 18.5'- 20.0' **Sample Length (in./cm.):**
**Location:**
**Description:** Brown Clayey Fine SAND w/ some rock fragments and organics
**PL:** 25 **LL:** 67
**PI:** 42 **Nat W.%:** 52.5

### Mechanical Analysis Data

| | Initial | After wash |
|---|---|---|
| Dry sample and tare= | 106.85 | 92.51 |
| Tare = | 50.76 | 50.76 |
| Dry sample weight = | 56.09 | 41.75 |
| Minus #200 from wash= | 25.6 % | |

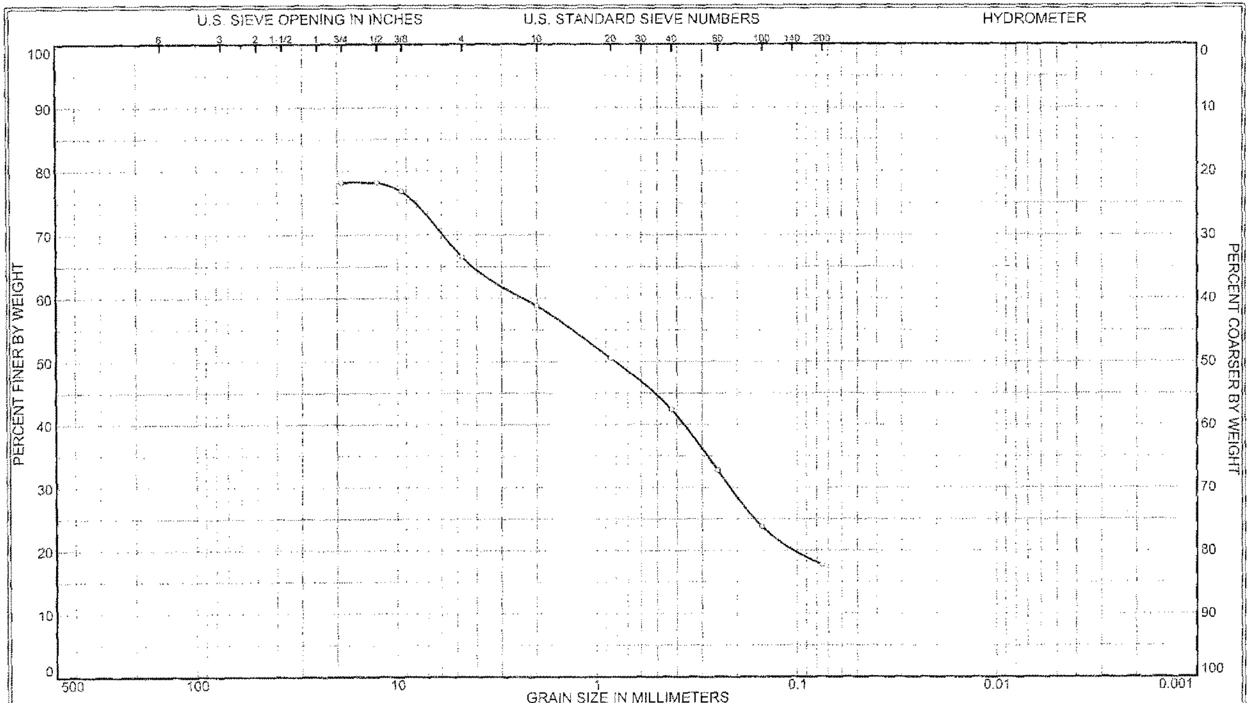
**Tare for cumulative weight retained=** .00

| Sieve | Cumul. Wt. retained | Percent finer |
|---|---|---|
| .75 inch | 0.00 | 100.0 |
| .50 inch | 0.00 | 100.0 |
| .375 inch | 2.83 | 95.0 |
| # 4 | 3.62 | 93.6 |
| # 10 | 4.46 | 92.1 |
| # 20 | 5.06 | 91.0 |
| # 40 | 6.04 | 89.2 |
| # 60 | 10.04 | 82.1 |
| # 100 | 30.16 | 46.2 |
| # 200 | 41.46 | 26.1 |

### Fractional Components

**Gravel/Sand based on** #10
**Sand/Fines based on** #200
% **COBBLES** = % **GRAVEL** = 7.9 % **SAND** = 66.0
% **FINES** = 26.1

$D_{85}$= 0.30 $D_{60}$= 0.19 $D_{50}$= 0.16
$D_{30}$= 0.09




| | Sample No. | Elev or Depth | Classification | Nat w% | LL | PL | PI |
|---|---|---|---|---|---|---|---|
| ○ | 2 | 4.5'- 6.0' | Brown Slightly Clayey Fine SAND w/ some rock fragments and organics (SC) | 30.6 | | | |

Project Savannah Harbor Expansion

Area

Boring No. Boring No. SH-410

Date: 1/17/2003

**WOLF TECHNOLOGIES, INC.**

Grain Size Distribution Report

ENG FORM 1 MAY 63 2087

## GRAIN SIZE DISTRIBUTION TEST DATA

**Project:** Savannah Harbor Expansion

### Sample Data

**Source:** Boring No. SH-410
**Sample No.:** 2
**Elev. or Depth:** 4.5'- 6.0' **Sample Length (in./cm.):**
**Location:**
**Description:** Brown Slightly Clayey Fine SAND w/ some rock fragments and organics (SC)
**PL:** **LL:**
**PI:** **Nat W.%:**

### Mechanical Analysis Data

| | Initial | After wash |
|---|---|---|
| **Dry sample and tare=** | 132.96 | 118.88 |
| **Tare =** | 50.54 | 50.54 |
| **Dry sample weight =** | 82.42 | 68.34 |
| **Minus #200 from wash=** | 17.1 % | |

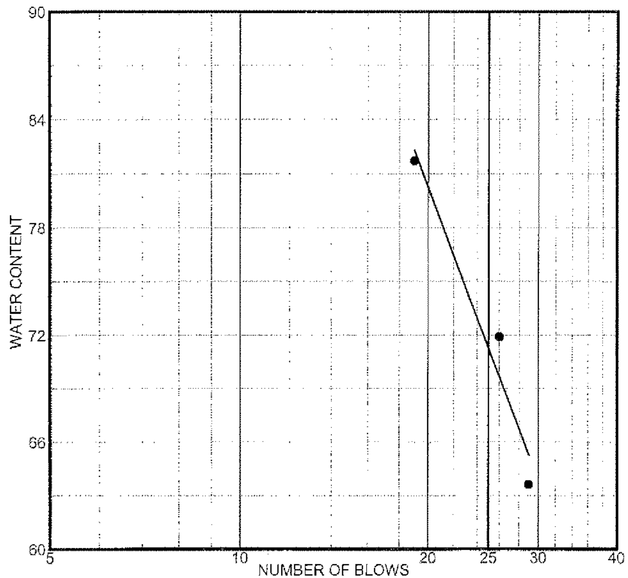
**Tare for cumulative weight retained=** .00

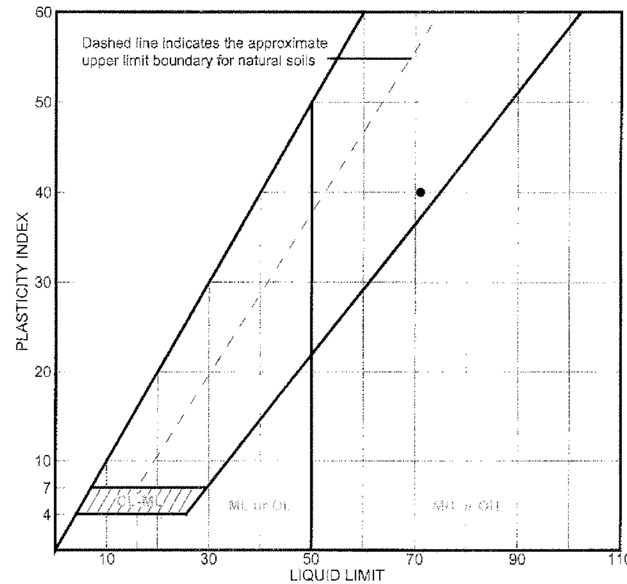
| Sieve | Cumul. Wt. retained | Percent finer |
|---|---|---|
| .75 inch | 17.97 | 78.2 |
| .50 inch | 17.97 | 78.2 |
| .375 inch | 19.15 | 76.8 |
| # 4 | 27.54 | 66.6 |
| # 10 | 33.95 | 58.8 |
| # 20 | 40.80 | 50.5 |
| # 40 | 47.50 | 42.4 |
| # 60 | 55.50 | 32.7 |
| # 100 | 62.83 | 23.8 |
| # 200 | 67.83 | 17.7 |

### Fractional Components

**Gravel/Sand based on** #10
**Sand/Fines based on** #200
% **COBBLES =** % **GRAVEL =** % **SAND =** 41.1
% **FINES =** 17.7

# LIQUID AND PLASTIC LIMITS TEST REPORT




| | SOURCE | SAMPLE # | DEPTH/ELEV. | DATE SAMPLED | USCS | MATERIAL DESCRIPTION | NM % | LL | PI |
|---|---|---|---|---|---|---|---|---|---|
| ● | Boring No. SH-411 | 12 | 45.5'- 47.0' | | CH | Yellow-Brown CLAY | 50.5 | 71 | 40 |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

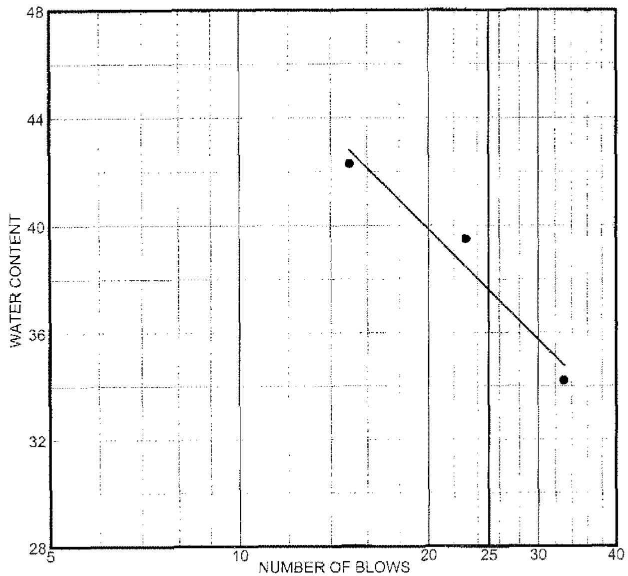
Client US Army Corps of Engineers
Project Savannah Harbor Expansion

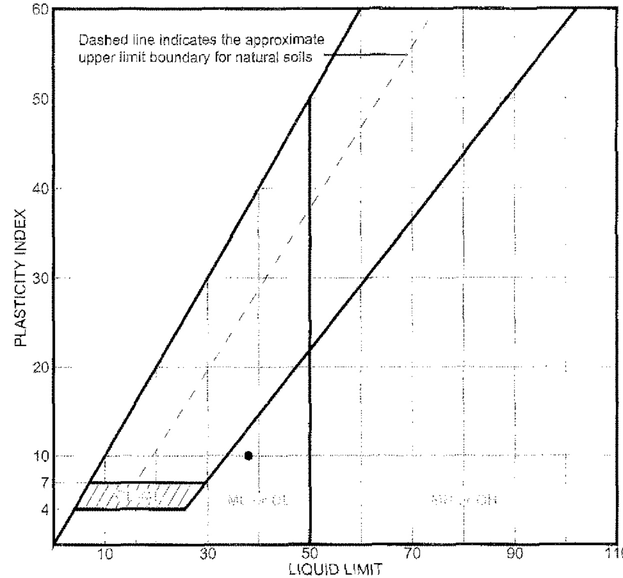
Project No. 1452-01-40

**WOLF TECHNOLOGIES, INC.**

●

# LIQUID AND PLASTIC LIMITS TEST REPORT




| | SOURCE | SAMPLE # | DEPTH/ELEV. | DATE SAMPLED | USCS | MATERIAL DESCRIPTION | NM % | LL | PI |
|---|---|---|---|---|---|---|---|---|---|
| ● | Boring No. SH-411 | 2 | 4.5'- 6.0' | | SM | Dark Gray-Brown Silty Fine SAND w/ some rock fragments and wood | 89.2 | 38 | 10 |

Client US Army Corps of Engineers

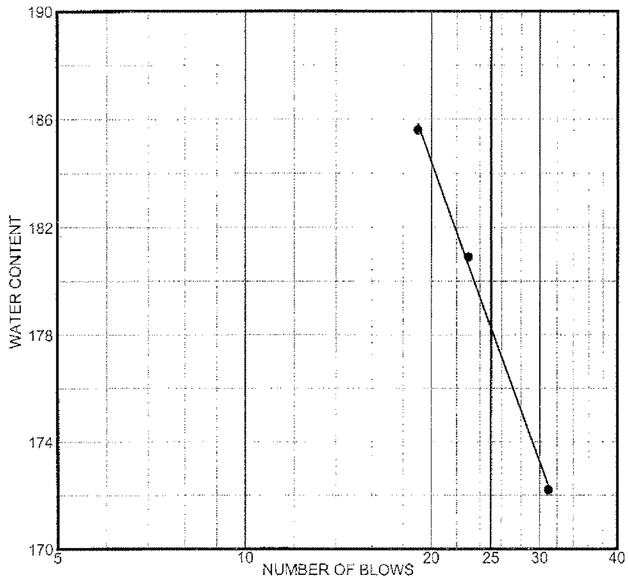
Project Savannah Harbor Expansion

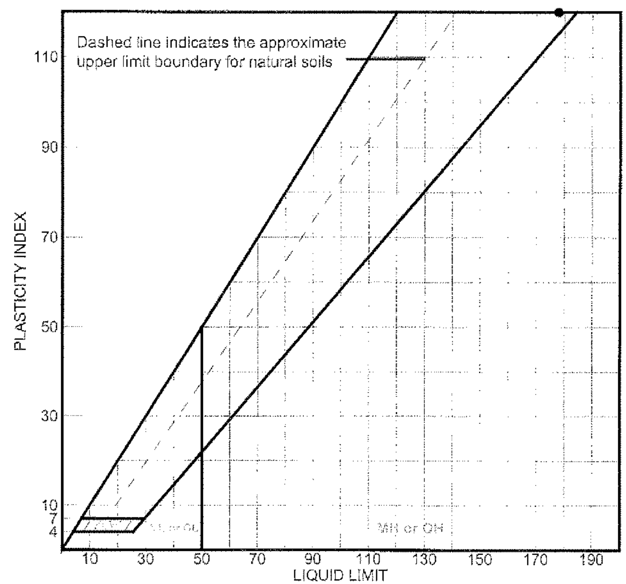
Project No. 1452-01-40

**WOLF TECHNOLOGIES, INC.**

●

# LIQUID AND PLASTIC LIMITS TEST REPORT




| | SOURCE | SAMPLE # | DEPTH/ELEV. | DATE SAMPLED | USCS | MATERIAL DESCRIPTION | NM % | LL | PI |
|---|---|---|---|---|---|---|---|---|---|
| ● | Boring No. SH-411 | 5 | 15.0'- 16.5' | | CH | Yellow-Brown CLAY w/ a trace of fine sand | 133.2 | 178 | 120 |

Client US Army Corps of Engineers

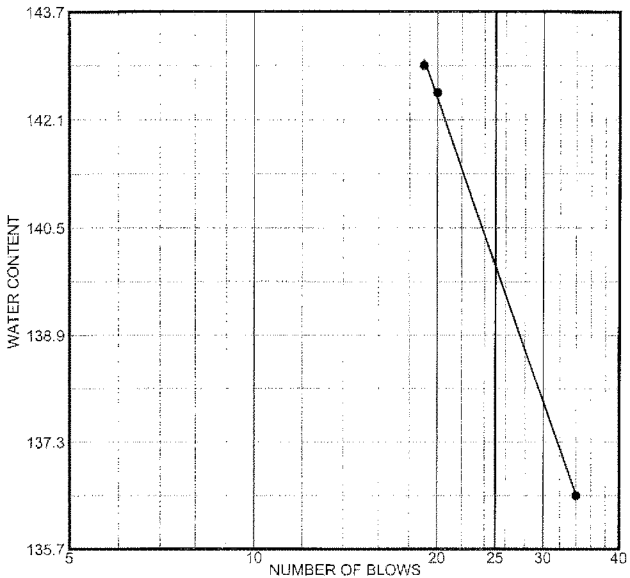
Project Savannah Harbor Expansion

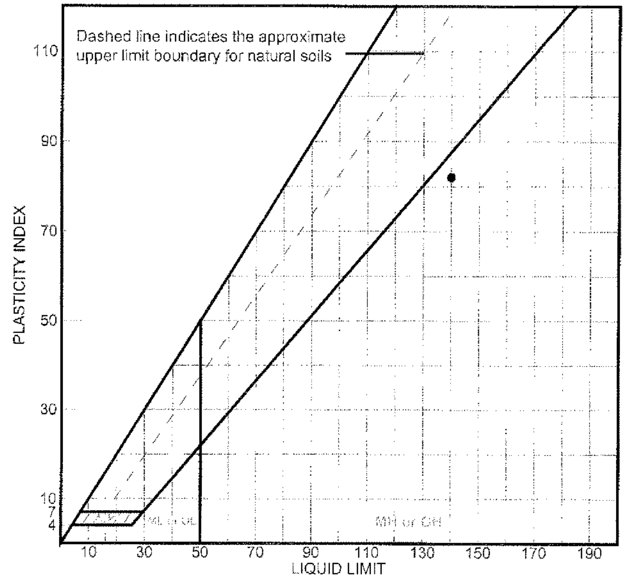
Project No. 1452-01-40

**WOLF TECHNOLOGIES, INC.**

●

# LIQUID AND PLASTIC LIMITS TEST REPORT



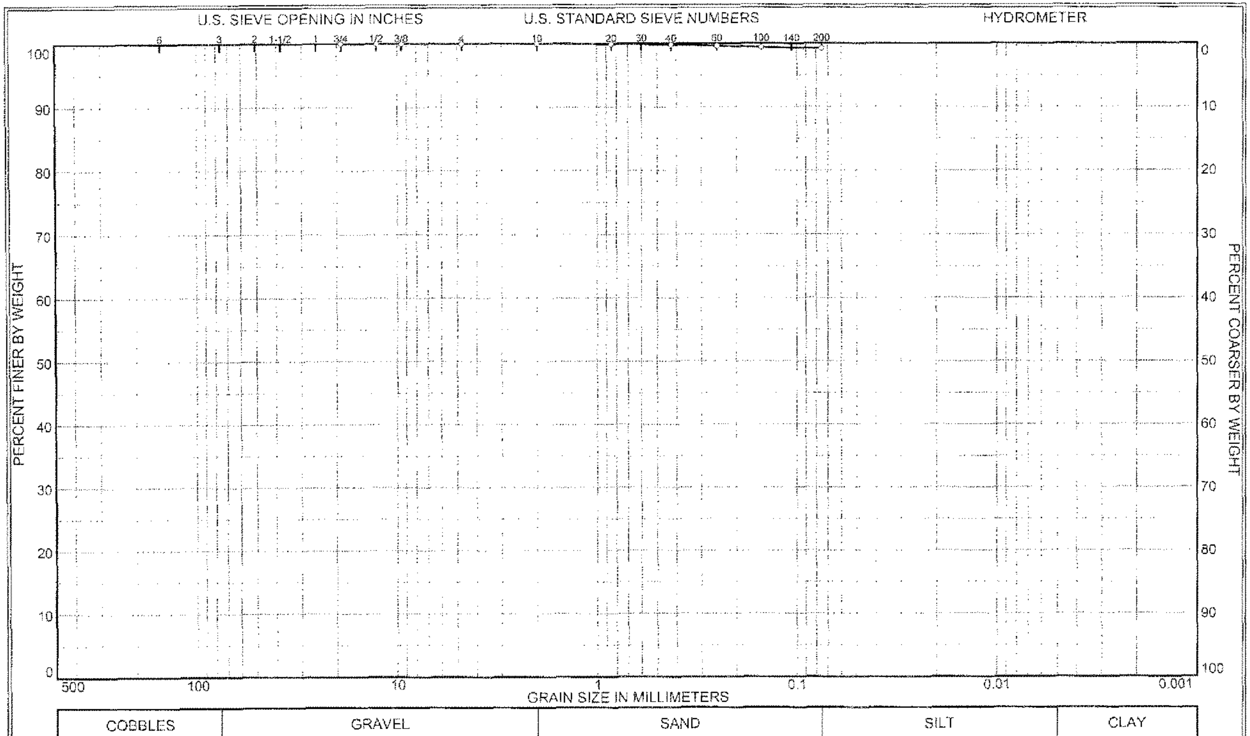

| | SOURCE | SAMPLE # | DEPTH/ELEV. | DATE SAMPLED | USCS | MATERIAL DESCRIPTION | NM % | LL | PI |
|---|---|---|---|---|---|---|---|---|---|
| ● | Boring No. SH-411 | 8 | 25.5'- 27.0' | | MH | Brown Sandy SILT | 127.1 | 140 | 82 |

Client US Army Corps of Engineers
Project Savannah Harbor Expansion

Project No. 1452-01-40

**WOLF TECHNOLOGIES, INC.**

●




| Sample No. | Elev or Depth | Classification | Nat w% | LL | PL | PI |
|---|---|---|---|---|---|---|
| 12 | 45.5'- 47.0' | Yellow-Brown CLAY | 50.5 | 71 | 31 | 40 |

**Project** Savannah Harbor Expansion

**Area**

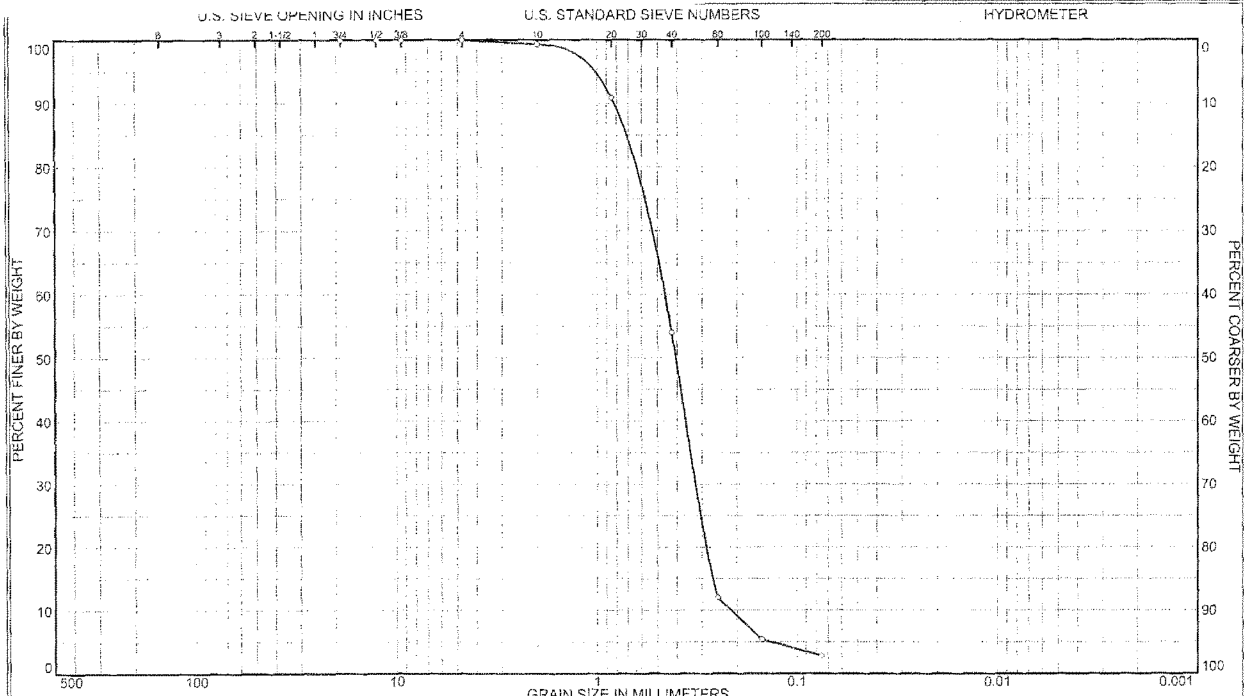
**Boring No.** Boring No. SH-411

**Date:** 1/17/2003

**WOLF TECHNOLOGIES, INC.**

Grain Size Distribution Report

**ENG** FORM 1 MAY 63 **2087**




| COBBLES | GRAVEL | SAND | SILT | CLAY |
|---|---|---|---|---|

| | Sample No. | Elev or Depth | Classification | Nat w% | LL | PL | PI |
|---|---|---|---|---|---|---|---|
| ○ | 14 | 58.5'- 60.0' | Brown Fine SAND w/ a trace of silt | 18.9 | | | |

**Project** Savannah Harbor Expansion

**Area**

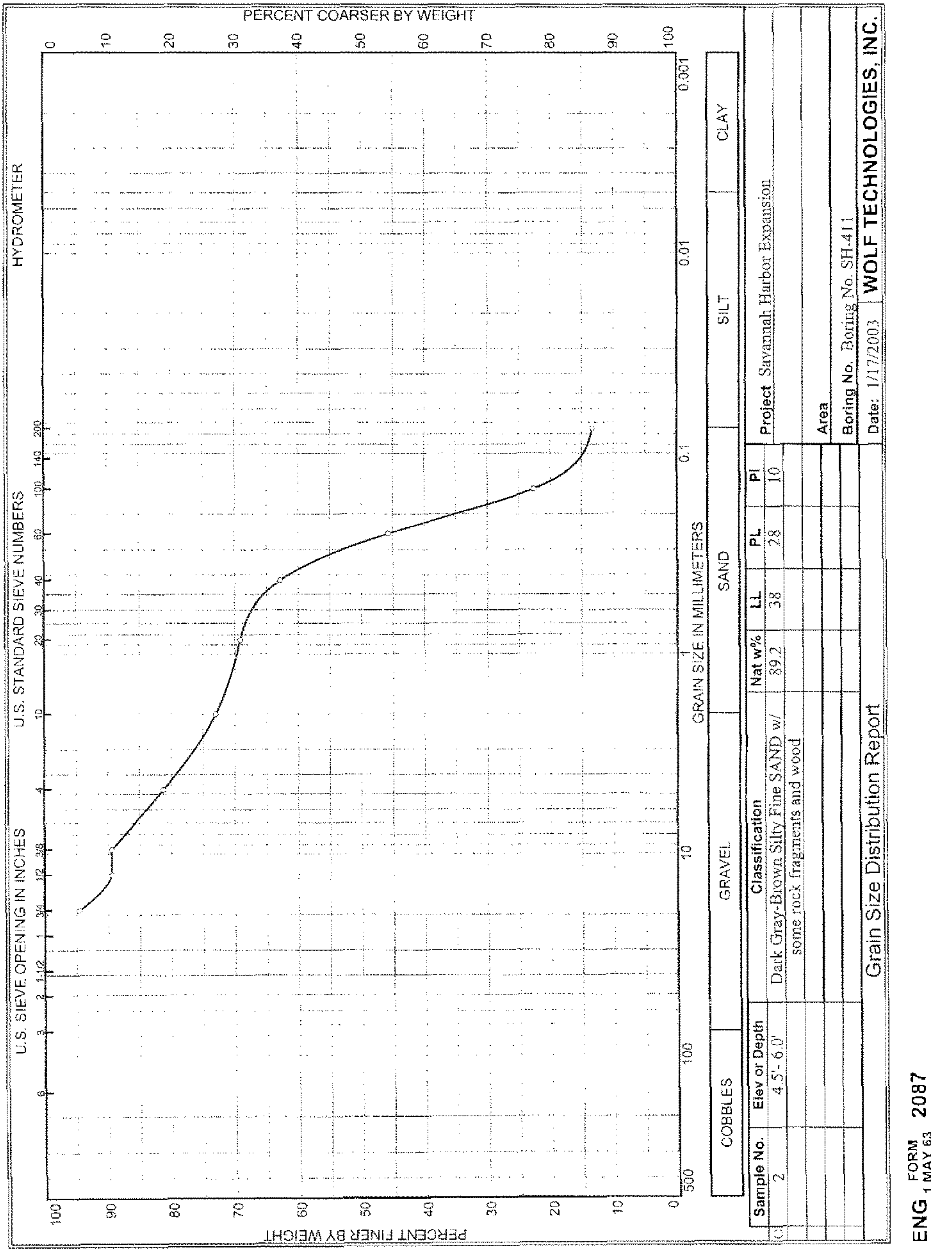
**Boring No.** Boring No. SH-411

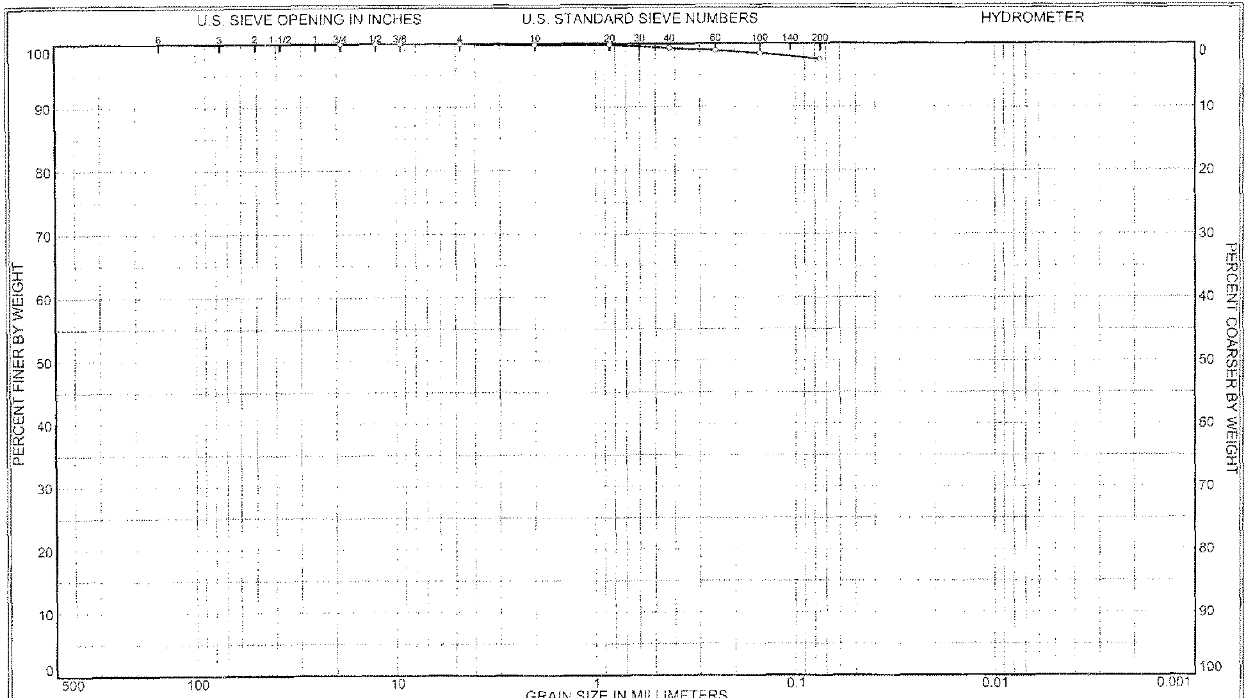
**Date:** 1/17/2003

**WOLF TECHNOLOGIES, INC.**

Grain Size Distribution Report

ENG FORM 1 MAY 63 2087


PERCENT COARSER BY WEIGHT
U.S. SIEVE OPENING IN INCHES
U.S. STANDARD SIEVE NUMBERS
HYDROMETER
PERCENT FINER BY WEIGHT
GRAIN SIZE IN MILLIMETERS
COBBLES
GRAVEL
SAND
SILT
CLAY
Sample No. | Elev or Depth | Classification | Nat w% | LL | PL | PI
2 | 4.5'- 6.0' | Dark Gray-Brown Silty Fine SAND w/ some rock fragments and wood | 89.2 | 38 | 28 | 10
Project Savannah Harbor Expansion
Area
Boring No. Boring No. SH-411
Date: 1/17/2003
Grain Size Distribution Report
WOLF TECHNOLOGIES, INC.
ENG FORM 1 MAY 63 2087




| Sample No. | Elev or Depth | Classification | Nat w% | LL | PL | PI |
|---|---|---|---|---|---|---|
| 5 | 15.0'- 16.5' | Yellow-Brown CLAY w/ a trace of fine sand | 133.2 | 178 | 58 | 120 |

**Project** Savannah Harbor Expansion

**Area**

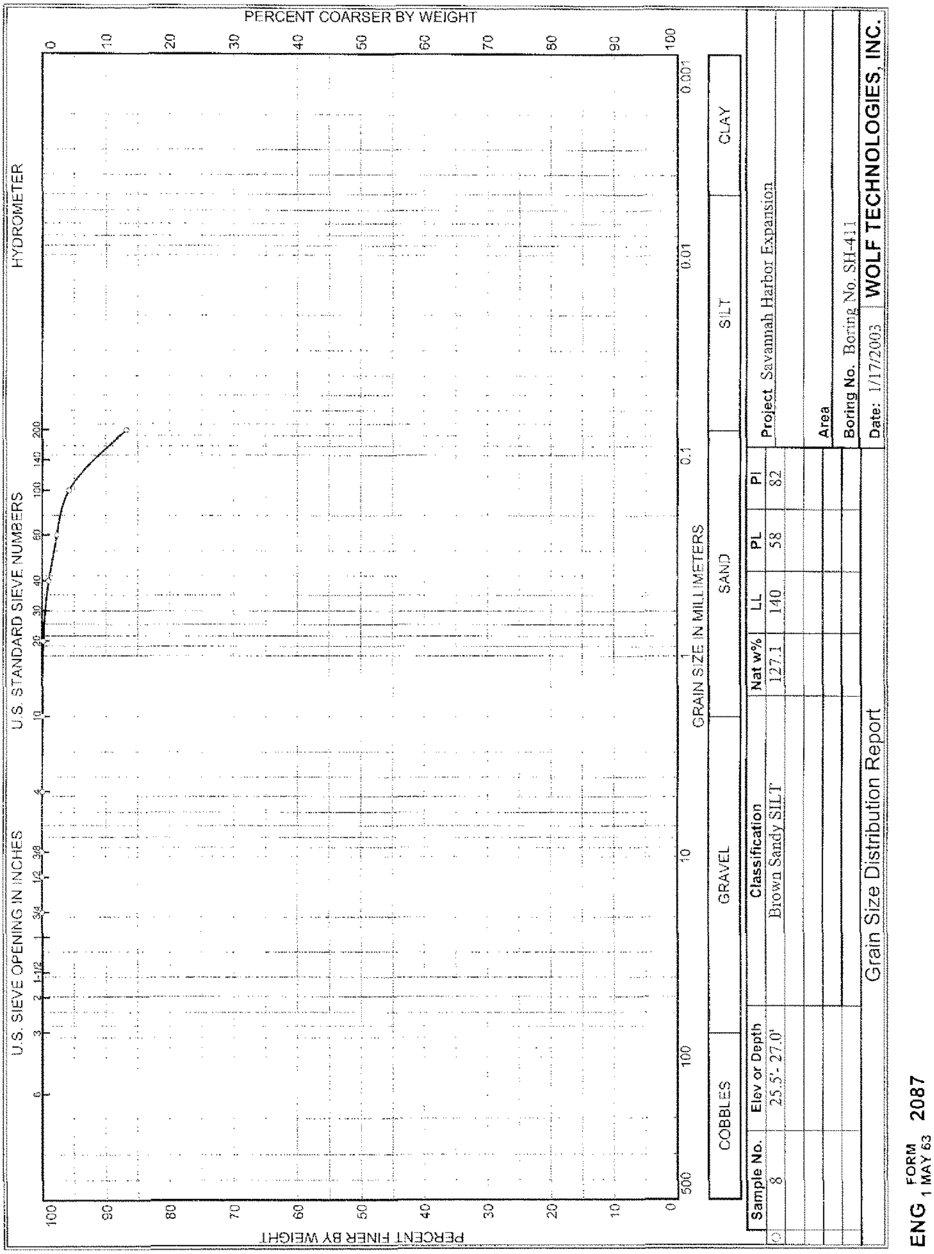
**Boring No.** Boring No. SH-411

**Date:** 1/17/2003

**WOLF TECHNOLOGIES, INC.**

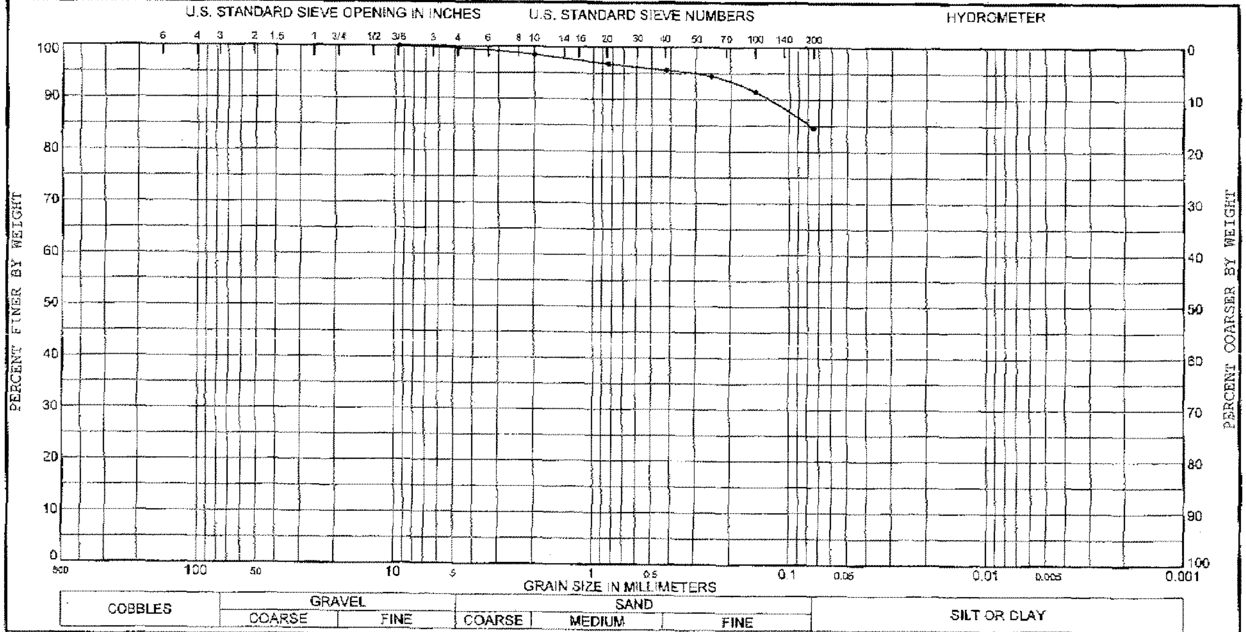
Grain Size Distribution Report

ENG FORM 1 MAY 63 2087


PERCENT COARSER BY WEIGHT
HYDROMETER
U.S. STANDARD SIEVE NUMBERS
U.S. SIEVE OPENING IN INCHES
PERCENT FINER BY WEIGHT
GRAIN SIZE IN MILLIMETERS
COBBLES
GRAVEL
SAND
SILT
CLAY
Sample No. | Elev or Depth | Classification | Nat w% | LL | PL | PI
8 | 25.5'- 27.0' | Brown Sandy SILT | 127.1 | 140 | 58 | 82
Project Savannah Harbor Expansion
Area
Boring No. Boring No. SH-411
Date: 1/17/2003
Grain Size Distribution Report
WOLF TECHNOLOGIES, INC.
ENG FORM 1 MAY 63 2087

**DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL & MATERIALS UNIT**
**CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA 30062**

WORK ORDER: 270e
REQUISITION: W33SJG30132375

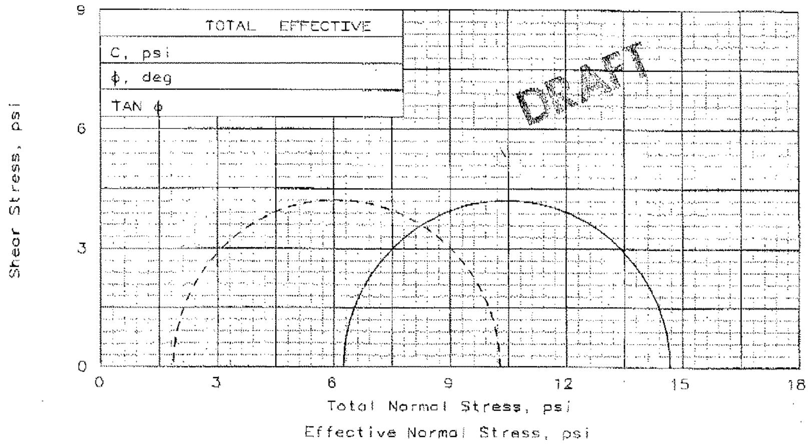


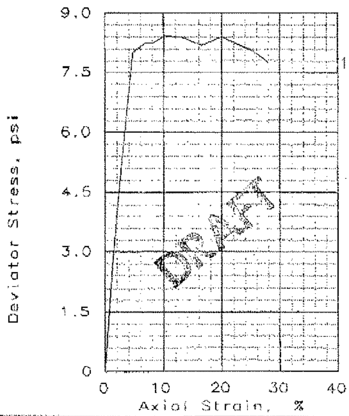

| Sample No. | Depth (ft) | Classification | Nat w% | LL | PL | PI |
|---|---|---|---|---|---|---|
| | 13.0 - 15.0 | Dark Gray, Clayey Inorganic Silt High Liquid Limit (MH), with | 103.0 | 85 | 39 | 46 |
| | | a little sand sizes, a trace of sand size wood fragments | | | | |
| | | and mica. | | | | |
| | | Plots Near the A-Line | | | | |
| | | Specific Gravity = 2.54. | | | | |

Project Savannah Harbor
Harbor Expansion, Savannah, Georgia
Lab No. K6/177
Boring No. SH411
Date 2/3/03

Tests Conducted in General Accordance with ASTM's D422, D4318, D854, & D2487.

**GRADATION CURVES**




| | | |
|---|---|---|
| SAMPLE NO.: | | 1 |
| INITIAL | WATER CONTENT, % | 81.2 |
| | DRY DENSITY, pcf | 51.8 |
| | SATURATION, % | 100.0 |
| | VOID RATIO | 2.062 |
| | DIAMETER, in | 2.76 |
| | HEIGHT, in | 4.58 |
| AT TEST | WATER CONTENT, % | 60.5 |
| | DRY DENSITY, pcf | 62.5 |
| | SATURATION, % | 100.0 |
| | VOID RATIO | 1.538 |
| | DIAMETER, in | 2.59 |
| | HEIGHT, in | 4.48 |
| BACK PRESSURE, psi | | 70.0 |
| INIT. EFF. STR., psi | | 6.3 |
| FAILURE STRESS, psi | | 8.4 |
| PORE PRESSURE, psi | | 74.4 |
| TIME TO FAILURE, min. | | 80.00 |
| RATE, %/min. | | 0.13 |
| ULTIMATE STRESS, psi | | 8.4 |

DRAFT

**DESCRIPTION** Dark Gray, Clayey Inorganic Silt High LL (MH), with a little sand sizes, and a trace of sand size wood fragments and mica.

| LL= 85 | PL= 39 | PI= 46 | Gs= 2.54 | CONTROLLED STRAIN TEST |
|---|---|---|---|---|
| TYPE OF SPECIMEN | UNDISTURBED | | | TYPE OF TEST R w/pore pressures |

**REMARKS** Tested in general accordance with ASTM's D4767, D422, D4318, D2216, D854, & D2487.

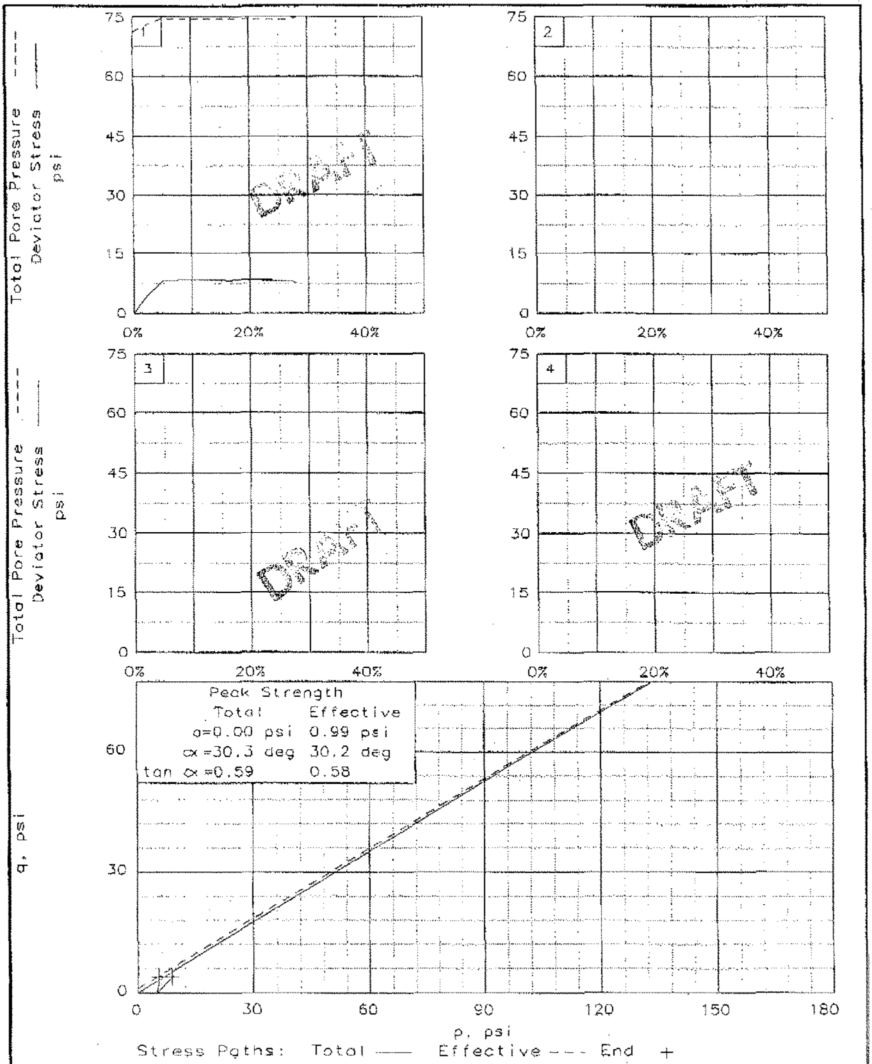
**PROJECT** SAVANNAH HARBOR EXPANSION
SLOPE STABILITY ANALYSIS
**AREA** Savannah, Georgia
**LAB. NO.** K6/177
**BORING. NO.** SH411
**SAMPLE. NO.**
**DEPTH/ELEV** 13.0 - 15.0'
**LABORATORY** **DATE** 3 FEB 2003

**TRIAXIAL SHEAR TEST REPORT**

Requisition No. W33SJG30132375 Work Order No. 270

Work Order No. 270e

Requisition No. W33SJG30132375




**PROJECT** SAVANNAH HARBOR EXPANSION SLOPE STABILITY ANALYSIS

**BORING** SH411 **SAMPLE** **DEPTH/ELEV** 13.0 - 15.0'

**TYPE OF TEST** R w/pore pressures **LAB NO.** K6/177

**LABORATORY** **Fig. No.:** 2/2 **DATE** 3 FEB 2003

## GRAIN SIZE DISTRIBUTION TEST DATA

**Project:** Savannah Harbor Expansion

### Sample Data

**Source:** Boring No. SH-411
**Sample No.:** 2
**Elev. or Depth:** 4.5'- 6.0' **Sample Length (in./cm.):**
**Location:**
**Description:** Dark Gray-Brown Silty Fine SAND w/ some rock fragments and wood
**PL:** 28 **LL:** 38
**PI:** 10 **Nat W.%:** 89.2

### Mechanical Analysis Data

| | Initial | After wash |
|---|---|---|
| **Dry sample and tare=** | 77.78 | 74.86 |
| **Tare =** | 50.09 | 50.09 |
| **Dry sample weight =** | 27.69 | 24.77 |

**Minus #200 from wash=** 10.5 %
**Tare for cumulative weight retained=** .00

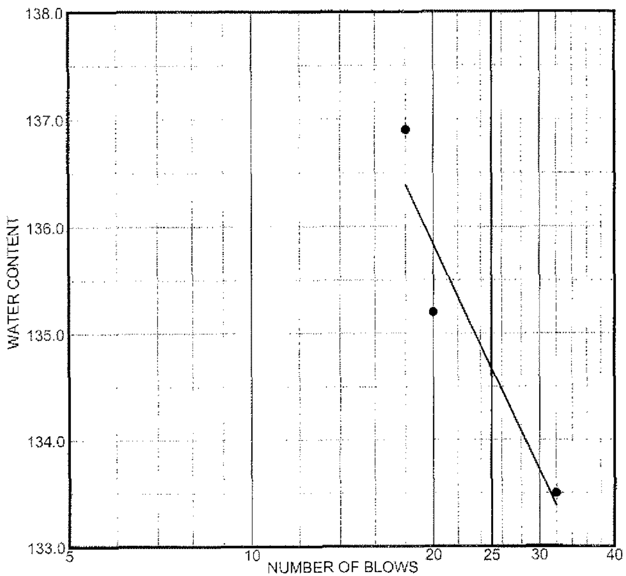
| Sieve | Cumul. Wt. retained | Percent finer |
|---|---|---|
| .75 inch | 1.53 | 94.5 |
| .50 inch | 2.94 | 89.4 |
| .375 inch | 2.94 | 89.4 |
| # 4 | 5.21 | 81.2 |
| # 10 | 7.48 | 73.0 |
| # 20 | 8.55 | 69.1 |
| # 40 | 10.30 | 62.8 |
| # 60 | 15.04 | 45.7 |
| # 100 | 21.42 | 22.6 |
| # 200 | 24.00 | 13.3 |

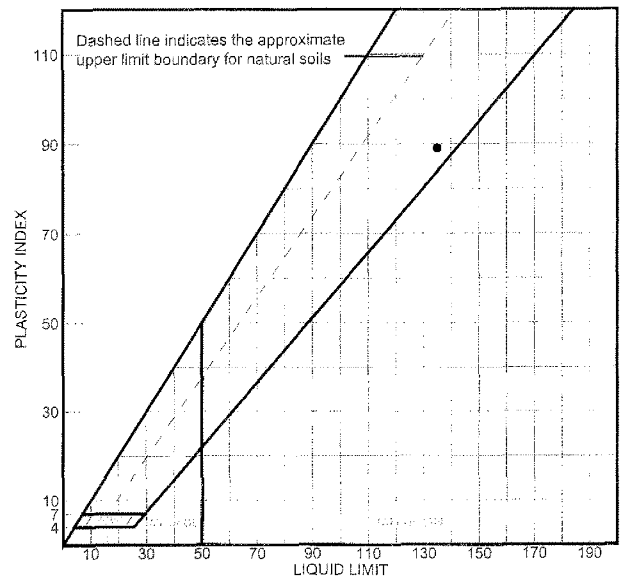
### Fractional Components

**Gravel/Sand based on** #10
**Sand/Fines based on** #200
**% COBBLES =** **% GRAVEL =** **% SAND =** 59.7
**% FINES =** 13.3

$D_{85}$= 6.59 $D_{60}$= 0.38 $D_{50}$= 0.28
$D_{30}$= 0.18 $D_{15}$= 0.10

# LIQUID AND PLASTIC LIMITS TEST REPORT



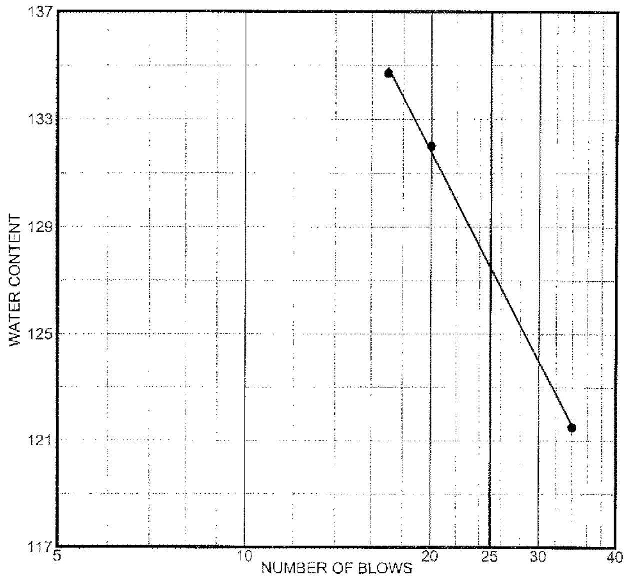

| | SOURCE | SAMPLE # | DEPTH/ELEV. | DATE SAMPLED | USCS | MATERIAL DESCRIPTION | NM % | LL | PI |
|---|---|---|---|---|---|---|---|---|---|
| ● | Boring No. SH-412 | 5 | 15.0'- 16.5' | | CH | Yellow-Brown Sandy CLAY w/ rock fragments and organics | 129.5 | 135 | 89 |

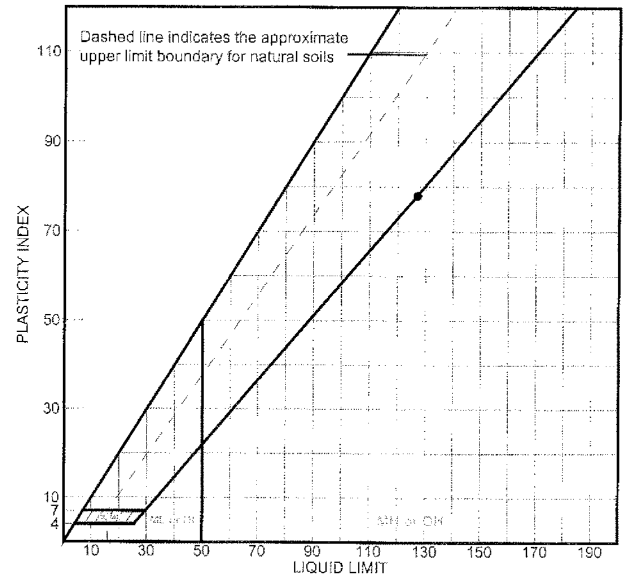
Client US Army Corps of Engineers
Project Savannah Harbor Expansion
Project No. 1452-01-40

**WOLF TECHNOLOGIES, INC.**

●

# LIQUID AND PLASTIC LIMITS TEST REPORT



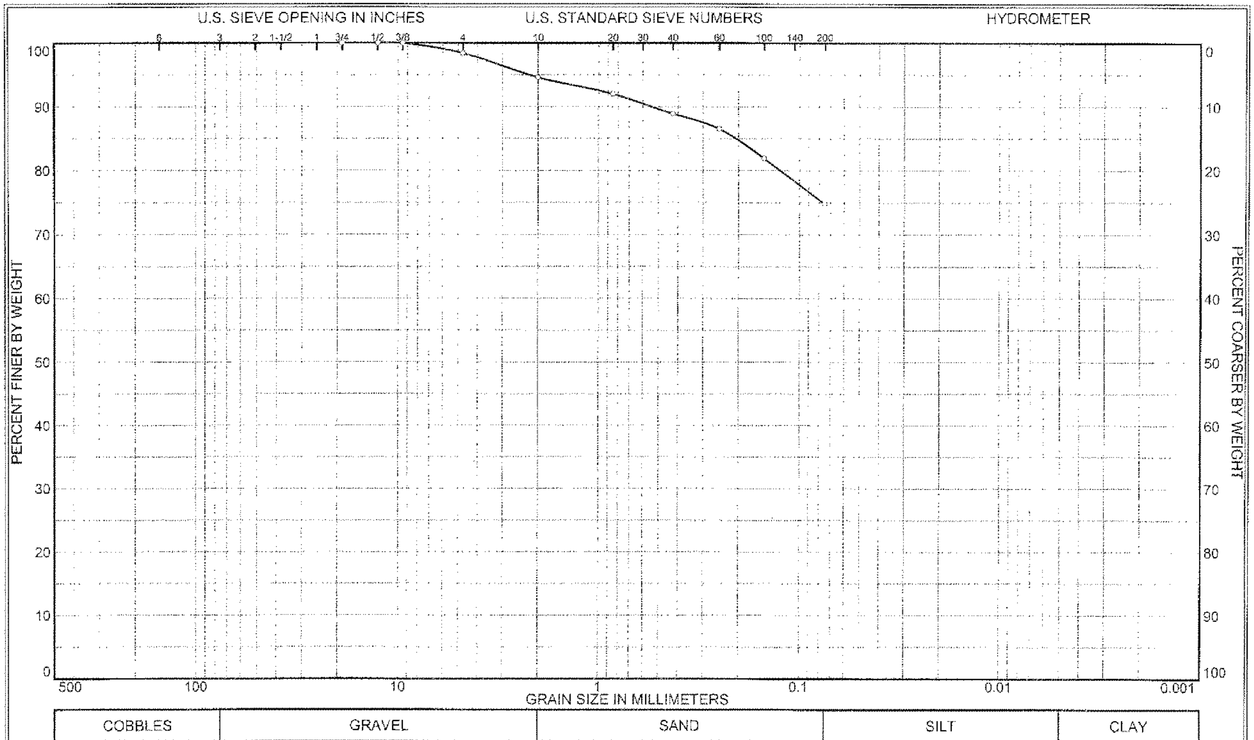




| | SOURCE | SAMPLE # | DEPTH/ELEV. | DATE SAMPLED | USCS | MATERIAL DESCRIPTION | NM % | LL | PI |
|---|---|---|---|---|---|---|---|---|---|
| ● | Boring No. SH-412 | UD-1 | 11.5'- 11.7' | | MH | Brown Sandy SILT w/ a trace of rock fragments and some organics | 90.9 | 127 | 78 |

Client US Army Corps of Engineers
Project Savannah Harbor Expansion
Project No. 1452-01-40

**WOLF TECHNOLOGIES, INC.**

●




| | Sample No. | Elev or Depth | Classification | Nat w% | LL | PL | PI |
|---|---|---|---|---|---|---|---|
| ○ | 5 | 15.0'- 16.5' | Yellow-Brown Sandy CLAY w/ rock fragments and organics | 129.5 | 135 | 46 | 89 |

**Project** Savannah Harbor Expansion

**Area**

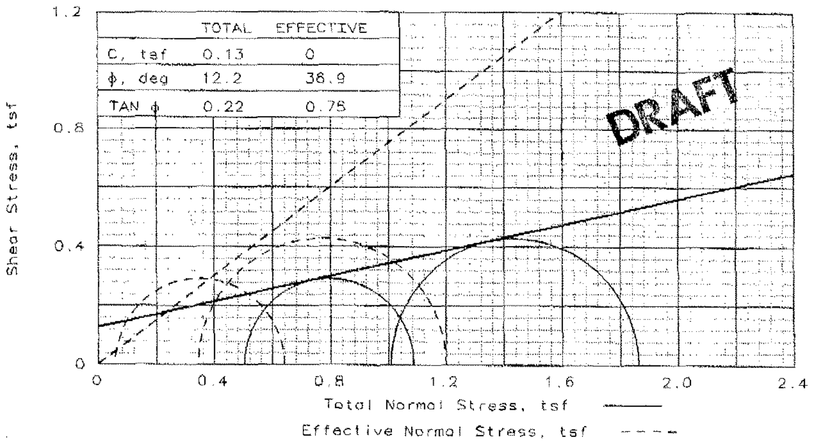
**Boring No.** Boring No. SH-412

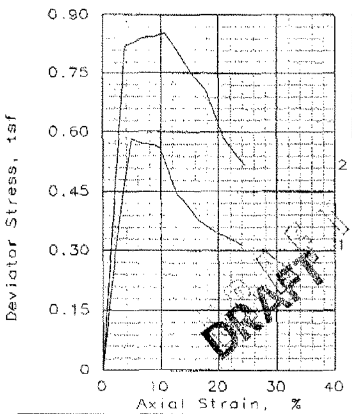
**Date:** 1/17/2003

Grain Size Distribution Report

**WOLF TECHNOLOGIES, INC.**

**ENG** FORM 1 MAY 63 **2087**




| SAMPLE NO.: | | 1 | 2 |
|---|---|---|---|
| INITIAL | WATER CONTENT, % | 83.0 | 83.0 |
| | DRY DENSITY, pcf | 50.0 | 49.0 |
| | SATURATION, % | 96.5 | 94.2 |
| | VOID RATIO | 2.219 | 2.238 |
| | DIAMETER, in | 2.79 | 2.64 |
| | HEIGHT, in | 5.05 | 5.07 |
| AT TEST | WATER CONTENT, % | 75.5 | 65.0 |
| | DRY DENSITY, pcf | 54.6 | 59.8 |
| | SATURATION, % | 100.0 | 100.0 |
| | VOID RATIO | 1.948 | 1.651 |
| | DIAMETER, in | 2.71 | 2.45 |
| | HEIGHT, in | 4.98 | 4.87 |
| BACK PRESSURE, tsf | | 5.04 | 5.04 |
| INIT. EFF. STR., tsf | | 0.50 | 1.01 |
| FAILURE STRESS, tsf | | 0.58 | 0.85 |
| PORE PRESSURE, tsf | | 5.49 | 5.70 |
| TIME TO FAILURE, min. | | 45.00 | 85.00 |
| RATE, %/min. | | 0.11 | 0.13 |
| ULTIMATE STRESS, tsf | | 0.35 | 0.56 |

DRAFT

**DESCRIPTION** Dark Grayish Brown, Sandy Fat Clay (CH), with some sand size wood fragments, and a trace of mica.

| LL= 76 | PL= 35 | PI= 41 | Gs= 2.58 | CONTROLLED STRAIN TEST |
|---|---|---|---|---|
| TYPE OF SPECIMEN UNDISTURBED | | | | TYPE OF TEST R w/pore pressures |

**REMARKS** Tested in general accordance with ASTM's D4767, D422, D4318, D2216, D854, & D2487.

**PROJECT** SAVANNAH RIVER HARBOR EXPANSION SLOPE STABILITY ANALYSIS
**AREA** Savannah, Georgia
**LAB. NO.** K5/185
**BORING. NO.** SH412
**SAMPLE. NO.**
**DEPTH/ELEV** 11.5 - 13.3'
**LABORATORY** **DATE** 3 FEB 2003

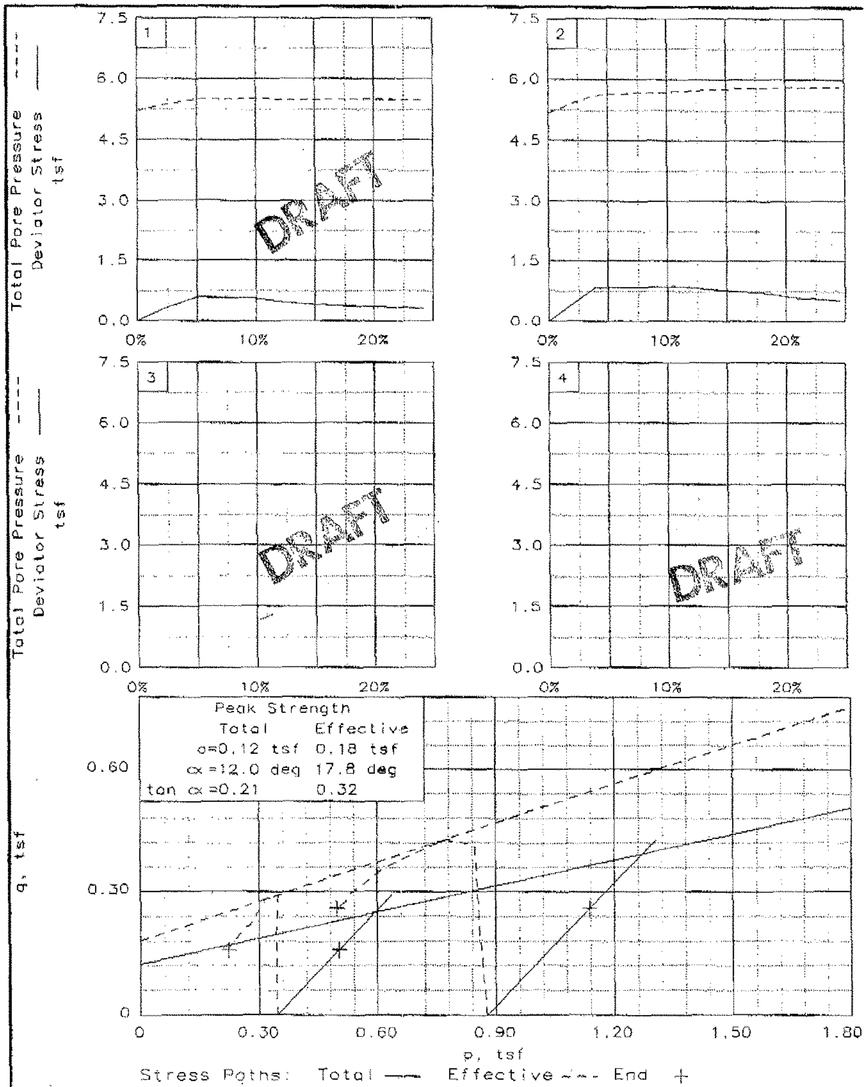
**TRIAXIAL SHEAR TEST REPORT**

Requisition No. W33SJG30132375 Work Order No. 270e

02/03/2003 14:11 6783540330 USACE PAGE 07

Work Order No. 270e

Requisition No. W33SJG3D132375

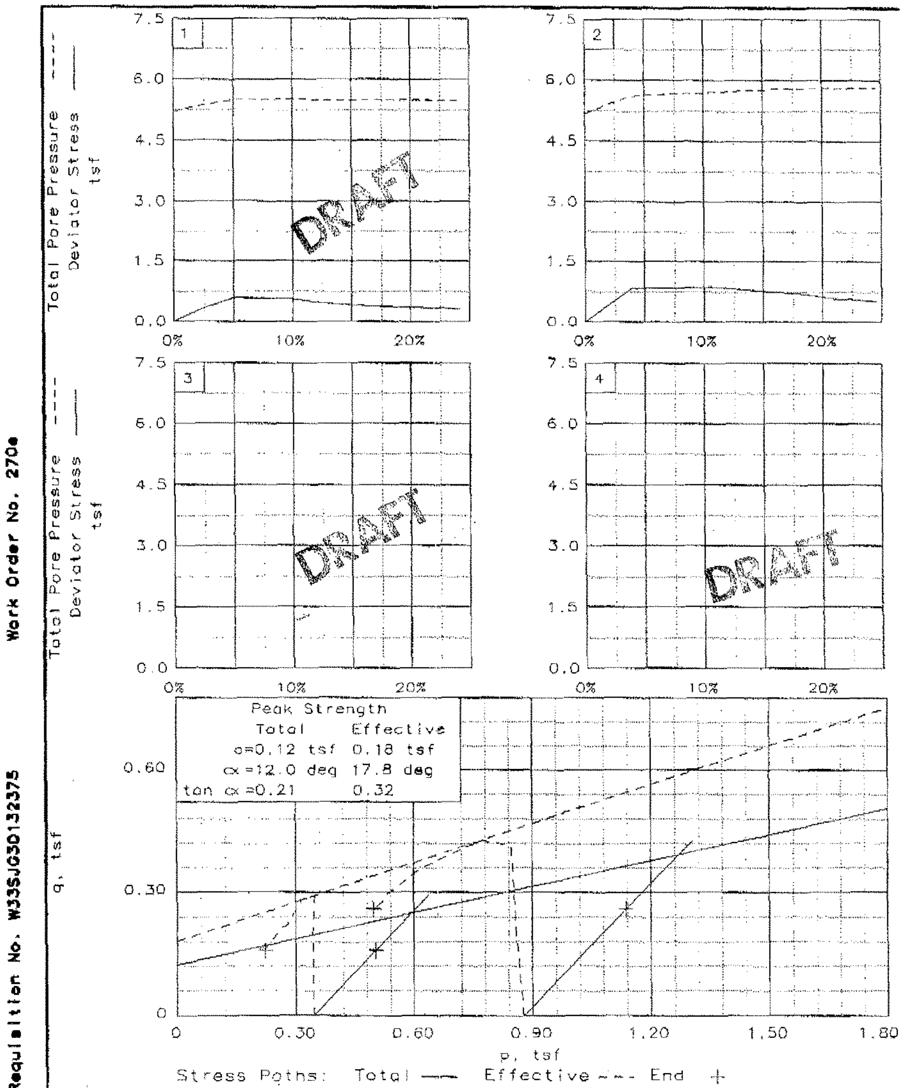



PROJECT SAVANNAH RIVER HARBOR EXPANSION SLOPE STABILITY ANALYSIS

BORING SH412 SAMPLE DEPTH/ELEV 11.5 - 13.3'

TYPE OF TEST R w/pore pressures LAB NO. K6/185

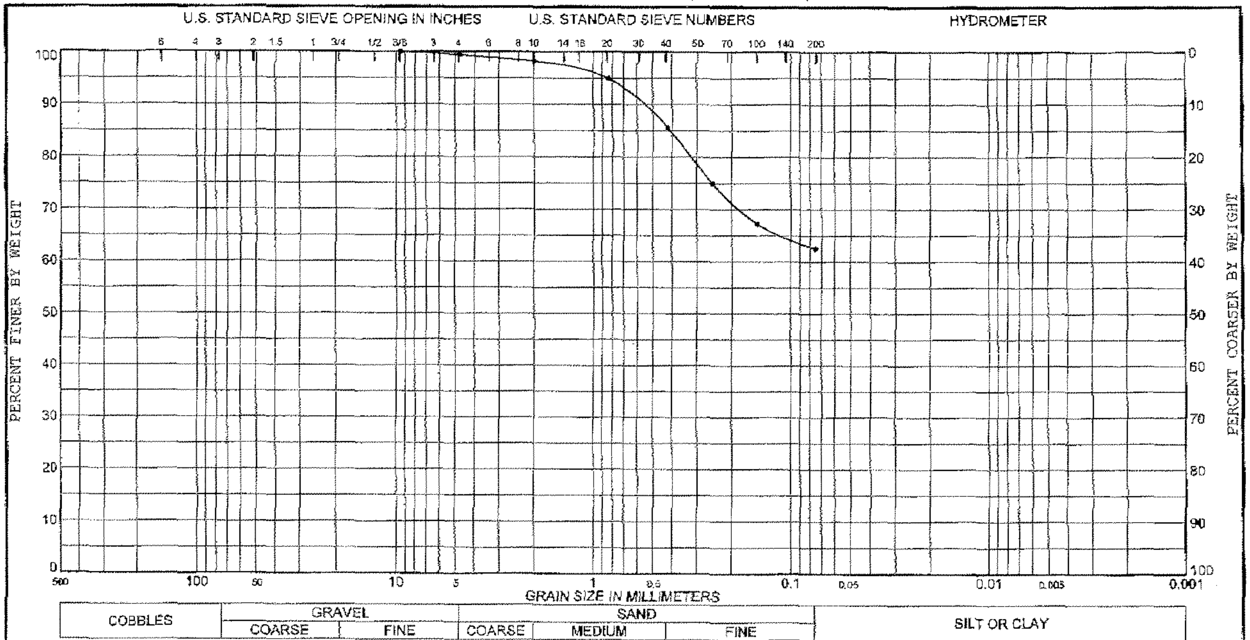
LABORATORY Fig. No.: 2/2 DATE 3 FEB 2003




| | | | |
|---|---|---|---|
| **PROJECT** SAVANNAH RIVER HARBOR EXPANSION SLOPE STABILITY ANALYSIS | | | |
| **BORING** SH412 | **SAMPLE** | | **DEPTH/ELEV** 11.5 - 13.3' |
| **TYPE OF TEST** R w/pore pressures | | **LAB NO.** K6/185 | |
| **LABORATORY** | **Fig. No.:** 2/2 | | **DATE** 3 FEB 2003 |

**DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL & MATERIALS UNIT**
**CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA 30062**

WORK ORDER: 270e
REQUISITION: W33SJG30132375

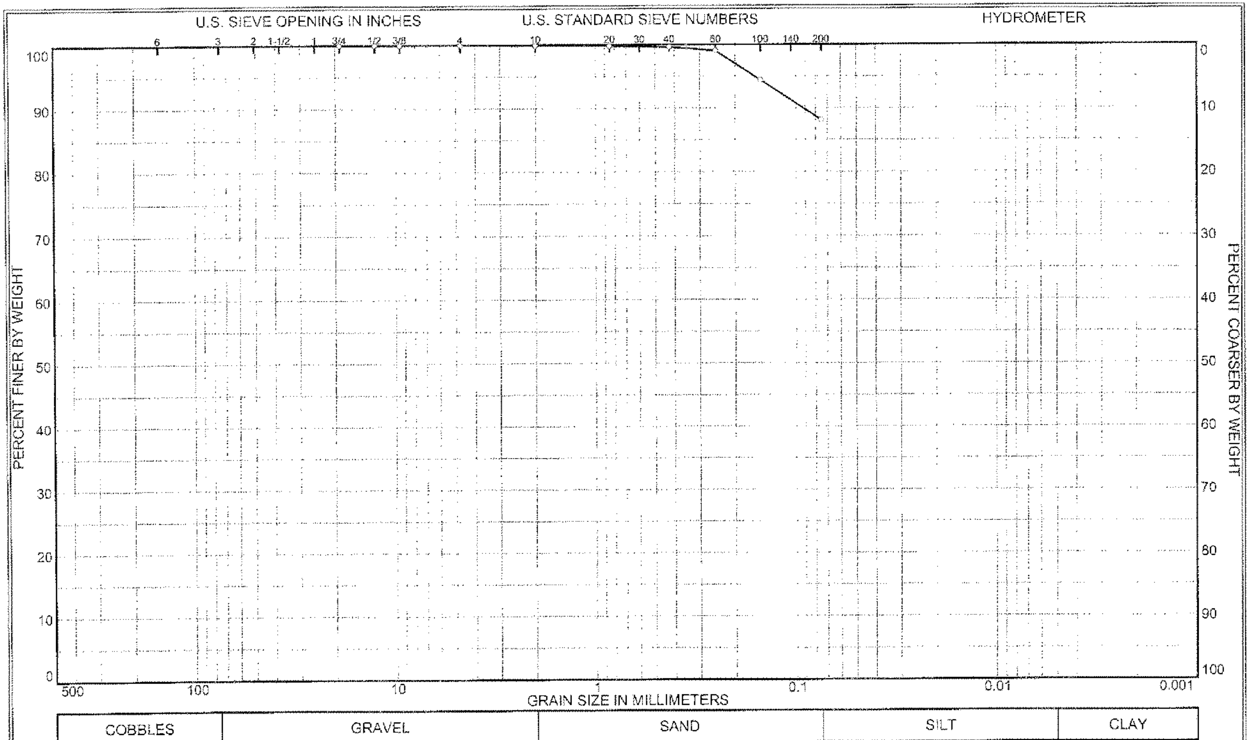



| Sample No. | Depth (ft) | Classification | Nat w% | LL | PL | PI |
|---|---|---|---|---|---|---|
| | 11.5 - 13.3 | Dark Grayish Brown, Sandy Fat Clay (CH), with some sand size | 83.0 | 76 | 35 | 41 |
| | | wood fragments, and a trace of mica. | | | | |
| | | | | | | |
| | | Plots Near the A-Line. | | | | |
| | | Specific Gravity = 2.58. | | | | |

Project Savannah Harbor
Harbor Expansion, Savannah, Georgia
Lab No. K6/185
Boring No. SH412
Date 2/3/03

**GRADATION CURVES**

Tests Conducted in General Accordance with ASTM's D422, D4318, D854, & D2487.




| Sample No. | Elev or Depth | Classification | Nat w% | LL | PL | PI |
|---|---|---|---|---|---|---|
| UD-1 | 11.5'- 11.7' | Brown Sandy SILT w/ a trace of rock fragments and some organics | 90.9 | 127 | 49 | 78 |

**Project** Savannah Harbor Expansion

**Area**

**Boring No.** Boring No. SH-412

**Date:** 1/17/2003

**WOLF TECHNOLOGIES, INC.**

Grain Size Distribution Report

ENG FORM 1 MAY 63 2087

# MOISTURE CONTENT DATA

Project Name: Savannah Harbor Expansion

Project No.: 1452-01-40

Date: 1-7-03

ASTM D2216

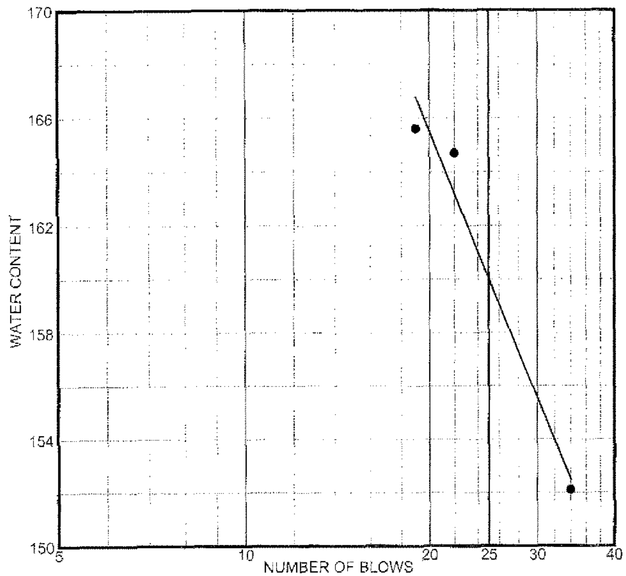
| Boring No. | Sample No. | Tare No. | Tare Wt. (grams) | Wet Wt. (grams) | Dry Wt. (grams) | Water Content, % |
|---|---|---|---|---|---|---|
| SH-410A | 7 | 18 | 49.88 | 113.91 | 76.42 | 141.26 |
| | 8 | 54 | 50.22 | 126.64 | 86.37 | 111.40 |
| | 17 | 81 | 49.56 | 109.17 | 84.92 | 68.58 |
| SH-411 | 4 | 13 | 50.04 | 114.73 | 78.86 | 124.46 |
| | 10 | 9 | 49.75 | 121.71 | 91.82 | 71.05 |
| SH-412 | 4 | 82 | 49.45 | 139.72 | 97.54 | 87.71 |

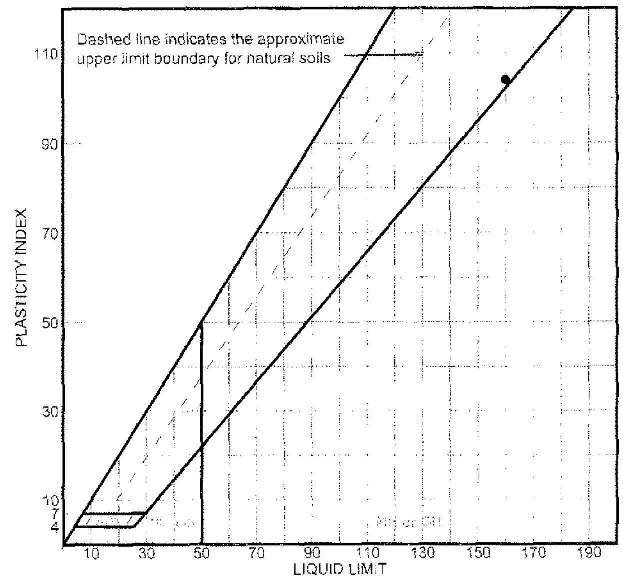
Performed by:CMjr    Equipment used: LB-1, LO-2

Checked by: CM

***WOLF TECHNOLOGIES, INC.***

# LIQUID AND PLASTIC LIMITS TEST REPORT




| | SOURCE | SAMPLE # | DEPTH/ELEV. | DATE SAMPLED | USCS | MATERIAL DESCRIPTION | NM % | LL | PI |
|---|---|---|---|---|---|---|---|---|---|
| ● | Boring No. SH-410A | 4 | 11.5'- 13.0' | | CH | Brown Sandy CLAY w/ some rock fragments | 107.3 | 160 | 104 |

Client US Army Corps of Engineers
Project Savannah Harbor Expansion
Project No. 1452-01-40

WOLF TECHNOLOGIES, INC.

# APPENDIX C

# MAPS GENERAL

# MAPS GENERAL
# SLOPE STABILITY STUDY AREAS

## OVERALL STUDY MAPS

**Savannah River Project Location Map**

**Savannah River Project Outline  Stations 114+000 to -85+000**

**Savannah River Project Outline  (ERDC) Stations 114+000 to -85+000**

## CLOSE STUDY MAPS

**Savannah River Channel Stations 66+000 to 68+000**

**Savannah River Channel Stations 69+500 to 71+500**

**Savannah River Channel Stations 73+000 to 73+700**

**Savannah River Channel Stations 75+000 to 76+500**

**Savannah River Channel Stations 77+000 to 79+000**

**Savannah River Channel Stations 85+000 to 88+500**

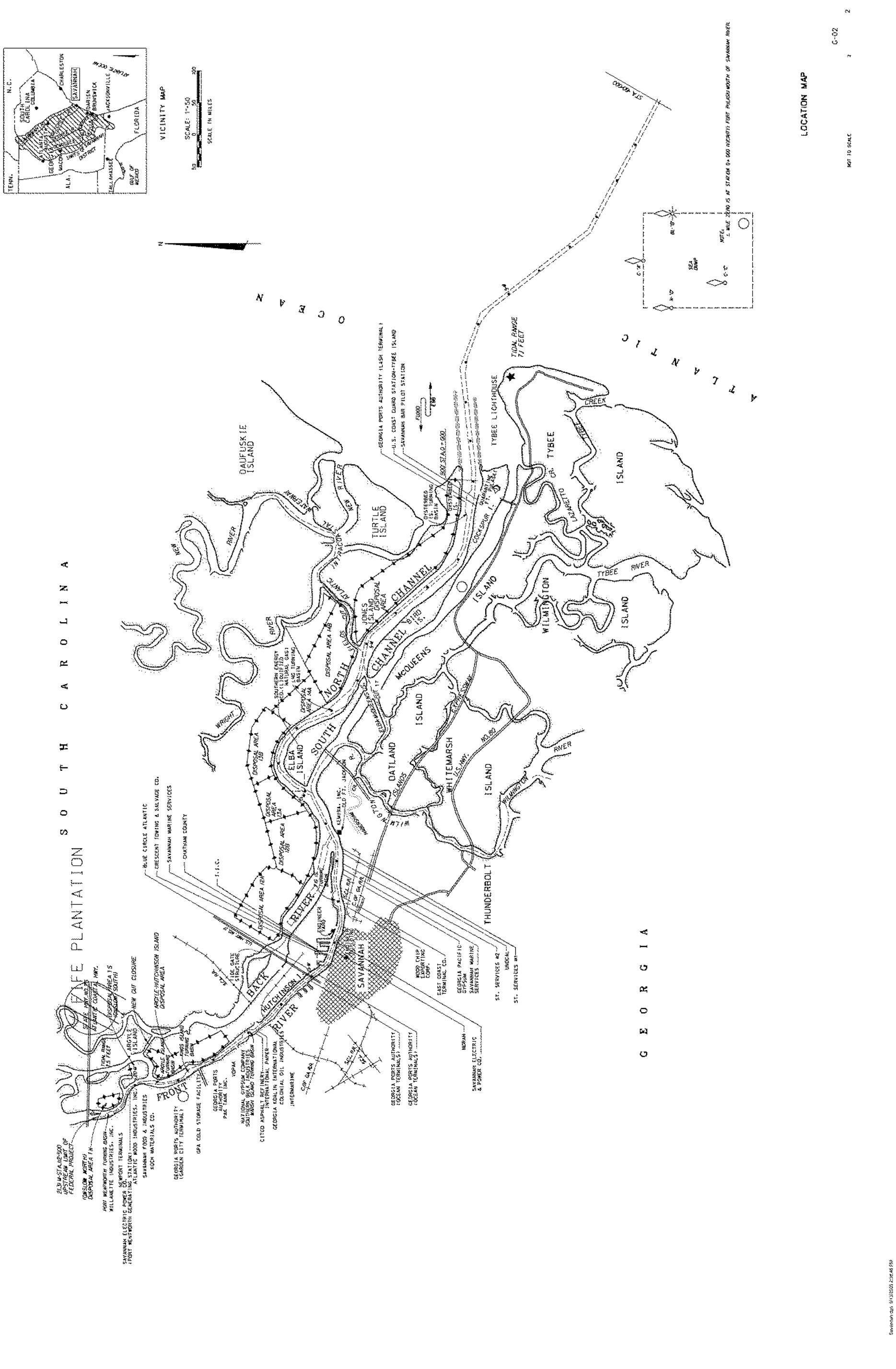
**Savannah River Channel Stations 96+000 to 97+500**

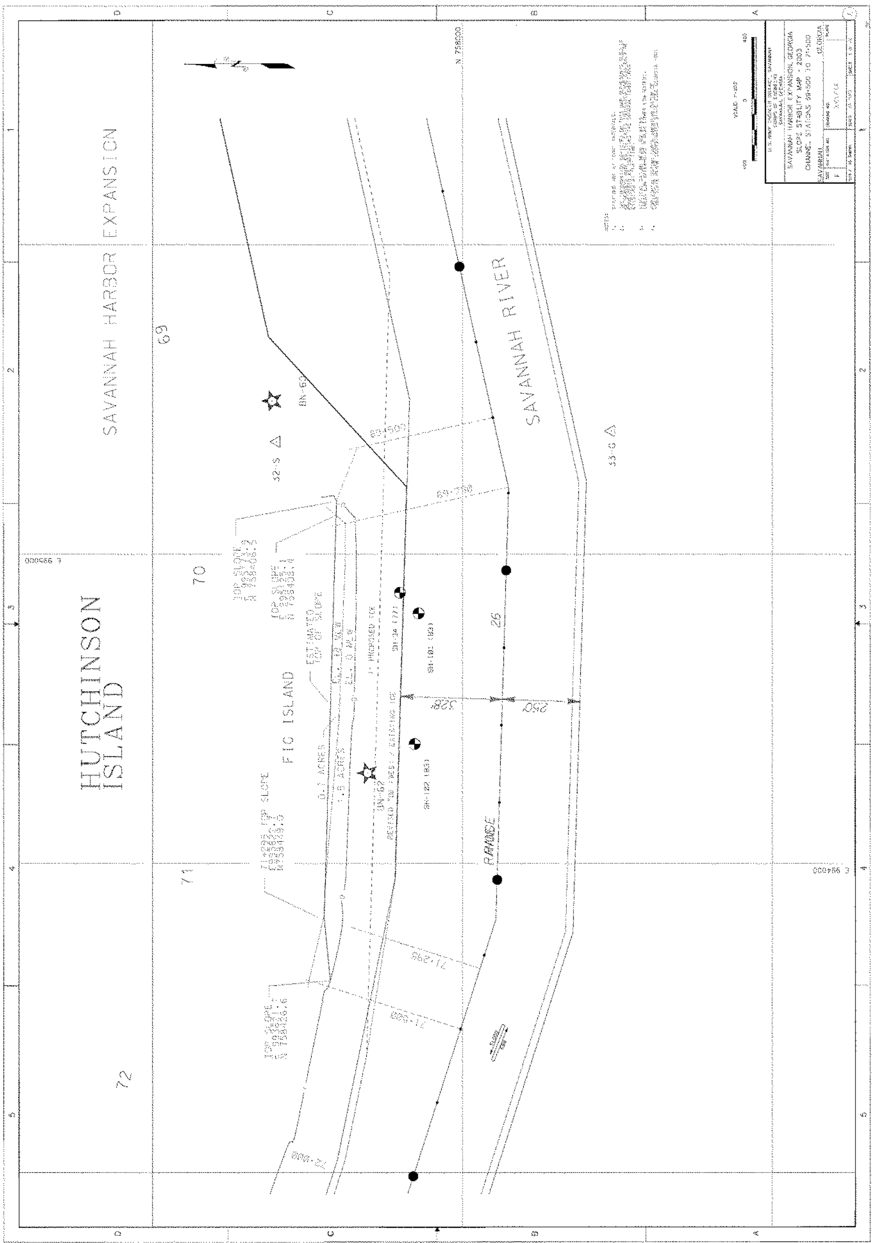
**Savannah River Channel Stations 98+000 to 103+000**

## ADDITIONAL INFORMATION

**General Project Information**

**Coastal GIS Site (Slow & Unreliable)**


LOCATION MAP
G-02
VICINITY MAP
SOUTH CAROLINA
GEORGIA
FLORIDA
ATLANTIC OCEAN
SAVANNAH
CHARLESTON
COLUMBIA
BRUNSWICK
DARIEN
JACKSONVILLE
TALLAHASSEE
GULF OF MEXICO
SOUTH CAROLINA
GEORGIA
ATLANTIC
OCEAN
DAUFUSKIE ISLAND
TURTLE ISLAND
JONES ISLAND
ELBA ISLAND
McQUEENS ISLAND
OATLAND ISLAND
WHITEMARSH ISLAND
WILMINGTON ISLAND
TYBEE ISLAND
COCKSPUR ISLAND
BIRD IS.
ARGYLE ISLAND
FIFE PLANTATION
THUNDERBOLT
SAVANNAH
TYBEE LIGHTHOUSE
TIDAL RANGE 7.1 FEET
NORTH CHANNEL
SOUTH CHANNEL
BACK RIVER
FRONT RIVER
WRIGHT RIVER
NEW RIVER
TYBEE RIVER
SEA DUMP


SAVANNAH HARBOR EXPANSION
HUTCHINSON ISLAND
SAVANNAH RIVER
FIG ISLAND
69
70
71
72


LEGEND
EXISTING CHANNEL TOES - LEVEL 20 - SOLID RED LINE
PRELIMINARY DESIGN TOES (SAV'H DISTRICT) - LEVEL 10 - DASHED WHITE LINE
PRELIMINARY DESIGN TOES BASED ON SHIP
SIMULATION (ERDC) - LEVEL 2 - DASH/DOT GREEN LINE
N
SAVANNAH RIVER

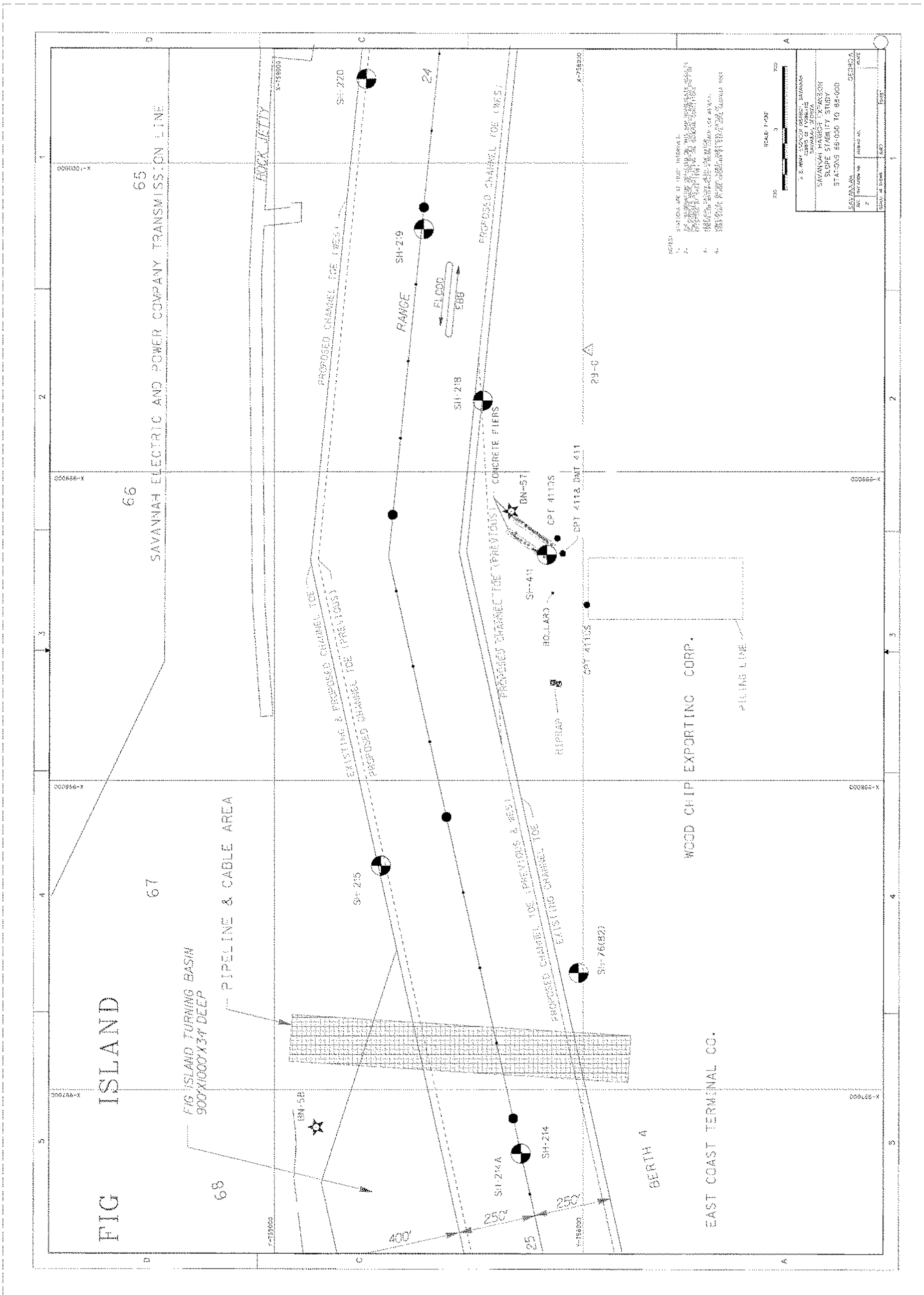
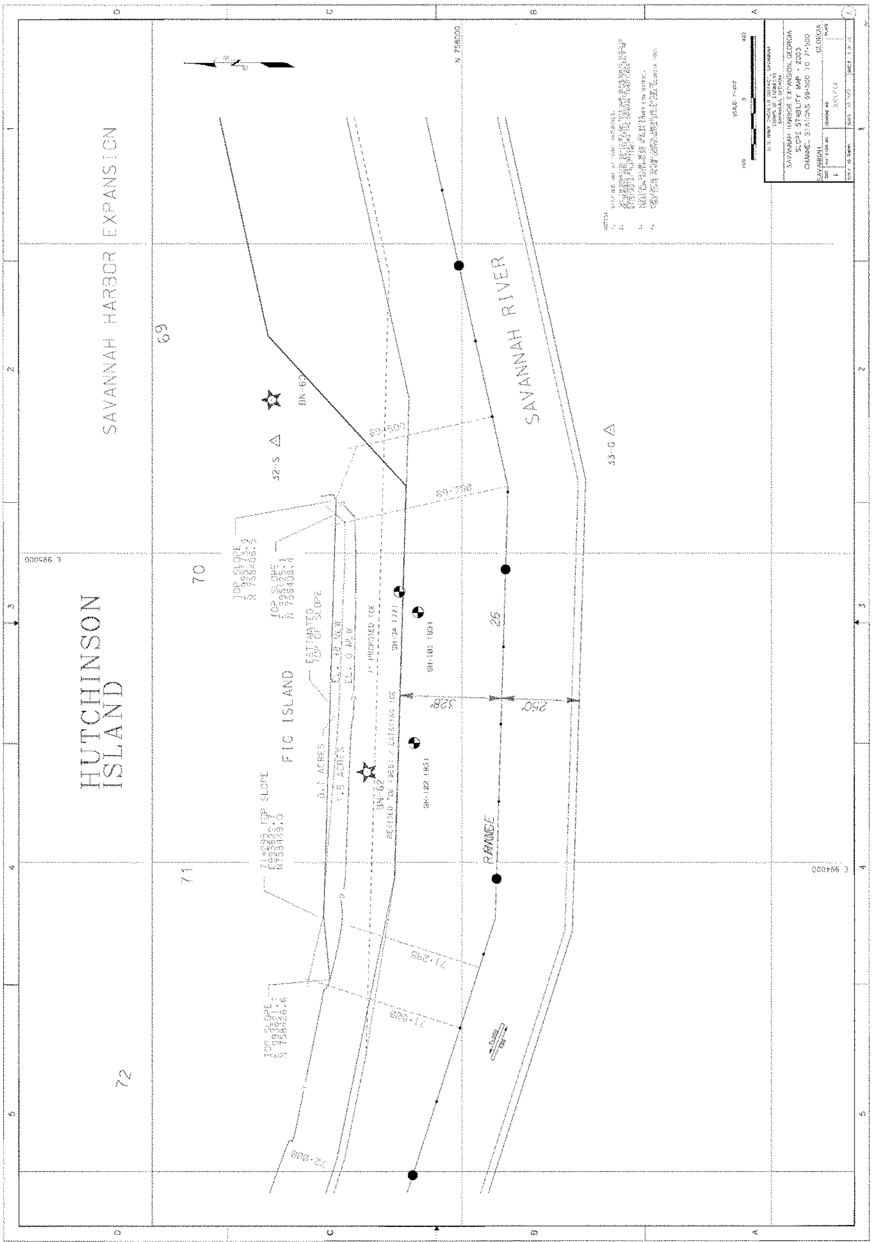
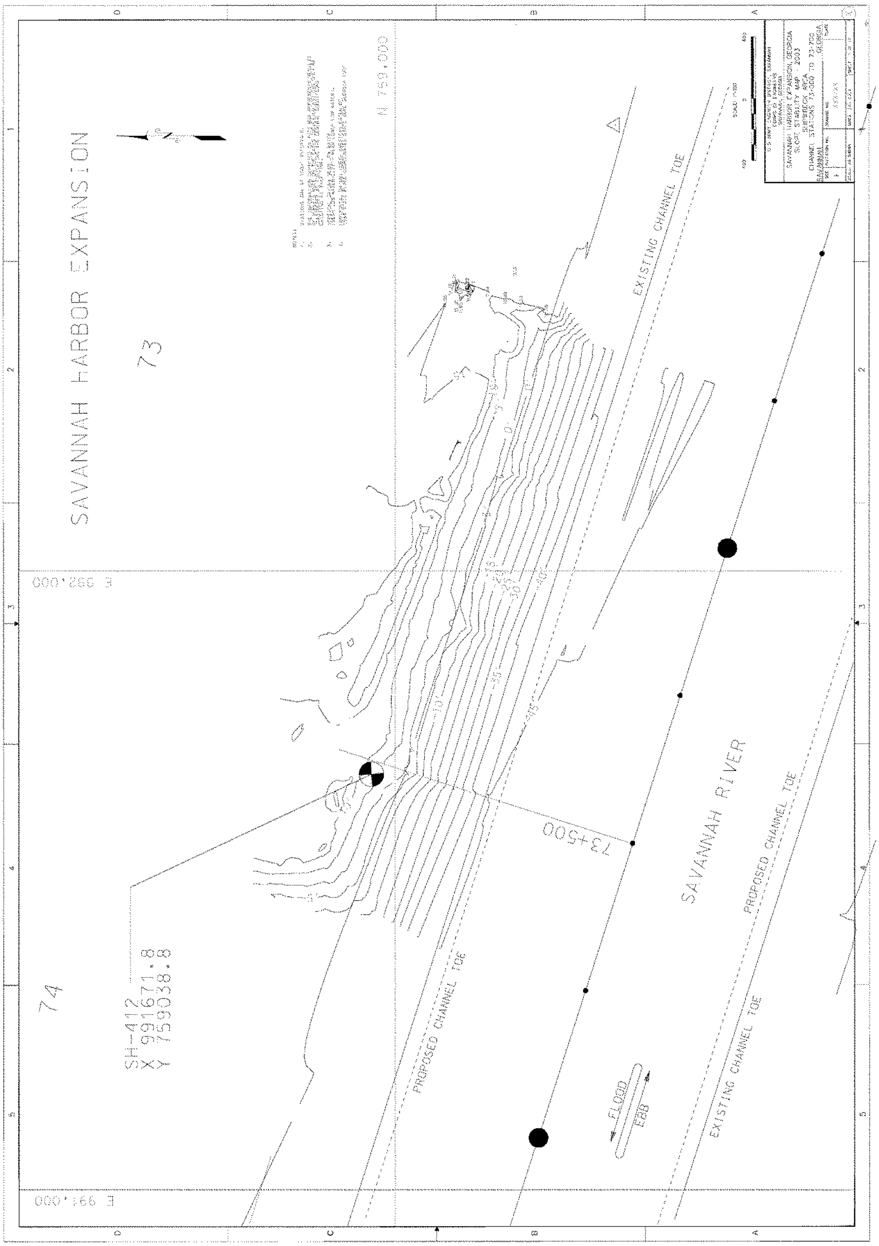
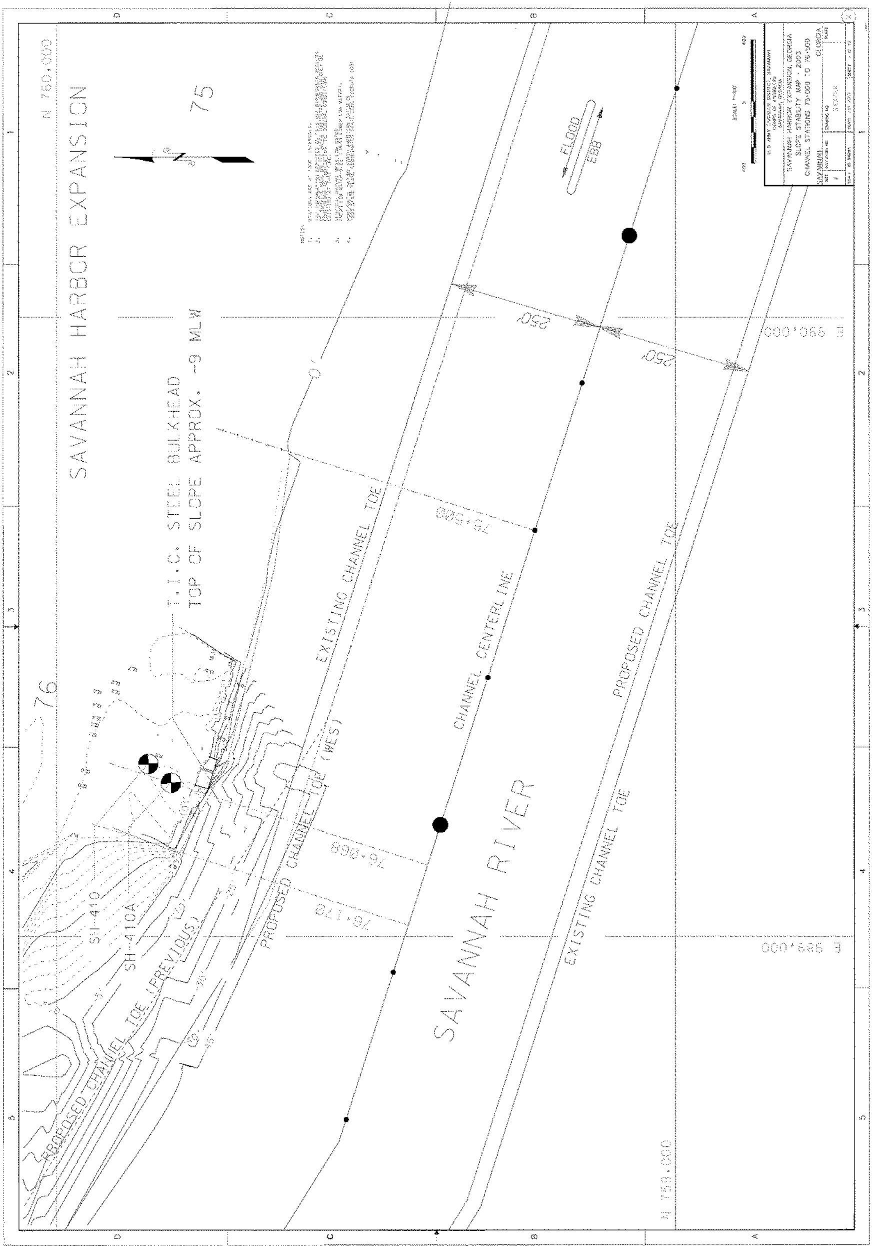
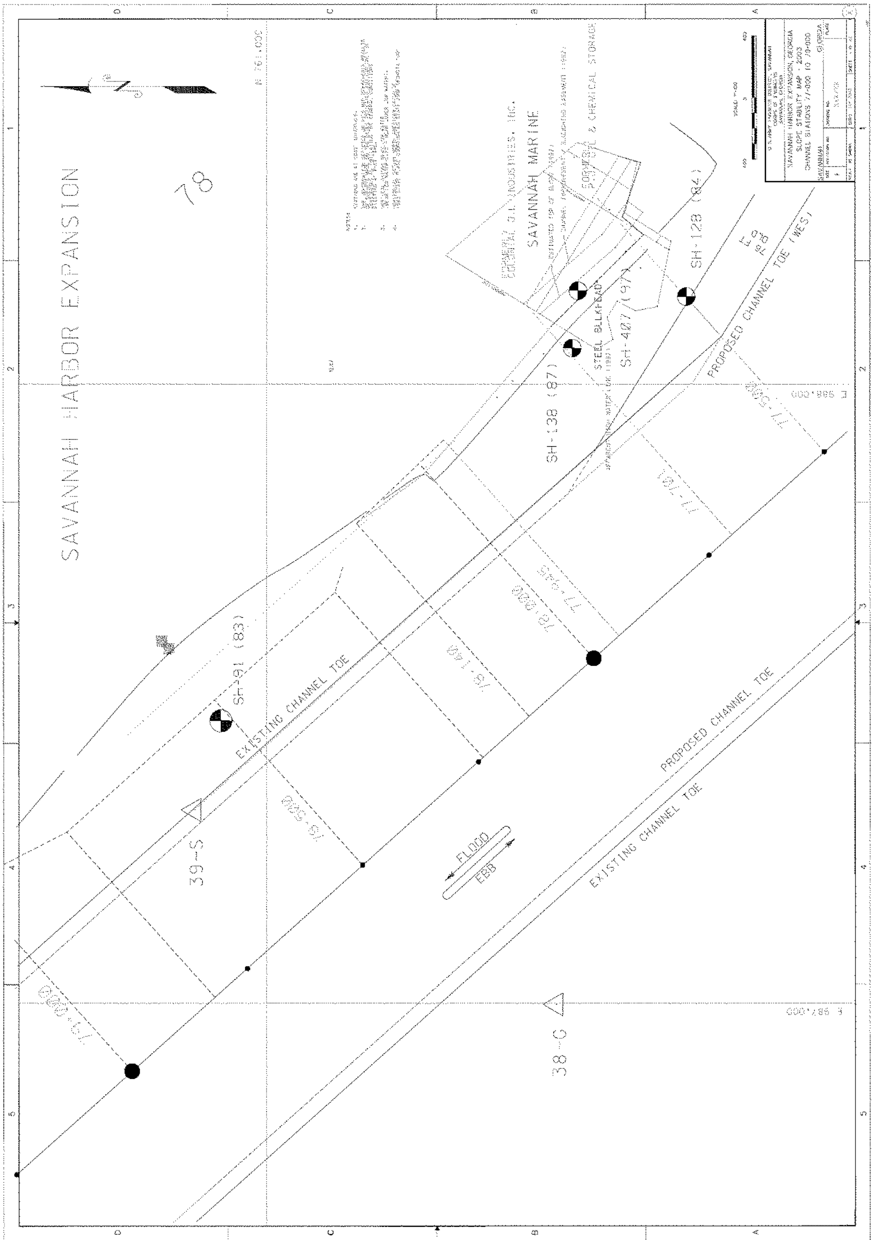


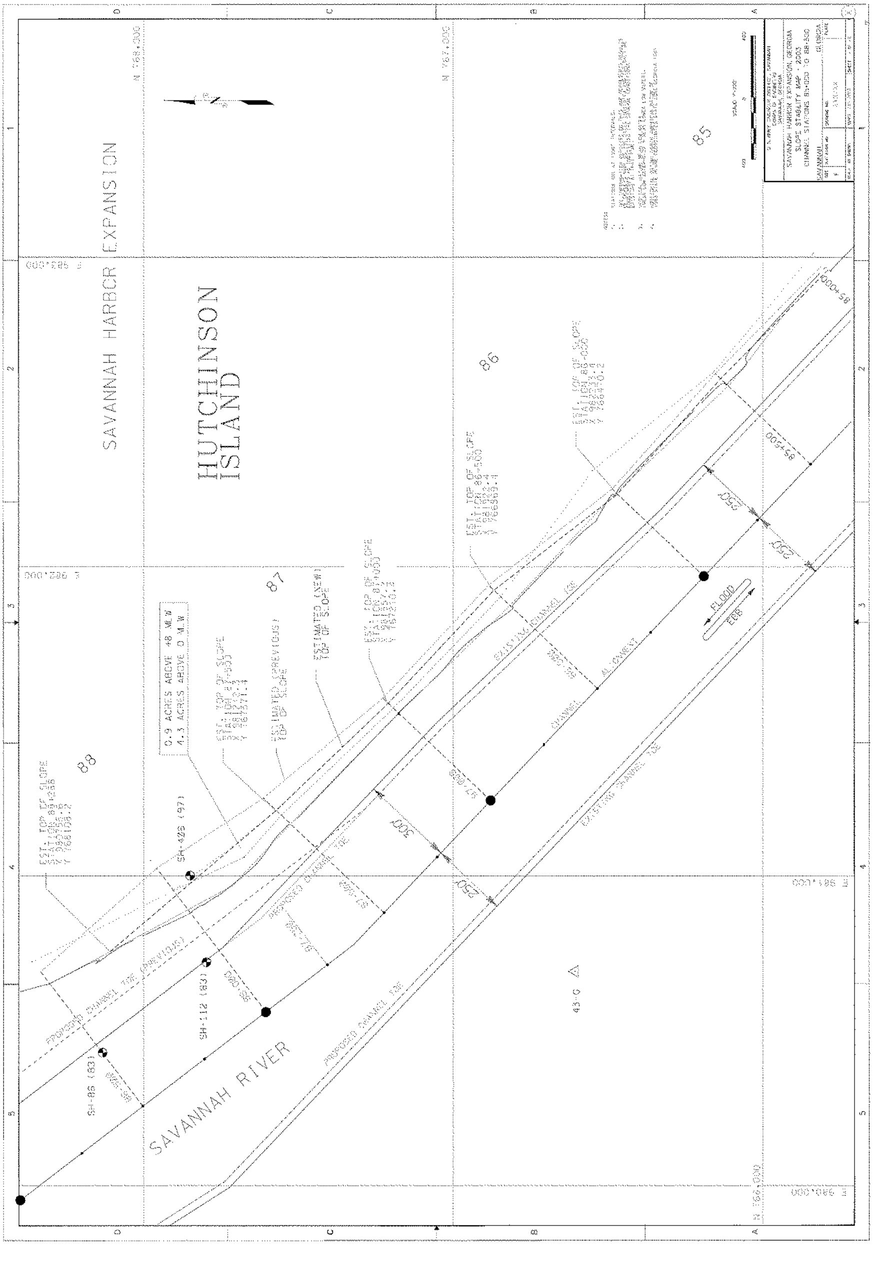
FIG ISLAND
SAVANNAH ELECTRIC AND POWER COMPANY TRANSMISSION LINE
65
66
67
68
ROCK JETTY
RANGE
FLOOD
EBB
SH-220
SH-219
SH-218
SH-215
SH-214
SH-214A
SH-411
SH-76(82)
CONCRETE PIERS
BOLLARD
RIPRAP
PROPOSED CHANNEL TOE (WEST)
EXISTING & PROPOSED CHANNEL TOE
PROPOSED CHANNEL TOE (PREVIOUS)
EXISTING CHANNEL TOE
PIPELINE & CABLE AREA
FIG ISLAND TURNING BASIN
900'X1000'X34' DEEP
WOOD CHIP EXPORTING CORP.
EAST COAST TERMINAL CO.
BERTH 4
24
25
400'
250'
250'


SAVANNAH HARBOR EXPANSION
HUTCHINSON ISLAND
SAVANNAH RIVER
FIC ISLAND
69
70
71
72

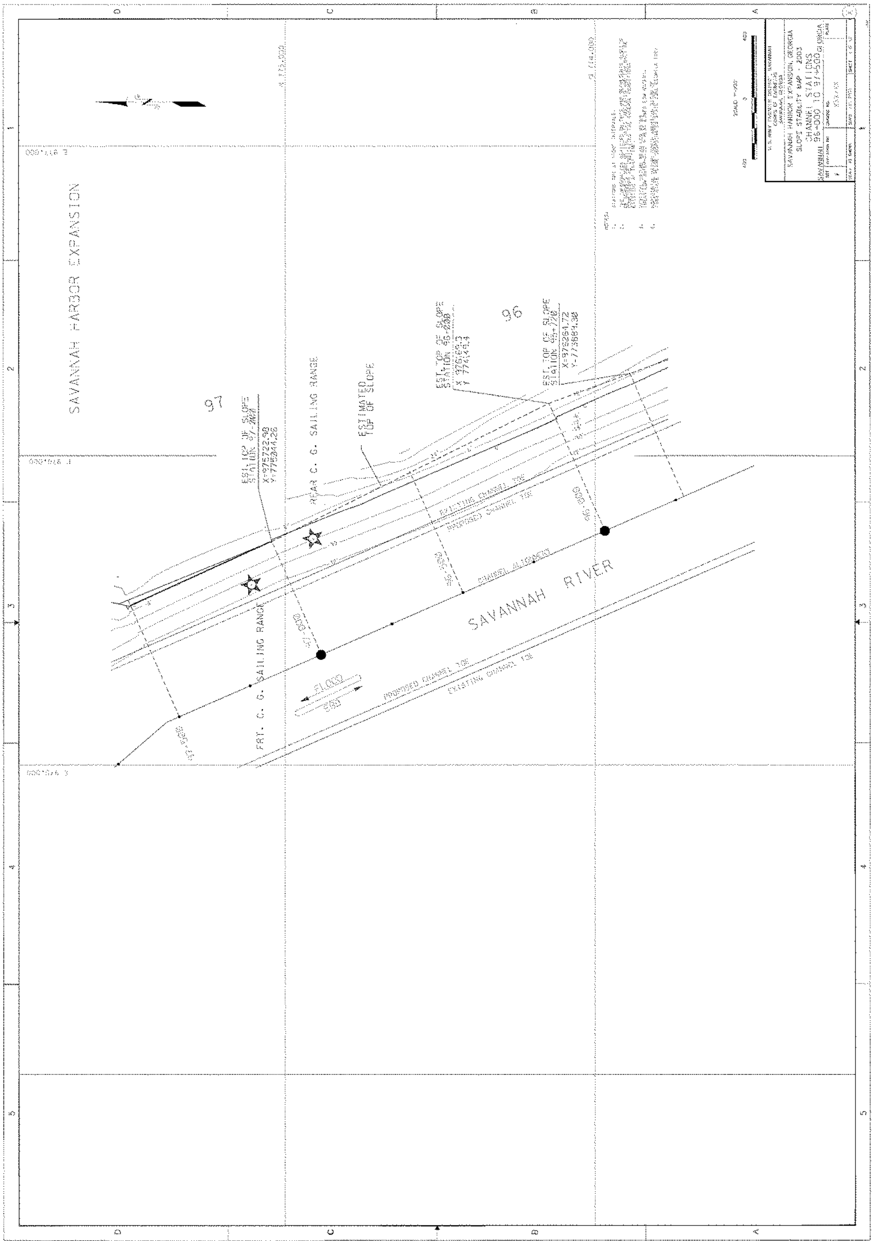

SAVANNAH HARBOR EXPANSION
73
74
N 759,000
E 992,000
E 991,000
SH-412
X 991671.8
Y 759038.8
73+500
SAVANNAH RIVER
EXISTING CHANNEL TOE
PROPOSED CHANNEL TOE
PROPOSED CHANNEL TOE
EXISTING CHANNEL TOE
FLOOD
EBB

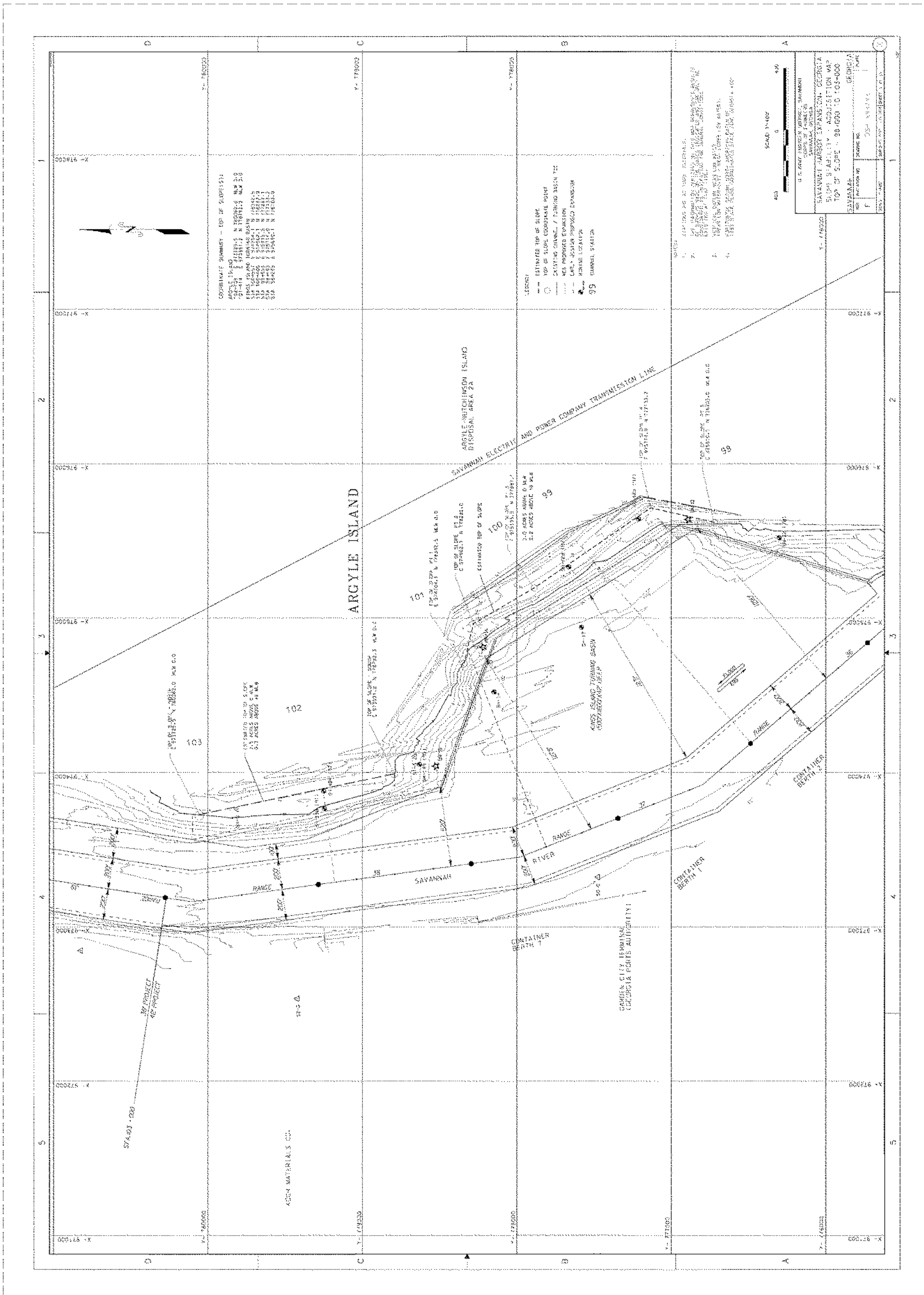

SAVANNAH HARBOR EXPANSION
75
76
T.I.C. STEEL BULKHEAD
TOP OF SLOPE APPROX. -9 MLW
FLOOD
EBB
250'
250'
E 990,000
E 989,000
N 760,000
N 759,000
75+500
76+068
76+179
EXISTING CHANNEL TOE
CHANNEL CENTERLINE
PROPOSED CHANNEL TOE
PROPOSED CHANNEL TOE (WES)
PROPOSED CHANNEL TOE (PREVIOUS)
SAVANNAH RIVER
EXISTING CHANNEL TOE
SH-410
SH-410A
PROPOSED CHANNEL TOE


SAVANNAH HARBOR EXPANSION
78
SAVANNAH MARINE
STEEL BULKHEAD
SH-138 (87)
SH-407 (97)
SH-128 (84)
SH-91 (83)
PROPOSED CHANNEL TOE (WEST)
EXISTING CHANNEL TOE
PROPOSED CHANNEL TOE
EXISTING CHANNEL TOE
FLOOD
EBB
39-S
38-G
SAVANNAH HARBOR EXPANSION, GEORGIA
SLOPE STABILITY MAP - 2003



SAVANNAH HARBOR EXPANSION
HUTCHINSON ISLAND
SAVANNAH RIVER
0.9 ACRES ABOVE +8 M.L.W
4.3 ACRES ABOVE 0 M.L.W
FLOOD
EBB
EXISTING CHANNEL TOE
PROPOSED CHANNEL TOE


SAVANNAH HARBOR EXPANSION
SAVANNAH RIVER
REAR C. G. SAILING RANGE
FRT. C. G. SAILING RANGE
ESTIMATED TOP OF SLOPE
EXISTING CHANNEL TOE
PROPOSED CHANNEL TOE
CHANNEL ALIGNMENT
FLOOD
EBB
97
96


ARGYLE ISLAND
SAVANNAH ELECTRIC AND POWER COMPANY TRANSMISSION LINE
ARGYLE-HUTCHINSON ISLAND DISPOSAL AREA 2A
SAVANNAH
RIVER
RANGE
CONTAINER BERTH 1
CONTAINER BERTH 7
GARDEN CITY TERMINAL (GEORGIA PORTS AUTHORITY)
ACEH MATERIALS CO.

# APPENDIX D

# CROSS SECTION DRAWINGS

# CROSS SECTIONS ANALYZED FOR SLOPE STABILITY

**Note: These drawings were originally developed using MicroStation Version 7. The files attached below have been converted to Adobe .pdf format and as such will not be readable without using zoom control to read layer soils data.**
**Originals may be requested by contacting the Corps of Engineers office in Savannah, Georgia for those with the ability to read original design files.**

**Channel Station 66+250**

**Channel Station 70+500**

**Channel Station 73+500**

**Channel Station 76+068**

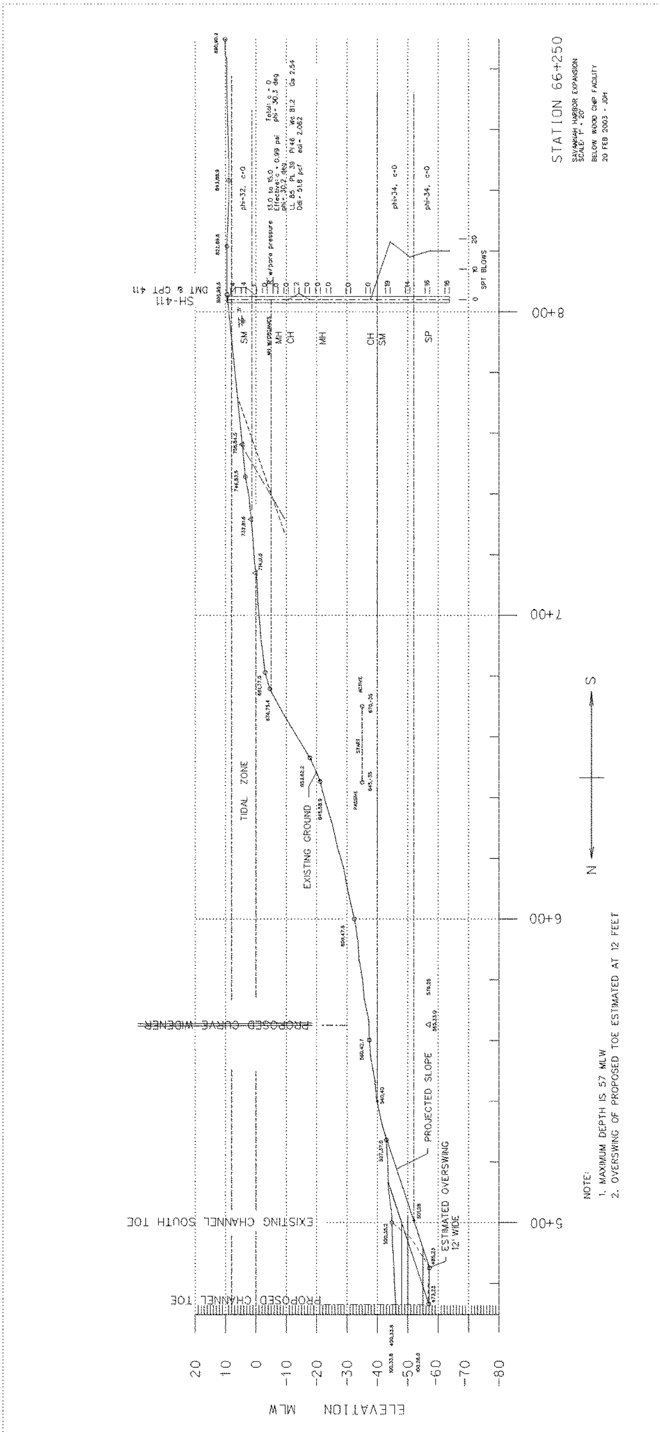
**Channel Station 77+500**

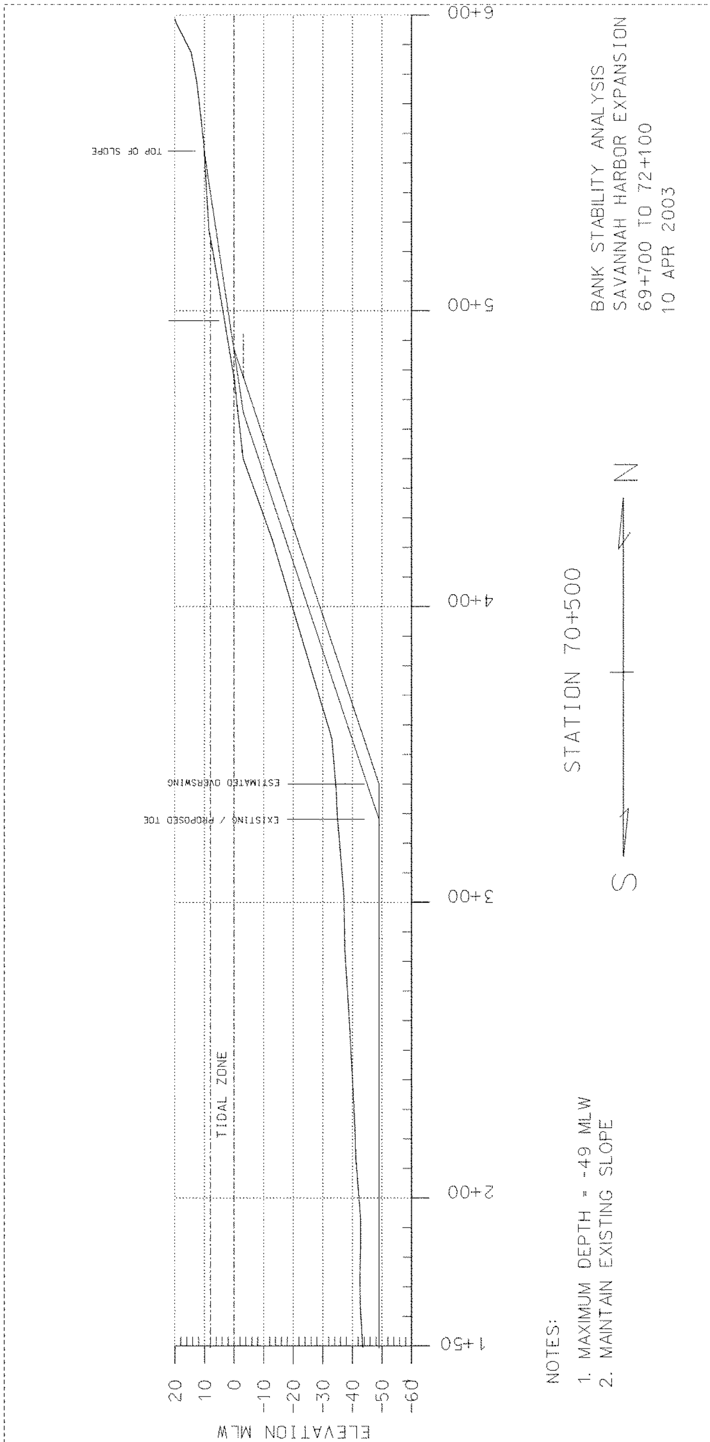
**Channel Station 88+000**

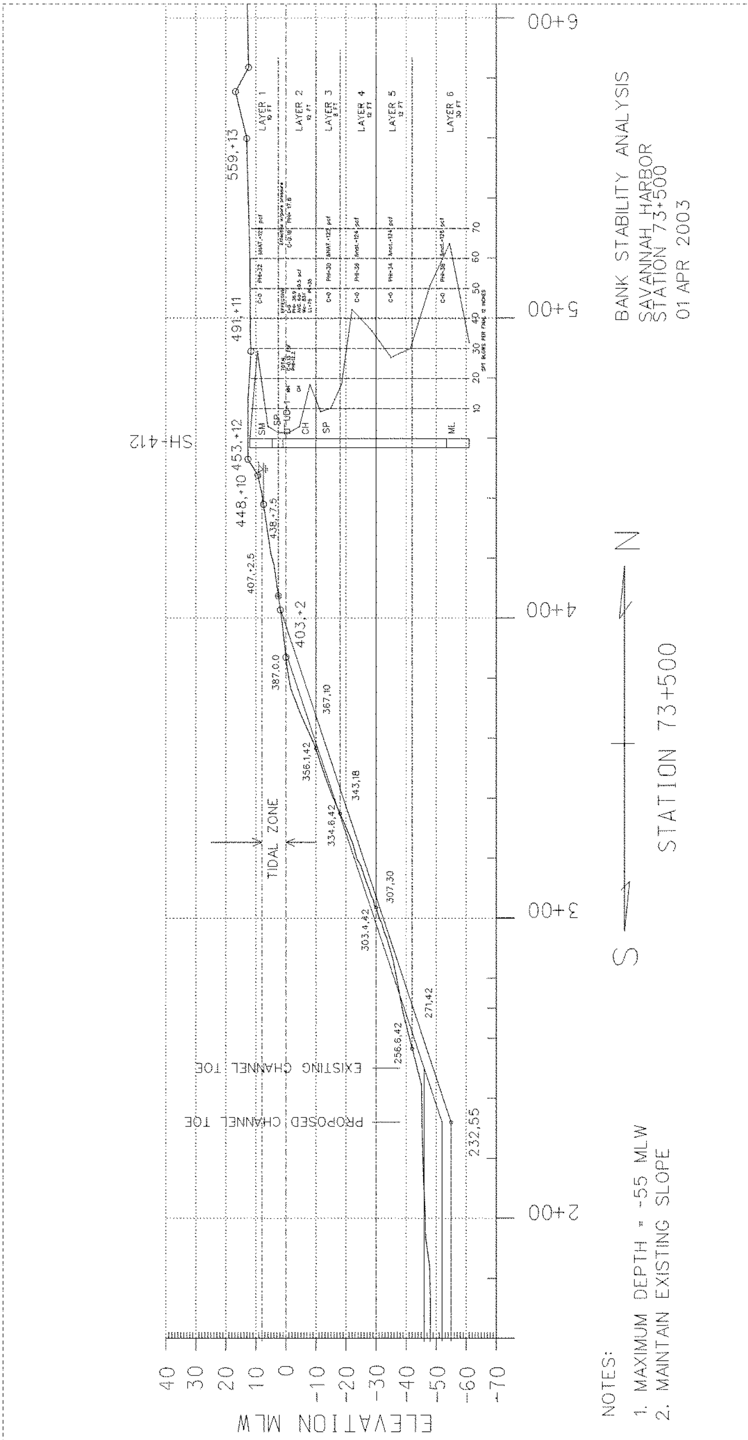
**Channel Station 96+500**

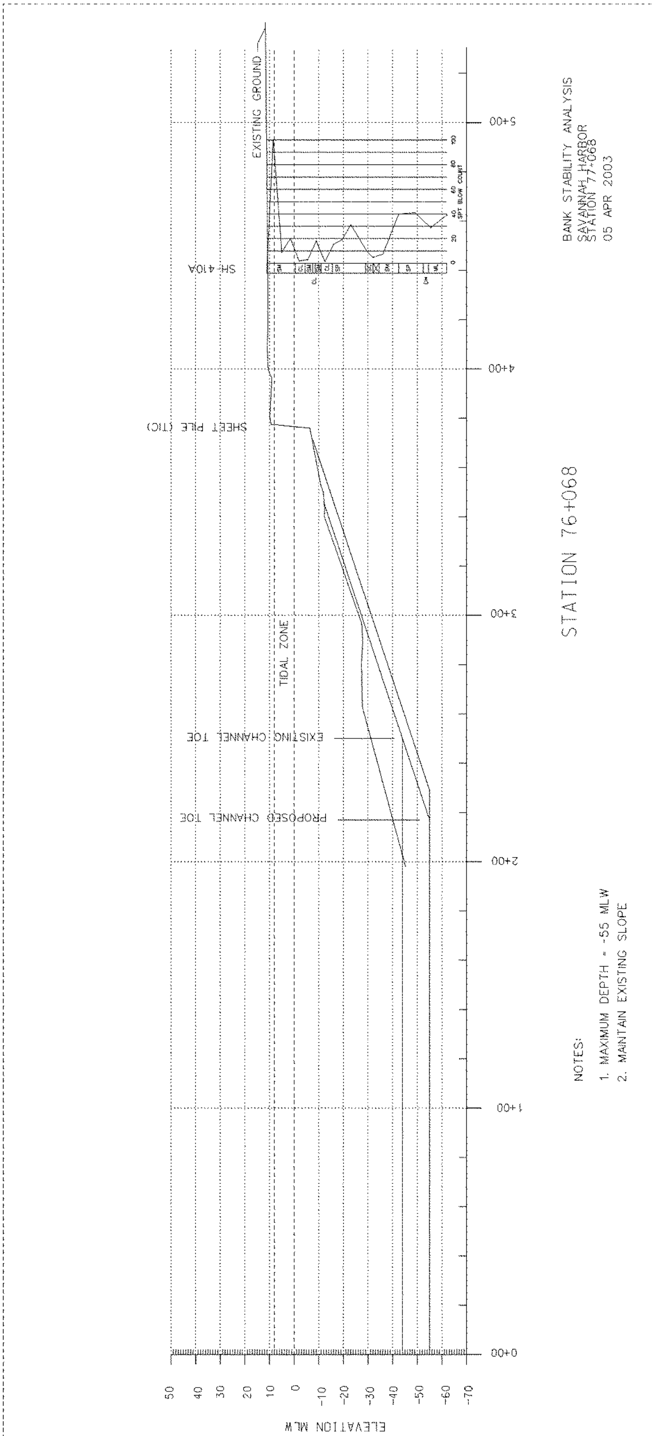
**Channel Station 98+605**

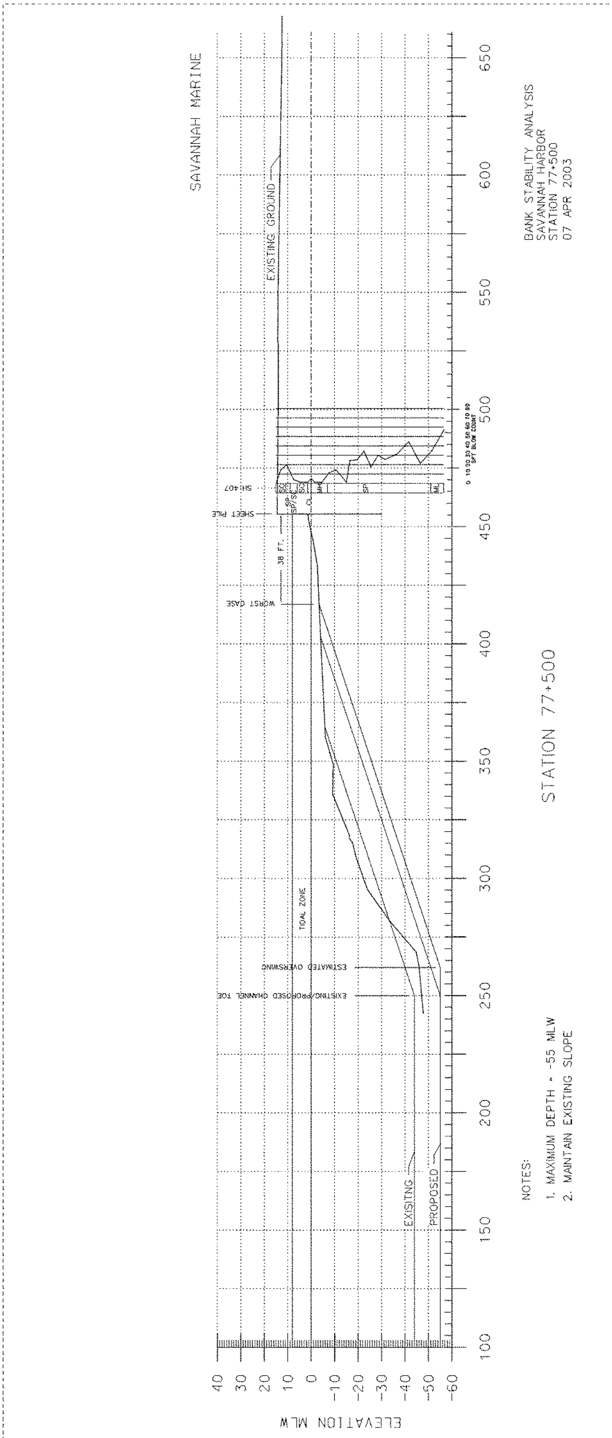
**Channel Station 101+887**

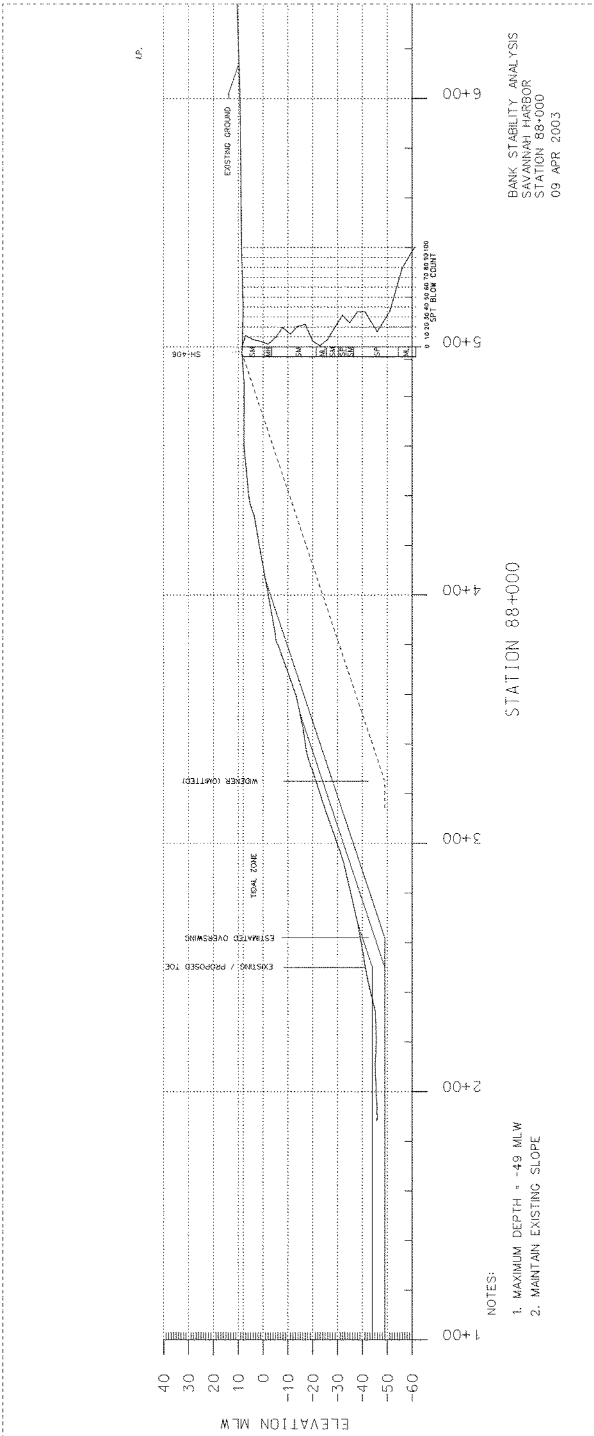

STATION 66+250
SAVANNAH HARBOR EXPANSION
BELOW WOOD CHIP FACILITY
20 FEB 2003 - JDH
ELEVATION MLW
SH-411
DMT & CPT 411
TIDAL ZONE
EXISTING GROUND
PROPOSED CURVE WIDENER
PROJECTED SLOPE
ESTIMATED OVERSWING
12' WIDE
EXISTING CHANNEL SOUTH TOE
PROPOSED CHANNEL TOE
SM
MH
CH
SM
SP
phi=32, c=0
phi=34, c=0
phi=34, c=0
SPT BLOWS
PASSIVE
START
ACTIVE
N
S
5+00
6+00
7+00
8+00
NOTE:
1. MAXIMUM DEPTH IS 57 MLW
2. OVERSWING OF PROPOSED TOE ESTIMATED AT 12 FEET

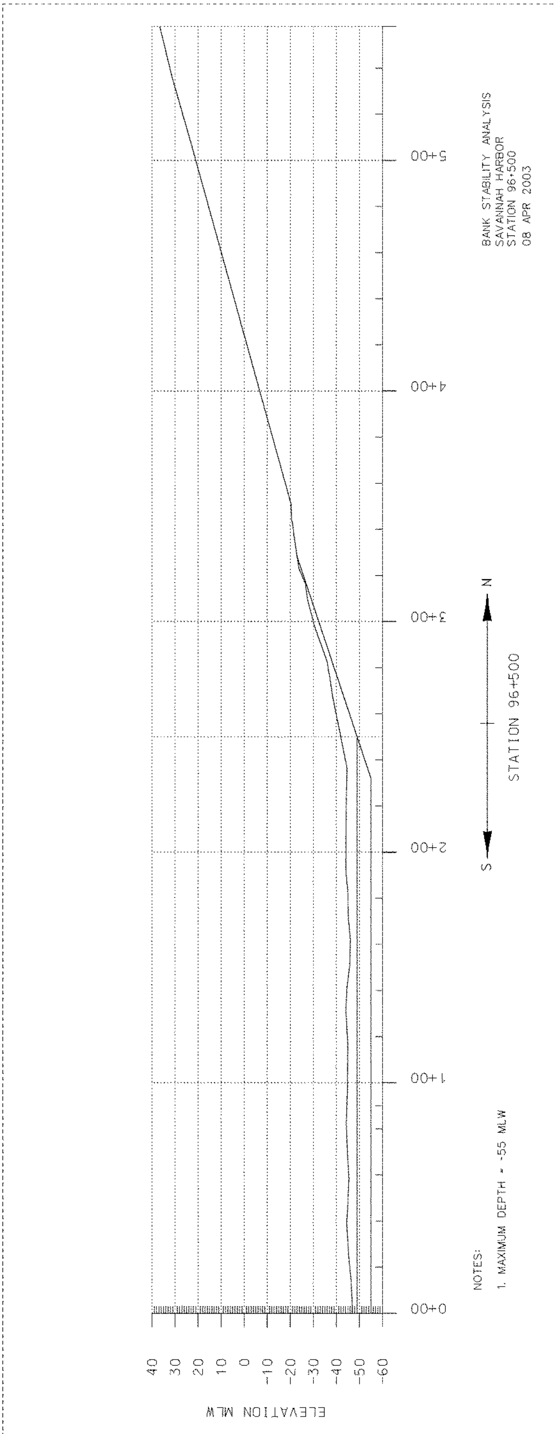

BANK STABILITY ANALYSIS
SAVANNAH HARBOR EXPANSION
69+700 TO 72+100
10 APR 2003
STATION 70+500
S
N
TOP OF SLOPE
ESTIMATED OVERSWING
EXISTING / PROPOSED TOE
TIDAL ZONE
ELEVATION MLW
20
10
0
-10
-20
-30
-40
-50
-60
1+50
2+00
3+00
4+00
5+00
6+00
NOTES:
1. MAXIMUM DEPTH = -49 MLW
2. MAINTAIN EXISTING SLOPE

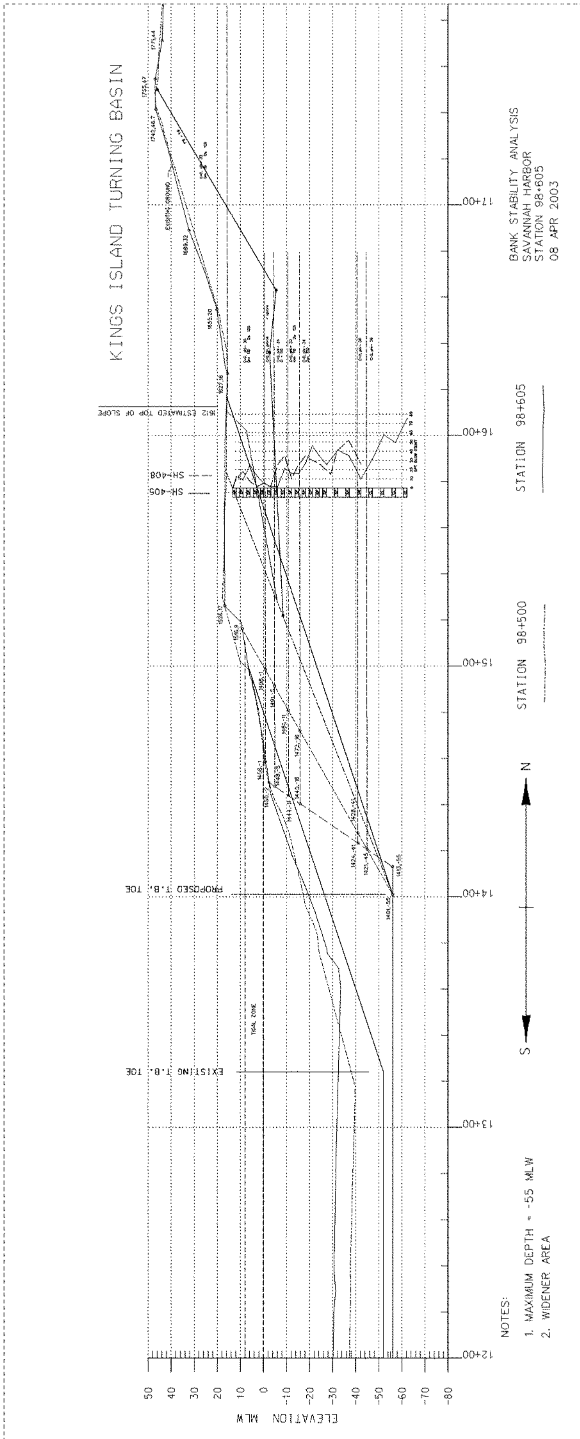

BANK STABILITY ANALYSIS
SAVANNAH HARBOR
STATION 73+500
01 APR 2003
STATION 73+500
S
N
ELEVATION MLW
TIDAL ZONE
EXISTING CHANNEL TOE
PROPOSED CHANNEL TOE
SH-412
LAYER 1
LAYER 2
LAYER 3
LAYER 4
LAYER 5
LAYER 6
SM
SP
CH
ML
2+00
3+00
4+00
5+00
6+00
559,+13
491,+11
453,+12
448,+10
438,+7.5
407,+2.5
403,+2
387,0.0
367,10
356,1,42
343,18
334,6,42
307,30
303,4,42
271,42
256,6,42
232,55
NOTES:
1. MAXIMUM DEPTH = -55 MLW
2. MAINTAIN EXISTING SLOPE

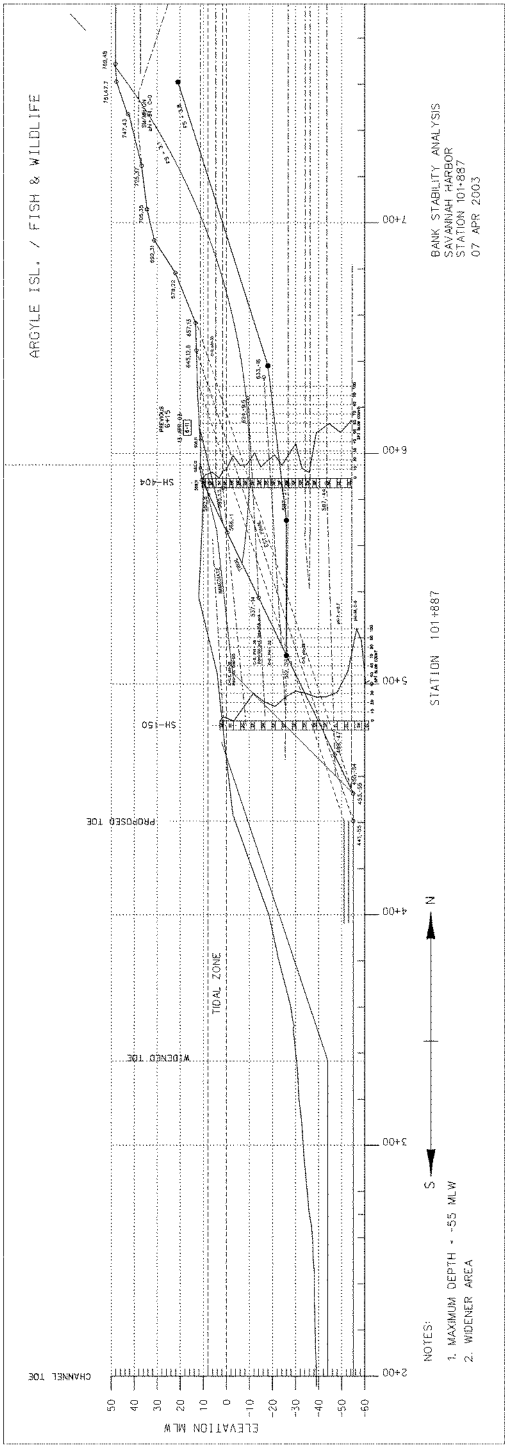

EXISTING GROUND
SH-410A
SPT BLOW COUNT
SHEET PILE (TIC)
TIDAL ZONE
EXISTING CHANNEL TOE
PROPOSED CHANNEL TOE
STATION 76+068
BANK STABILITY ANALYSIS
SAVANNAH HARBOR
STATION 77+068
05 APR 2003
NOTES:
1. MAXIMUM DEPTH - -55 MLW
2. MAINTAIN EXISTING SLOPE
ELEVATION MLW
50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70
0+00 1+00 2+00 3+00 4+00 5+00


SAVANNAH MARINE
EXISTING GROUND
BANK STABILITY ANALYSIS
SAVANNAH HARBOR
STATION 77+500
07 APR 2003
SPT BLOW COUNT
SH-407
SHEET PILE
38 FT.
WORST CASE
TIDAL ZONE
ESTIMATED OVERSWING
EXISTING/PROPOSED CHANNEL TOE
STATION 77+500
NOTES:
1. MAXIMUM DEPTH = -55 MLW
2. MAINTAIN EXISTING SLOPE
EXISITNG
PROPOSED
ELEVATION MLW
40 30 20 10 0 -10 -20 -30 -40 -50 -60
100 150 200 250 300 350 400 450 500 550 600 650


BANK STABILITY ANALYSIS
SAVANNAH HARBOR
STATION 88+000
09 APR 2003
STATION 88+000
ELEVATION MLW
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1+00
2+00
3+00
4+00
5+00
6+00
EXISTING GROUND
SPT BLOW COUNT
SH-406
WIDENER (OMITTED)
TIDAL ZONE
ESTIMATED OVERSWING
EXISTING / PROPOSED TOE
NOTES:
1. MAXIMUM DEPTH = -49 MLW
2. MAINTAIN EXISTING SLOPE


BANK STABILITY ANALYSIS
SAVANNAH HARBOR
STATION 96+500
08 APR 2003
STATION 96+500
N
S
NOTES:
1. MAXIMUM DEPTH - -55 MLW
ELEVATION MLW
40
30
20
10
0
-10
-20
-30
-40
-50
-60
0+00
1+00
2+00
3+00
4+00
5+00


KINGS ISLAND TURNING BASIN
BANK STABILITY ANALYSIS
SAVANNAH HARBOR
STATION 98+605
08 APR 2003
STATION 98+605
STATION 98+500
S
N
NOTES:
1. MAXIMUM DEPTH = -55 MLW
2. WIDENER AREA
ELEVATION MLW
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
12+00
13+00
14+00
15+00
16+00
17+00
EXISTING T.B. TOE
PROPOSED T.B. TOE
SH-405
SH-408
1612 ESTIMATED TOP OF SLOPE
TIDAL ZONE
EXISTING GROUND


ARGYLE ISL. / FISH & WILDLIFE
BANK STABILITY ANALYSIS
SAVANNAH HARBOR
STATION 101+887
07 APR 2003
STATION 101+887
NOTES:
1. MAXIMUM DEPTH = -55 MLW
2. WIDENER AREA
ELEVATION MLW
CHANNEL TOE
WIDENED TOE
PROPOSED TOE
TIDAL ZONE
SH-150
SH-404
N
S
2+00
3+00
4+00
5+00
6+00
7+00

# APPENDIX E

# SLOPE DATA
# INPUT & OUTPUT

# SLOPE DATA INPUT AND OUTPUT

**Depth Requirements**

**Soil Boring Analyses**

**Trial Setup - Station 66+250**

**Trial Setup - Station 98+500**

**Trial Setup - Station 101+887**

**UTexas3 Input File Station 98+605**

**UTexas3 Output File Station 98+605**

**UTexas3 Input File Station 101+887**

**UTexas3 Output File Station 101+887**

**UTexas3 Input File Station 101+887 Circular Arc**

**UTexas3 Output File Station 101+887 Circular Arc**

**Note:**
**The Annual Survey Sheets, Aerial photos, River Soundings, and River Borings have not been included in this report. These files are over 6 gigabits in size and should be available either on our GIS database or in paper form, upon request.**

**Savannah Harbor Depths**

| Station | Project Depth (feet below MLW) | Advance Maintenance (feet) | Allowable Overdepth (feet) | Disturbed Depth (feet) | Total O&M Dredging Depth (feet below MLW) | Channel Deepening: 2-Foot Improvement | Channel Deepening: 4-Foot Improvement | Channel Deepening: 6-Foot Improvement |
|---|---|---|---|---|---|---|---|---|
| 60+000B TO 14+000B | 44 | 0 | 2 | 3 | 49 | 51 | 53 | 55 |
| 14+000B TO 0+000B | 42 | 2 | 2 | 3 | 49 | 51 | 53 | 55 |
| 0+000B TO 24+000 | 42 | 2 | 2 | 3 | 49 | 51 | 53 | 55 |
| 24+000 TO 35+000 | 42 | 4 | 2 | 3 | 51 | 53 | 55 | 57 |
| 35+000 TO 37+000 | 42 | 6 | 2 | 3 | 53 | 55 | 57 | 59 |
| 37+000 TO 70+000 | 42 | 4 | 2 | 3 | 51 | 53 | 55 | 57 |
| 70+000 TO 102+000 | 42 | 2 | 2 | 3 | 49 | 51 | 53 | 55 |
| 102+000 TO 103+000 | 42 | 0 | 2 | 3 | 47 | 49 | 51 | 53 |
| 103+000 TO 105+500 | 36 | 2 | 2 | 3 | 43 | 45 | 47 | 49 |
| 105+500 TO 112+500 | 30 | 2 | 2 | 3 | 37 | 39 | 41 | 43 |
| | | | | | | | | |
| OYSTER ISLAND TURNING BASIN | 40 | 0 | 2 | 3 | 45 | | | |
| ELBA ISLAND TURNING BASIN | 38 | 0 | 2 | 3 | 43 | | | |
| FIG ISLAND TURNING BASIN | 34 | 4 | 2 | 3 | 43 | | | |
| MARSH ISLAND TURNING BASIN | 34 | 0 | 2 | 3 | 39 | | | |
| KINGS ISLAND TURNING BASIN | 42 | 8 | 2 | 3 | 55 | | | |
| ARGYLE ISLAND TURNING BASIN | 30 | 0 | 2 | 3 | 35 | | | |
| PORT WENTWORTH TURNING BASIN | 30 | 0 | 2 | 3 | 35 | | | |
| | | | | | | | | |
| SEDIMENT BASIN | 40 | 0 | 2 | 3 | 45 | | | |
| 0 to 2+000 | 38 | 0 | 2 | 3 | 43 | | | |
| | | | | | | | | |
| **ENV APPROVED BUT NOT CONSTRUCTED** | | | | | | | | |
| OYSTER ISLAND TURNING BASIN | | 4 | | | | | | |
| ELBA ISLAND TURNING BASIN | | 8 | | | | | | |
| FIG ISLAND TURNING BASIN | | 12 | | | | | | |
| MARSH ISLAND TURNING BASIN | | 8 | | | | | | |
| ARGYLE ISLAND TURNING BASIN | | 0 | | | | | | |
| PORT WENTWORTH TURNING BASIN | | 0 | | | | | | |
| SEDIMENT BASIN | | 6 | | | | | | |

## SOIL BORING ANALYSES LOCATIONS / PRELIMINARY ASSESSMENT

31 January 2002

1. The existing Savannah Harbor is approximately 32 miles long (along the centerline of the channel), stretching from the Atlantic Ocean to the former New Cut Channel (Channel Stations –60+000 to 103+000). The Savannah Harbor Expansion Project proposes to add 25,000 feet of outer channel (New Channel Stations (-60+000 to -85+000), widen selected turns within the inner harbor, and enlarge the existing Kings Island Turning Basin (Inner harbor). The outer channel work does not impact privately owned real estate. The inner harbor, for the purpose of this study, shall be described as being all reaches from Channel Station 0+000 to 103+000. There is approximately 20 miles of land on each side of the river (approximately 40 miles of river banks), and many properties that could be affected by the project depending, in part, on the proximity of the land to the proposed channel deepening and/or widening. The Corps of Engineers does not recommend taking soil samples from all properties located along the Savannah River and in the Savannah Harbor.

2. The publications by the Department of the Army, Corps of Engineers, Office of the Chief Engineers entitled "Engineering and Design, Geotechnical Investigations," EM 1110-1-1804 (29 February 1984) and "Soil Sampling," EM 1110-2-1907, are the primary sources on how to take soil samples. These engineering manuals indicate how to take the samples, but do not identify with any specificity the locations where samples must be taken. There are no regulations, internal guidelines, policies or other directives that specify the conditions under which soil samples must be obtained or the properties from which soil samples must be taken. The designing soils engineer has the discretion to decide, based on his or her best judgment as an engineer, the locations where it will be necessary to take soil samples for analysis.

3. The soils engineering staff for the Corps of Engineers is responsible for determining where soil samples for slope stability and demolition purposes will be taken in connection with the Savannah Harbor Expansion Project. During the course of determining the locations where it would be necessary for the Corps of Engineers to take soil samples for analysis, we considered the following factors: 1) the proximity of a property to the proposed project, 2) the type of material likely to be encountered (as obtained from past soil borings in the vicinity), 3) the slope of the riverbank, 4) the configuration of the existing channel, 5) hydrographic surveys, 6) topographic surveys and aerial photographs, 7) the configuration of the proposed navigation channel, 8) whether the proposed channel intersects with adjacent property, 9) the proposed method of dredging, 10) the available budget, 11) the cost of taking and analyzing soil borings,[1] and 12) the likelihood that soil sample analysis will yield necessary information. In

[1] The cost of a soil boring, including laboratory testing and analysis, and subsequent analysis of the drilling and test results, varies from approximately $10,000.00 to $12,500.00, per boring.

addition, we considered historic information, including: 1) most recent surveys, 2) problems arising out of most recent dredging projects, and 3) historic structures and artifacts.

4. In connection with the Savannah Harbor Expansion Project, we also conducted site inspections of all areas that could be affected by the project, by boat and by land. Documentation, photographs, and comment from the most recent inspections are contained in Memorandum For Record dated 06 December 2001, Subject: Trip Report, Savannah Harbor Expansion, Savannah, GA; Inspection of Dock Structures, Inner Harbor.

5. The decision whether to test certain property is based on an analysis of the above factors, and not the ownership of the property. The taking of soil samples, like any other expenditure in connection with a harbor expansion project, must be justifiable. Engineering judgment is used to determine the locations where the taking of soil samples will yield necessary information.



6. Soil borings and samples were taken during preliminary study analysis which will need to be augmented based on the now proposed channel configuration, and again (possibly) augmented after final model studies have been completed. Each of the following areas represents a 'taking' or real estate acquisition necessary to accommodate proposed channel widening. Areas which are known to involve 'taking' by virtue of direct intersection of proposed work to the existing channel/river configuration or where there is some question regarding existing bulkhead and/or channel bank stability are 1) Argyle Island between Channel Stations 101+000 and 103+000, 2) Kings Island Turning Basin between Channel Stations 98+700 and 100+500, 3) International Paper, northeast riverbank, between Channel Stations 87+450 and 89+500, 4) Savannah Marine Services and the former Graham Radio Corp. Property, Channel Stations 77+250 to 77+650, 5) T.I.C., Channel Stations 76+000 to 76+200, and 6) Property located at or adjacent to Wood Chip Exporting Corp., Channel Stations 65+950 to 66+200. Each of the above described areas either have been or will be investigated with regard to subsurface condition, profiles, material strength and bank stability.

7. Areas of concern that do not involve a direct intersection of the proposed project to the existing river configuration, and are recommended for soil testing are listed in the following:

a. Hutchinson/Fig Island between the U.S. Army Corps of Engineers Yard and Slip No.1, known as an archeological site consisting of soft fill materials and old ship/boat wrecks (Approximate Channel Stations 72+700 to 73+700). This area is recommended for subsurface exploration and testing to better determine bank stability with regard to the proposed project.

b. South Channel Training Wall, Elba Island side, Channel Stations 50+000 to 51+700, and near Southern Energy Corporation's natural gas pipeline crossing. Channel widening proposed along this reach will likely involve debris and/or training wall (or remnant) removal. Exploratory investigation is planned to determine size and extent of possible debris removal.

c. The extended bar channel area from -60+000 to -85+000. While not of concern to adjacent properties (none), subsurface sampling and testing will be performed to determine the character of materials proposed for removal.

d. Other areas are subject to subsurface testing and analysis. Such include aquifer studies for salt-water intrusion, which are considered beyond the scope of this writing.

8. Problematic areas exist that involve deteriorated, broken and/or highly questionable structures with regard to their stability and are located near or adjacent to the proposed project. These areas are not recommended for subsurface study, but will need to be addressed as separate issues. Each is listed in the following:

a. Cantilevered Parking Lot and Dock Facility (Owner: Sylvan Byck) located between Moran Towing and the eastern end of the original Rousakis Plaza, located opposite the Shrimp Factory on River Street, and approximately between Channel Stations 74+270 and 74+400. The foundation for the cantilevered concrete parking area consists of wood piling. As noted in the trip report dated 06 December 2001, a gap or open area exists that varies from about 1 foot to less than 1 foot between the pile tops and the concrete, depending on pile location. Given the relatively good condition of the pile tops, it is surmised that repeated loading and unloading of the parking lot has subsequently driven the piles into supporting soils beyond the depth that piles were originally installed. In any case, the gap between the pile tops and supporting concrete indicates a pile bearing failure that leaves the concrete section free to flex and move within existing constraints. Repeated movement or flexing of the concrete structure could lead to (if not already) structural problems for the parking facility. This facility in its present condition requires substantial foundation repair(s).

With regard to the proposed harbor expansion, it should be noted that over-swing normally associated with pipeline dredging (estimated at approximately 4 to 6 feet) could lead to an approximate loss of 2 feet of channel side slope soil material that currently helps support the outermost piling. While true for the outermost piles, the estimated 2 feet of possible material loss is unlikely to have an appreciable effect on remaining interior piles. In addition, it is noted that the same amount of remedial or repair work will be required, with or without the harbor expansion project.

Subsurface sampling and testing in this area isn't likely to yield any new or useful information with regard to the facility and therefore is not recommended. It is recommended that the property owner be advised of the foundation conditions discovered before actual dredging occurs

b. International Paper (formerly Union Camp), southwest side, located between Channel Stations 87+500 and 89+600. The sheet-piling bulkhead contains numerous holes approximately 1-foot square in size at or near the zero mlw elevation. It is unclear whether these holes have been cut deliberately (given the near uniform hole sizes), perhaps as a previous drainage effort, or if the holes are the result of long term pile corrosion at the low water mark.

With regard to the proposed project in this vicinity, the resulting side slope from project dredging is not expected to change or alter existing conditions directly adjacent to the bulkhead. The above expectation is based on the distance of the bulkhead from the proposed channel work and considering usual dredging practices.

Subsurface sampling and testing in this area is not likely to yield any new or useful information with regard to the facility or project and therefore is not recommended. However, it is recommended that the property owner be advised of the bulkhead conditions discovered during our site inspection.

c. Crescent Towing and Salvage Company approximately located between Channel Stations 75+500 and 75+800. Crescent's brick wall and brick retaining wall structures appear to be supported or partially supported on wood piling. The wall is severely cracked, with portions of the wall either removed, or broken and subsequently fallen into the river. The wood piling behind the brick wall and supporting the dock facility appears to exist in a fair to good condition.

With regard to the proposed project and the Crescent property, the harbor expansion could have some effect on the stability of the brick wall and supporting piles. While it is not recommend that sampling and testing be performed solely for this facility, testing and sampling is currently planned for Crescent's neighboring facility, T.I.C., located approximately 400 feet upstream. Given the contiguous nature and similar histories for this reach, the sampling, testing and analysis currently planned should be considered sufficient and cost effective. The results of the analysis for the reach between Channel Stations 75+500 and 76+250 will be applied to the landmass / riverbank without regard to who owns which part. Any subsequent recommendations will be addressed after analysis has been completed.

d. East Coast Terminal Company, approximate Channel Stations 68+000 to 69+700. Observations reveal the supporting foundation for the dock facility at East Coast Terminal exists in an advanced state of deterioration and disrepair. This includes piling, pile bracing, wood retaining structures and portions of the concrete deck.

With regard to the proposed project in this vicinity, the resulting side slope from project dredging is not expected to change or alter existing conditions adjacent to the East Coast dock facility. This conclusion is based on the distance of the dock from the proposed channel work (80 to 120 feet) and considered usual dredging practices.

Subsurface sampling and testing in this area is not is not recommended. However, it is recommended that the property owner be advised of the dock facility foundation conditions discovered during our site inspection.

9. The remaining properties, structures and/or other items within the scope of the proposed harbor expansion exists in or belongs to one of the following conditions:

a. Located by sufficient distances from the proposed work so as not to be impacted and are not recommended for sampling and testing of soil materials or further studies.

b. Located near, but outside, the proposed work and exist in an excellent to good condition. Sampling and testing in the vicinity of such facilities will not provide any useful information with regard to the proposed work and such sampling and testing is not recommended.

c. Is currently under design for remediation / repair of structural facilities to be implemented as an item separate from the proposed project. i.e. Old Fort Jackson moat and bank protection.

d. Belongs to a group or class probably best described as obstructions and are being addressed as separate issues. i.e. CSS Georgia, sunken barges, training wall(s), etc..

SAVANNAH HARBOR EXPANSION - STATION 66+250
SLOPE STABILTY 09 APRIL 2003

Trial Surface 1 - Worksheet

| X | Y | DESCRIPTION | C | phi | Dm | Ds |
|---|---|---|---|---|---|---|
| 0 | -57 | | | | | |
| 473 | -57 | | | | | |
| 485 | -57 | | | | | |
| 501 | -52 | SM | 0 | 38 | 118 | 126 |
| 527 | -43 | | | | | |
| 540 | -40 | SP | 0 | 34 | 118 | 126 |
| 560 | -37.3 | | | | | |
| 600 | -32.4 | | | | | |
| 645 | -21.1 | SC | 0.2 | 28 | 115 | 125 |
| 653 | -17.8 | | | | | |
| 676 | -4.6 | TOP CH | 0.071 | 30 | 58 | 90 |
| 681 | -3 | | | | | |
| 732 | 1.6 | | | | | |
| 756 | 4.5 | CH | 0.12 | 14 | 91 | 95 |
| 806 | 9.5 | SM | 0 | 32 | 115 | 123 |
| 822 | 9.6 | | | | | |
| 843 | 8.9 | | | | | |
| 890 | 10.2 | | | | | |

| | | |
|---|---|---|
| Embankment Water Level @ 5.0, Intersection @ | 756 | 4.5 |
| Channel Water Level taken at 0.0, Intersects @ | 714 | |

PH Input Line

| | |
|---|---|
| 0 | 0 |
| 714 | 0 |
| 756 | 4.5 |
| 1100 | 5 |

NE (Start Neutral Block, Size/Location)

| Active Side | | Passive Side | | Control | Act Inc | Pass Inc. | Vert Inc. |
|---|---|---|---|---|---|---|---|
| 670 | -35 | 645 | -35 | -2 | 5 | 5 | 2 |

SAVANNAH HARBOR EXPANSION - STATION 98+500
SLOPE STABILTY 09 APRIL 2003

Trial Surface 1 - Worksheet

| X | Y | DESCRIPTION | C | phi | Dm | Ds |
|---|---|---|---|---|---|---|
| 0 | -55 | | | | | |
| 1401 | -55 | | | | | |
| 1413 | -55 | | | | | |
| 1421 | -45 | CL | 0 | 36 | 120 | 128 |
| 1424 | -41 | SM | 0 | 32 | 118 | 126 |
| 1440 | -16 | SP | 0 | 34 | 115 | 125 |
| 1444 | -11 | SP | 0 | 30 | 115 | 125 |
| 1448 | -5 | CH / SC | 0 | 34 | 115 | 124 |
| 1450 | -2 | | | | | |
| 1458 | -1 | TOP CH | 0.12 | 14 | 91 | 95 |
| 1516 | 9 | | | | | |
| 1526 | 17 | | | | | |
| 1627 | 16 | TOP SM - SP | 0 | 30 | 115 | 122 |
| 1655 | 20 | | | | | |
| 1689 | 32 | | | | | |
| 1742 | 46.7 | SM / MH / OH | 0 | 32 | 115 | 125 |
| 1755 | 47 | | | | | |
| 1771 | 44 | | | | | |
| 1805 | 42 | | | | | |

Embankment Water Level @ 5.0, Intersection @ 1509
Channel Water Level taken at 0.0, Intersects @ 1500

PH Input Line

| | |
|---|---|
| 0 | 0 |
| 1500 | 0 |
| 1509 | 5 |
| 2000 | 9 |

NE (Start Neutral Block, Size/Location)

| Active Side | | Passive Side | Control | Act Inc | Pass Inc. | Vert Inc. |
|---|---|---|---|---|---|---|
| 1475 | -14 | 1465 | -14 | -2 | 5 | 5 | 2 |

SAVANNAH HARBOR EXPANSION - STATION 101+887
SLOPE STABILTY 09 APRIL 2003

Trial Surface 1 - Worksheet

| X | Y | DESCRIPTION | C | phi | Dm | Ds |
|---|---|---|---|---|---|---|
| 0 | -55 | | | | | |
| 441 | -55 | | | | | |
| 453 | -55 | | | | | |
| 455 | -54 | SM/SC/CL | 0 | 38 | 118 | 126 |
| 469 | -47 | CL | 0.7 | 7 | 91 | 96 |
| 512 | -26 | SP | 0 | 38 | 118 | 126 |
| 537 | -14 | SP | 0 | 32 | 115 | 125 |
| 566 | -1 | SM / SP | 0 | 36 | 120 | 128 |
| 582 | 8 | SC | 0.2 | 28 | 115 | 125 |
| 588 | 11 | | | | | |
| 593 | 12 | | | | | |
| 606 | 11 | TOP SM - SP | 0 | 30 | 115 | 122 |
| 657 | 13 | | | | | |
| 678 | 22 | | | | | |
| 692 | 31 | | | | | |
| 706 | 35 | | | | | |
| 725 | 37 | | | | | |
| 747 | 43 | | | | | |
| 761 | 47.7 | SM / MH / OH | 0 | 34 | 115 | 125 |
| 769 | 48 | | | | | |
| 902 | 48 | | | | | |
| 940 | 43 | | | | | |
| 1100 | 43 | | | | | |

Embankment Water Level @ 5.0, Intersection @ 577
Channel Water Level taken at 0.0, Intersects @ 566

PH Input Line

| | |
|---|---|
| 0 | 0 |
| 566 | 0 |
| 577 | 5 |
| 1100 | 30 |

NE (Start Neutral Block, Size/Location)

| Active Side | | Passive Side | | Control | Act Inc | Pass Inc. | Vert Inc. |
|---|---|---|---|---|---|---|---|
| 536 | -34 | 526 | -34 | -2 | 5 | 5 | 2 |

```
HEADING
  Kings Island Turning Basin, Station 98+605, Savannah, Georgia
  End of construction loading
  Single circular loading
PROFILE LINES
  1  1  Top Spoil Material
  1771  44
  2000  44

  2  2  Top DA Dike (SM-SC)
  1627  16.0
  1655  20.0
  1689  32.0
  1742  46.7
  1755  47.0
  1800  30.0
  1840  20.0
  1900  17.0

  3  3  Directly Beneath Dike & Spoil Area
  1498  17.0
  1526  17.0
  1627  16.0
  2000  16.0

  4  4  Soft River Bank Material
  1458  -1.0
  2000  -1.0

  5  5  Underlying Softer (SC) (Old marsh deposits)
  1481  -5.0
  2000  -5.0

  6  6  Sands & Sand Clay (SM-SC)
  1472 -11.0
  2000 -11.0

  7  7  Medium Dense Sands
  1428  -16.0
  2000  -16.0

  8  8  Dense Sands
  1421  -41.0
  2000  -41.0

  9 9   Dense Sand
     0  -45.0
  2000  -45.0


MATERIAL PROPERTIES
  1  Spoil
    98 = unit weight
   Conventional shear strength
     0 16
   NO pore pressures
  2  Sand (Dike)
   125 = unit weight
   Conventional shear strength
    0   32
   NO pore pressures
  3  Sand
   122 = unit weight
```

```
   Conventional shear strength
    0  30
   NO pore pressures
  4  Upper Embankment lean clay and clayey sand
    95 = unit weight
   Conventional shear strength
    20  14
   NO pore pressures
  5 Soft SC
   111.8 = unit weight
   Conventional shear strength
    80  12.6
   NO pore pressures
  6 Medium sand
   125 = unit weight
   Conventional shear strength
    0  30
   NO pore pressures
  7 Med Dense Sand
   120 = unit weight
   Conventional shear strength
   0  34
   NO pore pressures
  8 Dense Sand
   126 = unit weight
   Conventional shear strength
   0  32
   NO pore pressures
  9 Dense Sand
   128 = unit weight
   Conventional shear strength
   0  36
   NO pore pressures

SURFACE PRESSURES
    0 -55.0      0  0
 1413 -55.0      0  0
 1421 -45.0   2810  0
 1428 -41.0   2560  0
 1472 -16.0   1002  0
 1481 -11.0    688  0
 1526  17.0      0  0
 1627  16.0      0  0
 1655  20.0      0  0
 1689  32.0      0  0
 1742  46.7      0  0
 1755  47.0      0  0
 1771  44.0      0  0
 2000  44.0      0  0

SLOPE GEOMETRY
    0 -55.0
 1413 -55.0
 1421 -45.0
 1428 -41.0
 1472 -16.0
 1481 -11.0
 1526  17.0
 1627  16.0
 1655  20.0
 1689  32.0
 1742  46.7
 1755  47.0
```

```
 1771  44.0
 2000  44.0

ANALYSIS/COMPUTATION
  NonCircular Search
  1500.0, -22
  1640.0, -22
  1660.0, -6
  1750.0, 46

  10, 60
  ITErations
   500
  WATER DEPTH
   4.0
  FACTOR OF SAFETY
   16.0
  CHANGE TRIAL FACTOR

COMPUTE
ASCII
PRINT
```

TRIAL -4- 12 APR 2003

```
1          UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
           Date:  4:12:2003   Time: 16:17:18   Input file: kitb9


           TABLE NO. 1
           ******************************************
           * COMPUTER PROGRAM DESIGNATION - UTEXAS3 *
           * Originally Coded By Stephen G. Wright  *
           * Version No. 1.120                      *
           * Last Revision Date 10/08/92            *
           * (C) Copyright 1985-1992 S. G. Wright   *
           * All Rights Reserved                    *
           ******************************************

           **************************************************************
           *                                                            *
           *      RESULTS OF COMPUTATIONS PERFORMED USING THIS COMPUTER *
           * PROGRAM SHOULD NOT BE USED FOR DESIGN PURPOSES UNLESS THEY *
           * HAVE BEEN VERIFIED BY INDEPENDENT ANALYSES, EXPERIMENTAL   *
           * DATA OR FIELD EXPERIENCE. THE USER SHOULD UNDERSTAND THE   *
           * ALGORITHMS AND ANALYTICAL PROCEDURES USED IN THE COMPUTER  *
           * PROGRAM AND MUST HAVE READ ALL DOCUMENTATION FOR THIS      *
           * PROGRAM BEFORE ATTEMPTING ITS USE.                         *
           *                                                            *
           *      NEITHER THE UNIVERSITY OF TEXAS NOR STEPHEN G. WRIGHT *
           * MAKE OR ASSUME LIABILITY FOR ANY WARRANTIES, EXPRESSED OR  *
           * IMPLIED, CONCERNING THE ACCURACY, RELIABILITY, USEFULNESS  *
           * OR ADAPTABILITY OF THIS COMPUTER PROGRAM.                  *
           *                                                            *
           **************************************************************
1          UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
           Date:  4:12:2003   Time: 16:17:18   Input file: kitb9
             Kings Island Turning Basin, Station 98+605, Savannah, Georgia
             End of construction loading
             Single circular loading

           TABLE NO.  2
           *************************
           * NEW PROFILE LINE DATA *
           *************************

           PROFILE LINE  1 - MATERIAL TYPE =  1
           Top Spoil Material

                Point       X              Y

                  1      1771.000        44.000
                  2      2000.000        44.000

           PROFILE LINE  2 - MATERIAL TYPE =  2
           Top DA Dike (SM-SC)

                Point       X              Y

                  1      1627.000        16.000
                  2      1655.000        20.000
                  3      1689.000        32.000
                  4      1742.000        46.700
                  5      1755.000        47.000
                  6      1800.000        30.000
                  7      1840.000        20.000
```

```
        8      1900.000         17.000

PROFILE LINE  3 - MATERIAL TYPE =  3
Directly Beneath Dike & Spoil Area

     Point       X              Y

        1      1498.000         17.000
        2      1526.000         17.000
        3      1627.000         16.000
        4      2000.000         16.000

PROFILE LINE  4 - MATERIAL TYPE =  4
Soft River Bank Material

     Point       X              Y

        1      1458.000         -1.000
        2      2000.000         -1.000

PROFILE LINE  5 - MATERIAL TYPE =  5
Underlying Softer (SC) (Old marsh deposits)

     Point       X              Y

        1      1481.000         -5.000
        2      2000.000         -5.000

PROFILE LINE  6 - MATERIAL TYPE =  6
Sands & Sand Clay (SM-SC)

     Point       X              Y

        1      1472.000        -11.000
        2      2000.000        -11.000

PROFILE LINE  7 - MATERIAL TYPE =  7
Medium Dense Sands

     Point       X              Y

        1      1428.000        -16.000
        2      2000.000        -16.000

PROFILE LINE  8 - MATERIAL TYPE =  8
Dense Sands

     Point       X              Y

        1      1421.000        -41.000
        2      2000.000        -41.000

PROFILE LINE  9 - MATERIAL TYPE =  9
Dense Sand

     Point       X              Y

        1          .000        -45.000
        2      2000.000        -45.000

All new profile lines defined - No old lines retained
```

```
                  KITB98605.out.txt
  Kings Island Turning Basin, Station 98+605, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO.  3
**********************************************************************
* NEW MATERIAL PROPERTY DATA - CONVENTIONAL/FIRST-STAGE COMPUTATIONS *
**********************************************************************

DATA FOR MATERIAL TYPE  1
Spoil

     Unit weight of material =   98.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -        .000
     Friction angle - - - - -  16.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  2
Sand (Dike)

     Unit weight of material =  125.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -        .000
     Friction angle - - - - -  32.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  3
Sand

     Unit weight of material =  122.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -        .000
     Friction angle - - - - -  30.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  4
Upper Embankment lean clay and clayey sand

     Unit weight of material =   95.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -      20.000
     Friction angle - - - - -  14.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  5
Soft SC

     Unit weight of material =  111.800

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -      80.000
     Friction angle - - - - -  12.600 degrees

     No (or zero) pore water pressures
```

```
DATA FOR MATERIAL TYPE  6
Medium sand

     Unit weight of material =  125.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -         .000
     Friction angle - - - - -  30.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  7
Med Dense Sand

     Unit weight of material =  120.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -         .000
     Friction angle - - - - -  34.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  8
Dense Sand

     Unit weight of material =  126.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -         .000
     Friction angle - - - - -  32.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  9
Dense Sand

     Unit weight of material =  128.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -         .000
     Friction angle - - - - -  36.000 degrees

     No (or zero) pore water pressures

All new material properties defined - No old data retained
1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:12:2003   Time: 16:17:18   Input file: kitb9
  Kings Island Turning Basin, Station 98+605, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 10
*********************************************************************
* NEW SURFACE PRESSURE DATA - CONVENTIONAL/FIRST-STAGE COMPUTATIONS *
*********************************************************************

ALL NEW DATA INPUT - NO OLD DATA RETAINED

Surface Pressures -
                                      Normal        Shear
Point       X            Y           Pressure       Stress
```

| | | | | |
|---|---|---|---|---|
| 1 | .000 | -55.000 | .000 | .000 |
| 2 | 1413.000 | -55.000 | .000 | .000 |
| 3 | 1421.000 | -45.000 | 2810.000 | .000 |
| 4 | 1428.000 | -41.000 | 2560.000 | .000 |
| 5 | 1472.000 | -16.000 | 1002.000 | .000 |
| 6 | 1481.000 | -11.000 | 688.000 | .000 |
| 7 | 1526.000 | 17.000 | .000 | .000 |
| 8 | 1627.000 | 16.000 | .000 | .000 |
| 9 | 1655.000 | 20.000 | .000 | .000 |
| 10 | 1689.000 | 32.000 | .000 | .000 |
| 11 | 1742.000 | 46.700 | .000 | .000 |
| 12 | 1755.000 | 47.000 | .000 | .000 |
| 13 | 1771.000 | 44.000 | .000 | .000 |
| 14 | 2000.000 | 44.000 | .000 | .000 |

```
1         UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
          Date:  4:12:2003   Time: 16:17:18   Input file: kitb9
            Kings Island Turning Basin, Station 98+605, Savannah, Georgia
            End of construction loading
            Single circular loading

          TABLE NO.  9
          ***************************
          * NEW SLOPE GEOMETRY DATA *
          ***************************

          All new data input - No old data retained

          Slope Coordinates -

               Point        X           Y

                 1          .000     -55.000
                 2      1413.000     -55.000
                 3      1421.000     -45.000
                 4      1428.000     -41.000
                 5      1472.000     -16.000
                 6      1481.000     -11.000
                 7      1526.000      17.000
                 8      1627.000      16.000
                 9      1655.000      20.000
                10      1689.000      32.000
                11      1742.000      46.700
                12      1755.000      47.000
                13      1771.000      44.000
                14      2000.000      44.000
1         UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
          Date:  4:12:2003   Time: 16:17:18   Input file: kitb9
            Kings Island Turning Basin, Station 98+605, Savannah, Georgia
            End of construction loading
            Single circular loading

          TABLE NO. 15
          *********************************
          * NEW ANALYSIS/COMPUTATION DATA *
          *********************************

          Noncircular Shear Surface(s)

          Automatic Search Performed


          Coordinates of points on shear surface which are to be shifted -
```

```
Point          X              Y      Shift Angle

   1       1500.000        -22.000   angle to be computed - moveable
   2       1640.000        -22.000   angle to be computed - moveable
   3       1660.000         -6.000   angle to be computed - moveable
   4       1750.000         46.000   angle to be computed - moveable

Initial distance for shifting points on shear surface =  10.000
Maximum steepness permitted for toe of shear surface = 60.00 degrees

Maximum number of iterations allowed for
calculating the factor of safety =  500

Depth of water in crack =       4.000

Initial trial estimate for the factor of safety =  16.000

Initial trial values for factor of safety (and side force inclination
for Spencer's procedure) will be changed during search

---------------------------------------------------------------------
THE FOLLOWING REPRESENT EITHER DEFAULT OR PREVIOUSLY DEFINED VALUES:

Initial trial estimate for side force inclination =  15.000 degrees
(Applicable to Spencer's procedure only)

Allowed force imbalance for convergence =     100.000

Allowed moment imbalance for convergence =     100.000

Number of increments for slice subdivision =   30

Unit weight of water in crack =    62.400

Seismic coefficient =  .000

Conventional (single-stage) computations to be performed

Procedure used to compute the factor of safety: SPENCER
1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:12:2003   Time: 16:17:18   Input file: kitb9
  Kings Island Turning Basin, Station 98+605, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 22
*******************************************
* INITIAL COMPUTED INFORMATION FOR SEARCH *
* WITH NONCIRCULAR SHEAR SURFACE          *
*******************************************

CAUTION - INITIAL TRIAL SHEAR SURFACE IS BELOW SLOPE NEAR
          THE TOE OF THE SLOPE A DISTANCE =      22.82
          SOLUTION WILL BE ERRONEOUS IF THIS DISTANCE IS
          VERY LARGE

Crack depth computed to be - - -       .88

FOR INITIAL TRIAL NONCIRCULAR SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - -     4.056
Side Force Inclination - - - - - - - - -     12.53
Number of Iterations - - - - - - - - - -    27
```

```
TABLE NO. 23
******************************
* SEARCH TRIAL NUMBER    1 *
******************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES =   10.00

                                  1-Stage
                                  Factor
                                   of      Side Force
Point        X          Y         Safety   Inclination   Iterations

   1      1491.51     -27.28 See Message on Next Line(s)
ERROR AT SLICE   2      X =    .150E+04     Y =    -.271E+02

NO PROFILE DATA FOR TOP OF SLICE

   1      1508.49     -16.72   4.395      12.13           4
   2      1636.29     -12.72   3.165      11.60           5
   2      1643.71     -31.28   5.520      13.33           9
   3      1654.33       2.24   4.993      13.50           5
   3      1665.67     -14.24   3.765      11.83           4
   4      1740.03      45.27   4.175      12.39           3
   4      1759.97      45.18 See Message on Next Line(s)
ERROR AT SLICE  40      X =    .176E+04     Y =    .439E+02

NO PROFILE DATA FOR TOP OF SLICE


Maximum distance shifted for new estimate of shear
surface is    10.000 at point   3

Coordinates For New Estimate of Shear Surface

     Point       X           Y

        1     1500.00      -22.00
        2     1636.29      -12.72
        3     1665.67      -14.24
        4     1750.00       46.00

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - -   3.255
Side Force Inclination - - - - - - - - -    11.68
Number of Iterations - - - - - - - - - -   5
```
1

```
UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:12:2003   Time: 16:17:18   Input file: kitb9
  Kings Island Turning Basin, Station 98+605, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 23
******************************
* SEARCH TRIAL NUMBER    2 *
******************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES =   10.00

                                  1-Stage
                                  Factor
                                   of      Side Force
Point        X          Y         Safety   Inclination   Iterations
```

```
   1      1491.51     -27.28 See Message on Next Line(s)
ERROR AT SLICE   2     X =    .150E+04     Y =   -.267E+02

NO PROFILE DATA FOR TOP OF SLICE

   1      1508.49     -16.72   3.269      11.40          3
   2      1636.20      -2.72   2.552      12.42          5
   2      1636.37     -22.71   3.790      11.82          4
   3      1662.53      -4.74   3.158      11.60          3
   3      1668.82     -23.73   3.890      13.46          4
   4      1740.03      45.27   3.363      11.70          3
   4      1759.97      45.18 See Message on Next Line(s)
ERROR AT SLICE  40     X =    .176E+04     Y =    .436E+02

NO PROFILE DATA FOR TOP OF SLICE


Maximum distance shifted for new estimate of shear
surface is    10.000 at point   3

Coordinates For New Estimate of Shear Surface

     Point       X           Y

        1     1500.00      -22.00
        2     1636.20       -2.72
        3     1662.53       -4.74
        4     1750.00       46.00

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - -   2.324
Side Force Inclination - - - - - - - - -    10.89
Number of Iterations - - - - - - - - - -   7
1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:12:2003   Time: 16:17:18   Input file: kitb9
  Kings Island Turning Basin, Station 98+605, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 23
****************************
* SEARCH TRIAL NUMBER    3 *
****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES =   10.00

                               1-Stage
                               Factor
                                 of     Side Force
Point        X          Y      Safety   Inclination   Iterations

   1      1491.51     -27.28 See Message on Next Line(s)
ERROR AT SLICE   2     X =    .150E+04     Y =   -.263E+02

NO PROFILE DATA FOR TOP OF SLICE

   1      1508.49     -16.72   2.175      10.61          4
   2      1635.88       7.28   2.401      13.39          8
   2      1636.53     -12.71   3.160      11.60          5
   3      1660.09       4.96   2.497      11.20          4
   3      1664.97     -14.44   2.574      12.54          4
   4      1740.03      45.27   2.347      10.87          3
   4      1759.97      45.18 See Message on Next Line(s)
```

```
ERROR AT SLICE  38     X =    .176E+04     Y =    .439E+02

NO PROFILE DATA FOR TOP OF SLICE


Maximum distance shifted for new estimate of shear
surface is    10.000 at point   1

Coordinates For New Estimate of Shear Surface

     Point       X           Y

        1     1508.49      -16.72
        2     1636.07        1.45
        3     1662.31       -3.87
        4     1750.00       46.00

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - -   2.244
Side Force Inclination - - - - - - - - -    11.98
Number of Iterations - - - - - - - - - -   3
```

1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT

```
Date:  4:12:2003   Time: 16:17:18   Input file: kitb9
  Kings Island Turning Basin, Station 98+605, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 23
****************************
* SEARCH TRIAL NUMBER    4 *
****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES =   10.00

                                  1-Stage
                                  Factor
                                    of     Side Force
Point        X           Y        Safety   Inclination   Iterations

   1      1500.00     -22.00    2.328       11.64           3
   1      1516.98     -11.43    2.128       13.92           4
   2      1635.77      -8.55    2.605       10.47           4
   2      1636.37      11.44 See Message on Next Line(s)
FATAL ERROR IN CALCULATING FACTOR OF SAFETY

SOLUTION DID NOT CONVERGE WITHIN 500 ITERATIONS

   3      1660.51       5.97    2.281       11.82           5
   3      1664.11     -13.70    2.615       15.01           5
   4      1740.03      45.27    2.264       12.06           3
   4      1759.97      45.18 See Message on Next Line(s)
ERROR AT SLICE  38     X =    .176E+04     Y =    .439E+02

NO PROFILE DATA FOR TOP OF SLICE


Maximum distance shifted for new estimate of shear
surface is    10.000 at point   1

Coordinates For New Estimate of Shear Surface

     Point       X           Y
```

```
          1     1516.98       -11.43
          2     1636.07         1.45
          3     1661.57          .17
          4     1750.00        46.00

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - - -   2.225
Side Force Inclination - - - - - - - - - -    15.37
Number of Iterations - - - - - - - - - - -   3
1       UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:12:2003   Time: 16:17:18   Input file: kitb9
  Kings Island Turning Basin, Station 98+605, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 23
****************************
* SEARCH TRIAL NUMBER    5 *
****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES =   10.00

                                  1-Stage
                                  Factor
                                    of     Side Force
Point        X           Y        Safety   Inclination   Iterations

   1      1508.49     -16.72    2.337       12.67           4
   1      1525.47      -6.15    2.538       13.98           4
   2      1635.78      11.44 See Message on Next Line(s)
FATAL ERROR IN CALCULATING FACTOR OF SAFETY

SOLUTION DID NOT CONVERGE WITHIN 500 ITERATIONS

   2      1636.36      -8.55    2.156       10.11           4
   3      1659.29       9.90    2.129       13.80           3
   3      1663.85      -9.57    2.148       13.69           4
   4      1740.03      45.27    2.239       15.76           3
   4      1759.97      45.18 See Message on Next Line(s)
ERROR AT SLICE  37      X =     .176E+04      Y =     .440E+02

NO PROFILE DATA FOR TOP OF SLICE


Maximum distance shifted for new estimate of shear
surface is    10.000 at point   2

Coordinates For New Estimate of Shear Surface

     Point        X           Y

          1     1514.97       -12.69
          2     1636.36        -8.55
          3     1659.29         9.90
          4     1750.00        46.00

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - - -   2.776
Side Force Inclination - - - - - - - - - -    10.15
Number of Iterations - - - - - - - - - - -   8
1       UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:12:2003   Time: 16:17:18   Input file: kitb9
  Kings Island Turning Basin, Station 98+605, Savannah, Georgia
```

```
  End of construction loading
  Single circular loading

TABLE NO. 23
****************************
* SEARCH TRIAL NUMBER    6 *
****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES =     7.00

                               1-Stage
                               Factor
                                 of     Side Force
Point        X          Y      Safety   Inclination   Iterations

   1      1511.04     -15.13   2.309       13.03           4
   1      1522.92      -7.74   2.414       14.66           4
   2      1635.87       8.44   2.635       26.98           7
   2      1636.27      -5.55   2.009       10.81           4
   3      1659.97       6.98   2.127       14.08           3
   3      1663.16      -6.65   2.112       13.59           4
   4      1743.00      45.84   2.232       15.69           3
   4      1757.00      45.74 See Message on Next Line(s)
ERROR AT SLICE  37      X =    .176E+04     Y =    .453E+02

NO PROFILE DATA FOR TOP OF SLICE


Maximum distance shifted for new estimate of shear
surface is     7.000 at point   3

Coordinates For New Estimate of Shear Surface

     Point       X           Y

        1     1515.84      -12.14
        2     1636.27       -5.55
        3     1663.16       -6.65
        4     1750.00       46.00

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - -   2.004
Side Force Inclination - - - - - - - - -    10.21
Number of Iterations - - - - - - - - - -   4
1
UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:12:2003   Time: 16:17:18   Input file: kitb9
  Kings Island Turning Basin, Station 98+605, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 23
****************************
* SEARCH TRIAL NUMBER    7 *
****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES =     7.00

                               1-Stage
                               Factor
                                 of     Side Force
Point        X          Y      Safety   Inclination   Iterations

   1      1509.90     -15.84   2.252       10.23           4
```

```
   1      1521.78      -8.44   1.915      10.72          3
   2      1636.22       1.45   2.132      13.05          4
   2      1636.32     -12.55   3.191      10.76          6
   3      1661.26        .09   2.116      10.44          4
   3      1665.07     -13.39   2.236      12.12          4
   4      1743.00      45.84   2.010      10.23          3
   4      1757.00      45.74 See Message on Next Line(s)
ERROR AT SLICE  41      X =     .176E+04     Y =    .452E+02

NO PROFILE DATA FOR TOP OF SLICE


Maximum distance shifted for new estimate of shear
surface is     7.000 at point   1

Coordinates For New Estimate of Shear Surface

     Point        X           Y

        1     1521.78       -8.44
        2     1636.25       -2.73
        3     1662.83       -5.48
        4     1750.00       46.00

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - -   1.913
Side Force Inclination - - - - - - - - -    11.36
Number of Iterations - - - - - - - - - -   4
```

1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT

```
Date:  4:12:2003   Time: 16:17:18   Input file: kitb9
  Kings Island Turning Basin, Station 98+605, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 23
****************************
* SEARCH TRIAL NUMBER    8 *
****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES =     7.00

                                 1-Stage
                                 Factor
                                   of     Side Force
Point         X          Y      Safety   Inclination    Iterations
```

```
HEADING
  Kings Island Turning Basin, Station 101+887, Savannah, Georgia
  End of construction loading
  Single circular loading
PROFILE LINES
  1  1  Top Spoil Material
   771  47
  2000  47

  2  2  Top DA Dike (SM-SC-MH-OH)  0/32
   400  48.0
   769  48.0
   800  20.0
  2000  20.0

  3  3  Directly Beneath Dike & Spoil Area 0/30
   300  11.0
  2000  11.0

  4  4  SP River Bank  .2/28
     0   8.0
  2000   8.5

  5  5  Underlying Softer (SC) (Old marsh deposits) 0/36
     0  -3.0
   480  -3.0
   585   5.0
  2000   5.0

  6  6  Sands (SM-SP) 0/32
     0 -10.0
   480 -10.0
   585   0.0
  2000   0.0

  7  7  Medium Dense Sands 0/38
     0  -26.0
  2000  -28.0

  8  8  Clay Layer  .7/7
     0  -47.0
   587  -44.0
  2000  -44.0

  9 9   Dense Sand  0/38
     0  -54.0
  2000  -54.0


MATERIAL PROPERTIES
  1  Spoil
    98 = unit weight
   Conventional shear strength
     0 16
   NO pore pressures
  2  Sand (Dike)
   125 = unit weight
   Conventional shear strength
    0  32
   NO pore pressures
  3  Sand
   122 = unit weight
   Conventional shear strength
```

```
     0  30
    NO pore pressures
   4  Upper Embankment lean clay and clayey sand
     95 = unit weight
    Conventional shear strength
     200  28
    NO pore pressures
   5 SP
    125.0 = unit weight
    Conventional shear strength
     0  36.0
    NO pore pressures
   6 Medium sand
    125 = unit weight
    Conventional shear strength
     0  32
    NO pore pressures
   7 Med Dense Sand
    126 = unit weight
    Conventional shear strength
    0  38
    NO pore pressures
   8 Clay
    106 = unit weight
    Conventional shear strength
    1400  7
    NO pore pressures
   9 Dense Sand
    126 = unit weight
    Conventional shear strength
    0  38
    NO pore pressures

SURFACE PRESSURES
     0 -55.0  3025  0
   453 -55.0  3025  0
   469 -47.0  2575  0
   512 -26.0  1420  0
   537 -14.0   759  0
   566  -1.0   440  0
   582   8.0   120  0
   588  11.0     0  0
   593  12.0     0  0
   606  11.0     0  0
   657  13.0     0  0
   678  22.0     0  0
   692  31.0     0  0
   706  35.0     0  0
   725  37.0     0  0
   747  43.0     0  0
   761  47.7     0  0
   769  48.0     0  0
  2000  46.0     0  0

SLOPE GEOMETRY
     0 -55.0
   453 -55.0
   469 -47.0
   512 -26.0
   537 -14.0
   566  -1.0
   582   8.0
   588  11.0
```

```
  593  12.0
  606  11.0
  657  13.0
  678  22.0
  692  31.0
  706  35.0
  725  37.0
  747  43.0
  761  47.7
  769  48.0
 2000  46.0

ANALYSIS/COMPUTATION
  NonCircular Search
   535.0, -14
   570.0, -27
   640.0, -26
   725.0,  10

  10, 60
  ITErations
   500
  WATER DEPTH
   4.0
  FACTOR OF SAFETY
   10.0
  CHANGE TRIAL FACTOR

COMPUTE
ASCII
PRINT
```

```
Station 101+887  GLOBAL  FS = 3.85  TRIAL -5-

1          UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
           Date:  4:13:2003   Time: 12:41:49   Input file: k2


           TABLE NO. 1
           ******************************************
           * COMPUTER PROGRAM DESIGNATION - UTEXAS3 *
           * Originally Coded By Stephen G. Wright  *
           * Version No. 1.120                      *
           * Last Revision Date 10/08/92            *
           * (C) Copyright 1985-1992 S. G. Wright   *
           * All Rights Reserved                    *
           ******************************************

           ***************************************************************
           *                                                             *
           *      RESULTS OF COMPUTATIONS PERFORMED USING THIS COMPUTER *
           * PROGRAM SHOULD NOT BE USED FOR DESIGN PURPOSES UNLESS THEY *
           * HAVE BEEN VERIFIED BY INDEPENDENT ANALYSES, EXPERIMENTAL   *
           * DATA OR FIELD EXPERIENCE. THE USER SHOULD UNDERSTAND THE   *
           * ALGORITHMS AND ANALYTICAL PROCEDURES USED IN THE COMPUTER  *
           * PROGRAM AND MUST HAVE READ ALL DOCUMENTATION FOR THIS      *
           * PROGRAM BEFORE ATTEMPTING ITS USE.                         *
           *                                                             *
           *      NEITHER THE UNIVERSITY OF TEXAS NOR STEPHEN G. WRIGHT *
           * MAKE OR ASSUME LIABILITY FOR ANY WARRANTIES, EXPRESSED OR  *
           * IMPLIED, CONCERNING THE ACCURACY, RELIABILITY, USEFULNESS  *
           * OR ADAPTABILITY OF THIS COMPUTER PROGRAM.                  *
           *                                                             *
           ***************************************************************
1          UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
           Date:  4:13:2003   Time: 12:41:49   Input file: k2
             Kings Island Turning Basin, Station 101+887, Savannah, Georgia
             End of construction loading
             Single circular loading

           TABLE NO.  2
           *************************
           * NEW PROFILE LINE DATA *
           *************************

           PROFILE LINE  1 - MATERIAL TYPE =  1
           Top Spoil Material

                Point       X             Y

                  1       771.000        47.000
                  2      2000.000        47.000

           PROFILE LINE  2 - MATERIAL TYPE =  2
           Top DA Dike (SM-SC-MH-OH)  0/32

                Point       X             Y

                  1       400.000        48.000
                  2       769.000        48.000
                  3       800.000        20.000
                  4      2000.000        20.000

           PROFILE LINE  3 - MATERIAL TYPE =  3
           Directly Beneath Dike & Spoil Area 0/30
```

```
     Point       X             Y

       1      300.000        11.000
       2     2000.000        11.000

PROFILE LINE  4 - MATERIAL TYPE =  4
SP River Bank  .2/28

     Point       X             Y

       1         .000         8.000
       2     2000.000         8.500

PROFILE LINE  5 - MATERIAL TYPE =  5
Underlying Softer (SC) (Old marsh deposits) 0/36

     Point       X             Y

       1         .000        -3.000
       2      480.000        -3.000
       3      585.000         5.000
       4     2000.000         5.000

PROFILE LINE  6 - MATERIAL TYPE =  6
Sands (SM-SP) 0/32

     Point       X             Y

       1         .000       -10.000
       2      480.000       -10.000
       3      585.000          .000
       4     2000.000          .000

PROFILE LINE  7 - MATERIAL TYPE =  7
Medium Dense Sands 0/38

     Point       X             Y

       1         .000       -26.000
       2     2000.000       -28.000

PROFILE LINE  8 - MATERIAL TYPE =  8
Clay Layer  .7/7

     Point       X             Y

       1         .000       -47.000
       2      587.000       -44.000
       3     2000.000       -44.000

PROFILE LINE  9 - MATERIAL TYPE =  9
Dense Sand  0/38

     Point       X             Y

       1         .000       -54.000
       2     2000.000       -54.000

All new profile lines defined - No old lines retained
```

```
1       UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
        Date:  4:13:2003   Time: 12:41:49   Input file: k2
          Kings Island Turning Basin, Station 101+887, Savannah, Georgia
```

```
  End of construction loading
  Single circular loading

TABLE NO.  3
***********************************************************************
* NEW MATERIAL PROPERTY DATA - CONVENTIONAL/FIRST-STAGE COMPUTATIONS *
***********************************************************************

DATA FOR MATERIAL TYPE  1
Spoil

     Unit weight of material =   98.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -         .000
     Friction angle - - - - -  16.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  2
Sand (Dike)

     Unit weight of material =  125.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -         .000
     Friction angle - - - - -  32.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  3
Sand

     Unit weight of material =  122.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -         .000
     Friction angle - - - - -  30.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  4
Upper Embankment lean clay and clayey sand

     Unit weight of material =   95.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -      200.000
     Friction angle - - - - -  28.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  5
SP

     Unit weight of material =  125.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -         .000
     Friction angle - - - - -  36.000 degrees

     No (or zero) pore water pressures
```

```
DATA FOR MATERIAL TYPE  6
Medium sand

     Unit weight of material =  125.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -         .000
     Friction angle - - - - -   32.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  7
Med Dense Sand

     Unit weight of material =  126.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -         .000
     Friction angle - - - - -   38.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  8
Clay

     Unit weight of material =  106.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -     1400.000
     Friction angle - - - - -    7.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  9
Dense Sand

     Unit weight of material =  126.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -         .000
     Friction angle - - - - -   38.000 degrees

     No (or zero) pore water pressures

All new material properties defined - No old data retained
1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:13:2003   Time: 12:41:49   Input file: k2
  Kings Island Turning Basin, Station 101+887, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 10
*********************************************************************
* NEW SURFACE PRESSURE DATA - CONVENTIONAL/FIRST-STAGE COMPUTATIONS *
*********************************************************************

ALL NEW DATA INPUT - NO OLD DATA RETAINED

Surface Pressures -
                                 Normal       Shear
Point        X          Y       Pressure      Stress

   1        .000     -55.000    3025.000         .000
```

| | | | | |
|---|---|---|---|---|
| 2 | 453.000 | -55.000 | 3025.000 | .000 |
| 3 | 469.000 | -47.000 | 2575.000 | .000 |
| 4 | 512.000 | -26.000 | 1420.000 | .000 |
| 5 | 537.000 | -14.000 | 759.000 | .000 |
| 6 | 566.000 | -1.000 | 440.000 | .000 |
| 7 | 582.000 | 8.000 | 120.000 | .000 |
| 8 | 588.000 | 11.000 | .000 | .000 |
| 9 | 593.000 | 12.000 | .000 | .000 |
| 10 | 606.000 | 11.000 | .000 | .000 |
| 11 | 657.000 | 13.000 | .000 | .000 |
| 12 | 678.000 | 22.000 | .000 | .000 |
| 13 | 692.000 | 31.000 | .000 | .000 |
| 14 | 706.000 | 35.000 | .000 | .000 |
| 15 | 725.000 | 37.000 | .000 | .000 |
| 16 | 747.000 | 43.000 | .000 | .000 |
| 17 | 761.000 | 47.700 | .000 | .000 |
| 18 | 769.000 | 48.000 | .000 | .000 |
| 19 | 2000.000 | 46.000 | .000 | .000 |

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Date: 4:13:2003 Time: 12:41:49 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 9
****************************
* NEW SLOPE GEOMETRY DATA *
****************************

All new data input - No old data retained

Slope Coordinates -

| Point | X | Y |
|---|---|---|
| 1 | .000 | -55.000 |
| 2 | 453.000 | -55.000 |
| 3 | 469.000 | -47.000 |
| 4 | 512.000 | -26.000 |
| 5 | 537.000 | -14.000 |
| 6 | 566.000 | -1.000 |
| 7 | 582.000 | 8.000 |
| 8 | 588.000 | 11.000 |
| 9 | 593.000 | 12.000 |
| 10 | 606.000 | 11.000 |
| 11 | 657.000 | 13.000 |
| 12 | 678.000 | 22.000 |
| 13 | 692.000 | 31.000 |
| 14 | 706.000 | 35.000 |
| 15 | 725.000 | 37.000 |
| 16 | 747.000 | 43.000 |
| 17 | 761.000 | 47.700 |
| 18 | 769.000 | 48.000 |
| 19 | 2000.000 | 46.000 |

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Date: 4:13:2003 Time: 12:41:49 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 15
**********************************
* NEW ANALYSIS/COMPUTATION DATA *

```
*********************************

Noncircular Shear Surface(s)

Automatic Search Performed


Coordinates of points on shear surface which are to be shifted -

Point         X              Y      Shift Angle

   1        535.000        -14.000   angle to be computed - moveable
   2        570.000        -27.000   angle to be computed - moveable
   3        640.000        -26.000   angle to be computed - moveable
   4        725.000         10.000   angle to be computed - moveable

Initial distance for shifting points on shear surface =  10.000
Maximum steepness permitted for toe of shear surface = 60.00 degrees

Maximum number of iterations allowed for
calculating the factor of safety =  500

Depth of water in crack =       4.000

Initial trial estimate for the factor of safety =  10.000

Initial trial values for factor of safety (and side force inclination
for Spencer's procedure) will be changed during search

---------------------------------------------------------------------
THE FOLLOWING REPRESENT EITHER DEFAULT OR PREVIOUSLY DEFINED VALUES:

Initial trial estimate for side force inclination =  15.000 degrees
(Applicable to Spencer's procedure only)

Allowed force imbalance for convergence =     100.000

Allowed moment imbalance for convergence =     100.000

Number of increments for slice subdivision =   30

Unit weight of water in crack =    62.400

Seismic coefficient =  .000

Conventional (single-stage) computations to be performed

Procedure used to compute the factor of safety: SPENCER
1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:13:2003   Time: 12:41:49   Input file: k2
  Kings Island Turning Basin, Station 101+887, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 22
*******************************************
* INITIAL COMPUTED INFORMATION FOR SEARCH *
* WITH NONCIRCULAR SHEAR SURFACE          *
*******************************************

For the initial trial noncircular shear surface at X =        535.00
the Y coordinate was adjusted to       -14.96 because the point was
above the surface of the slope
```

Crack depth computed to be - - -     27.00

FOR INITIAL TRIAL NONCIRCULAR SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - -     5.091
Side Force Inclination - - - - - - - - -      7.39
Number of Iterations - - - - - - - - - -    13

TABLE NO. 23
****************************
* SEARCH TRIAL NUMBER    1 *
****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES =   10.00

| Point | X | Y | 1-Stage Factor of Safety | Side Force Inclination | Iterations |
|---|---|---|---|---|---|
| 1 | 525.98 | -19.29 | 4.874 | 7.57 | 3 |
| 1 | 544.10 | -10.82 | 5.494 | 7.04 | 3 |
| 2 | 568.37 | -36.87 | 5.849 | 7.70 | 4 |
| 2 | 571.63 | -17.13 | 5.183 | 7.18 | 3 |
| 3 | 637.86 | -16.23 | 4.871 | 6.75 | 3 |
| 3 | 642.14 | -35.77 | 6.024 | 8.15 | 4 |
| 4 | 715.05 | 8.95 | 5.276 | 7.35 | 3 |
| 4 | 734.65 | 12.63 | 4.831 | 7.80 | 3 |

Maximum distance shifted for new estimate of shear
surface is    10.000 at point   1

Coordinates For New Estimate of Shear Surface

| Point | X | Y |
|---|---|---|
| 1 | 525.98 | -19.29 |
| 2 | 570.64 | -23.14 |
| 3 | 637.86 | -16.23 |
| 4 | 734.65 | 12.63 |

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - -   4.445
Side Force Inclination - - - - - - - - -     7.18
Number of Iterations - - - - - - - - - -   4

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Date:  4:13:2003   Time: 12:41:49   Input file: k2
  Kings Island Turning Basin, Station 101+887, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 23
****************************
* SEARCH TRIAL NUMBER    2 *
****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES =   10.00

| Point | X | Y | 1-Stage Factor of Safety | Side Force Inclination | Iterations |
|---|---|---|---|---|---|

```
   1       516.97     -23.61 See Message on Next Line(s)
SHEAR SURFACE SEGMENT BETWEEN POINTS   1 AND   2 CROSSES SLOPE BETWEEN

POINTS   4 AND   5 AFTER SHIFT - THIS TRIAL SHEAR SURFACE WAS REJECTED

   1       535.00     -14.96   4.597       7.10          3
   2       570.55     -13.14   4.844       6.86          4
   2       570.72     -33.14   4.817       7.85          4
   3       635.90      -6.43   4.612       5.95          4
   3       639.83     -26.04   4.545       7.87          3
   4       725.00      10.00   4.666       6.69          3
   4       744.30      15.26   4.267       7.60          3

Maximum distance shifted for new estimate of shear
surface is    10.000 at point   4

Coordinates For New Estimate of Shear Surface

     Point       X           Y

        1      525.98      -19.29
        2      570.64      -23.31
        3      638.11      -17.47
        4      744.30       15.26

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - -    4.261
Side Force Inclination - - - - - - - - -      7.70
Number of Iterations - - - - - - - - - -    3
```

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```
Date:  4:13:2003   Time: 12:41:49   Input file: k2
  Kings Island Turning Basin, Station 101+887, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 23
*****************************
* SEARCH TRIAL NUMBER    3 *
*****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES =   10.00

                                   1-Stage
                                   Factor
                                     of     Side Force
Point        X          Y        Safety   Inclination   Iterations

   1       516.97     -23.61 See Message on Next Line(s)
SHEAR SURFACE SEGMENT BETWEEN POINTS   1 AND   2 CROSSES SLOPE BETWEEN

POINTS   4 AND   5 AFTER SHIFT - THIS TRIAL SHEAR SURFACE WAS REJECTED

   1       535.00     -14.96   4.392       7.62          3
   2       570.62     -33.31   4.641       8.30          4
   2       570.66     -13.31   4.588       7.41          4
   3       636.17      -7.66   4.387       6.72          4
   3       640.05     -27.28   4.466       8.43          4
   4       734.65      12.63   4.439       7.29          3
   4       753.83      18.29   4.081       8.17          3

Maximum distance shifted for new estimate of shear
surface is    10.000 at point   4
```

Coordinates For New Estimate of Shear Surface

| Point | X | Y |
|---|---|---|
| 1 | 525.98 | -19.29 |
| 2 | 570.64 | -22.94 |
| 3 | 637.88 | -16.31 |
| 4 | 753.83 | 18.29 |

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - - -   4.087
Side Force Inclination - - - - - - - - - -   8.09
Number of Iterations - - - - - - - - - - -   3

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Date: 4:13:2003 Time: 12:41:49 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 23
*****************************
* SEARCH TRIAL NUMBER 4 *
*****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES = 10.00

| Point | X | Y | 1-Stage Factor of Safety | Side Force Inclination | Iterations |
|---|---|---|---|---|---|
| 1 | 516.97 | -23.61 | See Message on Next Line(s) | | |

SHEAR SURFACE SEGMENT BETWEEN POINTS 1 AND 2 CROSSES SLOPE BETWEEN

POINTS 4 AND 5 AFTER SHIFT - THIS TRIAL SHEAR SURFACE WAS REJECTED

| Point | X | Y | 1-Stage Factor of Safety | Side Force Inclination | Iterations |
|---|---|---|---|---|---|
| 1 | 535.00 | -14.96 | 4.199 | 8.03 | 3 |
| 2 | 570.55 | -12.94 | 4.358 | 7.82 | 4 |
| 2 | 570.72 | -32.94 | 4.450 | 8.69 | 4 |
| 3 | 635.93 | -6.50 | 4.214 | 7.14 | 4 |
| 3 | 639.83 | -26.11 | 4.172 | 8.66 | 3 |
| 4 | 744.30 | 15.26 | 4.270 | 7.61 | 3 |
| 4 | 763.51 | 20.79 | 3.966 | 8.40 | 3 |

Maximum distance shifted for new estimate of shear
surface is 10.000 at point 4

Coordinates For New Estimate of Shear Surface

| Point | X | Y |
|---|---|---|
| 1 | 525.98 | -19.29 |
| 2 | 570.63 | -22.21 |
| 3 | 638.07 | -17.27 |
| 4 | 763.51 | 20.79 |

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - - -   3.972
Side Force Inclination - - - - - - - - - -   8.45
Number of Iterations - - - - - - - - - - -   3

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Date: 4:13:2003 Time: 12:41:49 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia

End of construction loading
Single circular loading

TABLE NO. 23
*****************************
* SEARCH TRIAL NUMBER 5 *
*****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES = 10.00

| Point | X | Y | 1-Stage Factor of Safety | Side Force Inclination | Iterations |
|---|---|---|---|---|---|
| 1 | 516.97 | -23.61 | See Message on Next Line(s) | | |

SHEAR SURFACE SEGMENT BETWEEN POINTS 1 AND 2 CROSSES SLOPE BETWEEN

POINTS 4 AND 5 AFTER SHIFT - THIS TRIAL SHEAR SURFACE WAS REJECTED

| | | | | | |
|---|---|---|---|---|---|
| 1 | 535.00 | -14.96 | 4.062 | 8.39 | 3 |
| 2 | 570.59 | -12.21 | 4.227 | 8.18 | 3 |
| 2 | 570.67 | -32.21 | 4.275 | 8.96 | 4 |
| 3 | 636.22 | -7.45 | 4.072 | 7.63 | 3 |
| 3 | 639.92 | -27.10 | 4.120 | 9.07 | 3 |
| 4 | 753.83 | 18.29 | 4.095 | 8.14 | 3 |
| 4 | 773.51 | 20.99 | See Message on Next Line(s) | | |

ERROR AT SLICE 45 X = .770E+03 Y = .200E+02

NO PROFILE DATA FOR TOP OF SLICE

Maximum distance shifted for new estimate of shear
surface is .967 at point 3

Coordinates For New Estimate of Shear Surface

| Point | X | Y |
|---|---|---|
| 1 | 525.98 | -19.29 |
| 2 | 570.63 | -21.79 |
| 3 | 637.89 | -16.32 |
| 4 | 763.51 | 20.79 |

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - - 3.978
Side Force Inclination - - - - - - - - - 8.38
Number of Iterations - - - - - - - - - - 3

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Date: 4:13:2003 Time: 12:41:49 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 23
*****************************
* SEARCH TRIAL NUMBER 6 *
*****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES = 7.00

1-Stage
Factor

```
                                   of     Side Force
Point        X           Y       Safety   Inclination   Iterations

   1       519.67      -22.32    3.940       8.46           3
   1       532.30      -16.26    4.028       8.42           3
   2       570.61      -15.21    4.123       8.30           3
   2       570.66      -29.21    4.112       8.74           3
   3       636.78      -10.39    4.022       7.94           3
   3       639.37      -24.15    4.020       8.84           3
   4       756.68       19.25    4.041       8.29           3
   4       770.50       21.00 See Message on Next Line(s)
ERROR AT SLICE  46      X =     .770E+03     Y =    .208E+02

NO PROFILE DATA FOR TOP OF SLICE


Maximum distance shifted for new estimate of shear
surface is     7.000 at point   1

Coordinates For New Estimate of Shear Surface

     Point        X          Y

        1      519.67      -22.32
        2      570.63      -22.34
        3      638.09      -17.34
        4      763.51       20.79

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - -   3.938
Side Force Inclination - - - - - - - - -     8.47
Number of Iterations - - - - - - - - - -   3
1          UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:13:2003   Time: 12:41:49   Input file: k2
  Kings Island Turning Basin, Station 101+887, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 23
****************************
* SEARCH TRIAL NUMBER    7 *
****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES =    7.00

                                 1-Stage
                                 Factor
                                   of     Side Force
Point        X           Y       Safety   Inclination   Iterations

   1       513.36      -25.35 See Message on Next Line(s)
SHEAR SURFACE SEGMENT BETWEEN POINTS    1 AND    2 CROSSES SLOPE BETWEEN

POINTS    4 AND    5 AFTER SHIFT - THIS TRIAL SHEAR SURFACE WAS REJECTED

   1       525.98      -19.29    3.970       8.46           3
   2       570.38      -15.34 See Message on Next Line(s)
SHEAR SURFACE SEGMENT BETWEEN POINTS    1 AND    2 CROSSES SLOPE BETWEEN

POINTS    4 AND    5 AFTER SHIFT - THIS TRIAL SHEAR SURFACE WAS REJECTED

   2       570.89      -29.34    4.070       8.77           3
   3       636.79      -10.47    3.983       7.93           3
```

```
   3       639.39     -24.22   3.988       8.87           3
   4       756.68      19.25   4.004       8.31           3
   4       770.50      21.00 See Message on Next Line(s)
ERROR AT SLICE  45     X =    .770E+03     Y =    .208E+02

NO PROFILE DATA FOR TOP OF SLICE


Maximum distance shifted for new estimate of shear
surface is      .209 at point   3

Coordinates For New Estimate of Shear Surface

     Point       X           Y

        1      519.67      -22.32
        2      570.63      -22.34
        3      638.05      -17.14
        4      763.51       20.79

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - -   3.938
Side Force Inclination - - - - - - - - -     8.45
Number of Iterations - - - - - - - - - -   2
```

1

```
UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:13:2003   Time: 12:41:49   Input file: k2
  Kings Island Turning Basin, Station 101+887, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 23
****************************
* SEARCH TRIAL NUMBER    8 *
****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES =    4.00

                                 1-Stage
                                 Factor
                                  of     Side Force
Point        X          Y       Safety   Inclination   Iterations

   1       516.07     -24.05   3.927       8.47           2
   1       523.28     -20.59 See Message on Next Line(s)
SHEAR SURFACE SEGMENT BETWEEN POINTS   1 AND   2 CROSSES SLOPE BETWEEN

POINTS   4 AND   5 AFTER SHIFT - THIS TRIAL SHEAR SURFACE WAS REJECTED

   2       570.49     -18.34 See Message on Next Line(s)
SHEAR SURFACE SEGMENT BETWEEN POINTS   1 AND   2 CROSSES SLOPE BETWEEN

POINTS   4 AND   5 AFTER SHIFT - THIS TRIAL SHEAR SURFACE WAS REJECTED

   2       570.78     -26.34   3.895       8.53           3
   3       637.34     -13.41   3.953       8.19           3
   3       638.83     -21.27   3.954       8.71           3
   4       759.55      20.21   3.955       8.45           3
   4       767.50      20.94   3.951       8.38           3

Maximum distance shifted for new estimate of shear
surface is     4.000 at point   2

Coordinates For New Estimate of Shear Surface
```

| Point | X | Y |
|---|---|---|
| 1 | 516.07 | -24.05 |
| 2 | 570.78 | -26.34 |
| 3 | 638.06 | -17.23 |
| 4 | 763.76 | 20.80 |

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - - 3.875
Side Force Inclination - - - - - - - - - 8.52
Number of Iterations - - - - - - - - - - 3

1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date: 4:13:2003 Time: 12:41:49 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 23
*****************************
* SEARCH TRIAL NUMBER 9 *
*****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES = 4.00

| Point | X | Y | 1-Stage Factor of Safety | Side Force Inclination | Iterations |
|---|---|---|---|---|---|
| 1 | 512.46 | -25.78 | 3.861 | 8.52 | 2 |
| 1 | 519.67 | -22.32 | 3.896 | 8.52 | 2 |
| 2 | 570.59 | -22.34 | 3.928 | 8.46 | 3 |
| 2 | 570.97 | -30.33 | 4.108 | 8.83 | 4 |
| 3 | 637.21 | -13.32 | 3.902 | 8.24 | 3 |
| 3 | 638.92 | -21.13 | 3.877 | 8.75 | 2 |
| 4 | 759.79 | 20.29 | 3.885 | 8.51 | 2 |
| 4 | 767.76 | 20.95 | 3.890 | 8.44 | 3 |

Maximum distance shifted for new estimate of shear
surface is 4.000 at point 1

Coordinates For New Estimate of Shear Surface

| Point | X | Y |
|---|---|---|
| 1 | 512.46 | -25.78 |
| 2 | 570.72 | -25.07 |
| 3 | 638.43 | -18.90 |
| 4 | 763.41 | 20.79 |

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - - 3.874
Side Force Inclination - - - - - - - - - 8.62
Number of Iterations - - - - - - - - - - 2

1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date: 4:13:2003 Time: 12:41:49 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 23
*****************************

```
* SEARCH TRIAL NUMBER   10 *
****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES =    4.00

                               1-Stage
                               Factor
                                 of     Side Force
Point         X          Y     Safety   Inclination   Iterations

   1       508.87     -27.53    3.923       8.58          3
   1       516.07     -24.05    3.886       8.61          2
   2       570.51     -21.08    3.953       8.56          3
   2       570.93     -29.07    4.079       8.80          3
   3       637.63     -14.98    3.883       8.35          3
   3       639.23     -22.82    3.894       8.84          3
   4       759.46      20.18    3.892       8.59          3
   4       767.41      20.94    3.886       8.53          3

Maximum distance shifted for new estimate of shear
surface is     1.232 at point   1

Coordinates For New Estimate of Shear Surface

     Point       X          Y

        1      513.57     -25.25
        2      570.68     -24.18
        3      638.28     -18.16
        4      763.85      20.81

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - - -   3.891
Side Force Inclination - - - - - - - - - -     8.55
Number of Iterations - - - - - - - - - - -   3
1         UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:13:2003   Time: 12:41:49   Input file: k2
  Kings Island Turning Basin, Station 101+887, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 23
****************************
* SEARCH TRIAL NUMBER   11 *
****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES =    1.00

                               1-Stage
                               Factor
                                 of     Side Force
Point         X          Y     Safety   Inclination   Iterations

   1       511.56     -26.21    3.872       8.62          2
   1       513.36     -25.35    3.877       8.61          2
   2       570.67     -24.07    3.890       8.60          2
   2       570.77     -26.07    3.861       8.63          2
   3       638.23     -17.92    3.874       8.55          2
   3       638.63     -19.88    3.876       8.67          2
   4       762.41      20.75    3.872       8.63          2
   4       764.41      20.83    3.877       8.60          2

Maximum distance shifted for new estimate of shear
```

surface is 1.000 at point 1

Coordinates For New Estimate of Shear Surface

| Point | X | Y |
|---|---|---|
| 1 | 511.56 | -26.21 |
| 2 | 570.77 | -26.07 |
| 3 | 638.23 | -17.92 |
| 4 | 762.41 | 20.75 |

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - - - 3.855
Side Force Inclination - - - - - - - - - - 8.59
Number of Iterations - - - - - - - - - - - 3

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Date: 4:13:2003 Time: 12:41:49 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 23
****************************
* SEARCH TRIAL NUMBER 12 *
****************************

INCREMENTAL SHIFT DISTANCE USED TO COMPUTE DERIVATIVES = 1.00

| Point | X | Y | 1-Stage Factor of Safety | Side Force Inclination | Iterations |
|---|---|---|---|---|---|
| 1 | 510.66 | -26.65 | 3.881 | 8.55 | 3 |
| 1 | 512.46 | -25.78 | 3.858 | 8.59 | 2 |
| 2 | 570.71 | -25.07 | 3.869 | 8.57 | 2 |
| 2 | 570.83 | -27.07 | 4.000 | 8.67 | 3 |
| 3 | 638.02 | -16.95 | 3.857 | 8.52 | 2 |
| 3 | 638.44 | -18.90 | 3.856 | 8.65 | 2 |
| 4 | 761.42 | 20.72 | 3.853 | 8.59 | 2 |
| 4 | 763.41 | 20.79 | 3.858 | 8.57 | 2 |

Maximum distance shifted for new estimate of shear
surface is 1.000 at point 4

Coordinates For New Estimate of Shear Surface

| Point | X | Y |
|---|---|---|
| 1 | 511.92 | -26.04 |
| 2 | 570.75 | -25.66 |
| 3 | 638.33 | -18.39 |
| 4 | 761.42 | 20.72 |

FOR NEW ESTIMATE OF SHEAR SURFACE
1-Stage Factor of Safety - - - - - - - - - 3.859
Side Force Inclination - - - - - - - - - - 8.62
Number of Iterations - - - - - - - - - - - 2

1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date: 4:13:2003 Time: 12:41:49 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 25

```
**********************************************************************
* FINAL CRITICAL SHEAR SURFACE (FOUND AFTER  12 TRIAL POSITIONS) *
**********************************************************************
```

| X | Y |
|---|---|
| 511.56 | -26.21 |
| 570.77 | -26.07 |
| 638.23 | -17.92 |
| 762.41 | 20.75 |

1-Stage Factor of Safety =   3.855

Side Force Inclination =   8.59

1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:13:2003   Time: 12:41:49   Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 26

```
******************************************************************
*  Coordinate, Weight, Strength and Pore Water Pressure          *
*  Information for Individual Slices for Conventional            *
*  Computations or First Stage of Multi-Stage Computations.      *
*  (Information is for the Critical Shear Surface in the         *
*  Case of an Automatic Search.)                                  *
******************************************************************
```

| Slice No. | X | Y | Slice Weight | Matl. Type | Cohesion | Friction Angle | Pore Pressure |
|---|---|---|---|---|---|---|---|
| | 511.6 | -26.2 | | | | | |
| 1 | 511.8 | -26.2 | 5.8 | 6 | .00 | 32.00 | .0 |
| | 512.0 | -26.2 | | | | | |
| 2 | 516.2 | -26.2 | 2294.7 | 6 | .00 | 32.00 | .0 |
| | 520.3 | -26.2 | | | | | |
| 3 | 524.5 | -26.2 | 6440.6 | 6 | .00 | 32.00 | .0 |
| | 528.7 | -26.2 | | | | | |
| 4 | 532.8 | -26.2 | 10586.6 | 6 | .00 | 32.00 | .0 |
| | 537.0 | -26.2 | | | | | |
| 5 | 540.3 | -26.1 | 11385.2 | 6 | .00 | 32.00 | .0 |
| | 543.7 | -26.1 | | | | | |
| 6 | 547.0 | -26.1 | 13869.9 | 6 | .00 | 32.00 | .0 |
| | 550.4 | -26.1 | | | | | |
| 7 | 553.7 | -26.1 | 16354.5 | 6 | .00 | 32.00 | .0 |
| | 557.0 | -26.1 | | | | | |
| 8 | 560.4 | -26.1 | 18839.0 | 6 | .00 | 32.00 | .0 |
| | 563.7 | -26.1 | | | | | |
| 9 | 564.9 | -26.1 | 7043.2 | 6 | .00 | 32.00 | .0 |
| | 566.0 | -26.1 | | | | | |
| 10 | 568.4 | -26.1 | 15762.1 | 6 | .00 | 32.00 | .0 |
| | 570.8 | -26.1 | | | | | |
| 11 | 573.1 | -25.8 | 16501.1 | 6 | .00 | 32.00 | .0 |
| | 575.4 | -25.5 | | | | | |
| 12 | 578.7 | -25.1 | 25611.6 | 6 | .00 | 32.00 | .0 |
| | 582.0 | -24.7 | | | | | |
| 13 | 582.1 | -24.7 | 1163.9 | 6 | .00 | 32.00 | .0 |
| | 582.3 | -24.7 | | | | | |
| 14 | 583.6 | -24.5 | 11019.6 | 6 | .00 | 32.00 | .0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 585.0 | -24.4 | | | | | |
| 15 | 586.0 | -24.2 | 8358.3 | 6 | .00 | 32.00 | .0 |
| | 587.0 | -24.1 | | | | | |
| 16 | 587.5 | -24.1 | 4248.0 | 6 | .00 | 32.00 | .0 |
| | 588.0 | -24.0 | | | | | |
| 17 | 590.5 | -23.7 | 21478.3 | 6 | .00 | 32.00 | .0 |
| | 593.0 | -23.4 | | | | | |
| 18 | 596.3 | -23.0 | 27560.2 | 6 | .00 | 32.00 | .0 |
| | 599.5 | -22.6 | | | | | |
| 19 | 602.8 | -22.2 | 26515.7 | 6 | .00 | 32.00 | .0 |
| | 606.0 | -21.8 | | | | | |
| 20 | 610.0 | -21.3 | 31890.7 | 6 | .00 | 32.00 | .0 |
| | 614.1 | -20.8 | | | | | |
| 21 | 618.1 | -20.4 | 31228.1 | 6 | .00 | 32.00 | .0 |
| | 622.1 | -19.9 | | | | | |

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Date: 4:13:2003 Time: 12:41:49 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 26

```
****************************************************************
*  Coordinate, Weight, Strength and Pore Water Pressure        *
*  Information for Individual Slices for Conventional          *
*  Computations or First Stage of Multi-Stage Computations.    *
*  (Information is for the Critical Shear Surface in the       *
*  Case of an Automatic Search.)                               *
****************************************************************
```

| Slice No. | X | Y | Slice Weight | Matl. Type | Cohesion | Friction Angle | Pore Pressure |
|---|---|---|---|---|---|---|---|
| | 622.1 | -19.9 | | | | | |
| 22 | 626.1 | -19.4 | 30565.5 | 6 | .00 | 32.00 | .0 |
| | 630.2 | -18.9 | | | | | |
| 23 | 634.2 | -18.4 | 29902.7 | 6 | .00 | 32.00 | .0 |
| | 638.2 | -17.9 | | | | | |
| 24 | 641.4 | -16.9 | 22295.9 | 6 | .00 | 32.00 | .0 |
| | 644.5 | -16.0 | | | | | |
| 25 | 647.6 | -15.0 | 20963.6 | 6 | .00 | 32.00 | .0 |
| | 650.7 | -14.0 | | | | | |
| 26 | 653.9 | -13.1 | 19631.5 | 6 | .00 | 32.00 | .0 |
| | 657.0 | -12.1 | | | | | |
| 27 | 660.5 | -11.0 | 21577.1 | 6 | .00 | 32.00 | .0 |
| | 664.0 | -9.9 | | | | | |
| 28 | 667.5 | -8.8 | 22294.2 | 6 | .00 | 32.00 | .0 |
| | 671.0 | -7.7 | | | | | |
| 29 | 674.5 | -6.6 | 23011.3 | 6 | .00 | 32.00 | .0 |
| | 678.0 | -5.5 | | | | | |
| 30 | 681.5 | -4.4 | 24384.6 | 6 | .00 | 32.00 | .0 |
| | 685.0 | -3.4 | | | | | |
| 31 | 688.5 | -2.3 | 26414.2 | 6 | .00 | 32.00 | .0 |
| | 692.0 | -1.2 | | | | | |
| 32 | 693.9 | -.6 | 14783.8 | 6 | .00 | 32.00 | .0 |
| | 695.8 | .0 | | | | | |
| 33 | 698.3 | .8 | 19921.5 | 5 | .00 | 36.00 | .0 |
| | 700.9 | 1.6 | | | | | |
| 34 | 703.4 | 2.4 | 19837.1 | 5 | .00 | 36.00 | .0 |
| | 706.0 | 3.2 | | | | | |
| 35 | 708.9 | 4.1 | 22155.2 | 5 | .00 | 36.00 | .0 |
| | 711.8 | 5.0 | | | | | |
| 36 | 714.4 | 5.8 | 18795.6 | 4 | 200.00 | 28.00 | .0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 716.9 | 6.6 | | | | | |
| 37 | 719.5 | 7.4 | 18367.1 | 4 | 200.00 | 28.00 | .0 |
| | 722.0 | 8.2 | | | | | |
| 38 | 723.5 | 8.6 | 10395.2 | 3 | .00 | 30.00 | .0 |
| | 725.0 | 9.1 | | | | | |
| 39 | 728.0 | 10.1 | 21160.7 | 3 | .00 | 30.00 | .0 |
| | 731.1 | 11.0 | | | | | |
| 40 | 735.1 | 12.2 | 27340.0 | 2 | .00 | 32.00 | .0 |
| | 739.0 | 13.5 | | | | | |
| 41 | 743.0 | 14.7 | 27034.1 | 2 | .00 | 32.00 | .0 |
| | 747.0 | 16.0 | | | | | |
| 42 | 750.5 | 17.0 | 23741.0 | 2 | .00 | 32.00 | .0 |
| | 754.0 | 18.1 | | | | | |

1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date: 4:13:2003 Time: 12:41:49 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 26

```
*****************************************************************
*  Coordinate, Weight, Strength and Pore Water Pressure         *
*  Information for Individual Slices for Conventional           *
*  Computations or First Stage of Multi-Stage Computations.     *
*  (Information is for the Critical Shear Surface in the        *
*  Case of an Automatic Search.)                                *
*****************************************************************
```

| Slice No. | X | Y | Slice Weight | Matl. Type | Cohesion | Friction Angle | Pore Pressure |
|---|---|---|---|---|---|---|---|
| | 754.0 | 18.1 | | | | | |
| 43 | 757.5 | 19.2 | 23889.7 | 2 | .00 | 32.00 | .0 |
| | 761.0 | 20.3 | | | | | |
| 44 | 761.7 | 20.5 | 4808.2 | 2 | .00 | 32.00 | .0 |
| | 762.4 | 20.8 | | | | | |

1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date: 4:13:2003 Time: 12:41:49 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 27

```
****************************************************************
*  Seismic Forces and Forces Due to Surface Pressures for      *
*  Individual Slices for Conventional  Computations or the     *
*  First Stage of Multi-Stage Computations.                    *
*  (Information is for the Critical Shear Surface in the       *
*  Case of an Automatic Search.)                               *
****************************************************************
```

| | | | | FORCES DUE TO SURFACE PRESSURES | | | |
|---|---|---|---|---|---|---|---|
| Slice No. | X | Seismic Force | Y for Seismic Force | Normal Force | Shear Force | X | Y |
| 1 | 511.8 | 0. | -26.2 | 695. | 0. | 511.8 | -26.1 |
| 2 | 516.2 | 0. | -25.1 | 12108. | 0. | 516.0 | -24.1 |
| 3 | 524.5 | 0. | -23.1 | 10071. | 0. | 524.4 | -20.1 |
| 4 | 532.8 | 0. | -21.1 | 8034. | 0. | 532.7 | -16.1 |
| 5 | 540.3 | 0. | -19.3 | 5285. | 0. | 540.3 | -12.5 |
| 6 | 547.0 | 0. | -17.8 | 4747. | 0. | 547.0 | -9.5 |
| 7 | 553.7 | 0. | -16.3 | 4210. | 0. | 553.6 | -6.5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8 | 560.4 | 0. | -14.8 | 3673. | 0. | 560.3 | -3.6 |
| 9 | 564.9 | 0. | -13.8 | 1137. | 0. | 564.8 | -1.5 |
| 10 | 568.4 | 0. | -12.9 | 2148. | 0. | 568.3 | .3 |
| 11 | 573.1 | 0. | -11.4 | 1572. | 0. | 572.9 | 2.9 |
| 12 | 578.7 | 0. | -9.7 | 1420. | 0. | 578.3 | 5.9 |
| 13 | 582.1 | 0. | -8.7 | 38. | 0. | 582.1 | 8.1 |
| 14 | 583.6 | 0. | -8.2 | 264. | 0. | 583.5 | 8.8 |
| 15 | 586.0 | 0. | -7.4 | 89. | 0. | 585.8 | 9.9 |
| 16 | 587.5 | 0. | -7.0 | 11. | 0. | 587.3 | 10.7 |
| 17 | 590.5 | 0. | -6.4 | 0. | 0. | 590.5 | 11.5 |
| 18 | 596.3 | 0. | -5.9 | 0. | 0. | 596.3 | 11.8 |
| 19 | 602.8 | 0. | -5.8 | 0. | 0. | 602.8 | 11.3 |
| 20 | 610.0 | 0. | -5.4 | 0. | 0. | 610.0 | 11.2 |
| 21 | 618.1 | 0. | -4.7 | 0. | 0. | 618.1 | 11.5 |
| 22 | 626.1 | 0. | -4.1 | 0. | 0. | 626.1 | 11.8 |
| 23 | 634.2 | 0. | -3.4 | 0. | 0. | 634.2 | 12.1 |
| 24 | 641.4 | 0. | -2.5 | 0. | 0. | 641.4 | 12.4 |
| 25 | 647.6 | 0. | -1.4 | 0. | 0. | 647.6 | 12.6 |
| 26 | 653.9 | 0. | -.3 | 0. | 0. | 653.9 | 12.9 |
| 27 | 660.5 | 0. | 1.6 | 0. | 0. | 660.5 | 14.5 |
| 28 | 667.5 | 0. | 4.3 | 0. | 0. | 667.5 | 17.5 |
| 29 | 674.5 | 0. | 6.9 | 0. | 0. | 674.5 | 20.5 |
| 30 | 681.5 | 0. | 10.0 | 0. | 0. | 681.5 | 24.3 |
| 31 | 688.5 | 0. | 13.4 | 0. | 0. | 688.5 | 28.8 |
| 32 | 693.9 | 0. | 15.7 | 0. | 0. | 693.9 | 31.5 |
| 33 | 698.3 | 0. | 17.1 | 0. | 0. | 698.3 | 32.8 |
| 34 | 703.4 | 0. | 18.6 | 0. | 0. | 703.4 | 34.3 |
| 35 | 708.9 | 0. | 20.1 | 0. | 0. | 708.9 | 35.3 |
| 36 | 714.4 | 0. | 21.1 | 0. | 0. | 714.4 | 35.9 |
| 37 | 719.5 | 0. | 22.0 | 0. | 0. | 719.5 | 36.4 |
| 38 | 723.5 | 0. | 22.8 | 0. | 0. | 723.5 | 36.8 |
| 39 | 728.0 | 0. | 24.0 | 0. | 0. | 728.0 | 37.8 |
| 40 | 735.1 | 0. | 26.0 | 0. | 0. | 735.1 | 39.7 |

1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date: 4:13:2003 Time: 12:41:49 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 27

```
***************************************************************
*  Seismic Forces and Forces Due to Surface Pressures for     *
*  Individual Slices for Conventional  Computations or the    *
*  First Stage of Multi-Stage Computations.                   *
*  (Information is for the Critical Shear Surface in the      *
*  Case of an Automatic Search.)                              *
***************************************************************
```

| Slice No. | X | Seismic Force | Y for Seismic Force | FORCES DUE TO SURFACE PRESSURES Normal Force | Shear Force | X | Y |
|---|---|---|---|---|---|---|---|
| 41 | 743.0 | 0. | 28.3 | 0. | 0. | 743.0 | 41.9 |
| 42 | 750.5 | 0. | 30.6 | 0. | 0. | 750.5 | 44.2 |
| 43 | 757.5 | 0. | 32.9 | 0. | 0. | 757.5 | 46.5 |
| 44 | 761.7 | 0. | 34.1 | 0. | 0. | 761.7 | 47.7 |

1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date: 4:13:2003 Time: 12:41:49 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

```
TABLE NO. 29
***********************************************************************
*  Information Generated During Iterative Solution for the Factor   *
*  of Safety and Side Force Inclination by Spencer's Procedure      *
***********************************************************************

         Trial      Trial
        Factor   Side Force    Force      Moment              Delta
 Iter-    of    Inclination  Imbalance  Imbalance   Delta-F    Theta
 ation  Safety   (degrees)    (lbs.)    (ft.-lbs.)           (degrees)

   1  10.00000    15.0000   .8419E+05   .1591E+08
First-order corrections to F and THETA .........  -.157E+02 -.975E+00
Values factored by  .318E-01 - Deltas too large   -.500E+00 -.310E-01

   2   9.50000    14.9690   .8137E+05   .1537E+08
First-order corrections to F and THETA .........  -.137E+02 -.999E+00
Values factored by  .365E-01 - Deltas too large   -.500E+00 -.365E-01

   3   9.00000    14.9325   .7823E+05   .1479E+08
First-order corrections to F and THETA .........  -.118E+02 -.103E+01
Values factored by  .423E-01 - Deltas too large   -.500E+00 -.434E-01

   4   8.50000    14.8891   .7472E+05   .1413E+08
First-order corrections to F and THETA .........  -.101E+02 -.106E+01
Values factored by  .497E-01 - Deltas too large   -.500E+00 -.526E-01

   5   8.00000    14.8364   .7078E+05   .1339E+08
First-order corrections to F and THETA .........  -.844E+01 -.110E+01
Values factored by  .593E-01 - Deltas too large   -.500E+00 -.651E-01

   6   7.50000    14.7714   .6630E+05   .1255E+08
First-order corrections to F and THETA .........  -.694E+01 -.115E+01
Values factored by  .720E-01 - Deltas too large   -.500E+00 -.825E-01

   7   7.00000    14.6889   .6118E+05   .1159E+08
First-order corrections to F and THETA .........  -.558E+01 -.121E+01
Values factored by  .896E-01 - Deltas too large   -.500E+00 -.108E+00

   8   6.50000    14.5809   .5528E+05   .1048E+08
First-order corrections to F and THETA .........  -.435E+01 -.128E+01
Values factored by  .115E+00 - Deltas too large   -.500E+00 -.148E+00

   9   6.00000    14.4334   .4839E+05   .9197E+07
First-order corrections to F and THETA .........  -.324E+01 -.139E+01
Values factored by  .154E+00 - Deltas too large   -.500E+00 -.213E+00

  10   5.50000    14.2199   .4025E+05   .7682E+07
First-order corrections to F and THETA .........  -.227E+01 -.153E+01
Values factored by  .220E+00 - Deltas too large   -.500E+00 -.336E+00

  11   5.00000    13.8835   .3050E+05   .5877E+07
First-order corrections to F and THETA .........  -.143E+01 -.174E+01
Values factored by  .350E+00 - Deltas too large   -.500E+00 -.609E+00

  12   4.50000    13.2747   .1864E+05   .3702E+07
First-order corrections to F and THETA .........  -.718E+00 -.207E+01
Values factored by  .696E+00 - Deltas too large   -.500E+00 -.144E+01

  13   4.00000    11.8320   .4053E+04   .1099E+07
First-order corrections to F and THETA .........  -.143E+00 -.252E+01
Second-order correction - Iteration   1 ........  -.139E+00 -.252E+01
Second-order correction - Iteration   2 ........  -.139E+00 -.252E+01
```

```
  14   3.86131      9.3089  -.7314E+01   .1145E+06
First-order corrections to F and THETA .........  -.586E-02 -.721E+00
Second-order correction - Iteration   1 ........  -.584E-02 -.721E+00
Second-order correction - Iteration   2 ........  -.584E-02 -.721E+00

  15   3.85548      8.5876   .2881E-01   .2244E+03
First-order corrections to F and THETA .........  -.124E-04 -.139E-02
Second-order correction - Iteration   1 ........  -.124E-04 -.139E-02

  16   3.85546      8.5862  -.1501E-01   .1199E+01
First-order corrections to F and THETA .........   .272E-06 -.176E-04

Factor of Safety - - - - - - - -     3.855
Side Force Inclination - - - - -      8.59
Number of Iterations - - - - - -    16
```

```
1       UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
        Date:  4:13:2003   Time: 12:41:49   Input file: k2
          Kings Island Turning Basin, Station 101+887, Savannah, Georgia
          End of construction loading
          Single circular loading

        TABLE NO. 38
        ***************************************************************
        *  Final Results for Stresses Along the Shear Surface         *
        *  (Results for Critical Shear Surface in Case of a Search.)  *
        ***************************************************************

        SPENCER'S PROCEDURE USED TO COMPUTE FACTOR OF SAFETY
        Factor of Safety =  3.855     Side Force Inclination =   8.59 Degrees

               -------- VALUES AT CENTER OF BASE OF SLICE---------
```

| Slice No. | X-center | Y-center | Total Normal Stress | Effective Normal Stress | Shear Stress |
|---|---|---|---|---|---|
| 1 | 511.8 | -26.2 | 1581.9 | 1581.9 | 256.4 |
| 2 | 516.2 | -26.2 | 1721.0 | 1721.0 | 278.9 |
| 3 | 524.5 | -26.2 | 1988.5 | 1988.5 | 322.3 |
| 4 | 532.8 | -26.2 | 2256.1 | 2256.1 | 365.6 |
| 5 | 540.3 | -26.1 | 2536.5 | 2536.5 | 411.1 |
| 6 | 547.0 | -26.1 | 2837.4 | 2837.4 | 459.9 |
| 7 | 553.7 | -26.1 | 3138.3 | 3138.3 | 508.6 |
| 8 | 560.4 | -26.1 | 3439.1 | 3439.1 | 557.4 |
| 9 | 564.9 | -26.1 | 3641.2 | 3641.2 | 590.1 |
| 10 | 568.4 | -26.1 | 3818.7 | 3818.7 | 618.9 |
| 11 | 573.1 | -25.8 | 3868.7 | 3868.7 | 627.0 |
| 12 | 578.7 | -25.1 | 4006.5 | 4006.5 | 649.4 |
| 13 | 582.1 | -24.7 | 4069.3 | 4069.3 | 659.5 |
| 14 | 583.6 | -24.5 | 4106.8 | 4106.8 | 665.6 |
| 15 | 586.0 | -24.2 | 4166.5 | 4166.5 | 675.3 |
| 16 | 587.5 | -24.1 | 4202.6 | 4202.6 | 681.1 |
| 17 | 590.5 | -23.7 | 4239.1 | 4239.1 | 687.0 |
| 18 | 596.3 | -23.0 | 4184.2 | 4184.2 | 678.1 |
| 19 | 602.8 | -22.2 | 4025.6 | 4025.6 | 652.4 |
| 20 | 610.0 | -21.3 | 3905.7 | 3905.7 | 633.0 |
| 21 | 618.1 | -20.4 | 3824.6 | 3824.6 | 619.9 |
| 22 | 626.1 | -19.4 | 3743.4 | 3743.4 | 606.7 |
| 23 | 634.2 | -18.4 | 3662.3 | 3662.3 | 593.6 |
| 24 | 641.4 | -16.9 | 3321.0 | 3321.0 | 538.3 |
| 25 | 647.6 | -15.0 | 3122.6 | 3122.6 | 506.1 |
| 26 | 653.9 | -13.1 | 2924.1 | 2924.1 | 473.9 |

| | | | | | |
|---|---|---|---|---|---|
| 27 | 660.5 | -11.0 | 2872.7 | 2872.7 | 465.6 |
| 28 | 667.5 | -8.8 | 2968.1 | 2968.1 | 481.1 |
| 29 | 674.5 | -6.6 | 3063.6 | 3063.6 | 496.5 |
| 30 | 681.5 | -4.4 | 3246.4 | 3246.4 | 526.2 |
| 31 | 688.5 | -2.3 | 3516.6 | 3516.6 | 570.0 |
| 32 | 693.9 | -.6 | 3646.1 | 3646.1 | 590.9 |
| 33 | 698.3 | .8 | 3618.5 | 3618.5 | 681.9 |
| 34 | 703.4 | 2.4 | 3603.2 | 3603.2 | 679.0 |
| 35 | 708.9 | 4.1 | 3525.7 | 3525.7 | 664.4 |
| 36 | 714.4 | 5.8 | 3435.1 | 3435.1 | 525.6 |
| 37 | 719.5 | 7.4 | 3356.6 | 3356.6 | 514.8 |
| 38 | 723.5 | 8.6 | 3285.0 | 3285.0 | 491.9 |
| 39 | 728.0 | 10.1 | 3239.6 | 3239.6 | 485.1 |
| 40 | 735.1 | 12.2 | 3204.6 | 3204.6 | 519.4 |

1

-------- VALUES AT CENTER OF BASE OF SLICE---------

| Slice No. | X-center | Y-center | Total Normal Stress | Effective Normal Stress | Shear Stress |
|---|---|---|---|---|---|
| 41 | 743.0 | 14.7 | 3168.8 | 3168.8 | 513.6 |
| 42 | 750.5 | 17.0 | 3160.7 | 3160.7 | 512.3 |
| 43 | 757.5 | 19.2 | 3180.5 | 3180.5 | 515.5 |
| 44 | 761.7 | 20.5 | 3118.2 | 3118.2 | 505.4 |

```
CHECK SUMS - (ALL SHOULD BE SMALL)
SUM OF FORCES IN VERTICAL DIRECTION     =         .02  (=  .200E-01)
     SHOULD NOT EXCEED     .100E+03
SUM OF FORCES IN HORIZONTAL DIRECTION   =         .03  (=  .264E-01)
     SHOULD NOT EXCEED     .100E+03
SUM OF MOMENTS ABOUT COORDINATE ORIGIN  =        -.94  (= -.942E+00)
     SHOULD NOT EXCEED     .100E+03
SHEAR STRENGTH/SHEAR FORCE CHECK-SUM    =         .00  (=  .419E-02)
     SHOULD NOT EXCEED     .100E+03
```

1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date: 4:13:2003 Time: 12:41:49 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 39

```
*****************************************************************
*  Final Results for Side Forces and Stresses Between Slices.   *
*  (Results for Critical Shear Surface in Case of a Search.)    *
*****************************************************************
```

SPENCER'S PROCEDURE USED TO COMPUTE FACTOR OF SAFETY
Factor of Safety = 3.855 Side Force Inclination = 8.59 Degrees

--------------- VALUES AT RIGHT SIDE OF SLICE ----------------

| Slice No. | X-Right | Side Force | Y-Coord. of Side Force Location | Fraction of Height | Sigma at Top | Sigma at Bottom |
|---|---|---|---|---|---|---|
| 1 | 512.0 | 421. | -26.1 | .563 | 2934.7 | 1319.2 |
| 2 | 520.3 | 8035. | -24.3 | .456 | 1396.1 | 2393.6 |
| 3 | 528.7 | 15119. | -22.5 | .448 | 1259.3 | 2398.8 |
| 4 | 537.0 | 21671. | -21.0 | .428 | 1008.4 | 2533.3 |
| 5 | 543.7 | 26592. | -19.9 | .412 | 819.3 | 2656.4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 6 | 550.4 | 31616. | -18.9 | .396 | 653.0 | 2799.9 |
| 7 | 557.0 | 36741. | -18.1 | .380 | 485.8 | 2960.3 |
| 8 | 563.7 | 41968. | -17.3 | .364 | 317.9 | 3131.4 |
| 9 | 566.0 | 43787. | -17.1 | .357 | 239.6 | 3194.0 |
| 10 | 570.8 | 47796. | -16.6 | .342 | 91.9 | 3313.3 |
| 11 | 575.4 | 49316. | -15.7 | .329 | -43.5 | 3318.0 |
| 12 | 582.0 | 51130. | -14.7 | .308 | -238.4 | 3329.5 |
| 13 | 582.3 | 51197. | -14.6 | .307 | -246.0 | 3330.2 |
| 14 | 585.0 | 51780. | -14.2 | .299 | -313.9 | 3338.7 |
| 15 | 587.0 | 52169. | -14.0 | .293 | -365.0 | 3345.7 |
| 16 | 588.0 | 52349. | -13.9 | .292 | -366.9 | 3357.6 |
| 17 | 593.0 | 53234. | -13.3 | .289 | -398.8 | 3412.0 |
| 18 | 599.5 | 54369. | -12.5 | .296 | -354.9 | 3507.8 |
| 19 | 606.0 | 55461. | -11.7 | .305 | -281.2 | 3599.7 |
| 20 | 614.1 | 56774. | -10.8 | .314 | -205.0 | 3696.2 |
| 21 | 622.1 | 58060. | -9.8 | .321 | -136.5 | 3781.3 |
| 22 | 630.2 | 59319. | -8.8 | .329 | -54.7 | 3858.0 |
| 23 | 638.2 | 60550. | -7.8 | .337 | 41.7 | 3925.0 |
| 24 | 644.5 | 57412. | -6.3 | .340 | 83.2 | 3902.9 |
| 25 | 650.7 | 54460. | -4.8 | .343 | 117.1 | 3904.5 |
| 26 | 657.0 | 51697. | -3.4 | .336 | 28.2 | 3940.7 |
| 27 | 664.0 | 48659. | -1.9 | .310 | -259.8 | 3975.6 |
| 28 | 671.0 | 45521. | -.3 | .278 | -561.9 | 3931.3 |
| 29 | 678.0 | 42281. | 1.3 | .244 | -798.9 | 3794.5 |
| 30 | 685.0 | 38848. | 2.9 | .209 | -956.4 | 3529.6 |
| 31 | 692.0 | 35130. | 4.6 | .180 | -1003.4 | 3185.4 |
| 32 | 695.8 | 33048. | 5.5 | .170 | -995.5 | 3032.9 |
| 33 | 700.9 | 30748. | 6.6 | .157 | -1005.0 | 2908.3 |
| 34 | 706.0 | 28458. | 7.8 | .145 | -1007.3 | 2790.8 |
| 35 | 711.8 | 25899. | 9.0 | .132 | -1009.4 | 2682.4 |
| 36 | 716.9 | 23089. | 10.3 | .124 | -969.1 | 2513.7 |
| 37 | 722.0 | 20349. | 11.5 | .115 | -922.7 | 2334.3 |
| 38 | 725.0 | 18762. | 12.2 | .109 | -886.0 | 2203.8 |
| 39 | 731.1 | 15531. | 13.6 | .095 | -793.0 | 1903.3 |
| 40 | 739.0 | 11682. | 15.5 | .074 | -657.7 | 1502.2 |

1

--------------- VALUES AT RIGHT SIDE OF SLICE ----------------

| Slice No. | X-Right | Side Force | Y-Coord. of Side Force Location | Fraction of Height | Sigma at Top | Sigma at Bottom |
|---|---|---|---|---|---|---|
| 41 | 747.0 | 7877. | 17.4 | .052 | -484.3 | 1057.9 |
| 42 | 754.0 | 4534. | 19.0 | .033 | -296.4 | 625.9 |
| 43 | 761.0 | 1171. | 21.1 | .029 | -77.6 | 162.5 |
| 44 | 762.4 | 0. | 216.4 | ABOVE | .0 | .0 |

```
CHECK SUMS - (ALL SHOULD BE SMALL)
SUM OF FORCES IN VERTICAL DIRECTION    =        .02  (=  .200E-01)
     SHOULD NOT EXCEED     .100E+03
SUM OF FORCES IN HORIZONTAL DIRECTION  =        .03  (=  .264E-01)
     SHOULD NOT EXCEED     .100E+03
SUM OF MOMENTS ABOUT COORDINATE ORIGIN =       -.94  (= -.942E+00)
     SHOULD NOT EXCEED     .100E+03
SHEAR STRENGTH/SHEAR FORCE CHECK-SUM   =        .00  (=  .419E-02)
     SHOULD NOT EXCEED     .100E+03
```

END-OF-FILE ENCOUNTERED WHILE READING COMMAND
WORDS - END OF PROBLEM(S) ASSUMED

```
STATION 101+887 CIRCULAR ARC FS = 3.1

HEADING
  Kings Island Turning Basin, Station 101+887, Savannah, Georgia
  End of construction loading
  Single circular loading
PROFILE LINES
  1  1  Top Spoil Material
   771  47
  2000  47

  2  2  Top DA Dike (SM-SC-MH-OH)  0/32
   400  48.0
   769  48.0
   800  20.0
  2000  20.0

  3  3  Directly Beneath Dike & Spoil Area 0/30
   300  11.0
  2000  11.0

  4  4  SP River Bank  .2/28
     0   8.0
  2000   8.5

  5  5  Underlying Softer (SC) (Old marsh deposits) 0/36
     0  -3.0
   480  -3.0
   585   5.0
  2000   5.0

  6  6  Sands (SM-SP) 0/32
     0 -10.0
   480 -10.0
   585   0.0
  2000   0.0

  7  7  Medium Dense Sands 0/38
     0  -26.0
  2000  -28.0

  8  8  Clay Layer  .7/7
     0  -47.0
   587  -44.0
  2000  -44.0

  9 9   Dense Sand  0/38
     0  -54.0
  2000  -54.0


MATERIAL PROPERTIES
  1  Spoil
    98 = unit weight
   Conventional shear strength
     0 16
   NO pore pressures
  2  Sand (Dike)
   125 = unit weight
   Conventional shear strength
    0  32
   NO pore pressures
  3  Sand
```

```
    122 = unit weight
    Conventional shear strength
     0  30
    NO pore pressures
   4  Upper Embankment lean clay and clayey sand
     95 = unit weight
    Conventional shear strength
     200  28
    NO pore pressures
   5 SP
    125.0 = unit weight
    Conventional shear strength
     0  36.0
    NO pore pressures
   6 Medium sand
    125 = unit weight
    Conventional shear strength
     0  32
    NO pore pressures
   7 Med Dense Sand
    126 = unit weight
    Conventional shear strength
    0  38
    NO pore pressures
   8 Clay
    106 = unit weight
    Conventional shear strength
    1400  7
    NO pore pressures
   9 Dense Sand
    126 = unit weight
    Conventional shear strength
    0  38
    NO pore pressures

SURFACE PRESSURES
     0 -55.0  3025  0
   453 -55.0  3025  0
   469 -47.0  2575  0
   512 -26.0  1420  0
   537 -14.0   759  0
   566  -1.0   440  0
   582   8.0   120  0
   588  11.0     0  0
   593  12.0     0  0
   606  11.0     0  0
   657  13.0     0  0
   678  22.0     0  0
   692  31.0     0  0
   706  35.0     0  0
   725  37.0     0  0
   747  43.0     0  0
   761  47.7     0  0
   769  48.0     0  0
  2000  46.0     0  0

SLOPE GEOMETRY
     0 -55.0
   453 -55.0
   469 -47.0
   512 -26.0
   537 -14.0
   566  -1.0
```

```
  582   8.0
  588  11.0
  593  12.0
  606  11.0
  657  13.0
  678  22.0
  692  31.0
  706  35.0
  725  37.0
  747  43.0
  761  47.7
  769  48.0
 2000  46.0

ANALYSIS/COMPUTATION
  NonCircular Search
   535.0, -14
   570.0, -27
   640.0, -26
   725.0,  10

  10, 60
  ITErations
   500
  WATER DEPTH
   4.0
  FACTOR OF SAFETY
   10.0
  CHANGE TRIAL FACTOR

ANALYSIS/COMPUTATION data follow -
     Circle Search
    570 250  5 -60
     Point through which circles pass follows -
        600 -10

COMPUTE
ASCII
PRINT
```

```
1        UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
         Date:  4:13:2003   Time: 13: 9:22   Input file: k2


         TABLE NO. 1
         ******************************************
         * COMPUTER PROGRAM DESIGNATION - UTEXAS3 *
         * Originally Coded By Stephen G. Wright  *
         * Version No. 1.120                      *
         * Last Revision Date 10/08/92            *
         * (C) Copyright 1985-1992 S. G. Wright   *
         * All Rights Reserved                    *
         ******************************************

         **************************************************************
         *                                                            *
         *      RESULTS OF COMPUTATIONS PERFORMED USING THIS COMPUTER *
         * PROGRAM SHOULD NOT BE USED FOR DESIGN PURPOSES UNLESS THEY *
         * HAVE BEEN VERIFIED BY INDEPENDENT ANALYSES, EXPERIMENTAL   *
         * DATA OR FIELD EXPERIENCE. THE USER SHOULD UNDERSTAND THE   *
         * ALGORITHMS AND ANALYTICAL PROCEDURES USED IN THE COMPUTER  *
         * PROGRAM AND MUST HAVE READ ALL DOCUMENTATION FOR THIS      *
         * PROGRAM BEFORE ATTEMPTING ITS USE.                         *
         *                                                            *
         *      NEITHER THE UNIVERSITY OF TEXAS NOR STEPHEN G. WRIGHT *
         * MAKE OR ASSUME LIABILITY FOR ANY WARRANTIES, EXPRESSED OR  *
         * IMPLIED, CONCERNING THE ACCURACY, RELIABILITY, USEFULNESS  *
         * OR ADAPTABILITY OF THIS COMPUTER PROGRAM.                  *
         *                                                            *
         **************************************************************
1        UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
         Date:  4:13:2003   Time: 13: 9:22   Input file: k2
           Kings Island Turning Basin, Station 101+887, Savannah, Georgia
           End of construction loading
           Single circular loading

         TABLE NO.  2
         *************************
         * NEW PROFILE LINE DATA *
         *************************

         PROFILE LINE  1 - MATERIAL TYPE =  1
         Top Spoil Material

              Point      X             Y

                1       771.000        47.000
                2      2000.000        47.000

         PROFILE LINE  2 - MATERIAL TYPE =  2
         Top DA Dike (SM-SC-MH-OH)  0/32

              Point      X             Y

                1       400.000        48.000
                2       769.000        48.000
                3       800.000        20.000
                4      2000.000        20.000

         PROFILE LINE  3 - MATERIAL TYPE =  3
         Directly Beneath Dike & Spoil Area 0/30

              Point      X             Y
```

```
        1       300.000         11.000
        2      2000.000         11.000

PROFILE LINE  4 - MATERIAL TYPE =  4
SP River Bank  .2/28

     Point       X              Y

        1          .000          8.000
        2      2000.000          8.500

PROFILE LINE  5 - MATERIAL TYPE =  5
Underlying Softer (SC) (Old marsh deposits) 0/36

     Point       X              Y

        1          .000         -3.000
        2       480.000         -3.000
        3       585.000          5.000
        4      2000.000          5.000

PROFILE LINE  6 - MATERIAL TYPE =  6
Sands (SM-SP) 0/32

     Point       X              Y

        1          .000        -10.000
        2       480.000        -10.000
        3       585.000           .000
        4      2000.000           .000

PROFILE LINE  7 - MATERIAL TYPE =  7
Medium Dense Sands 0/38

     Point       X              Y

        1          .000        -26.000
        2      2000.000        -28.000

PROFILE LINE  8 - MATERIAL TYPE =  8
Clay Layer  .7/7

     Point       X              Y

        1          .000        -47.000
        2       587.000        -44.000
        3      2000.000        -44.000

PROFILE LINE  9 - MATERIAL TYPE =  9
Dense Sand  0/38

     Point       X              Y

        1          .000        -54.000
        2      2000.000        -54.000

All new profile lines defined - No old lines retained
```

```
1   UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
    Date:  4:13:2003   Time: 13: 9:22   Input file: k2
      Kings Island Turning Basin, Station 101+887, Savannah, Georgia
      End of construction loading
      Single circular loading
```

```
TABLE NO.  3
**************************************************************************
* NEW MATERIAL PROPERTY DATA - CONVENTIONAL/FIRST-STAGE COMPUTATIONS *
**************************************************************************

DATA FOR MATERIAL TYPE  1
Spoil

     Unit weight of material =   98.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - - -        .000
     Friction angle - - - - -  16.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  2
Sand (Dike)

     Unit weight of material =  125.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - - -        .000
     Friction angle - - - - -  32.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  3
Sand

     Unit weight of material =  122.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - - -        .000
     Friction angle - - - - -  30.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  4
Upper Embankment lean clay and clayey sand

     Unit weight of material =   95.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - - -     200.000
     Friction angle - - - - -  28.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  5
SP

     Unit weight of material =  125.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - - -        .000
     Friction angle - - - - -  36.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  6
Medium sand
```

```
     Unit weight of material =  125.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -          .000
     Friction angle - - - - -  32.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  7
Med Dense Sand

     Unit weight of material =  126.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -          .000
     Friction angle - - - - -  38.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  8
Clay

     Unit weight of material =  106.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -      1400.000
     Friction angle - - - - -   7.000 degrees

     No (or zero) pore water pressures

DATA FOR MATERIAL TYPE  9
Dense Sand

     Unit weight of material =  126.000

     CONVENTIONAL (ISOTROPIC) SHEAR STRENGTHS
     Cohesion - - - - - - - -          .000
     Friction angle - - - - -  38.000 degrees

     No (or zero) pore water pressures

All new material properties defined - No old data retained
1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:13:2003   Time: 13: 9:22   Input file: k2
  Kings Island Turning Basin, Station 101+887, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 10
**********************************************************************
* NEW SURFACE PRESSURE DATA - CONVENTIONAL/FIRST-STAGE COMPUTATIONS *
**********************************************************************

ALL NEW DATA INPUT - NO OLD DATA RETAINED

Surface Pressures -
                                        Normal        Shear
Point        X            Y            Pressure      Stress

   1        .000       -55.000       3025.000         .000
   2     453.000       -55.000       3025.000         .000
   3     469.000       -47.000       2575.000         .000
```

| | | | | |
|---|---|---|---|---|
| 4 | 512.000 | -26.000 | 1420.000 | .000 |
| 5 | 537.000 | -14.000 | 759.000 | .000 |
| 6 | 566.000 | -1.000 | 440.000 | .000 |
| 7 | 582.000 | 8.000 | 120.000 | .000 |
| 8 | 588.000 | 11.000 | .000 | .000 |
| 9 | 593.000 | 12.000 | .000 | .000 |
| 10 | 606.000 | 11.000 | .000 | .000 |
| 11 | 657.000 | 13.000 | .000 | .000 |
| 12 | 678.000 | 22.000 | .000 | .000 |
| 13 | 692.000 | 31.000 | .000 | .000 |
| 14 | 706.000 | 35.000 | .000 | .000 |
| 15 | 725.000 | 37.000 | .000 | .000 |
| 16 | 747.000 | 43.000 | .000 | .000 |
| 17 | 761.000 | 47.700 | .000 | .000 |
| 18 | 769.000 | 48.000 | .000 | .000 |
| 19 | 2000.000 | 46.000 | .000 | .000 |

```
1        UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
         Date:  4:13:2003   Time: 13: 9:22   Input file: k2
           Kings Island Turning Basin, Station 101+887, Savannah, Georgia
           End of construction loading
           Single circular loading

         TABLE NO.  9
         ***************************
         * NEW SLOPE GEOMETRY DATA *
         ***************************

         All new data input - No old data retained

         Slope Coordinates -
```

| Point | X | Y |
|---|---|---|
| 1 | .000 | -55.000 |
| 2 | 453.000 | -55.000 |
| 3 | 469.000 | -47.000 |
| 4 | 512.000 | -26.000 |
| 5 | 537.000 | -14.000 |
| 6 | 566.000 | -1.000 |
| 7 | 582.000 | 8.000 |
| 8 | 588.000 | 11.000 |
| 9 | 593.000 | 12.000 |
| 10 | 606.000 | 11.000 |
| 11 | 657.000 | 13.000 |
| 12 | 678.000 | 22.000 |
| 13 | 692.000 | 31.000 |
| 14 | 706.000 | 35.000 |
| 15 | 725.000 | 37.000 |
| 16 | 747.000 | 43.000 |
| 17 | 761.000 | 47.700 |
| 18 | 769.000 | 48.000 |
| 19 | 2000.000 | 46.000 |

```
1        UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
         Date:  4:13:2003   Time: 13: 9:22   Input file: k2
           Kings Island Turning Basin, Station 101+887, Savannah, Georgia
           End of construction loading
           Single circular loading

         TABLE NO. 15
         *********************************
         * NEW ANALYSIS/COMPUTATION DATA *
         *********************************
```

```
Noncircular Shear Surface(s)

Automatic Search Performed


Coordinates of points on shear surface which are to be shifted -

Point          X              Y       Shift Angle

   1        535.000        -14.000   angle to be computed - moveable
   2        570.000        -27.000   angle to be computed - moveable
   3        640.000        -26.000   angle to be computed - moveable
   4        725.000         10.000   angle to be computed - moveable

Initial distance for shifting points on shear surface =  10.000
Maximum steepness permitted for toe of shear surface = 60.00 degrees

Maximum number of iterations allowed for
calculating the factor of safety =  500

Depth of water in crack =       4.000

Initial trial estimate for the factor of safety =  10.000

Initial trial values for factor of safety (and side force inclination
for Spencer's procedure) will be changed during search

---------------------------------------------------------------------
THE FOLLOWING REPRESENT EITHER DEFAULT OR PREVIOUSLY DEFINED VALUES:

Initial trial estimate for side force inclination =  15.000 degrees
(Applicable to Spencer's procedure only)

Allowed force imbalance for convergence =     100.000

Allowed moment imbalance for convergence =     100.000

Number of increments for slice subdivision =   30

Unit weight of water in crack =    62.400

Seismic coefficient =  .000

Conventional (single-stage) computations to be performed

Procedure used to compute the factor of safety: SPENCER
1         UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:13:2003   Time: 13: 9:22   Input file: k2
  Kings Island Turning Basin, Station 101+887, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 15
*********************************
* NEW ANALYSIS/COMPUTATION DATA *
*********************************

Circular Shear Surface(s)

Automatic Search Performed

Starting Center Coordinate for Search at -
                                          X =      570.000
```

```
                                              Y =      250.000

Required accuracy for critical center (= minimum
spacing between grid points) =       5.000

Critical shear surface not allowed to pass below Y =      -60.000

For the initial mode of search
all circles pass through the point at -
                                              X =      600.000
                                              Y =      -10.000

---------------------------------------------------------------------
THE FOLLOWING REPRESENT EITHER DEFAULT OR PREVIOUSLY DEFINED VALUES:

Initial trial estimate for the factor of safety =  10.000

Initial trial estimate for side force inclination =  15.000 degrees
(Applicable to Spencer's procedure only)

Maximum number of iterations allowed for
calculating the factor of safety =  500

Allowed force imbalance for convergence =     100.000

Allowed moment imbalance for convergence =     100.000

Initial trial values for factor of safety (and side force inclination
for Spencer's procedure) will be changed during search

Maximum subtended angle to be used for subdivision of the
circle into slices =   3.00 degrees

Depth of crack =        .000

Search will be continued to locate a more critical shear
surface (if one exists) after the initial mode is complete

Depth of water in crack =       4.000

Unit weight of water in crack =    62.400

Seismic coefficient =  .000

Conventional (single-stage) computations to be performed

Procedure used to compute the factor of safety: SPENCER
1  UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:13:2003   Time: 13: 9:22   Input file: k2
  Kings Island Turning Basin, Station 101+887, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 17
INFORMATION FOR CURRENT MODE OF SEARCH - All Circles Pass Through
the Fixed Point at   X =   600.000  and Y =   -10.000
-----------------------------------------------------------------
                                 1-Stage
Center Coordinates               Factor  Side Force
                                   of    Inclination
     X         Y       Radius    Safety   (degrees)    Iterations
```

```
    420.00    100.00    210.95 Bottom of circle exceeds allowable
                               depth - CIRCLE REJECTED
    570.00    100.00    114.02   4.730        6.34         13
    720.00    100.00    162.79 Bottom of circle exceeds allowable
                               depth - CIRCLE REJECTED
    420.00    250.00    316.23 Bottom of circle exceeds allowable
                               depth - CIRCLE REJECTED
    570.00    250.00    261.73   3.591       11.78         16
    720.00    250.00    286.36 See Message on Next Line(s)
ERROR AT SLICE  24      X =    .770E+03     Y =   -.320E+02

NO PROFILE DATA FOR TOP OF SLICE

    420.00    400.00    447.77   4.539        9.68         14
    570.00    400.00    411.10 See Message on Next Line(s)
ERROR AT SLICE  27      X =    .770E+03     Y =    .408E+02

NO PROFILE DATA FOR TOP OF SLICE

    720.00    400.00    427.20 See Message on Next Line(s)
ERROR AT SLICE  23      X =    .770E+03     Y =   -.243E+02

NO PROFILE DATA FOR TOP OF SLICE


    545.00    225.00    241.35   4.510        6.43         14
    570.00    225.00    236.91   3.839       11.55         15
    595.00    225.00    235.05   3.393       11.59         16
    545.00    250.00    265.75   4.224        9.01         14
    595.00    250.00    260.05   3.259       11.72         16
    545.00    275.00    290.26   3.861       10.87         15
    570.00    275.00    286.57   3.444       11.78         16
    595.00    275.00    285.04   3.151       11.85         17

    620.00    250.00    260.77 See Message on Next Line(s)
ERROR AT SLICE  31      X =    .770E+03     Y =    .367E+02

NO PROFILE DATA FOR TOP OF SLICE

    620.00    275.00    285.70 See Message on Next Line(s)
ERROR AT SLICE  29      X =    .770E+03     Y =    .318E+02

NO PROFILE DATA FOR TOP OF SLICE

    570.00    300.00    311.45   3.325       11.84          3
    595.00    300.00    310.04 See Message on Next Line(s)
ERROR AT SLICE  31      X =    .770E+03     Y =    .441E+02

NO PROFILE DATA FOR TOP OF SLICE

    620.00    300.00    310.64 See Message on Next Line(s)
ERROR AT SLICE  27      X =    .770E+03     Y =    .280E+02

NO PROFILE DATA FOR TOP OF SLICE


    580.00    260.00    270.74   3.398       11.75          4
    595.00    260.00    270.05   3.208       11.80          3
    610.00    260.00    270.19 See Message on Next Line(s)
ERROR AT SLICE  30      X =    .770E+03     Y =    .423E+02

NO PROFILE DATA FOR TOP OF SLICE
```

```
    580.00    275.00    285.70   3.324      11.79          3
    610.00    275.00    285.18 See Message on Next Line(s)
ERROR AT SLICE  30     X =    .770E+03     Y =    .389E+02

NO PROFILE DATA FOR TOP OF SLICE

    580.00    290.00    300.67   3.253      11.87          3
    595.00    290.00    300.04 See Message on Next Line(s)
ERROR AT SLICE  30     X =    .770E+03     Y =    .461E+02

NO PROFILE DATA FOR TOP OF SLICE

    610.00    290.00    300.17 See Message on Next Line(s)
ERROR AT SLICE  30     X =    .770E+03     Y =    .360E+02

NO PROFILE DATA FOR TOP OF SLICE


    590.00    270.00    280.18   3.222      11.83          3
    595.00    270.00    280.04   3.167      11.85          2
    600.00    270.00    280.00 See Message on Next Line(s)
ERROR AT SLICE  31     X =    .769E+03     Y =    .470E+02

NO PROFILE DATA FOR TOP OF SLICE

    590.00    275.00    285.18   3.198      11.87          3
    600.00    275.00    285.00 See Message on Next Line(s)
ERROR AT SLICE  31     X =    .770E+03     Y =    .461E+02

NO PROFILE DATA FOR TOP OF SLICE

    590.00    280.00    290.17   3.177      11.89          3
    595.00    280.00    290.04 See Message on Next Line(s)
ERROR AT SLICE  30     X =    .769E+03     Y =    .480E+02

NO PROFILE DATA FOR TOP OF SLICE

    600.00    280.00    290.00 See Message on Next Line(s)
ERROR AT SLICE  31     X =    .770E+03     Y =    .451E+02

NO PROFILE DATA FOR TOP OF SLICE


At the end of the current mode of search the most critical
circle which was found has the following values -
X-center =    595.00    Y-center =    275.00     Radius =    285.04
Factor of Safety =   3.151     Side Force Inclination =  11.85


***** CAUTION ***** FACTOR OF SAFETY COULD NOT BE COMPUTED FOR SOME
                    OF GRID POINTS AROUND THE MINIMUM
***** RESULTS MAY BE ERRONEOUS *****
1  UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:13:2003   Time: 13: 9:22   Input file: k2
  Kings Island Turning Basin, Station 101+887, Savannah, Georgia
  End of construction loading
  Single circular loading

TABLE NO. 18
INFORMATION FOR CURRENT MODE OF SEARCH - All Circles Are Tangent
to a Horizontal Line at   Y =   -10.044
----------------------------------------------------------------
```

```
Center Coordinates                 Factor  Side Force
                                     of    Inclination
     X          Y        Radius   Safety   (degrees)   Iterations


    445.00    125.00    135.04 See Message on Next Line(s)
CIRCLE DOES NOT INTERSECT SLOPE

    595.00    125.00    135.04   5.629       8.81         29
    745.00    125.00    135.04 See Message on Next Line(s)
ERROR AT SLICE  22     X =    .770E+03     Y =   -.771E+01

NO PROFILE DATA FOR TOP OF SLICE

    445.00    275.00    285.04 See Message on Next Line(s)
CIRCLE DOES NOT INTERSECT SLOPE

    745.00    275.00    285.04 See Message on Next Line(s)
ERROR AT SLICE  16     X =    .770E+03     Y =   -.894E+01

NO PROFILE DATA FOR TOP OF SLICE

    445.00    425.00    435.04 See Message on Next Line(s)
CIRCLE DOES NOT INTERSECT SLOPE

    595.00    425.00    435.04 See Message on Next Line(s)
ERROR AT SLICE  26     X =    .770E+03     Y =    .267E+02

NO PROFILE DATA FOR TOP OF SLICE

    745.00    425.00    435.04 See Message on Next Line(s)
ERROR AT SLICE  14     X =    .770E+03     Y =   -.932E+01

NO PROFILE DATA FOR TOP OF SLICE


    570.00    250.00    260.04   3.693      11.81          4
    595.00    250.00    260.04   3.259      11.72          3
    620.00    250.00    260.04 See Message on Next Line(s)
ERROR AT SLICE  32     X =    .770E+03     Y =    .376E+02

NO PROFILE DATA FOR TOP OF SLICE

    570.00    275.00    285.04   3.503      11.80          4
    620.00    275.00    285.04 See Message on Next Line(s)
ERROR AT SLICE  29     X =    .770E+03     Y =    .326E+02

NO PROFILE DATA FOR TOP OF SLICE

    570.00    300.00    310.04   3.365      11.83          3
    595.00    300.00    310.04 See Message on Next Line(s)
ERROR AT SLICE  31     X =    .770E+03     Y =    .441E+02

NO PROFILE DATA FOR TOP OF SLICE

    620.00    300.00    310.04 See Message on Next Line(s)
ERROR AT SLICE  27     X =    .770E+03     Y =    .287E+02

NO PROFILE DATA FOR TOP OF SLICE


    580.00    260.00    270.04   3.416      11.75          4
    595.00    260.00    270.04   3.208      11.80          3
```

```
    610.00    260.00    270.04 See Message on Next Line(s)
ERROR AT SLICE  30     X =    .770E+03     Y =    .425E+02

NO PROFILE DATA FOR TOP OF SLICE

    580.00    275.00    285.04   3.337      11.78         3
    610.00    275.00    285.04 See Message on Next Line(s)
ERROR AT SLICE  30     X =    .770E+03     Y =    .391E+02

NO PROFILE DATA FOR TOP OF SLICE

    580.00    290.00    300.04   3.265      11.84         3
    595.00    290.00    300.04 See Message on Next Line(s)
ERROR AT SLICE  30     X =    .770E+03     Y =    .461E+02

NO PROFILE DATA FOR TOP OF SLICE

    610.00    290.00    300.04 See Message on Next Line(s)
ERROR AT SLICE  30     X =    .770E+03     Y =    .362E+02

NO PROFILE DATA FOR TOP OF SLICE


    590.00    270.00    280.04   3.224      11.82         3
    595.00    270.00    280.04   3.167      11.85         2
    600.00    270.00    280.04 See Message on Next Line(s)
ERROR AT SLICE  31     X =    .769E+03     Y =    .470E+02

NO PROFILE DATA FOR TOP OF SLICE

    590.00    275.00    285.04   3.200      11.86         3
    600.00    275.00    285.04 See Message on Next Line(s)
ERROR AT SLICE  31     X =    .770E+03     Y =    .460E+02

NO PROFILE DATA FOR TOP OF SLICE

    590.00    280.00    290.04   3.178      11.89         3
    595.00    280.00    290.04 See Message on Next Line(s)
ERROR AT SLICE  30     X =    .769E+03     Y =    .480E+02

NO PROFILE DATA FOR TOP OF SLICE

    600.00    280.00    290.04 See Message on Next Line(s)
ERROR AT SLICE  31     X =    .770E+03     Y =    .450E+02

NO PROFILE DATA FOR TOP OF SLICE


At the end of the current mode of search the most critical
circle which was found has the following values -
X-center =     595.00     Y-center =    275.00     Radius =    285.04
Factor of Safety =   3.151     Side Force Inclination =  11.85


***** CAUTION ***** FACTOR OF SAFETY COULD NOT BE COMPUTED FOR SOME
                    OF GRID POINTS AROUND THE MINIMUM
***** RESULTS MAY BE ERRONEOUS *****
1       UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:13:2003   Time: 13: 9:22   Input file: k2
  Kings Island Turning Basin, Station 101+887, Savannah, Georgia
  End of construction loading
  Single circular loading
```

TABLE NO. 21
***** 1-STAGE FINAL CRITICAL CIRCLE INFORMATION *****
X Coordinate of Center - - - - - - - 595.000
Y Coordinate of Center - - - - - - - 275.000
Radius - - - - - - - - - - - - - - - 285.044
Factor of Safety - - - - - - - - - - 3.151
Side Force Inclination - - - - - - - 11.85

Number of circles tried - - - - - - 70
No. of circles F calc. for - - - - - 33

***** CAUTION ***** FACTOR OF SAFETY COULD NOT BE COMPUTED FOR SOME
OF GRID POINTS AROUND THE MINIMUM
***** RESULTS MAY BE ERRONEOUS *****
1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date: 4:13:2003 Time: 13: 9:22 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 26
*****************************************************************
* Coordinate, Weight, Strength and Pore Water Pressure *
* Information for Individual Slices for Conventional *
* Computations or First Stage of Multi-Stage Computations. *
* (Information is for the Critical Shear Surface in the *
* Case of an Automatic Search.) *
*****************************************************************

| Slice No. | X | Y | Slice Weight | Matl. Type | Cohesion | Friction Angle | Pore Pressure |
|---|---|---|---|---|---|---|---|
| | 552.8 | -6.9 | | | | | |
| 1 | 558.3 | -7.6 | 4280.3 | 6 | .00 | 32.00 | .0 |
| | 563.7 | -8.3 | | | | | |
| 2 | 564.9 | -8.4 | 1986.0 | 6 | .00 | 32.00 | .0 |
| | 566.0 | -8.6 | | | | | |
| 3 | 570.7 | -9.0 | 12401.6 | 6 | .00 | 32.00 | .0 |
| | 575.4 | -9.4 | | | | | |
| 4 | 578.7 | -9.6 | 12698.8 | 6 | .00 | 32.00 | .0 |
| | 582.0 | -9.7 | | | | | |
| 5 | 582.1 | -9.8 | 620.0 | 6 | .00 | 32.00 | .0 |
| | 582.3 | -9.8 | | | | | |
| 6 | 583.6 | -9.8 | 6041.1 | 6 | .00 | 32.00 | .0 |
| | 585.0 | -9.9 | | | | | |
| 7 | 586.0 | -9.9 | 4775.1 | 6 | .00 | 32.00 | .0 |
| | 587.0 | -9.9 | | | | | |
| 8 | 587.5 | -9.9 | 2484.6 | 6 | .00 | 32.00 | .0 |
| | 588.0 | -10.0 | | | | | |
| 9 | 590.5 | -10.0 | 12920.9 | 6 | .00 | 32.00 | .0 |
| | 593.0 | -10.0 | | | | | |
| 10 | 594.0 | -10.0 | 5284.8 | 6 | .00 | 32.00 | .0 |
| | 595.0 | -10.0 | | | | | |
| 11 | 600.5 | -9.9 | 28237.4 | 6 | .00 | 32.00 | .0 |
| | 606.0 | -9.8 | | | | | |
| 12 | 613.4 | -9.3 | 36885.9 | 6 | .00 | 32.00 | .0 |
| | 620.9 | -8.9 | | | | | |
| 13 | 628.3 | -8.0 | 35277.5 | 6 | .00 | 32.00 | .0 |
| | 635.7 | -7.1 | | | | | |
| 14 | 643.1 | -5.9 | 32157.4 | 6 | .00 | 32.00 | .0 |
| | 650.4 | -4.6 | | | | | |
| 15 | 653.7 | -3.9 | 13119.3 | 6 | .00 | 32.00 | .0 |

```
             657.0      -3.2
       16    663.5      -1.6     26922.0     6        .00     32.00          .0
             670.0        .0
       17    674.0       1.2     18303.6     5        .00     36.00          .0
             678.0       2.3
       18    682.2       3.7     21165.7     5        .00     36.00          .0
             686.4       5.0
       19    689.2       6.0     15892.6     4     200.00     28.00          .0
             692.0       7.0
       20    693.6       7.6      9676.3     4     200.00     28.00          .0
             695.3       8.2
       21    698.9       9.6     21071.1     3        .00     30.00          .0
             702.5      11.0
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     Date:  4:13:2003   Time: 13: 9:22   Input file: k2
       Kings Island Turning Basin, Station 101+887, Savannah, Georgia
       End of construction loading
       Single circular loading

     TABLE NO. 26
     **************************************************************
     *  Coordinate, Weight, Strength and Pore Water Pressure       *
     *  Information for Individual Slices for Conventional         *
     *  Computations or First Stage of Multi-Stage Computations.   *
     *  (Information is for the Critical Shear Surface in the      *
     *  Case of an Automatic Search.)                              *
     **************************************************************

     Slice                          Slice   Matl.            Friction    Pore
       No.      X          Y        Weight  Type   Cohesion    Angle   Pressure

             702.5      11.0
       22    704.2      11.7      9992.0     2        .00     32.00          .0
             706.0      12.5
       23    712.8      15.5     34266.2     2        .00     32.00          .0
             719.6      18.6
       24    722.3      20.0     11323.1     2        .00     32.00          .0
             725.0      21.3
       25    731.5      24.9     22730.8     2        .00     32.00          .0
             738.1      28.5
       26    742.5      31.2     11811.0     2        .00     32.00          .0
             747.0      33.9
       27    753.2      38.0     10977.2     2        .00     32.00          .0
             759.4      42.2
       28    760.2      42.7       936.7     2        .00     32.00          .0
             761.0      43.3
       29    764.2      45.6      1744.2     2        .00     32.00          .0
             767.3      47.9
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     Date:  4:13:2003   Time: 13: 9:22   Input file: k2
       Kings Island Turning Basin, Station 101+887, Savannah, Georgia
       End of construction loading
       Single circular loading

     TABLE NO. 27
     *************************************************************
     *  Seismic Forces and Forces Due to Surface Pressures for    *
     *  Individual Slices for Conventional  Computations or the   *
     *  First Stage of Multi-Stage Computations.                  *
     *  (Information is for the Critical Shear Surface in the     *
     *  Case of an Automatic Search.)                             *
     *************************************************************
```

| Slice No. | X | Seismic Force | Y for Seismic Force | FORCES DUE TO SURFACE PRESSURES Normal Force | Shear Force | X | Y |
|---|---|---|---|---|---|---|---|
| 1 | 558.3 | 0. | -6.0 | 6262. | 0. | 558.1 | -4.6 |
| 2 | 564.9 | 0. | -5.0 | 1137. | 0. | 564.8 | -1.5 |
| 3 | 570.7 | 0. | -3.7 | 3720. | 0. | 570.3 | 1.4 |
| 4 | 578.7 | 0. | -1.9 | 1420. | 0. | 578.3 | 5.9 |
| 5 | 582.1 | 0. | -1.2 | 38. | 0. | 582.1 | 8.1 |
| 6 | 583.6 | 0. | -.8 | 264. | 0. | 583.5 | 8.8 |
| 7 | 586.0 | 0. | -.2 | 89. | 0. | 585.8 | 9.9 |
| 8 | 587.5 | 0. | .1 | 11. | 0. | 587.3 | 10.7 |
| 9 | 590.5 | 0. | .5 | 0. | 0. | 590.5 | 11.5 |
| 10 | 594.0 | 0. | .7 | 0. | 0. | 594.0 | 11.9 |
| 11 | 600.5 | 0. | .5 | 0. | 0. | 600.5 | 11.4 |
| 12 | 613.4 | 0. | .7 | 0. | 0. | 613.4 | 11.3 |
| 13 | 628.3 | 0. | 1.7 | 0. | 0. | 628.3 | 11.9 |
| 14 | 643.1 | 0. | 3.1 | 0. | 0. | 643.1 | 12.5 |
| 15 | 653.7 | 0. | 4.4 | 0. | 0. | 653.7 | 12.9 |
| 16 | 663.5 | 0. | 7.1 | 0. | 0. | 663.5 | 15.8 |
| 17 | 674.0 | 0. | 10.9 | 0. | 0. | 674.0 | 20.3 |
| 18 | 682.2 | 0. | 14.5 | 0. | 0. | 682.2 | 24.7 |
| 19 | 689.2 | 0. | 17.9 | 0. | 0. | 689.2 | 29.2 |
| 20 | 693.6 | 0. | 19.6 | 0. | 0. | 693.6 | 31.5 |
| 21 | 698.9 | 0. | 21.3 | 0. | 0. | 698.9 | 33.0 |
| 22 | 704.2 | 0. | 23.1 | 0. | 0. | 704.2 | 34.5 |
| 23 | 712.8 | 0. | 25.6 | 0. | 0. | 712.8 | 35.7 |
| 24 | 722.3 | 0. | 28.3 | 0. | 0. | 722.3 | 36.7 |
| 25 | 731.5 | 0. | 31.8 | 0. | 0. | 731.5 | 38.8 |
| 26 | 742.5 | 0. | 36.5 | 0. | 0. | 742.5 | 41.8 |
| 27 | 753.2 | 0. | 41.5 | 0. | 0. | 753.2 | 45.1 |
| 28 | 760.2 | 0. | 45.1 | 0. | 0. | 760.2 | 47.4 |
| 29 | 764.2 | 0. | 46.7 | 0. | 0. | 764.2 | 47.8 |

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Date: 4:13:2003 Time: 13: 9:22 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 29
```
**************************************************************************
*  Information Generated During Iterative Solution for the Factor       *
*  of Safety and Side Force Inclination by Spencer's Procedure          *
**************************************************************************
```

| Iter-ation | Trial Factor of Safety | Trial Side Force Inclination (degrees) | Force Imbalance (lbs.) | Moment Imbalance (ft.-lbs.) | Delta-F | Delta Theta (degrees) |
|---|---|---|---|---|---|---|
| 1 | 10.00000 | 15.0000 | .6039E+05 | .1042E+08 | | |
| First-order corrections to F and THETA ......... | | | | | -.215E+02 | -.408E+00 |
| Values factored by .232E-01 - Deltas too large | | | | | -.500E+00 | -.946E-02 |
| 2 | 9.50000 | 14.9905 | .5891E+05 | .1016E+08 | | |
| First-order corrections to F and THETA ......... | | | | | -.190E+02 | -.415E+00 |
| Values factored by .264E-01 - Deltas too large | | | | | -.500E+00 | -.110E-01 |
| 3 | 9.00000 | 14.9796 | .5727E+05 | .9879E+07 | | |
| First-order corrections to F and THETA ......... | | | | | -.165E+02 | -.424E+00 |
| Values factored by .302E-01 - Deltas too large | | | | | -.500E+00 | -.128E-01 |

```
   4   8.50000     14.9667   .5544E+05    .9563E+07
First-order corrections to F and THETA .........  -.143E+02 -.435E+00
Values factored by  .350E-01 - Deltas too large   -.500E+00 -.152E-01

   5   8.00000     14.9515   .5337E+05    .9208E+07
First-order corrections to F and THETA .........  -.122E+02 -.448E+00
Values factored by  .411E-01 - Deltas too large   -.500E+00 -.184E-01

   6   7.50000     14.9331   .5103E+05    .8806E+07
First-order corrections to F and THETA .........  -.102E+02 -.463E+00
Values factored by  .489E-01 - Deltas too large   -.500E+00 -.226E-01

   7   7.00000     14.9105   .4836E+05    .8345E+07
First-order corrections to F and THETA .........  -.843E+01 -.481E+00
Values factored by  .593E-01 - Deltas too large   -.500E+00 -.285E-01

   8   6.50000     14.8820   .4527E+05    .7815E+07
First-order corrections to F and THETA .........  -.680E+01 -.504E+00
Values factored by  .735E-01 - Deltas too large   -.500E+00 -.370E-01

   9   6.00000     14.8449   .4166E+05    .7195E+07
First-order corrections to F and THETA .........  -.533E+01 -.533E+00
Values factored by  .938E-01 - Deltas too large   -.500E+00 -.500E-01

  10   5.50000     14.7949   .3739E+05    .6463E+07
First-order corrections to F and THETA .........  -.402E+01 -.573E+00
Values factored by  .124E+00 - Deltas too large   -.500E+00 -.713E-01

  11   5.00000     14.7236   .3227E+05    .5586E+07
First-order corrections to F and THETA .........  -.287E+01 -.629E+00
Values factored by  .174E+00 - Deltas too large   -.500E+00 -.110E+00

  12   4.50000     14.6140   .2601E+05    .4516E+07
First-order corrections to F and THETA .........  -.187E+01 -.713E+00
Values factored by  .267E+00 - Deltas too large   -.500E+00 -.190E+00

  13   4.00000     14.4238   .1820E+05    .3184E+07
First-order corrections to F and THETA .........  -.104E+01 -.853E+00
Values factored by  .480E+00 - Deltas too large   -.500E+00 -.410E+00

  14   3.50000     14.0139   .8193E+04    .1497E+07
First-order corrections to F and THETA .........  -.370E+00 -.113E+01
Second-order correction - Iteration   1 ........  -.339E+00 -.113E+01
Second-order correction - Iteration   2 ........  -.339E+00 -.113E+01

  15   3.16137     12.8840  -.7757E+02    .9128E+05
First-order corrections to F and THETA .........  -.110E-01 -.103E+01
Second-order correction - Iteration   1 ........  -.109E-01 -.103E+01
Second-order correction - Iteration   2 ........  -.109E-01 -.103E+01

  16   3.15051     11.8495   .6641E-01  -.4874E+03
First-order corrections to F and THETA .........   .630E-04  .501E-02
Second-order correction - Iteration   1 ........   .631E-04  .501E-02

  17   3.15057     11.8545   .1953E-02    .1214E+01
First-order corrections to F and THETA .........  -.195E-06 -.963E-05

Factor of Safety - - - - - - - -     3.151
Side Force Inclination - - - - -     11.85
Number of Iterations - - - - - -    17
1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date:  4:13:2003   Time: 13: 9:22   Input file: k2
  Kings Island Turning Basin, Station 101+887, Savannah, Georgia
```

End of construction loading
Single circular loading

TABLE NO. 38

****************************************************************

* Final Results for Stresses Along the Shear Surface *
* (Results for Critical Shear Surface in Case of a Search.) *

****************************************************************

SPENCER'S PROCEDURE USED TO COMPUTE FACTOR OF SAFETY
Factor of Safety = 3.151 Side Force Inclination = 11.85 Degrees

-------- VALUES AT CENTER OF BASE OF SLICE---------

| Slice No. | X-center | Y-center | Total Normal Stress | Effective Normal Stress | Shear Stress |
|---|---|---|---|---|---|
| 1 | 558.3 | -7.6 | 1069.0 | 1069.0 | 212.0 |
| 2 | 564.9 | -8.4 | 1487.9 | 1487.9 | 295.1 |
| 3 | 570.7 | -9.0 | 1854.1 | 1854.1 | 367.7 |
| 4 | 578.7 | -9.6 | 2268.7 | 2268.7 | 450.0 |
| 5 | 582.1 | -9.8 | 2403.3 | 2403.3 | 476.7 |
| 6 | 583.6 | -9.8 | 2469.4 | 2469.4 | 489.8 |
| 7 | 586.0 | -9.9 | 2572.0 | 2572.0 | 510.1 |
| 8 | 587.5 | -9.9 | 2633.6 | 2633.6 | 522.3 |
| 9 | 590.5 | -10.0 | 2714.7 | 2714.7 | 538.4 |
| 10 | 594.0 | -10.0 | 2761.3 | 2761.3 | 547.7 |
| 11 | 600.5 | -9.9 | 2656.7 | 2656.7 | 526.9 |
| 12 | 613.4 | -9.3 | 2515.0 | 2515.0 | 498.8 |
| 13 | 628.3 | -8.0 | 2365.1 | 2365.1 | 469.1 |
| 14 | 643.1 | -5.9 | 2126.2 | 2126.2 | 421.7 |
| 15 | 653.7 | -3.9 | 1909.8 | 1909.8 | 378.8 |
| 16 | 663.5 | -1.6 | 1954.7 | 1954.7 | 387.7 |
| 17 | 674.0 | 1.2 | 2121.0 | 2121.0 | 489.1 |
| 18 | 682.2 | 3.7 | 2311.0 | 2311.0 | 532.9 |
| 19 | 689.2 | 6.0 | 2568.5 | 2568.5 | 497.0 |
| 20 | 693.6 | 7.6 | 2671.8 | 2671.8 | 514.4 |
| 21 | 698.9 | 9.6 | 2616.1 | 2616.1 | 479.4 |
| 22 | 704.2 | 11.7 | 2523.8 | 2523.8 | 500.6 |
| 23 | 712.8 | 15.5 | 2204.9 | 2204.9 | 437.3 |
| 24 | 722.3 | 20.0 | 1800.4 | 1800.4 | 357.1 |
| 25 | 731.5 | 24.9 | 1469.1 | 1469.1 | 291.4 |
| 26 | 742.5 | 31.2 | 1100.7 | 1100.7 | 218.3 |
| 27 | 753.2 | 38.0 | 718.5 | 718.5 | 142.5 |
| 28 | 760.2 | 42.7 | 472.3 | 472.3 | 93.7 |
| 29 | 764.2 | 45.6 | 206.2 | 206.2 | 40.9 |

CHECK SUMS - (ALL SHOULD BE SMALL)
SUM OF FORCES IN VERTICAL DIRECTION = .01 (= .116E-01)
SHOULD NOT EXCEED .100E+03
SUM OF FORCES IN HORIZONTAL DIRECTION = .02 (= .176E-01)
SHOULD NOT EXCEED .100E+03
SUM OF MOMENTS ABOUT COORDINATE ORIGIN = -1.30 (= -.130E+01)
SHOULD NOT EXCEED .100E+03
SHEAR STRENGTH/SHEAR FORCE CHECK-SUM = .00 (= .329E-02)
SHOULD NOT EXCEED .100E+03

1 UTEXAS3 - VER. 1.120 - 10/08/92 - (C) 1985-1992 S. G. WRIGHT
Date: 4:13:2003 Time: 13: 9:22 Input file: k2
Kings Island Turning Basin, Station 101+887, Savannah, Georgia
End of construction loading
Single circular loading

TABLE NO. 39
```
*******************************************************************
*  Final Results for Side Forces and Stresses Between Slices.    *
*  (Results for Critical Shear Surface in Case of a Search.)     *
*******************************************************************
```

SPENCER'S PROCEDURE USED TO COMPUTE FACTOR OF SAFETY
Factor of Safety = 3.151     Side Force Inclination = 11.85 Degrees

--------------- VALUES AT RIGHT SIDE OF SLICE ----------------

| Slice No. | X-Right | Side Force | Y-Coord. of Side Force Location | Fraction of Height | Sigma at Top | Sigma at Bottom |
|---|---|---|---|---|---|---|
| 1 | 563.7 | 6520. | -5.4 | .459 | 766.2 | 1261.8 |
| 2 | 566.0 | 8058. | -5.2 | .434 | 610.2 | 1403.5 |
| 3 | 575.4 | 14958. | -4.2 | .378 | 290.5 | 1857.2 |
| 4 | 582.0 | 19604. | -3.7 | .340 | 44.5 | 2118.2 |
| 5 | 582.3 | 19795. | -3.7 | .339 | 35.7 | 2128.2 |
| 6 | 585.0 | 21544. | -3.5 | .327 | -43.9 | 2221.1 |
| 7 | 587.0 | 22793. | -3.4 | .317 | -104.7 | 2288.3 |
| 8 | 588.0 | 23403. | -3.4 | .318 | -100.0 | 2325.6 |
| 9 | 593.0 | 26373. | -3.2 | .314 | -135.6 | 2492.9 |
| 10 | 595.0 | 27512. | -3.0 | .320 | -95.7 | 2555.7 |
| 11 | 606.0 | 32858. | -2.0 | .367 | 302.9 | 2721.6 |
| 12 | 620.9 | 37966. | -.1 | .429 | 1037.9 | 2596.0 |
| 13 | 635.7 | 40854. | 2.3 | .491 | 1956.3 | 2189.9 |
| 14 | 650.4 | 41723. | 5.2 | .567 | 3295.6 | 1412.5 |
| 15 | 657.0 | 41567. | 6.6 | .564 | 3220.9 | 1432.4 |
| 16 | 670.0 | 40287. | 9.7 | .521 | 2391.7 | 1854.4 |
| 17 | 678.0 | 39283. | 11.6 | .461 | 1463.8 | 2353.8 |
| 18 | 686.4 | 37489. | 13.8 | .392 | 577.5 | 2700.3 |
| 19 | 692.0 | 35178. | 15.5 | .360 | 229.4 | 2671.0 |
| 20 | 695.3 | 33604. | 16.6 | .354 | 170.3 | 2598.0 |
| 21 | 702.5 | 29587. | 19.1 | .354 | 158.9 | 2359.3 |
| 22 | 706.0 | 27626. | 20.4 | .364 | 226.8 | 2238.9 |
| 23 | 719.6 | 19799. | 25.8 | .402 | 451.4 | 1725.2 |
| 24 | 725.0 | 16804. | 28.1 | .415 | 499.1 | 1528.6 |
| 25 | 738.1 | 9969. | 33.9 | .450 | 566.6 | 1046.8 |
| 26 | 747.0 | 5896. | 38.3 | .480 | 543.4 | 693.5 |
| 27 | 759.4 | 1620. | 45.3 | .621 | 545.2 | 87.0 |
| 28 | 761.0 | 1227. | 46.5 | .807 | 864.8 | -256.5 |
| 29 | 767.3 | 0. | -6.3 | BELOW | .0 | .0 |

CHECK SUMS - (ALL SHOULD BE SMALL)
SUM OF FORCES IN VERTICAL DIRECTION = .01 (= .116E-01)
SHOULD NOT EXCEED .100E+03
SUM OF FORCES IN HORIZONTAL DIRECTION = .02 (= .176E-01)
SHOULD NOT EXCEED .100E+03
SUM OF MOMENTS ABOUT COORDINATE ORIGIN = -1.30 (= -.130E+01)
SHOULD NOT EXCEED .100E+03
SHEAR STRENGTH/SHEAR FORCE CHECK-SUM = .00 (= .329E-02)
SHOULD NOT EXCEED .100E+03

END-OF-FILE ENCOUNTERED WHILE READING COMMAND
WORDS - END OF PROBLEM(S) ASSUMED

# APPENDIX F

# MAPS ACQUISITION

**(Links Below)**

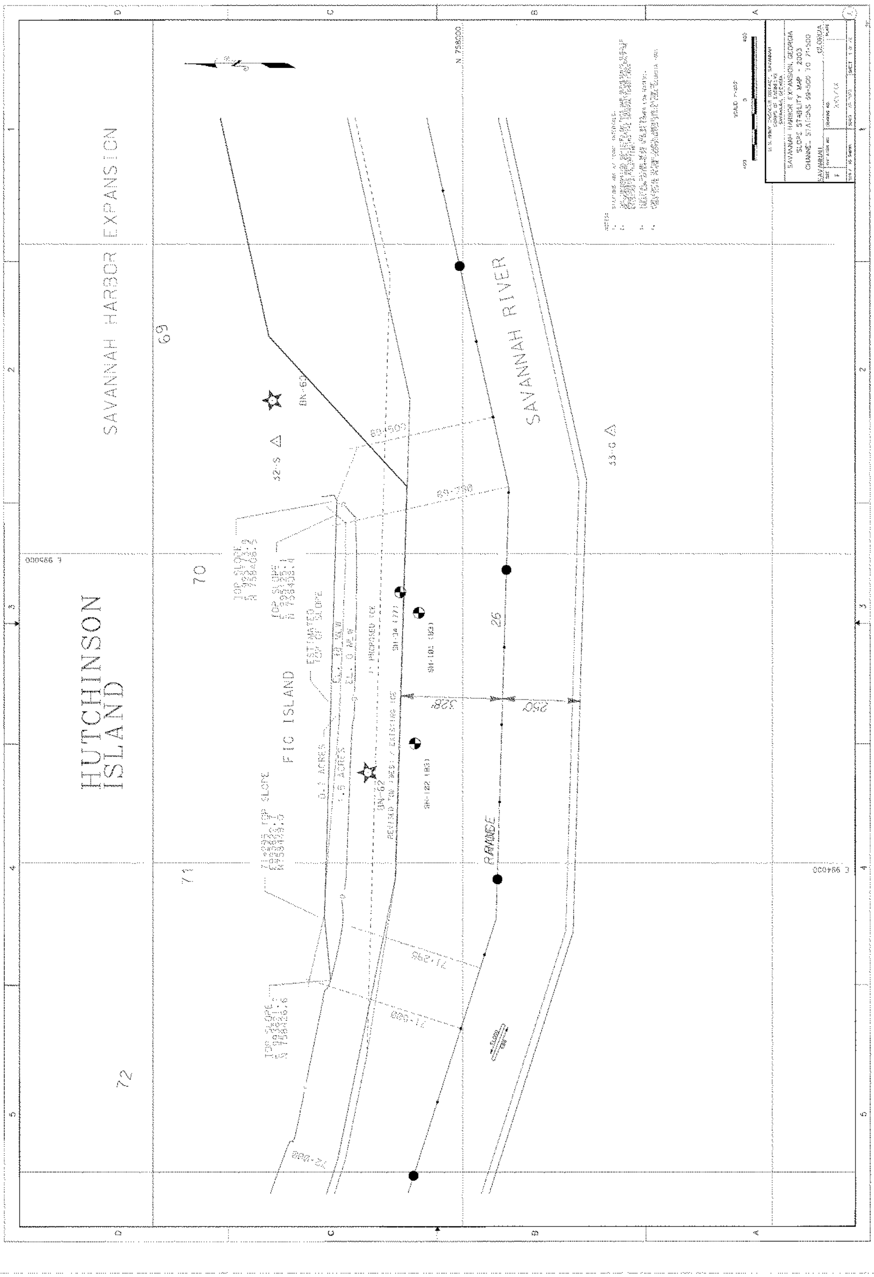
**MAP 1 - 69+500 to 71+295   1.5ac/0 + 0.7ac/+8 MLW**

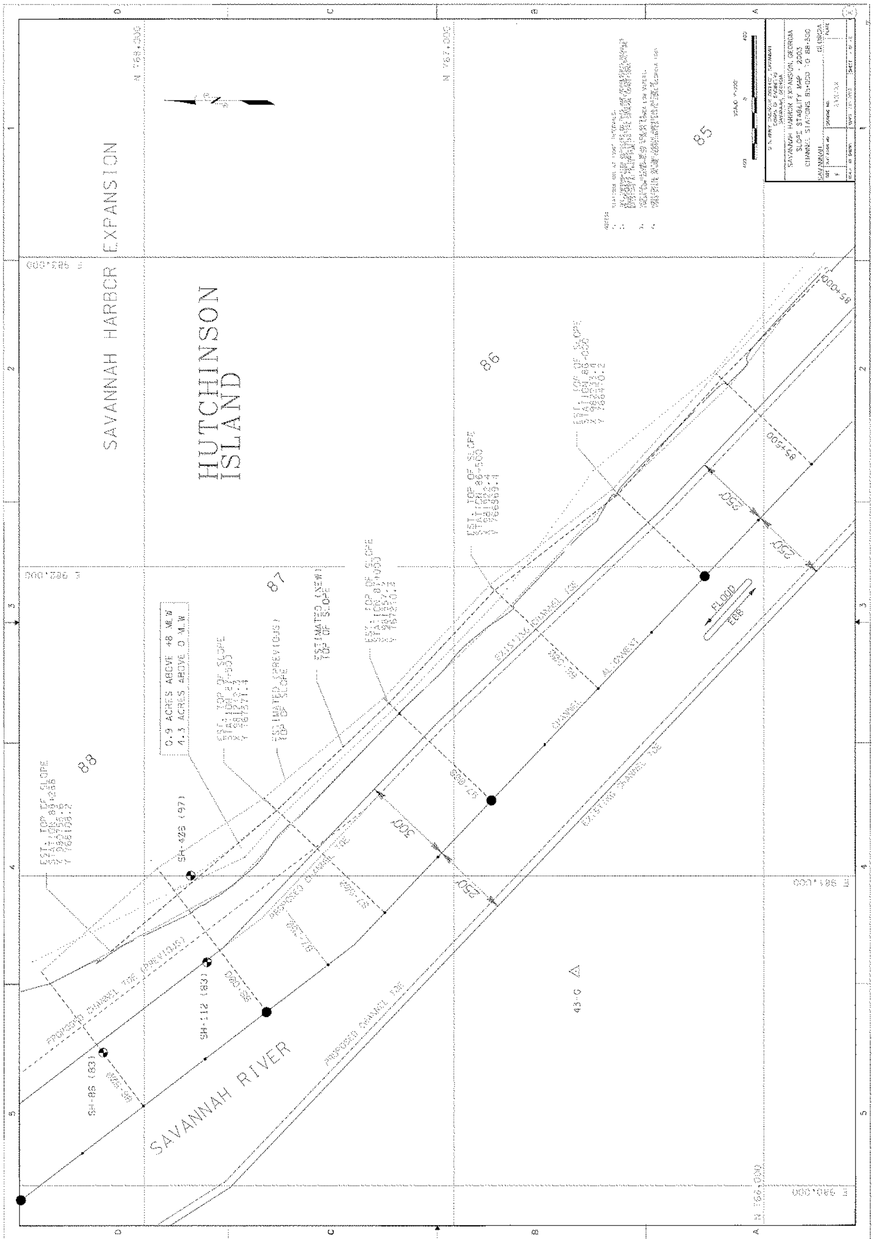
**MAP 2 - 86+000 to 88+500   4.3ac/0 + 0.9ac/+8 MLW**

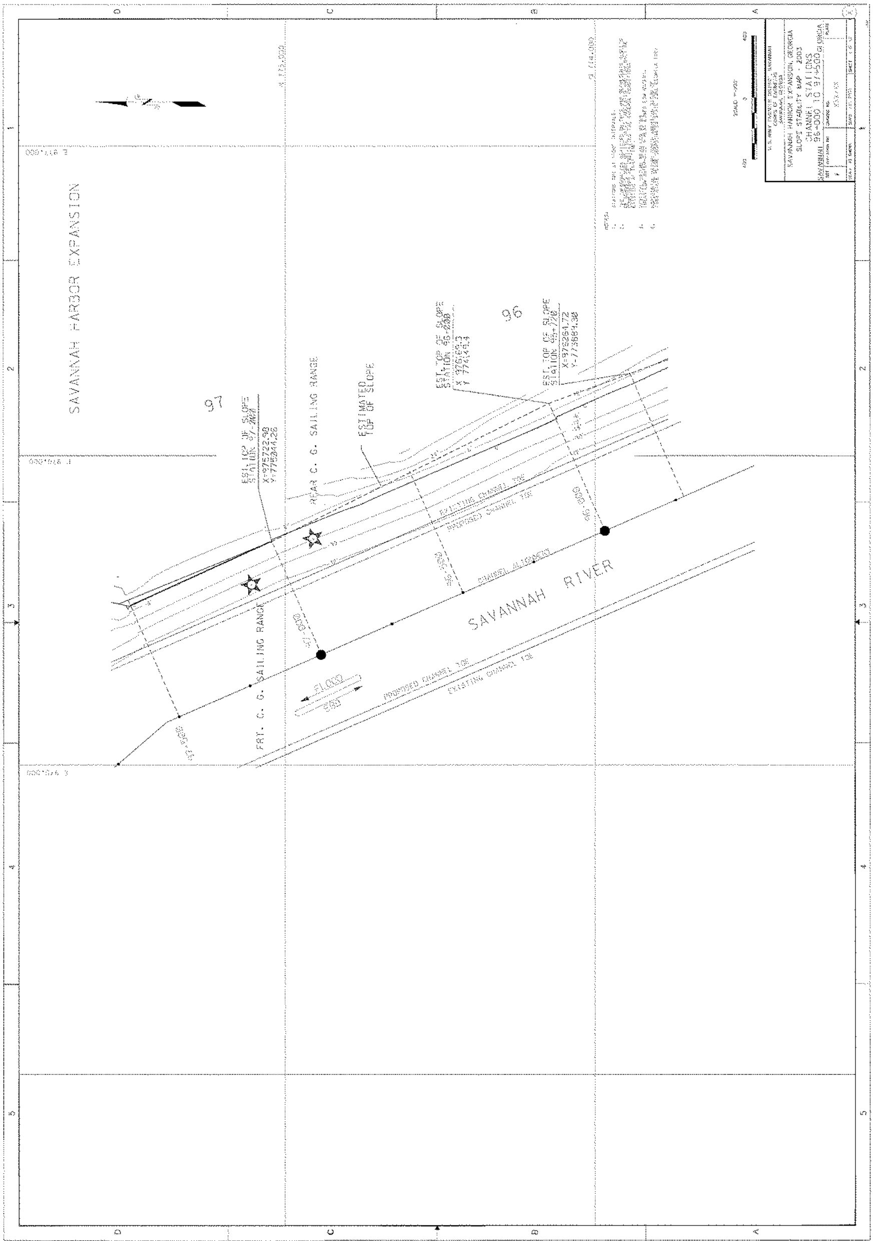
**MAP 3 - 96+000 to 97+000 (owner State of Georgia)**

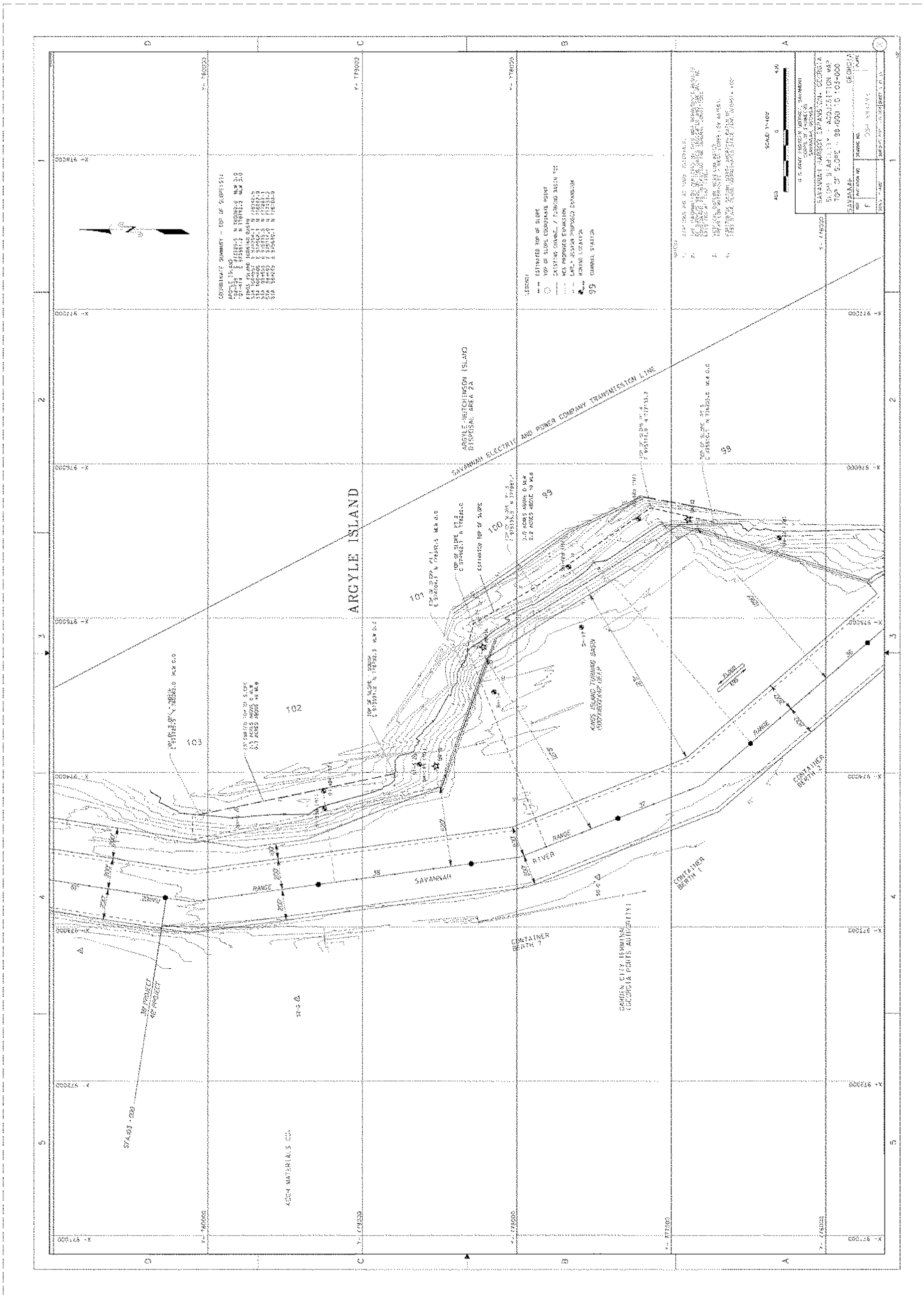
**MAP 4 - 98+200 to 100+500  Kings Island Turning Basin**

**MAP 4a - 101+200 to 102+500  2.5ac/0 + 0.3ac/+8 MLW**


SAVANNAH HARBOR EXPANSION
HUTCHINSON ISLAND
FIG ISLAND
SAVANNAH RIVER
69
70
71
72
26
RANGE


SAVANNAH HARBOR EXPANSION
HUTCHINSON ISLAND
SAVANNAH RIVER
0.9 ACRES ABOVE +8 MLW
4.3 ACRES ABOVE 0 MLW
EXISTING CHANNEL TOE
PROPOSED CHANNEL TOE
FLOOD
EBB


SAVANNAH HARBOR EXPANSION
SAVANNAH RIVER
97
96
ESTIMATED TOP OF SLOPE
REAR C. G. SAILING RANGE
FRT. C. G. SAILING RANGE
EXISTING CHANNEL TOE
PROPOSED CHANNEL TOE
CHANNEL ALIGNMENT
FLOOD
EBB


ARGYLE ISLAND
SAVANNAH ELECTRIC AND POWER COMPANY TRANSMISSION LINE
ARGYLE-HUTCHINSON ISLAND DISPOSAL AREA 2A
SAVANNAH
RIVER
RANGE
CONTAINER BERTH 1
GARDEN CITY TERMINALS (GEORGIA PORTS AUTHORITY)

# APPENDIX G

# INSPECTION SUMMARY

**(Click here)**

CESAS-EN-GS 06 DEC 01

MEMORANDUM FOR RECORD

SUBJECT: Trip Report, Savannah Harbor Expansion, Savannah, GA; Inspection of Dock Structures, Inner Harbor

1. DATE OF TRIP: 14 and 15 NOV 2001

2. PURPOSE OF TRIP: To inspect the condition of existing docks and structures located on the Savannah River. Inspection is intended only to document existing conditions prior to the work anticipated for the Savannah Harbor Expansion.

3. PERSONS MAKING TRIP:

| | |
|---|---|
| Joseph Hudak Jr., | EN-GS |
| Judy Wood, | PD-EI |
| Wilbur Wiggins, | EN-HC |
| Gabriele Supon, | PD-E |
| Cone Bostwick, | OP-NE |

4. PERSONS CONTACTED:

None

5. BACKGROUND: The Savannah Harbor expansion proposes to deepen the existing shipping channel from approximately -42 to -48 feet mean low water (mlw), while maintaining the existing channel side slopes. The work also anticipates expanding Kings Island Turning Basin and widening selected areas at curves or turns to allow larger ship size(s) access to the port facilities. Based on past experience involving property owners and their claims that channel dredging could impact their facilities, it was decided by the Savannah Harbor Expansion Team that we should try to document conditions of existing facilities along the banks of the proposed new work. Therefore, a trip was planned to take photos and notes under low tide conditions using a small boat and camera.

6. OBSERVATIONS:

The following docks and structures were photographed over a two-day period, 14 and 15 November, 2001. The majority of structures appear to be in good to excellent condition, to the extent they could be observed from a low tide condition. All observations were made while the tide was at or near zero mean low water (mlw) elevation. Photographs are attached illustrating observations. The following condition assessments are the subjective opinion of the observer and do not reflect detailed analyses, as-built research, or underwater investigations. Exceptions to the good or excellent opinion are discussed separately herein.

| Property | Condition | | | | |
|---|---|---|---|---|---|
| | Excellent | Good | Fair | Poor | Very Poor |
| Southern Energy Co. Docks | X | | | | |
| Kemira Inc. Docks | X | | | | |
| Old Fort Jackson, Moat/Riprap | | | X | | |
| ST Services #1, Concrete & Steel | X | | | | |
| Unocal Docks | X | | | | |
| ST Services #2, Wood & Steel | | X | | | |
| Standard Concrete Products | X | | | | |
| Georgia Pacific Gypsum | | X | | | |
| Wood Chip Exp. Facility | | X | | | |

| Property (Con't) | Condition | | | | |
|---|---|---|---|---|---|
| | Excellent | Good | Fair | Poor | Very Poor |
| East Cost Terminal, Wood Dock | | | | | X |
| U.S. Army Corps of Engineers, Dock | | X | | | |
| Marriott Hotel, Deck | | X | | | |
| River Walk/Savannah Electric | | X | | | |
| Retaining Structure, Wood (73+000 to 73+400) | | | | | X |
| Weston Hotel, Steel | X | | | | |
| Convention Center, Steel | X | | | | |
| Moran Towing, Dock | | X | | | |
| Parking and Ferry Dock, 74+500 | | | | X | |
| River Street, 74+800 to 75+200 | | X | | | |
| Crescent Towing, Wood Piles | | | X | | |
| Crescent Towing, Brick Wall | | | | | X |
| T.I.C | | X | | | |
| Powell Duffryn Dock, Piles | | X | | | |
| River Street/Hyatt, Concrete Piles | X | | | | |
| Savannah Electric Substation, Steel | | X | | | |
| Savannah Marine Services, 77+300 | | X (located in widener) | | | |
| Former Graham Radio Property, 78+000 | (No Dock, but in a Widener Area) | | | | |
| Blue Circle Cement, Concrete/Steel | X | | | | |
| Tallmadge Bridge Pier North, Concrete | X | | | | |
| Georgia Ports Authority Docks (All) | X | | | | |
| and others on GA Side, 79+300 to 103+000 | | X | | | |
| Colonial Terminals | | X | | | |
| Intermarine | | X | | | |
| Union Camp, GA Side, Steel | | | | X | |
| Citgo, Steel | | X | | | |
| Georgia Kaolin Terminals, Steel | | X | | | |

Old Fort Jackson:

The timber piles and wood retaining structure supporting the moat foundation were observed to be in a deteriorated condition. The newer steel sheet piling supporting the moat intake structure was observed to be in excellent condition. Rip rap on both sides of the moat, upstream and downstream, had minor deficiencies consisting of sloughed or failed riprap areas. The Fort Jackson area is designated for remedial work under the O&M program and will not be addressed as a part of the Savannah Harbor Expansion work.

East Coast Terminal Docks:

There's a new concrete dock structure located downstream of East Coast's wood supported docks that appears to be in excellent condition. However, at the time of this writing, it is not clear whether this dock is the property of East Coast Terminal. The wood piling and foundations supporting East Coast's dock was observed to be in an advanced state of disrepair. The vast majority of wood piles and cross-member supports were observed to be worn, broken, and reduced from original size by wear and tear over an extended period of time. All of East Coast Terminal docks are located from 90 feet to 120 feet from the shipping channel.

The retaining structure consists (consisted) of wood piling driven along the riverbank to help retain the softer soils placed for filling an old connecting waterway (many years ago). Some of these piles were removed, and a small

Retaining Structure, Wood, (73+000 to 73+400), Between the Engineer Yard and Slip No.1

portion remains. Due to the expected soft nature of the bank material, side slopes flatter than 1 vertical on 3 horizontal may result. For this reason, subsurface investigation is planned to determine the extent of possible sloughing. It is also noted that the bank at zero mlw is located approximately 130 feet to 150 feet from the shipping channel, well outside the influence of proposed dredging operations.

Parking Area and Ferry Dock, River Street Area, Approximately 74+500

The parking area and dock facility is supported on concrete type bent structures supported on wood piling. The bottom of the concrete and the top of piling occurs at approximate elevation +2 mlw. The contact between the concrete and the wood was observed to mostly open, meaning that a gap exists between the piling and the concrete. The gap is estimated to vary approximately evenly from several inches on the outside to complete contact near the shoreline. While both the wood and the concrete appeared to be in reasonably good condition, the gap suggests that repetitive loading and unloading of the dock resulted in pushing the wood piling lower than original design. Tops of piles did not appear to be 'broommed', broken or otherwise damaged. Minor spalling of the concrete portion was noted and photographed. The distance (horizontal) between the nearest piling and the shipping channel is approximately 100 feet.

Crescent Towing & Salvage Co., Brick Wall, Approximately 75+600

The condition of the brick wall and the observable wood supporting structure appears to be in a deteriorated condition. However, the piling and dock immediately behind the wall appear to be in good to fair condition. The horizontal distance between the wall and the shipping channel is approximately 150 feet.

Union Camp, GA Side, Steel, Approximately 87+000 to 88+000

The sheet-piling wall along the Union Camp property was observed to be in an altered, modified and/or deteriorated condition from approximate elevation of 0 to plus 2 mean low water (mlw). The condition noted consisted of irregular to rectangular shape holes breaching the sheet piling. Holes are estimated to be approximately 1 to 2 square feet in size each. The proximity of the sheet piling to the shipping channel varies from approximately 230 feet to 300 feet.

7. DISCUSSION:

a. General

Approximately 101 photographs representing 36 separate properties have been taken and are attached to this report. The properties photographed and addressed herein are not all inclusive of all properties along the Savannah River Expansion Project. Properties outside the scope of work and above channel station 103+000 were not included nor viewed. Properties within the scope of work and located well beyond the proposed new work were not observed or addressed herein. Distances estimated from aerial survey maps and channel alignments of 300 to 1000 feet or more are examples of properties considered beyond the influence of the new work. However, each of these areas was reviewed using the available maps and soundings at the time of this report.

CESAS-EN-GS 06 DEC 01
Subject: Trip Report, Savannah Harbor Expansion, Savannah, GA; Inspection of Dock Structures, Inner Harbor

Properties within the scope of work between 91+000 and 103+00 on the Georgia side were observed, but not photographed. These properties are identified on the Annual Survey Sheets as Southern Bulk Industries, National Gypsum Company, Rubberoid Company, G.A.F. Corporation, PAK Tank Incorporation, and GPA's Garden City Terminals. These facilities exist in locations where soundings indicate relatively deep water. Due to existing river depths and proximity of the property to the shipping channel, the proposed expansion work is not anticipated to have any effect whatsoever on these facilities or their respective bank slopes.

The U.S. Coast Guard Station at Tybee, the Savannah Bar Pilots Dock and Oysterbed Island Training Wall were not observed during this trip. However, the depth of water and their respective distances (190 feet to more than 1000 feet)from the shipping channel suggest that the proposed work will have no effect on these structures whatsoever.

b. Structures Considered in Excellent and/or Good Condition

The structures observed and considered in excellent and/or good condition are either (1) in good condition and by their proximity or distance away from the shipping channel, not likely to be influenced by the proposed expansion; or (2) appear to be well engineered, soundly constructed, well maintained, and unlikely to be effected by the proposed expansion regardless of proximity. Again, the above statement is based on observations of the visible and is the opinion of the observer.

c. Structures Considered as Fair, Poor, or Very Poor Condition

Each of these structures appears to need repairs, replacement, or other remedial effort. The proposed expansion work is not expected to affect these structures. However, the property owners should probably be advised of observations made and we should request additional information regarding the as-built construction of these structures (if available) as a supplement to observations.

d. Structures and Properties Located Adjacent to Channel Wideners

Several properties and structures are located in widening areas where such 'wideners' will likely have some impact. These areas are itemized in the following:

(1) Kings Island Turning Basin and North to Station 103+00 adjacent to DMCA 2A. The turning basin expansion and wideners proposed will result directly in a 'taking' situation.

(2) Union Camp Property, Hutchinson Island, Stations 87+500 to 88+300. The proposed widener will result directly in a 'taking' situation.

(3) Savannah Marine Services and the former Graham Radio Corp. Property, Stations 77+500 to 77+800. The proposed widener should be expected to influence the stability of Savannah Marine's sheet pile wall, depending on the as-built construction properties of the wall and may result in a 'taking' situation. Immediately adjacent is the former Graham Radio property and unprotected riverbank where the proposed widener is expected to result directly in a 'taking' situation.

(4) T.I.C. Station 76+200. The proposed widener should be expected to influence the stability of T.I.C.'s sheet pile wall, depending on the as-built construction properties of the wall and may result in a 'taking' situation.

(5) Wood Chip Exporting Corp., Stations 65+900 to 66+200. The proposed widener will result directly in a 'taking' situation.

8. RECOMMENDATIONS:

The only recommendation at this time would be to notify all property owners along the proposed harbor expansion of the intent to deepen and selectively widen certain areas of the shipping channel and request from them any available structural as-built dock information. Specifically, ask for depths of piles, types and sizes of piles, size and location of pile wall tie-backs, and any other information regarding year of construction, type of construction, and allow owners to add any other information they feel is appropriate.

9. If you have any questions, please call Mr. Joe Hudak at (912) 652-5681.

JOSEPH D. HUDAK JR., P.E.
Geotechnical & HTRW Branch,
Soils Section

Trip photos are attached from the following files. Each photo has a short description and associated channel station location.

Trip Report photos 'p14NovA.doc' (first) Attached

Trip Report photos 'p14NovB.doc' (Second) Attached

Trip Report photos 'p15NovA.doc' Attached

## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

Southern Energy Company LNG–Location M2 between Stations 38+300 to 39+500, Concrete and Steel Piling, Excellent Condition

Southern Energy Company LNG–Dock Fender between Stations 38+300 to 39+500, Steel Piling, Excellent Condition

## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

Southern Energy Company LNG–Dock Piling between Stations 38+300 to 39+500, Concrete Piling, Excellent Condition

Southern Energy Company LNG–Location M2 between Stations 38+300 to 39+500, Concrete and Steel Piling, Excellent Condition

**SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001**

Southern Energy Company LNG–Dock and Piling between Stations 38+300 to 39+500, Concrete Piling, Excellent Condition

## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

Kemira Inc. River Station 56+000, Pipe Dock. Wood Piles, Good Condition

Kemira Inc. River Station 56+000, Pipe Dock. Wood Piles, Good Condition

## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

Kemira Inc. Dock and Pier. Stations 57+000 to 58+000, Foundation – Concrete and Steel, Good Condition

Kemira Inc. Dock and Pier. Stations 57+000 to 58+000, Foundation – Concrete and Steel, Good Condition

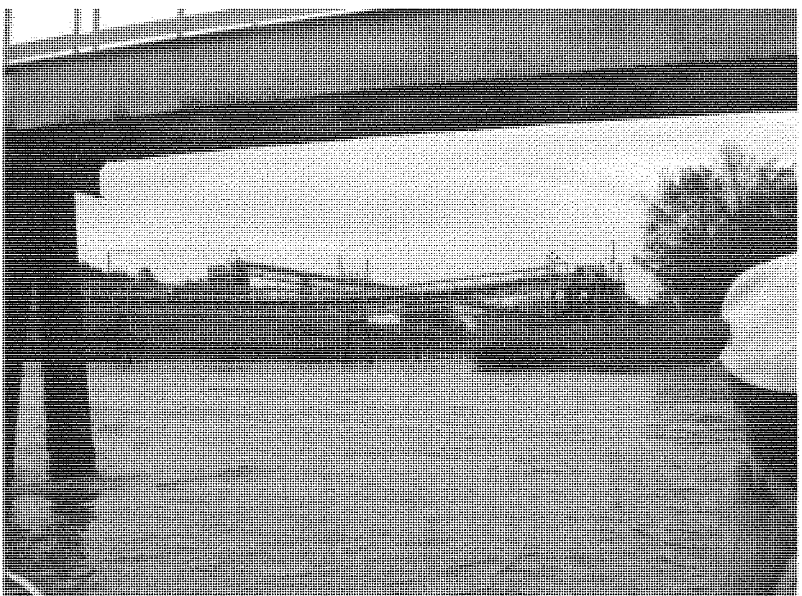
**SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001**

Kemira Inc. Dock and Pier. Stations 57+000 to 58+000, Foundation – Good Condition, Looking Downstream

Kemira Inc. Dock and Pier. Stations 57+000 to 58+000, Piling Foundation – Good Condition, Steel Dock Beams Showing Deterioration

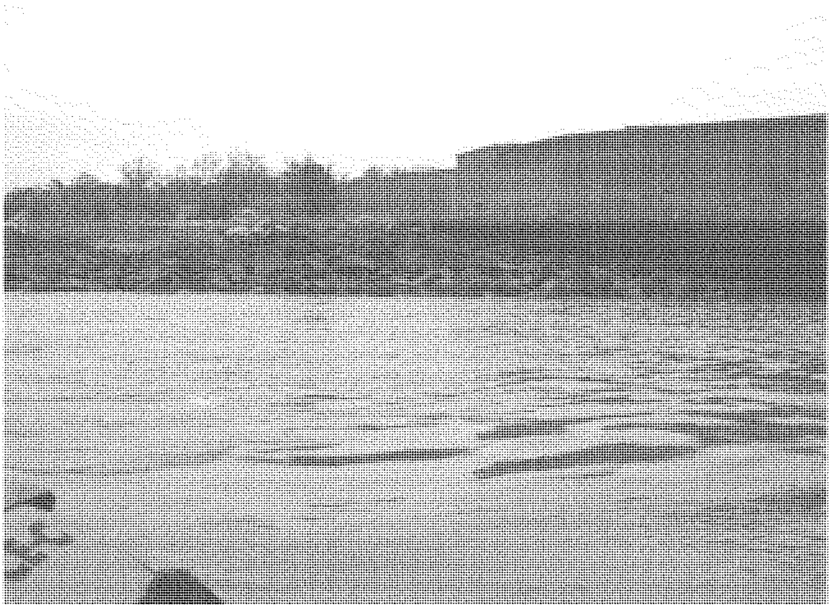
**SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001**

Kemira Inc. Dock and Pier. Stations 57+000 to 58+000, Piling Foundation – Good Condition, Steel Beams Showing Deterioration



Kemira Inc. Dock and Pier. Stations 57+000 to 58+000, Piling Foundation – Good Condition,

**SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001**



Old Fort Jackson, Downstream RipRap, Station 58+500

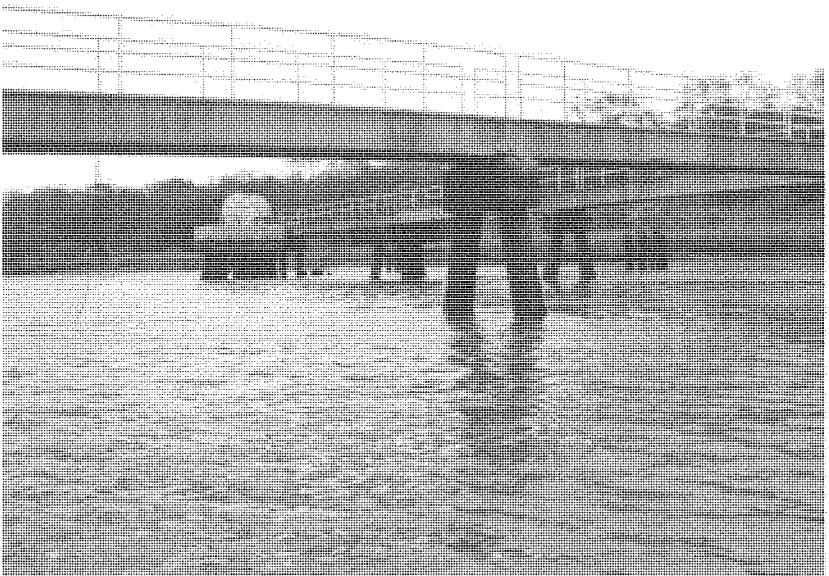
Old Fort Jackson, Downstream Moat Brickwork, Station 58+500

## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

Old Fort Jackson, Downstream Moat Brickwork, Station 58+500

Old Fort Jackson, Upstream Riprap, Station 58+700

## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001



ST Services #1, Concrete Piling, Station 60+500, Good Condition

ST Services #1, Concrete and Steel Piling, Station 60+500, Good Condition

# SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

Unocal, Concrete Piles, Station 61+000, Good Condition

Unocal, Concrete Piles, Station 61+100, Good Condition

## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

ST Services #2, Station 61+900, Wood Piles, Fair Condition

ST Services #2, Station 62+000, Steel Piles, Good Condition

## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

ST Services #2, Station 62+200, Wood Piles, Fair Condition

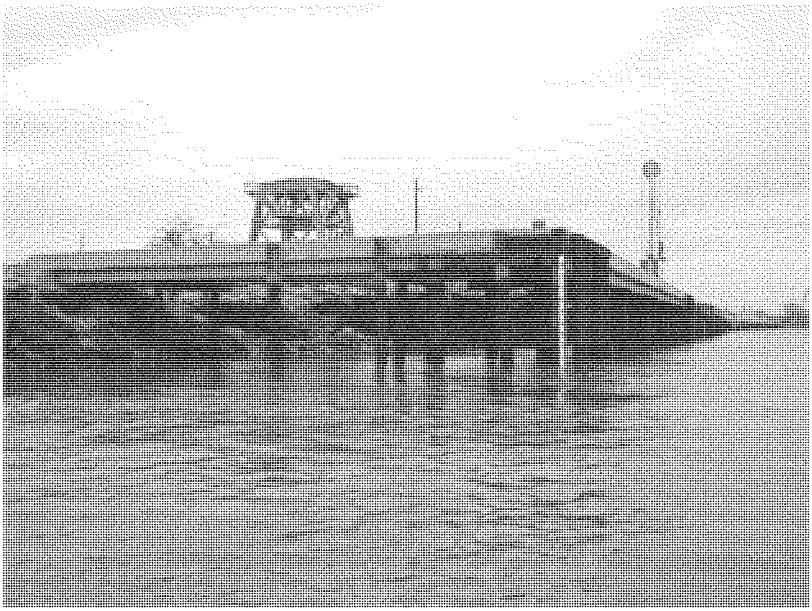
ST Services #2, Station 62+300, Wood Piles, Fair Condition

# SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

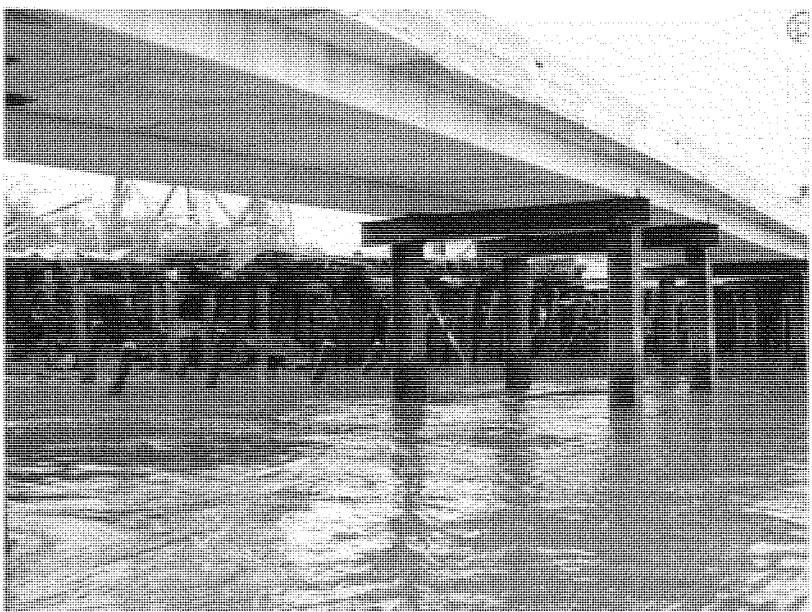
Georgia Pacific Gypsum, Station 63+250, Concrete Piles, Good Condition

Georgia Pacific Gypsum, Station 63+250, Concrete Piles, Good Condition (Close-Up)

## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

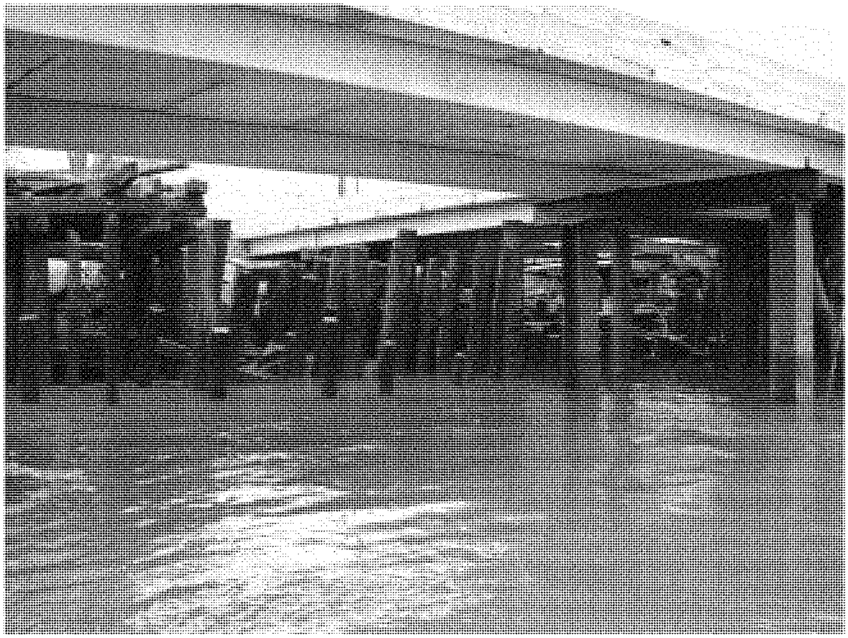


Standard Concrete Products, Steel Piles, Station 62+700, Good Condition



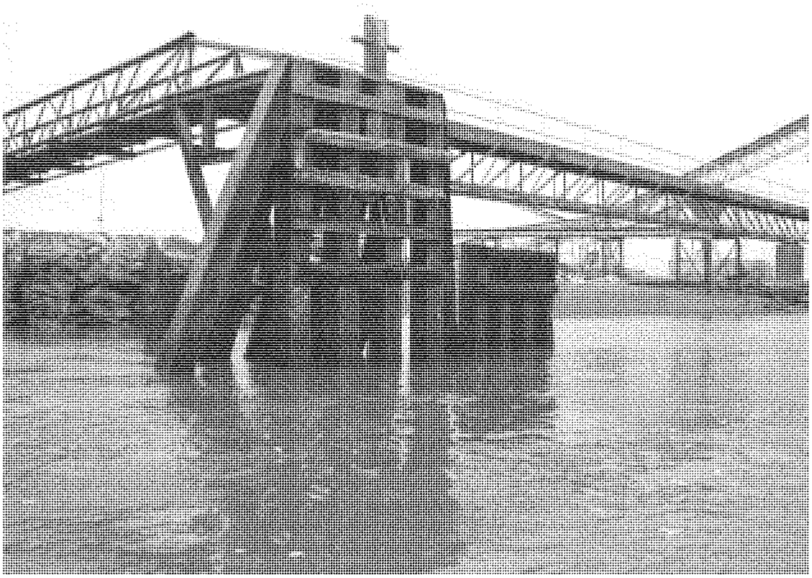
Georgia Pacific Gypsum, Steel Piles, Station 63+000, Good Condition

**SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001**



Georgia Pacific Gypsum, Steel Piles, Station 63+000, Good Condition

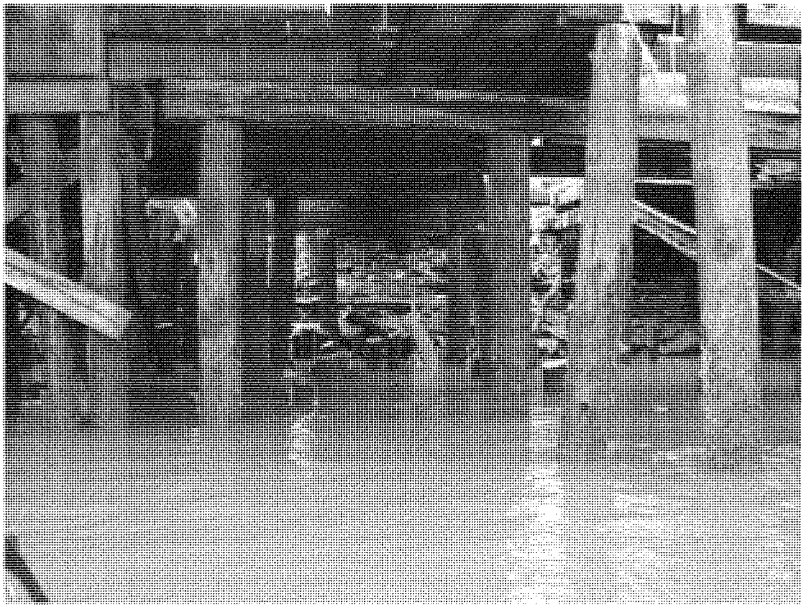
## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001



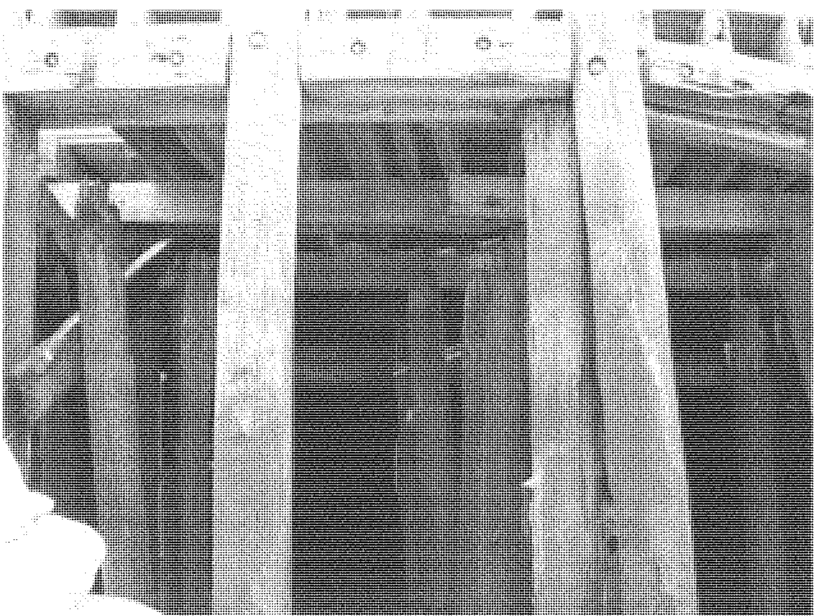
Wood Chip Facility, Station 66+800, Steel Piling, Good Condition

Wood Chip Facility, Station 67+000, Steel Piling, Good Condition

## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

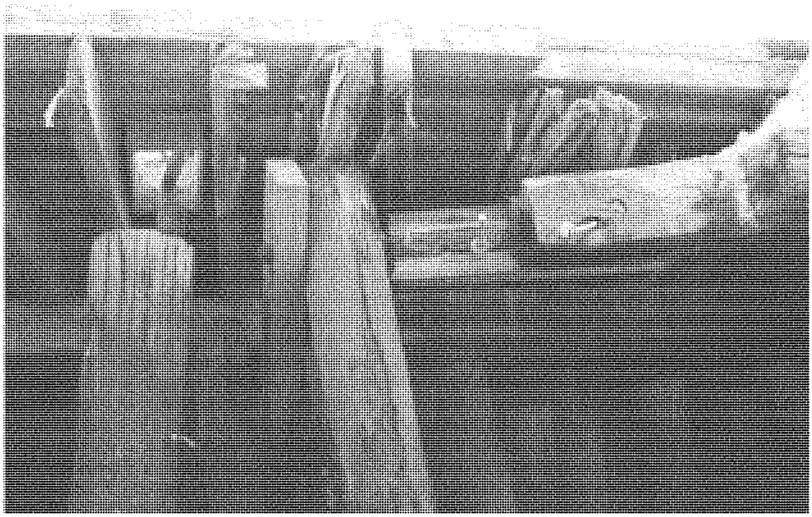


East Coast Terminal Company, Station 68+500, Wood Piles

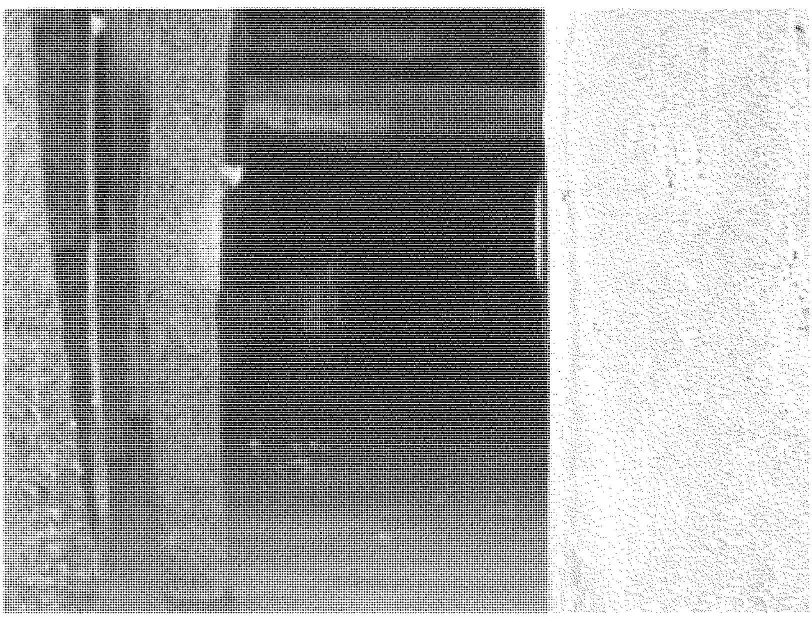


East Coast Terminal Company, Station 69+800, Wood Piles

**SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001**



East Coast Terminal, Station 68+100, Wood Piling, Berth 4, Deteriorated/Broken Condition



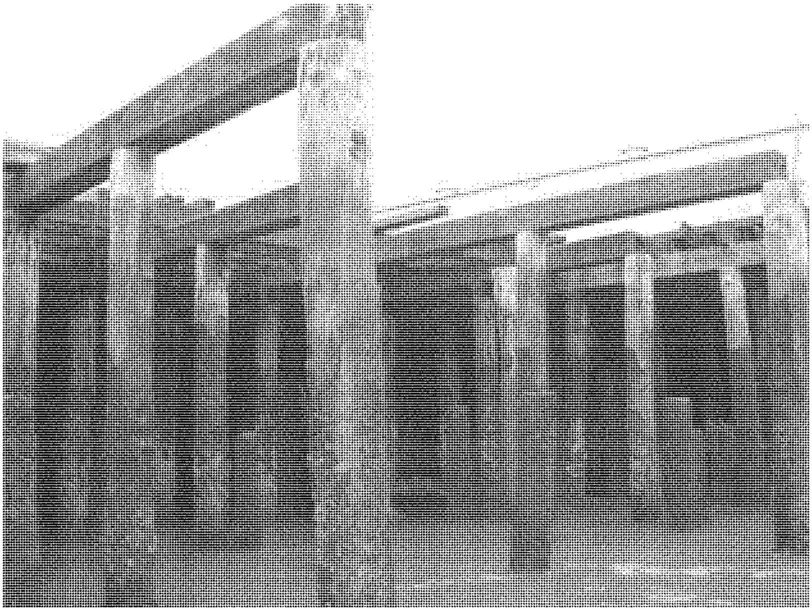
East Coast Terminal, Station 68+100, Wood Piling, Berth 4, Deteriorated/Broken Condition

## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

East Coast Terminal, Station 68+500, Wood Piling, Berth 4, Deteriorated/Broken Condition

East Coast Terminal, Station 68+500, Wood Piling, Deteriorated/Broken Condition

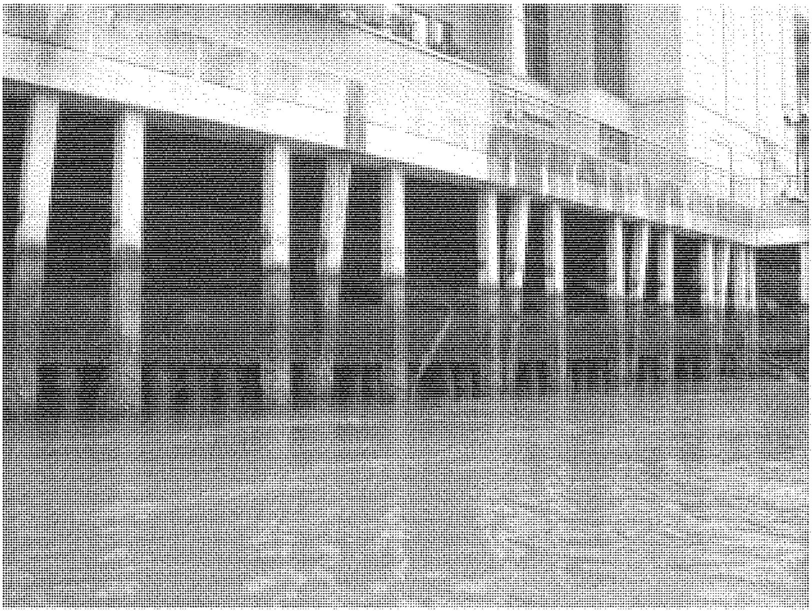
## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001



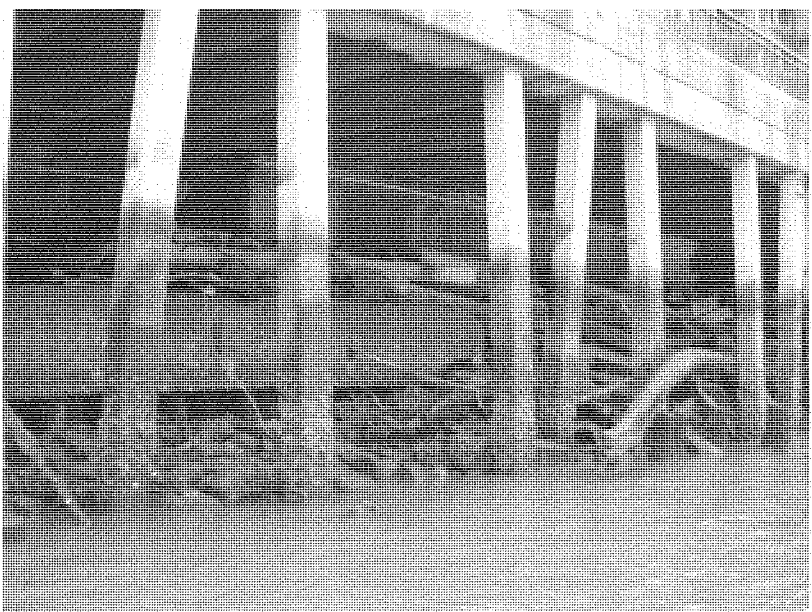
East Coast Terminal, Station 69+400, Wood Piling, Deteriorated/Broken Condition

East Coast Terminal, Station 70+000, Wood Piling, Deteriorated Condition

## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001



Marriott Hotel, Concrete Piles, Station 72+300, Good Condition



Marriott Hotel, Concrete Piles, Station 72+350, Good Condition

## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

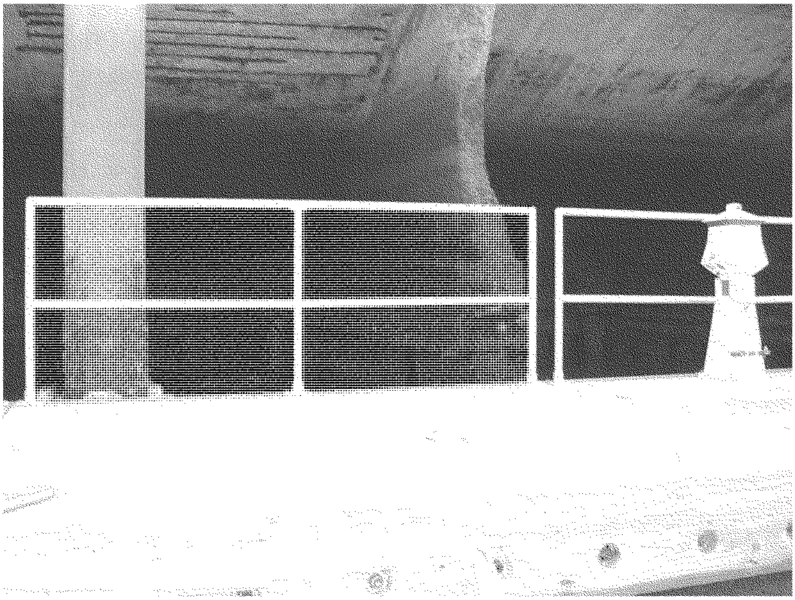
Marriott Hotel, Concrete Piles, Station 72+500, Good Condition
Note blocked and broken flap gate at drainage pipe

**SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001**

River Walk/Savannah Electric, Concrete Piles, Station 72+600, Good Condition

River Walk/Savannah Electric, Concrete Piles, Station 72+800, Good Condition

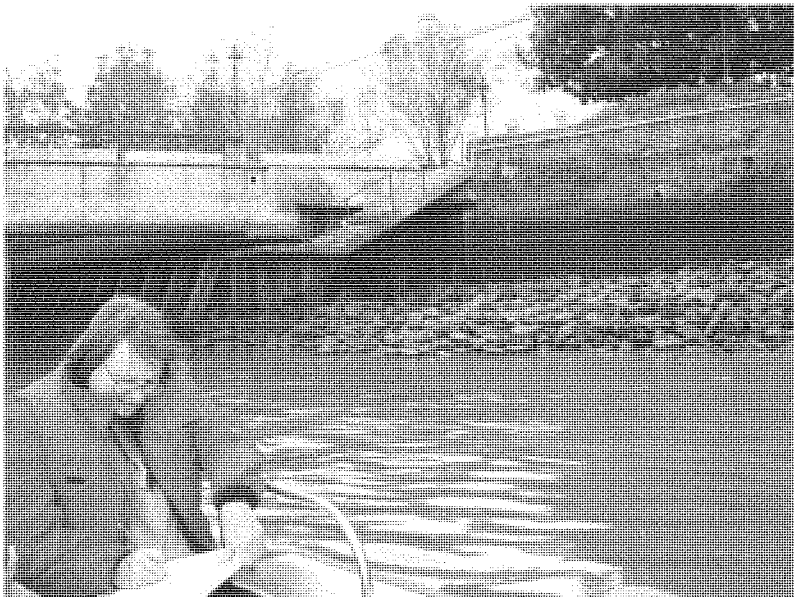
## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001



Turecamo/Parking Lot, Concrete Support on Wood Piles, Station 74+400, Poor Condition

Parking Lot/Ferry Dock, Concrete Support on Wood Piles, Station 74+600, Poor Condition
Note: Several to many wood piles not in contact with concrete support(s),Elevation ~1 MLW.

## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001



River Street, Station 74+800

River Street, Approximate Station 75+200, Concrete and Steel Piling, Good Condition
City Hall Area

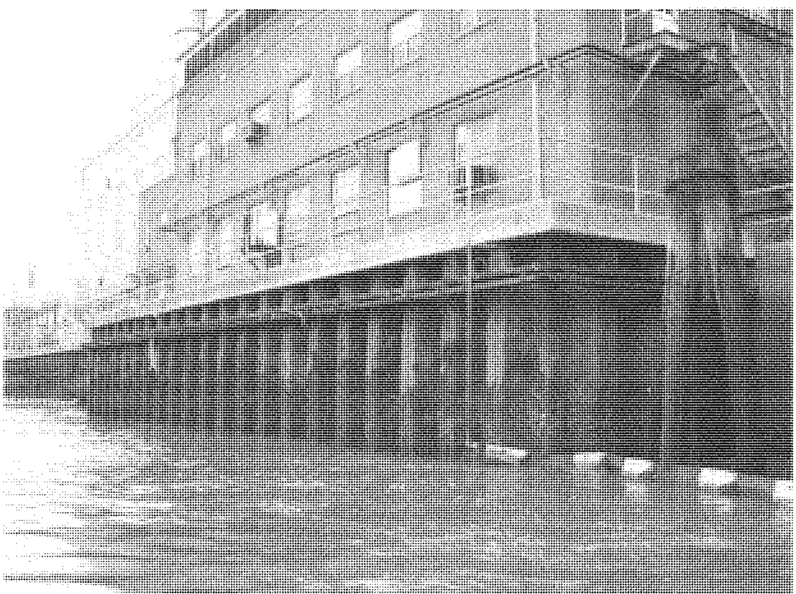
## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

River Street, Approximate Station 75+500, Hyatt Area

River Street/Savannah Electric, Station 77+000

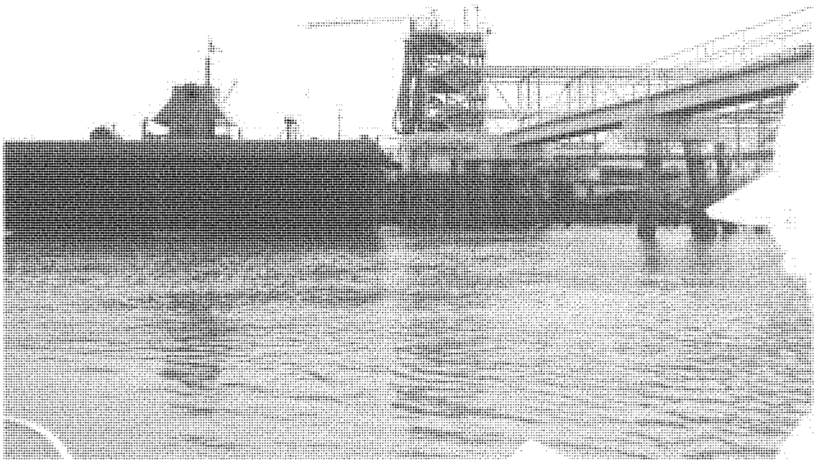
## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

Savannah Electric Peaking Plant, Station 77+000, Good Condition



Savannah Electric Peaking Plant, Approx. Station 77+500, Good Condition

## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

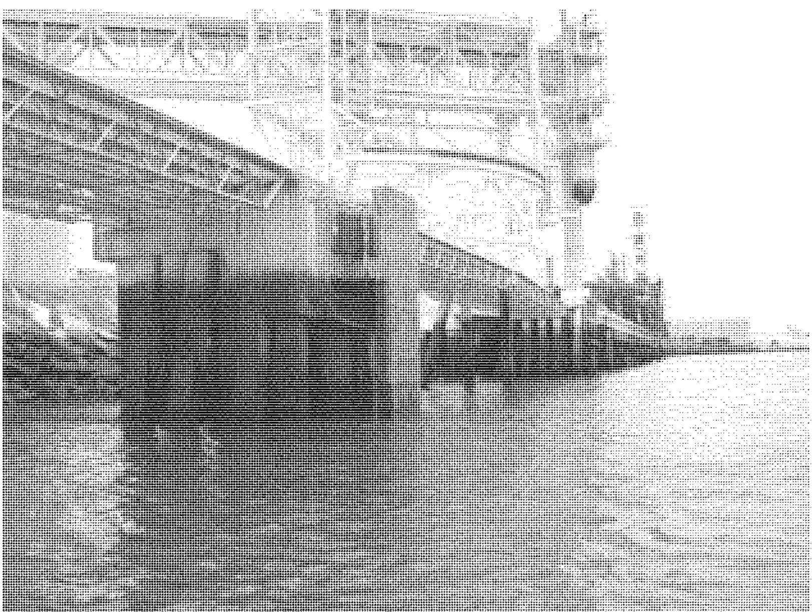


Colonial Terminals, Approx. Station 83+000, Piling in Good Condition

Station 83+500

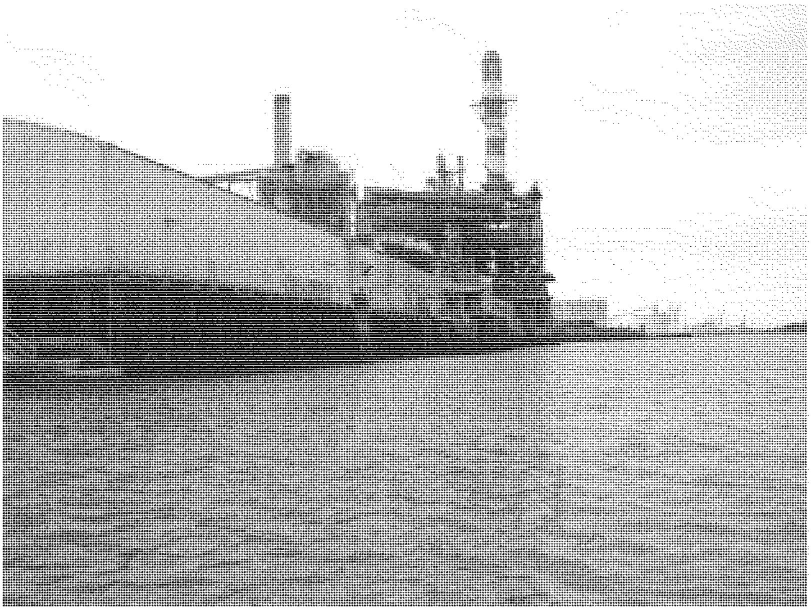
## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

Intermarine, Station 83+900, Dock and Piling in Good Condition

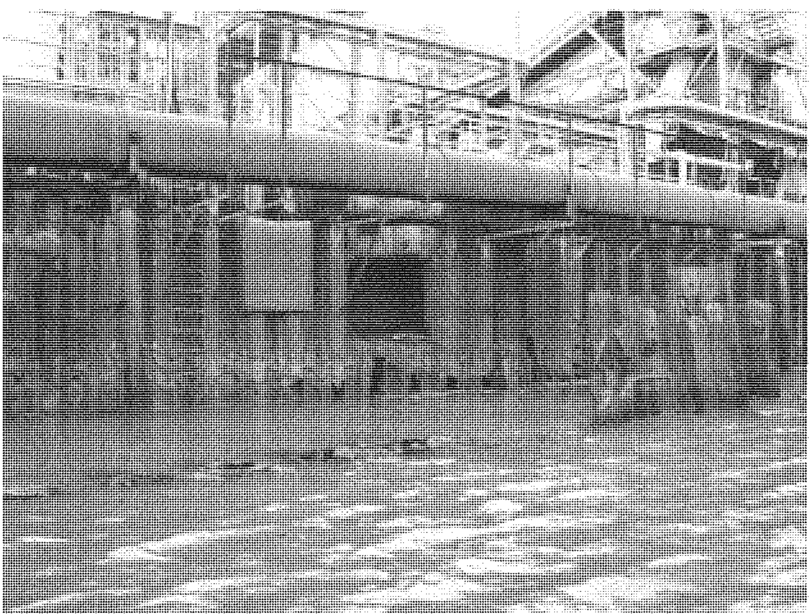


Colonial Terminals, Station 86+000, Concrete Piles, Excellent Condition

# SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

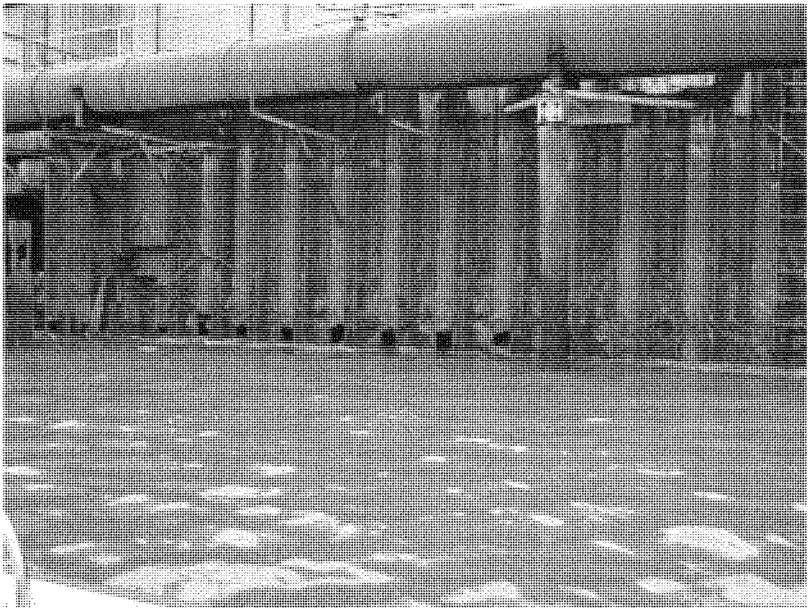


Colonial Terminals/Union Camp Corp. Approx. Station 86+900

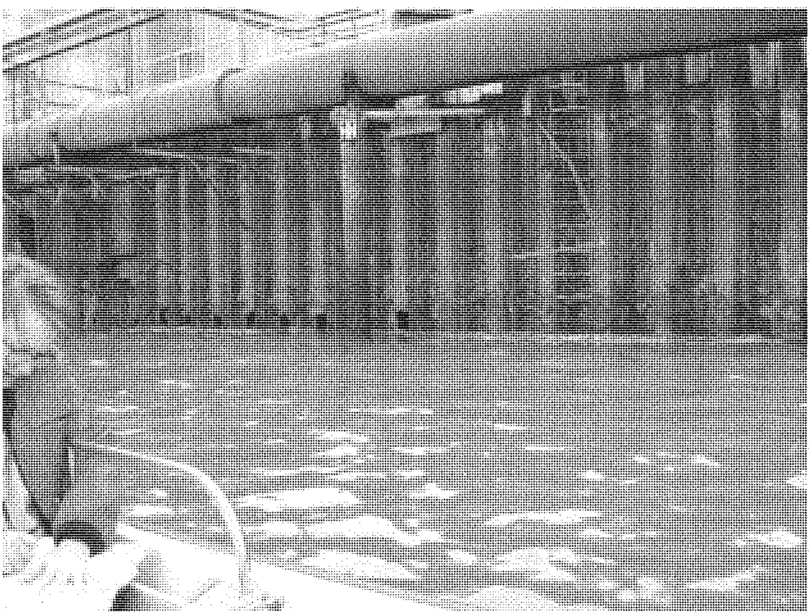


Union Camp Corp., Approx. Station 88+000, Steel Sheet Piling rusted thru at low water line

## SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001



Union Camp Corp., Approx. Station 88+000, Steel Sheet Piling rusted thru at low water line



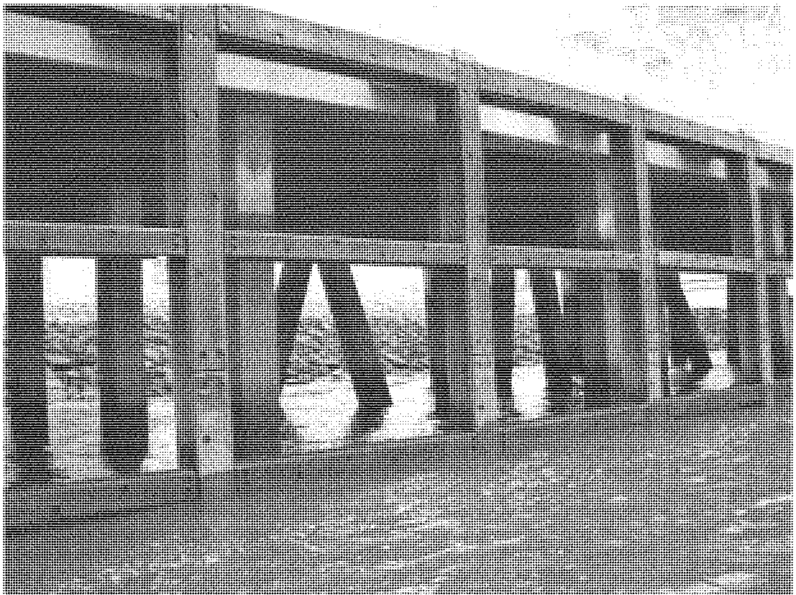
Union Camp Corp., Approx. Station 88+000, Steel Sheet Piling rusted thru at low water line

**SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001**

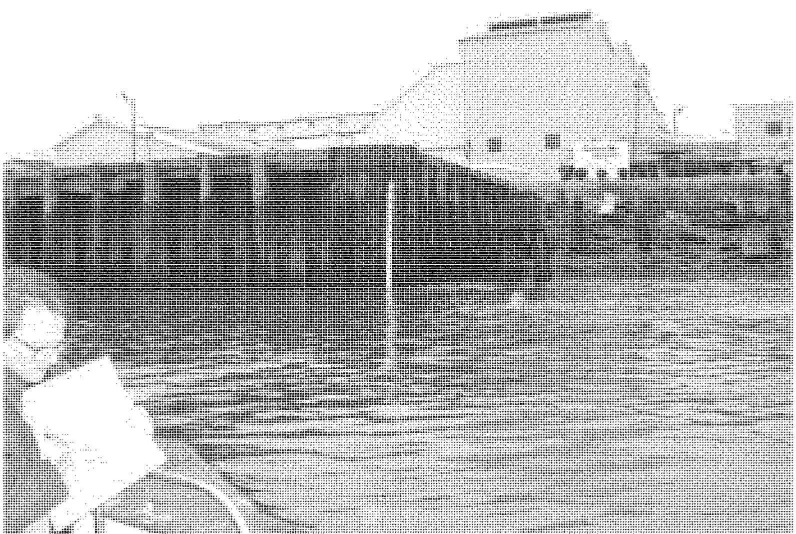
Union Camp Corp., Approx. Station 88+000, Steel Sheet Piling

Citgo Asphalt Refining Co., Station 90+000, Steel Sheet Piling, Good Condition

**SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001**



Citgo Asphalt Refining Co., Station 90+000, Steel Sheet Piling, Good Condition



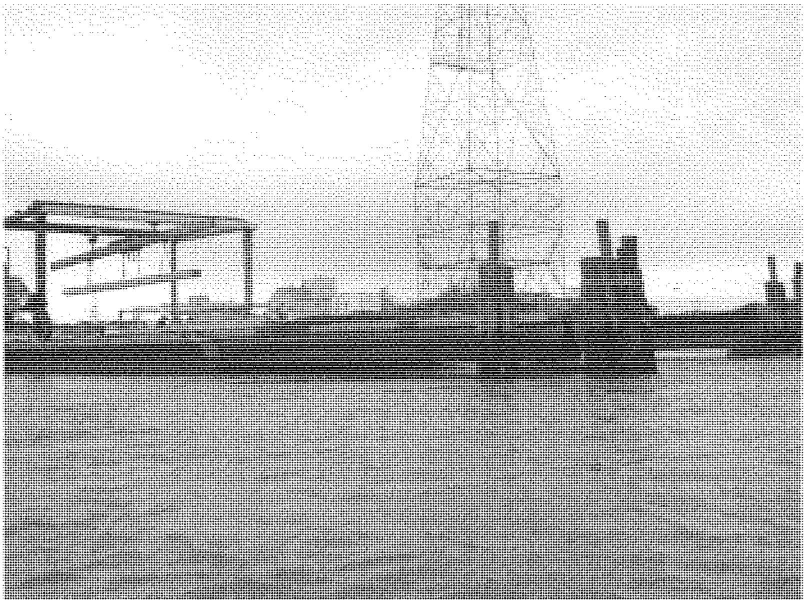
Georgia Kaolin Terminals, Station 90+700, Steel Sheet Piles, Good Condition

# SAVANNAH HARBOR EXPANSION – DOCKS – 14 NOVEMBER 2001

North of Kings Island TB, Station 101+400, Widener/Taking Area

North of Kings Island TB, Station 102+200, Widener/Taking Area

**SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001**



Standard Concrete Products, Station 62+600, Concrete Piers and Beams, Excellent Condition

ST Services #2, Station 62+200, Wood/Steel Piling, Good Condition

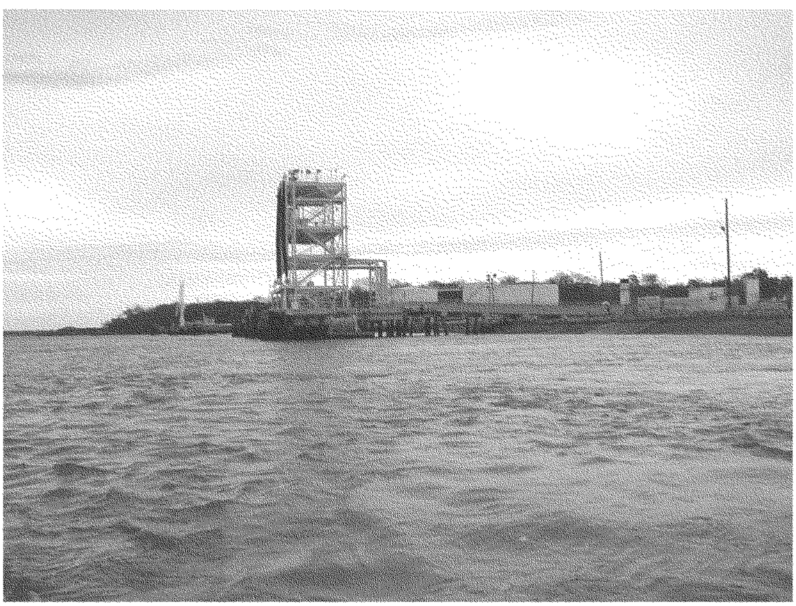
## SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001

ST Services #2, Station 62+200 to 61+800, Wood/Steel Piling, Good Condition

ST Services #2, Station 61+900, Wood/Steel Piling, Good Condition

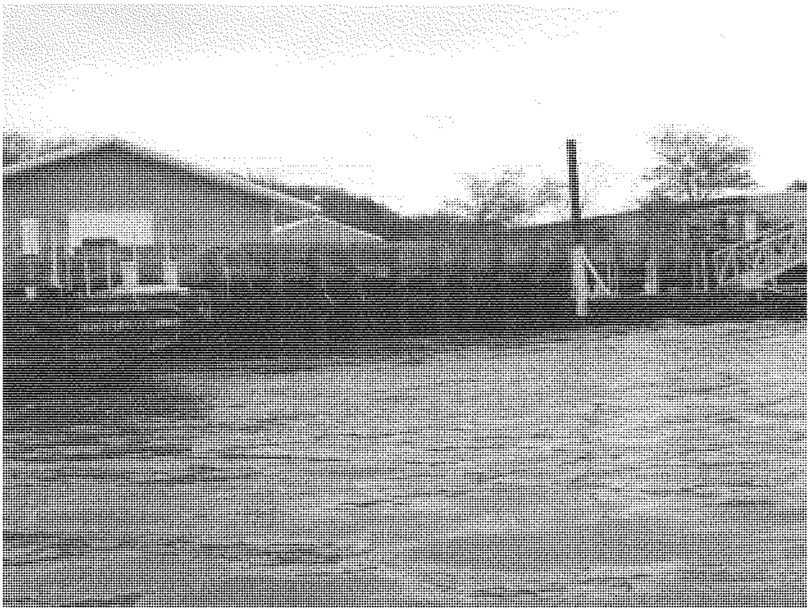
**SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001**

Unocal, Station 61+800, Wood Piling, Good Condition

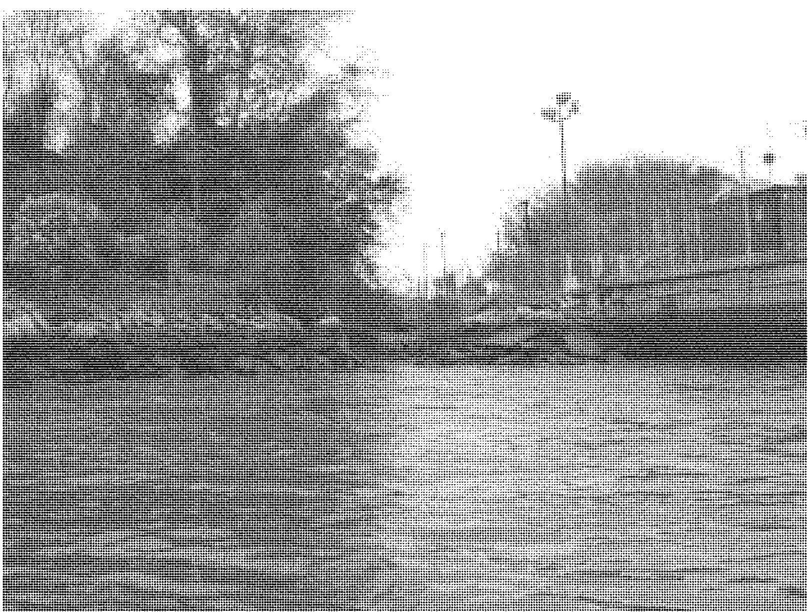


Unocal, Station 61+500, Concrete Piling, Good Condition

## SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001



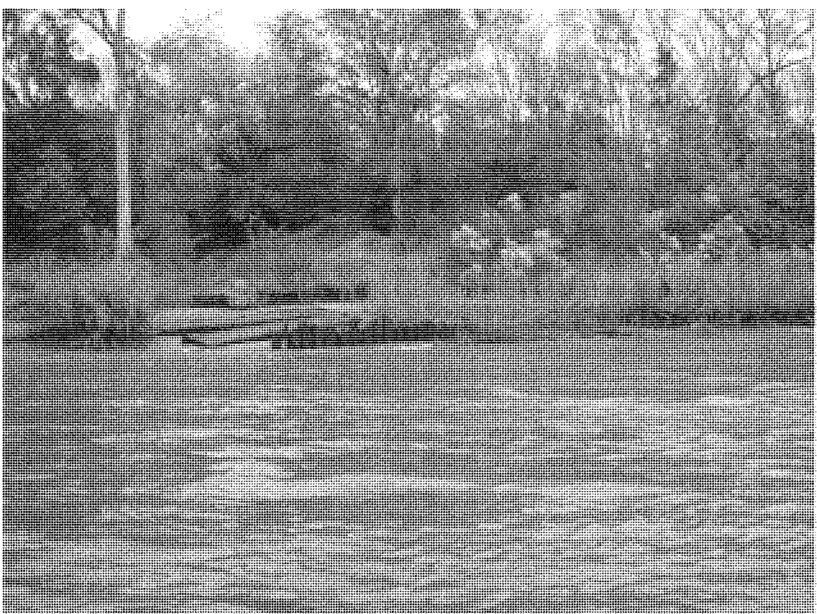
U.S. Army Corps of Engineers Yard, Concrete Piles, Station 72+500, Good Condition



U.S. Army Corps of Engineers Yard, Concrete Sheet Piles, Station 72+800, Good Condition

**SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001**

Artifact Area, Wood Piles/Retaining, Station 73+000



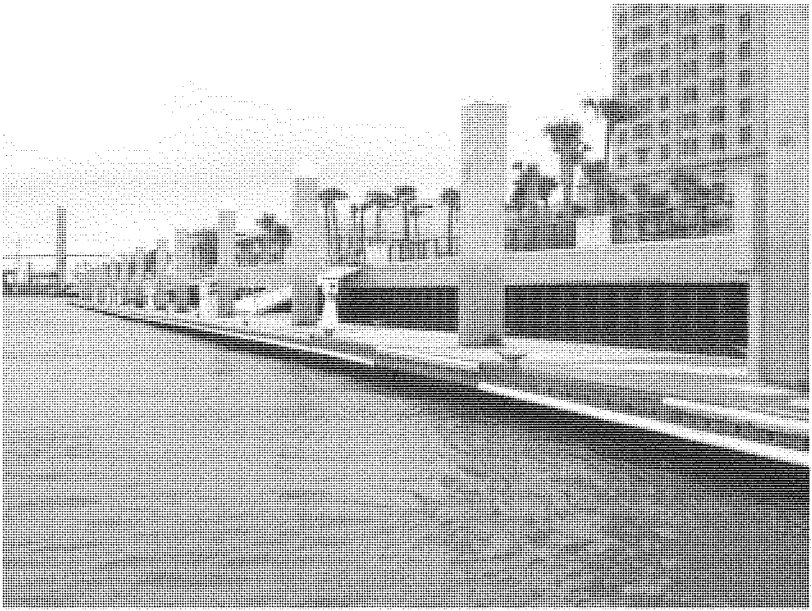
Artifact Area, Wood Piles/Retaining, Station 73+400

## SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001

Weston Hotel, Steel Sheet Piles, Station 74+000, Good Condition

Weston Hotel, Steel Sheet Piles, Station 74+000, Good Condition

# SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001



Weston Hotel, Steel Sheet Piles, Station 74+500, Good Condition

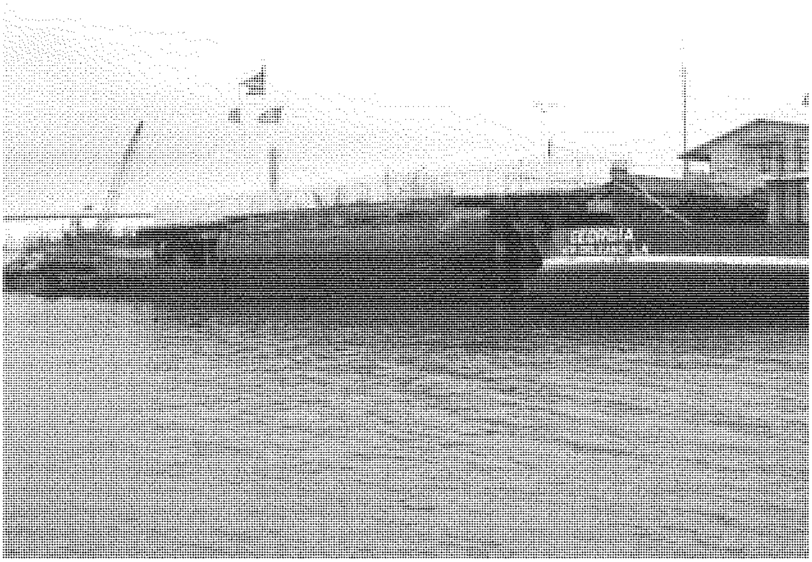
Convention Center, Steel Sheet Piles, Station 74+700, Good Condition

**SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001**

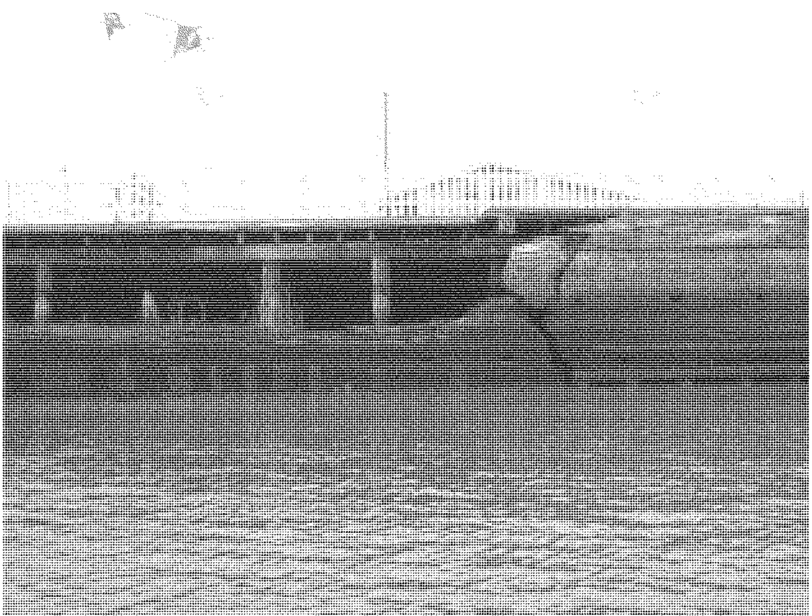
Convention Center, Steel Sheet Piles, Station 74+700, Good Condition

Convention Center, Steel Sheet Piles, Station 75+000, Good Condition

## SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001



Cresent Towing & Salvage Company, Station 75+500, Brick Retaining Wall



Cresent Towing & Salvage Company, Station 75+600, Brick Retaining Wall

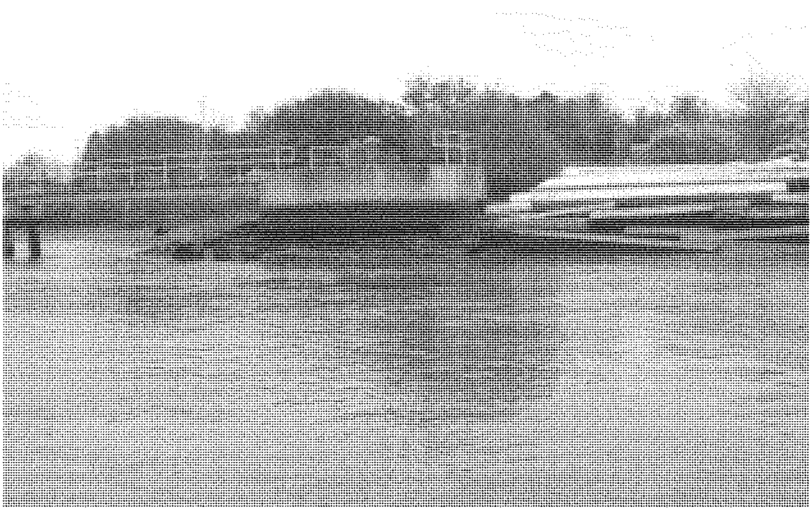
## SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001

TIC, Station 76+000, Spud Barge

TIC, Station 76+000, Spud Barge

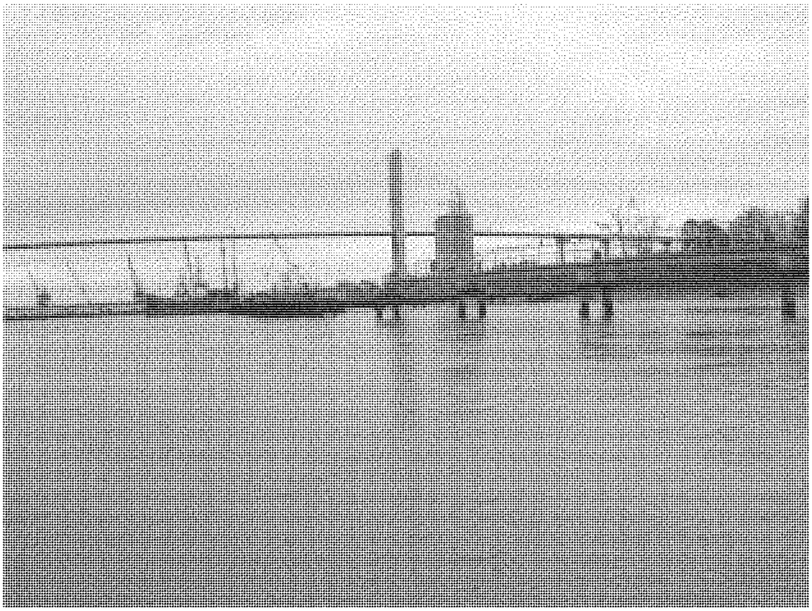
## SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001


TIC, Approx. Station 76+100, Steel Sheet Piling in Good Condition



Powell Duffryn Dock, Station 76+200

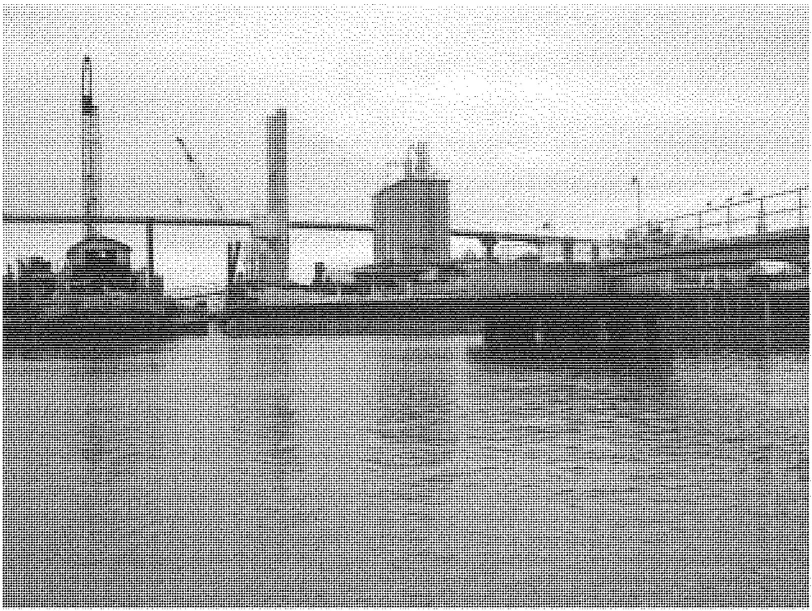
## SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001



Powell Duffryn Dock, Station 76+300

Powell Duffryn Dock, Station 76+500

## SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001



Powell Duffryn Dock, Station 77+000

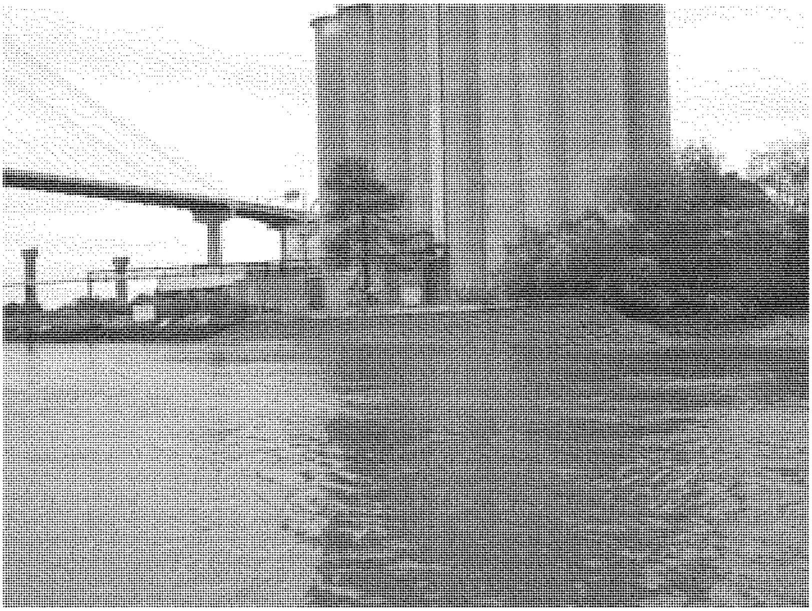
Savannah Marine Services, Station 77+250

## SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001

Savannah Marine Services, Station 77+350

Chatham County/Old Radio Station Property, Station 78+000

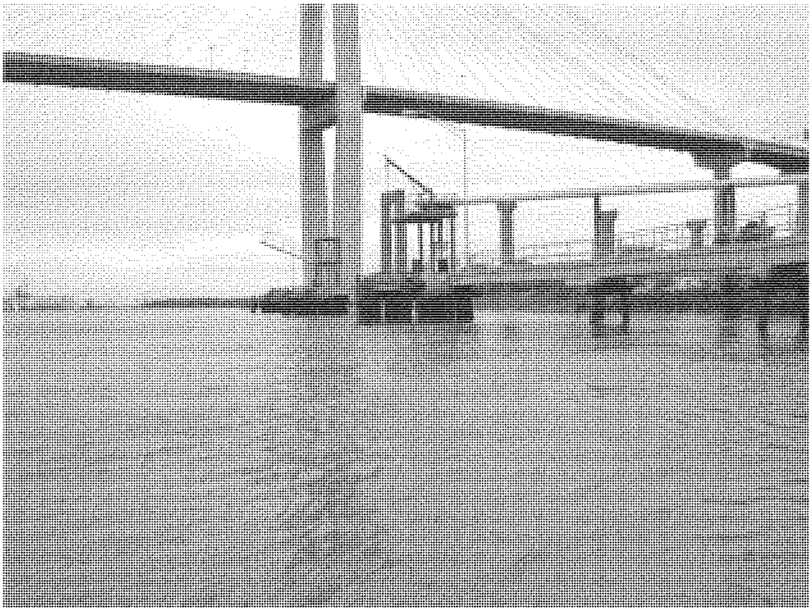
# SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001



Blue Circle Cement, Approx. Station 78+300

Blue Circle Cement, Approx. Station 78+550, Steel Shell Piles, Excellent Condition

## SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001



Blue Circle Cement, Approx. Station 78+600, Steel Shell Piles, Excellent Condition

Blue Circle Cement, Approx. Station 78+800, Steel Shell Piles, Excellent Condition

## SAVANNAH HARBOR EXPANSION – DOCKS – 15 NOVEMBER 2001

Tallmadge Bridge Pier North Side, Station 79+300, Good Condition

Georgia Ports Authority Berth 13, Station 79+700, Concrete Piles, Excellent Condition

# APPENDIX H

# PRELIMINARY ASSESSMENT

**(Click here)**

**SOIL BORING ANALYSES LOCATIONS / PRELIMINARY ASSESSMENT**

31 January 2002

1. The existing Savannah Harbor is approximately 32 miles long (along the centerline of the channel), stretching from the Atlantic Ocean to the former New Cut Channel (Channel Stations –60+000 to 103+000). The Savannah Harbor Expansion Project proposes to add 25,000 feet of outer channel (New Channel Stations (-60+000 to -85+000), widen selected turns within the inner harbor, and enlarge the existing Kings Island Turning Basin (Inner harbor). The outer channel work does not impact privately owned real estate. The inner harbor, for the purpose of this study, shall be described as being all reaches from Channel Station 0+000 to 103+000. There is approximately 20 miles of land on each side of the river (approximately 40 miles of river banks), and many properties that could be affected by the project depending, in part, on the proximity of the land to the proposed channel deepening and/or widening. The Corps of Engineers does not recommend taking soil samples from all properties located along the Savannah River and in the Savannah Harbor.

2. The publications by the Department of the Army, Corps of Engineers, Office of the Chief Engineers entitled "Engineering and Design, Geotechnical Investigations," EM 1110-1-1804 (29 February 1984) and "Soil Sampling," EM 1110-2-1907, are the primary sources on how to take soil samples. These engineering manuals indicate how to take the samples, but do not identify with any specificity the locations where samples must be taken. There are no regulations, internal guidelines, policies or other directives that specify the conditions under which soil samples must be obtained or the properties from which soil samples must be taken. The designing soils engineer has the discretion to decide, based on his or her best judgment as an engineer, the locations where it will be necessary to take soil samples for analysis.

3. The soils engineering staff for the Corps of Engineers is responsible for determining where soil samples for slope stability and demolition purposes will be taken in connection with the Savannah Harbor Expansion Project. During the course of determining the locations where it would be necessary for the Corps of Engineers to take soil samples for analysis, we considered the following factors: 1) the proximity of a property to the proposed project, 2) the type of material likely to be encountered (as obtained from past soil borings in the vicinity), 3) the slope of the riverbank, 4) the configuration of the existing channel, 5) hydrographic surveys, 6) topographic surveys and aerial photographs, 7) the configuration of the proposed navigation channel, 8) whether the proposed channel intersects with adjacent property, 9) the proposed method of dredging, 10) the available budget, 11) the cost of taking and analyzing soil borings,[1] and 12) the likelihood that soil sample analysis will yield necessary information. In

[1] The cost of a soil boring, including laboratory testing and analysis, and subsequent analysis of the drilling and test results, varies from approximately $10,000.00 to $12,500.00, per boring.

addition, we considered historic information, including: 1) most recent surveys, 2) problems arising out of most recent dredging projects, and 3) historic structures and artifacts.

4. In connection with the Savannah Harbor Expansion Project, we also conducted site inspections of all areas that could be affected by the project, by boat and by land. Documentation, photographs, and comment from the most recent inspections are contained in Memorandum For Record dated 06 December 2001, Subject: Trip Report, Savannah Harbor Expansion, Savannah, GA; Inspection of Dock Structures, Inner Harbor.



5. The decision whether to test certain property is based on an analysis of the above factors, and not the ownership of the property. The taking of soil samples, like any other expenditure in connection with a harbor expansion project, must be justifiable. Engineering judgment is used to determine the locations where the taking of soil samples will yield necessary information.

6. Soil borings and samples were taken during preliminary study analysis which will need to be augmented based on the now proposed channel configuration, and again (possibly) augmented after final model studies have been completed. Each of the following areas represents a 'taking' or real estate acquisition necessary to accommodate proposed channel widening. Areas which are known to involve 'taking' by virtue of direct intersection of proposed work to the existing channel/river configuration or where there is some question regarding existing bulkhead and/or channel bank stability are 1) Argyle Island between Channel Stations 101+000 and 103+000, 2) Kings Island Turning Basin between Channel Stations 98+700 and 100+500, 3) International Paper, northeast riverbank, between Channel Stations 87+450 and 89+500, 4) Savannah Marine Services and the former Graham Radio Corp. Property, Channel Stations 77+250 to 77+650, 5) T.I.C., Channel Stations 76+000 to 76+200, and 6) Property located at or adjacent to Wood Chip Exporting Corp., Channel Stations 65+950 to 66+200. Each of the above described areas either have been or will be investigated with regard to subsurface condition, profiles, material strength and bank stability.

7. Areas of concern that do not involve a direct intersection of the proposed project to the existing river configuration, and are recommended for soil testing are listed in the following:

a. Hutchinson/Fig Island between the U.S. Army Corps of Engineers Yard and Slip No.1, known as an archeological site consisting of soft fill materials and old ship/boat wrecks (Approximate Channel Stations 72+700 to 73+700). This area is recommended for subsurface exploration and testing to better determine bank stability with regard to the proposed project.

b. South Channel Training Wall, Elba Island side, Channel Stations 50+000 to 51+700, and near Southern Energy Corporation's natural gas pipeline crossing. Channel widening proposed along this reach will likely involve debris and/or training wall (or remnant) removal. Exploratory investigation is planned to determine size and extent of possible debris removal.

c. The extended bar channel area from -60+000 to -85+000. While not of concern to adjacent properties (none), subsurface sampling and testing will be performed to determine the character of materials proposed for removal.

d. Other areas are subject to subsurface testing and analysis. Such include aquifer studies for salt-water intrusion, which are considered beyond the scope of this writing.

8. Problematic areas exist that involve deteriorated, broken and/or highly questionable structures with regard to their stability and are located near or adjacent to the proposed project. These areas are not recommended for subsurface study, but will need to be addressed as separate issues. Each is listed in the following:

a. Cantilevered Parking Lot and Dock Facility (Owner: Sylvan Byck) located between Moran Towing and the eastern end of the original Rousakis Plaza, located opposite the Shrimp Factory on River Street, and approximately between Channel Stations 74+270 and 74+400. The foundation for the cantilevered concrete parking area consists of wood piling. As noted in the trip report dated 06 December 2001, a gap or open area exists that varies from about 1 foot to less than 1 foot between the pile tops and the concrete, depending on pile location. Given the relatively good condition of the pile tops, it is surmised that repeated loading and unloading of the parking lot has subsequently driven the piles into supporting soils beyond the depth that piles were originally installed. In any case, the gap between the pile tops and supporting concrete indicates a pile bearing failure that leaves the concrete section free to flex and move within existing constraints. Repeated movement or flexing of the concrete structure could lead to (if not already) structural problems for the parking facility. This facility in its present condition requires substantial foundation repair(s).

With regard to the proposed harbor expansion, it should be noted that over-swing normally associated with pipeline dredging (estimated at approximately 4 to 6 feet) could lead to an approximate loss of 2 feet of channel side slope soil material that currently helps support the outermost piling. While true for the outermost piles, the estimated 2 feet of possible material loss is unlikely to have an appreciable effect on remaining interior piles. In addition, it is noted that the same amount of remedial or repair work will be required, with or without the harbor expansion project.

Subsurface sampling and testing in this area isn't likely to yield any new or useful information with regard to the facility and therefore is not recommended. It is recommended that the property owner be advised of the foundation conditions discovered before actual dredging occurs

b. International Paper (formerly Union Camp), southwest side, located between Channel Stations 87+500 and 89+600. The sheet-piling bulkhead contains numerous holes approximately 1-foot square in size at or near the zero mlw elevation. It is unclear whether these holes have been cut deliberately (given the near uniform hole sizes), perhaps as a previous drainage effort, or if the holes are the result of long term pile corrosion at the low water mark.

With regard to the proposed project in this vicinity, the resulting side slope from project dredging is not expected to change or alter existing conditions directly adjacent to the bulkhead. The above expectation is based on the distance of the bulkhead from the proposed channel work and considering usual dredging practices.

Subsurface sampling and testing in this area is not likely to yield any new or useful information with regard to the facility or project and therefore is not recommended. However, it is recommended that the property owner be advised of the bulkhead conditions discovered during our site inspection.

c. Crescent Towing and Salvage Company approximately located between Channel Stations 75+500 and 75+800. Crescent's brick wall and brick retaining wall structures appear to be supported or partially supported on wood piling. The wall is severely cracked, with portions of the wall either removed, or broken and subsequently fallen into the river. The wood piling behind the brick wall and supporting the dock facility appears to exist in a fair to good condition.



With regard to the proposed project and the Crescent property, the harbor expansion could have some effect on the stability of the brick wall and supporting piles. While it is not recommend that sampling and testing be performed solely for this facility, testing and sampling is currently planned for Crescent's neighboring facility, T.I.C., located approximately 400 feet upstream. Given the contiguous nature and similar histories for this reach, the sampling, testing and analysis currently planned should be considered sufficient and cost effective. The results of the analysis for the reach between Channel Stations 75+500 and 76+250 will be applied to the landmass / riverbank without regard to who owns which part. Any subsequent recommendations will be addressed after analysis has been completed.

d. East Coast Terminal Company, approximate Channel Stations 68+000 to 69+700. Observations reveal the supporting foundation for the dock facility at East Coast Terminal exists in an advanced state of deterioration and disrepair. This includes piling, pile bracing, wood retaining structures and portions of the concrete deck.

With regard to the proposed project in this vicinity, the resulting side slope from project dredging is not expected to change or alter existing conditions adjacent to the East Coast dock facility. This conclusion is based on the distance of the dock from the proposed channel work (80 to 120 feet) and considered usual dredging practices.

Subsurface sampling and testing in this area is not is not recommended. However, it is recommended that the property owner be advised of the dock facility foundation conditions discovered during our site inspection.

9. The remaining properties, structures and/or other items within the scope of the proposed harbor expansion exists in or belongs to one of the following conditions:

a. Located by sufficient distances from the proposed work so as not to be impacted and are not recommended for sampling and testing of soil materials or further studies.

b. Located near, but outside, the proposed work and exist in an excellent to good condition. Sampling and testing in the vicinity of such facilities will not provide any useful information with regard to the proposed work and such sampling and testing is not recommended.

c. Is currently under design for remediation / repair of structural facilities to be implemented as an item separate from the proposed project. i.e. Old Fort Jackson moat and bank protection.

d. Belongs to a group or class probably best described as obstructions and are being addressed as separate issues. i.e. CSS Georgia, sunken barges, training wall(s), etc..

# APPENDIX I

# GENERAL CORRESPONDENCE

## GENERAL CORRESPONDENCE

**NOTE: Not all files available in the Correspondence directory are listed below. Reading availability is dependent on viewing software programs including Arc Info, Arc GIS, MicroStation and/or AutoCad, and Visio.**

1. **Assumptions and Problems**
2. **Bridge Article**
3. **Container Facilities Feasibility Study**
4. **Expansion Plan Formulation**
5. **Preliminary Alternative SavHarb Expansion**
6. **Savannah Harbor Expansion**
7. **Savannah Harbor Questions**
8. **Savannah Harbor**
9. **Savannah Harbor Area Map**

# APPENDIX J

# REVIEW OF PREVIOUS STUDIES

## REVIEW OF PREVIOUS STUDIES

**The following links represent partial, but important reviews of past geotechnical and slope stability studies made in the process of widening and deepening the Savannah River.**

**Appendix D of the first DM listed, starting on page 168, contains earlier slope stability studies performed for the Savannah River. (Required reading for the not-so feint of heart)**

**1992 Savannah Harbor Deepening - Design Memorandum and Appendices B-E - Vol 1**

**1992 Savannah Harbor Deepening - Design Memorandum Appendices F through I - Vol 2**

**1992 Savannah Harbor Comprehensive Study Main Report**

**1975 Feasibility Report**

**FOR CONTINUATION OF HOUSE DOCUMENT 112-153**

**SAVANNAH HARBOR EXPANSION PROJECT CHATMAN CO., GEORGIA & JASPER CO., S. CAROLINA: FINAL GENERAL RE-EVALUATION REPORT AND ENVIRONMENTAL IMPACT STATEMENT**

**SEE PART 5**