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Coastal and Hydraulics Laboratory

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Vertical Ship Motion Study for Savannah, GA Entrance Channel

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Final report

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Abstract: The Savannah District (SAS) is preparing a Final Engineering Appendix for the Savannah Harbor Expansion project. Initial vertical motion studies addressed extension of the entrance channel to deeper water along the existing alignment. After initial channel design, shallower offshore shoals were identified that could influence the safety and efficiency of navigation on the proposed channel alignment. 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 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.

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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. 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 in the horizontal channel design. 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 Harbors, Entrances, and Structures Branch. The final report was written by Dr. Briggs with assistance from William Henderson. We gratefully acknowledge the support of Andrew Silver and 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, Harbors, Entrances, 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
degrees (angle)	0.01745329	radians
feet	0.3048	meters
knots	0.5144444	meters per second
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters

1 Introduction

1.1 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.

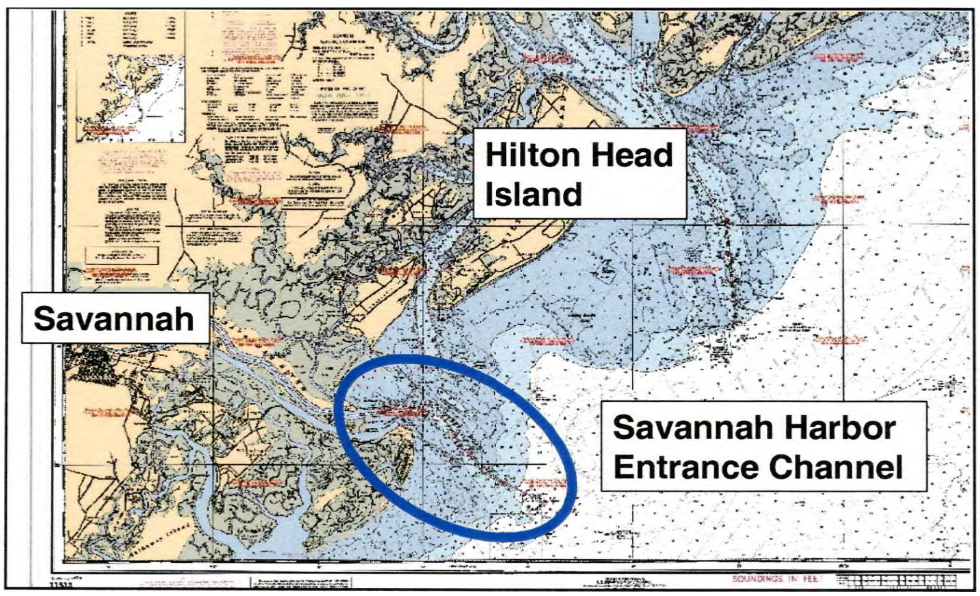


Figure 1. Location map of Savannah study.

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 are 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 accommodated easily 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.

1.2 Design ship

The *Susan Maersk* Post-Panamax containership (Figure 2) is the design ship for this study. It was completed in 1997 with a capacity of 8,680 twenty-foot equivalent units (TEU) 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*.

1.3 Purpose

The Savannah District (SAS) is preparing a Final Engineering Appendix for the Savannah Harbor Expansion project. Initial vertical motion studies addressed extension of the entrance channel to deeper water along the

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

existing alignment. After initial channel design, shallower offshore shoals were identified that could influence the safety and efficiency of navigation on the proposed channel alignment. Several additional channel extensions are now being considered based on length, dredging requirements, and pilot considerations. These alignment changes (doglegs) are proposed because 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.

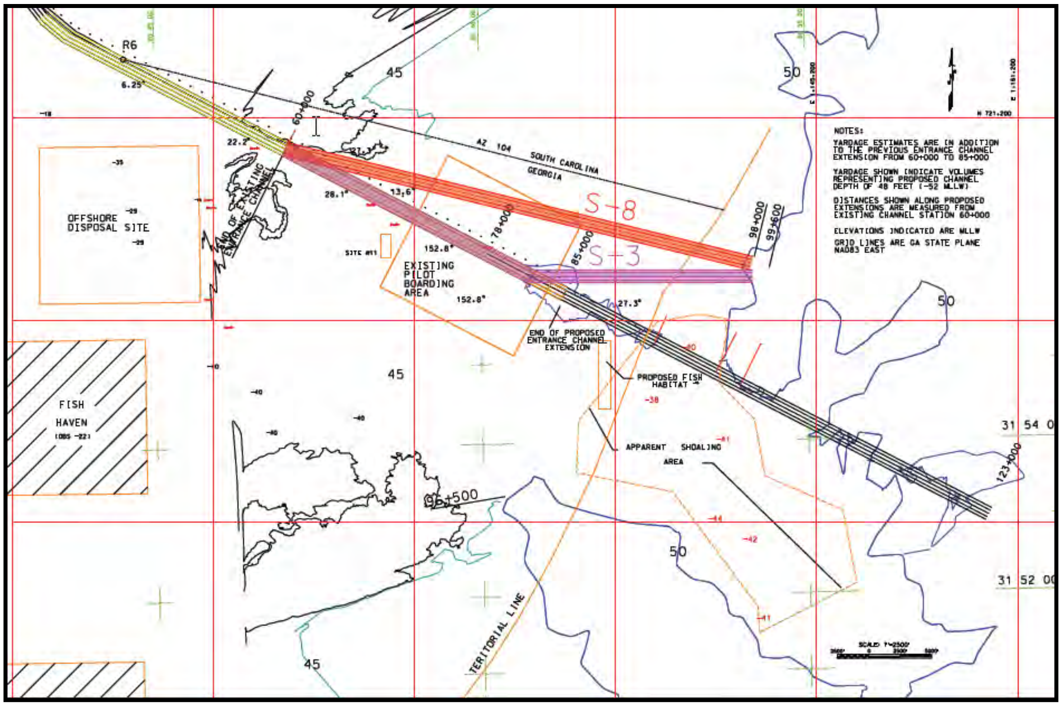


Figure 3. Savannah Entrance Channel proposed channel alignments showing Option S-1 extension to Existing, Option S-3, and Option S-8.

1.4 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.
- 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 relied historically 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.

1.5 Report organization

In this report, the CADET numerical model is described briefly in Chapter 2. Chapter 3 contains a description of the PIANC, Ankudinov, and CADET 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 are presented in Chapter 8.

2 CADET Numerical Model

2.1 Background

CADET (Kopp and Silver 2005) was developed by the Naval Surface Warfare Center, Carderock Division (NSWCCD) under contract to the ERDC, 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.

2.2 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 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 the hull surface usually corresponding to bow, stern, rudder, or bilges) is given by

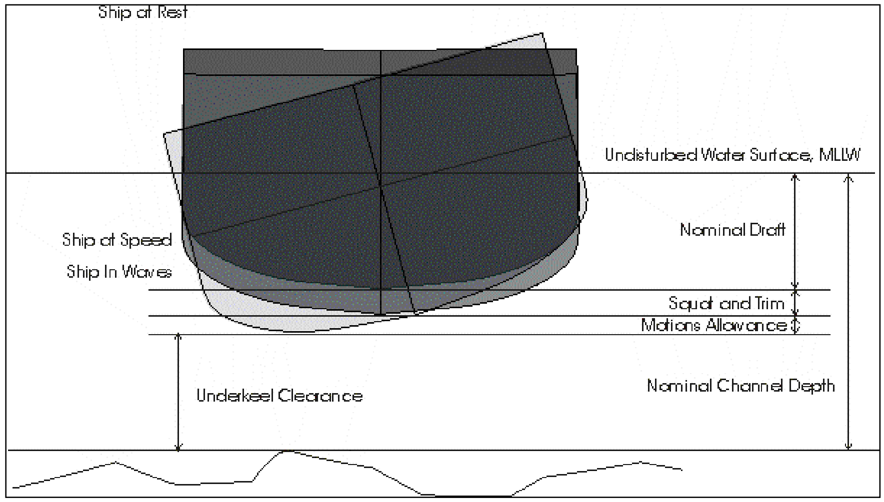


Figure 4. Cross-section of a ship in a channel.

$$UKC_j = D_c + E_t - \left(T_j + S_j + A_j\right) \quad (1)$$

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.

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

$$H_j\left(f,\theta\right) = Z + X_j \Theta\left(f,\theta\right) \quad (2)$$

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 σ_j given by

$$\sigma_j = \sqrt{\sigma_j^2} = \sqrt{\sum_f \sum_\theta s(f,\theta) \,|\, H_j(f,\theta)|^2 \, \Delta f \Delta \theta} \qquad (3)$$

where:

σ_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)
Δf = increment in frequency, Hz
$\Delta \theta$ = increment in direction, deg.

Because of phase differences, σ_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

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

where:

T_d = exposure time in the channel (i.e., reach length/ship speed), sec
σ_{vj} = vertical velocity of the vertical motion (i.e., time derivative of σ_j) at location j, ft/sec
α = risk parameter, normally taken to be 0.01 (i.e., 1/100) in CADET. If α = 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.

2.3 Uncertainty and risk analysis

Each of the parameters in Equation 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 amid-ships 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 1997). 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, and the primary direction 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.

2.4 CADET organization

CADET is 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. It is organized into four basic modules in FORTRAN and C++ for defining and performing calculations relative to:

- Ship
- Project
- Analyses
- Results

English units (i.e., ft, ft^2/Hz, etc.) are the standard for the program, although metric equivalents can be converted for some inputs.

2.4.1 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.

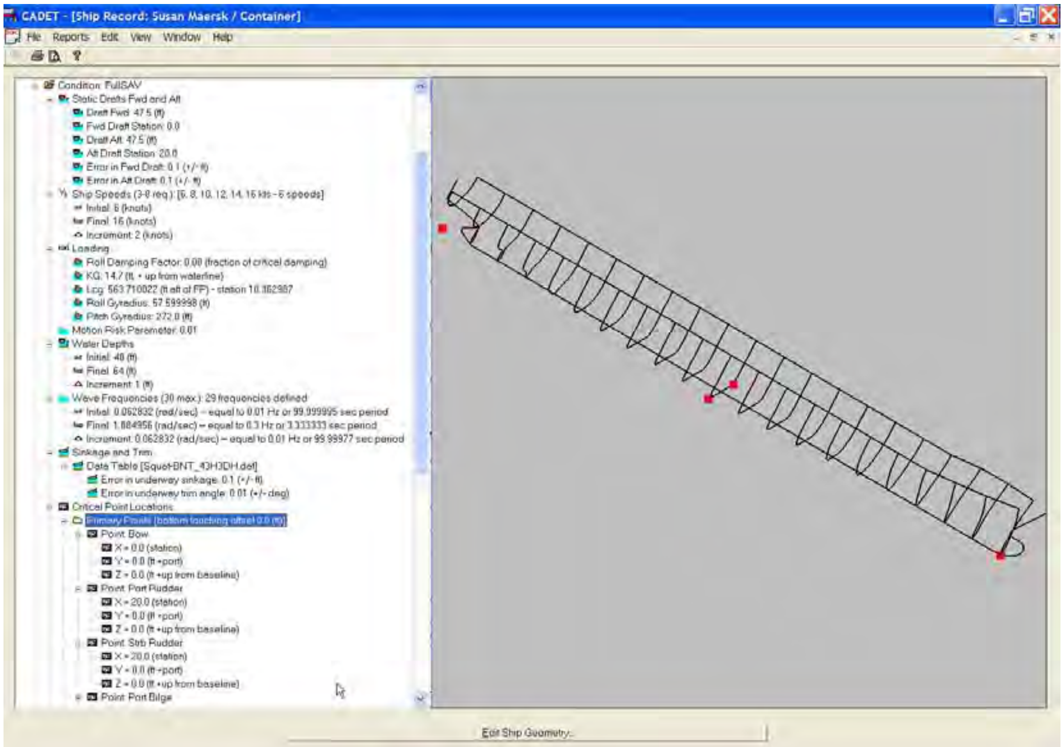


Figure 5. Example CADET ship record with red dots denoting the critical point locations.

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 perpendiculars. 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 is defined by these cross-sections. Points defining the x, y, and z coordinates along the ship lines have specific "types" to identify the ship lines properly 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 the transverse distance from the center line. The z-location is positive upward from the baseline of the ship.

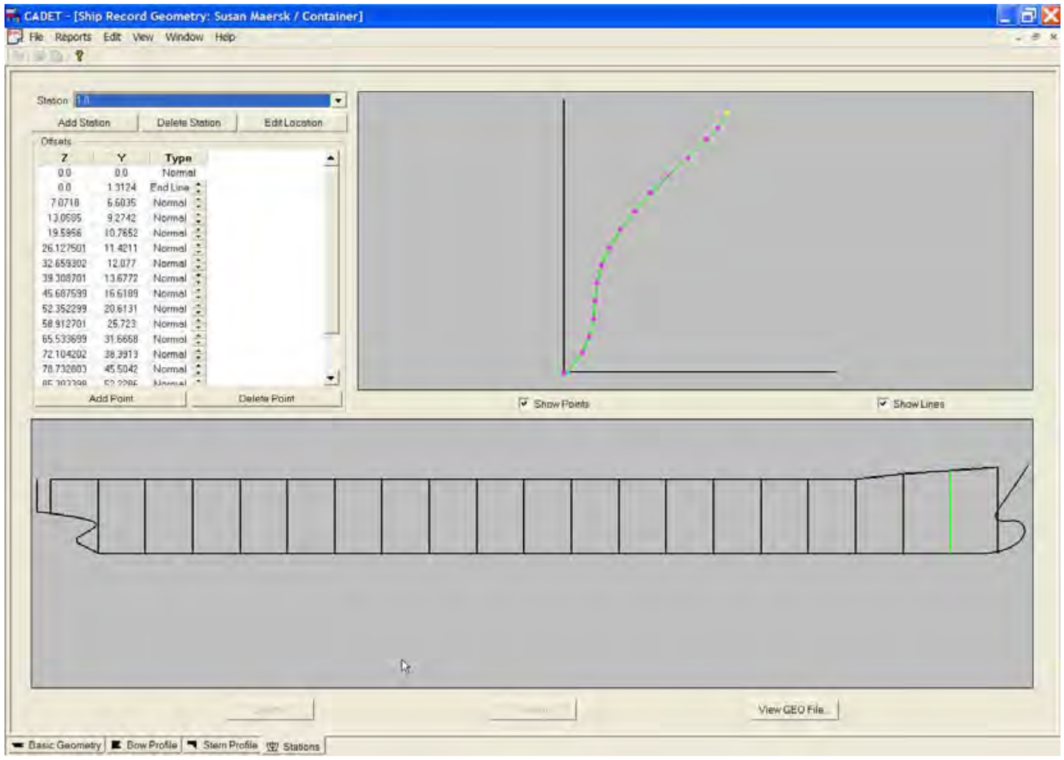


Figure 6. Example CADET ship record geometry for stations. The green highlighted station ship line cross-section is shown in the upper right plot.

2.4.1.1 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) amidships draft and a trim angle in degrees. Up to 8 ship speeds in knots can be entered. These values must be whole integers.

2.4.1.2 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 K_G, (c) roll damping factor, (d) roll mass radius of gyration k_4, and (e) pitch and yaw mass radius of gyration k_6. Figure 7 is an example of the built-in calculated hydrostatics that provides some insight into the values for the loading section.

Figure 8 illustrates ship stability for static equilibrium and free unresisted rolling. Static equilibrium is based on the 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

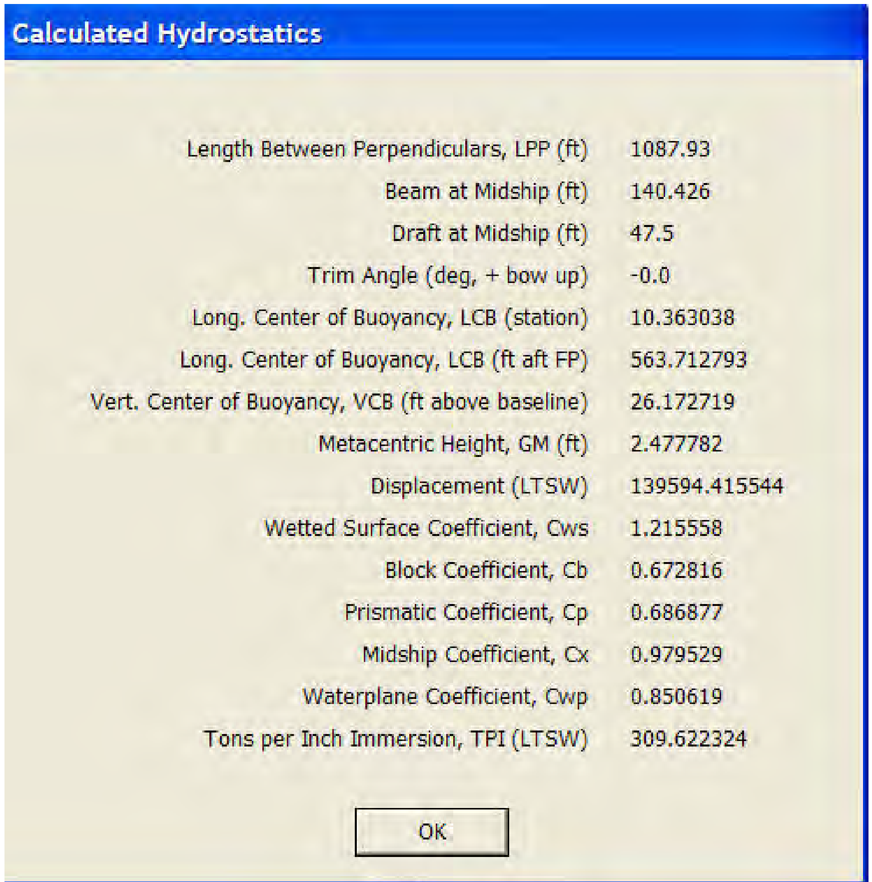


Figure 7. Example CADET hydrostatics.

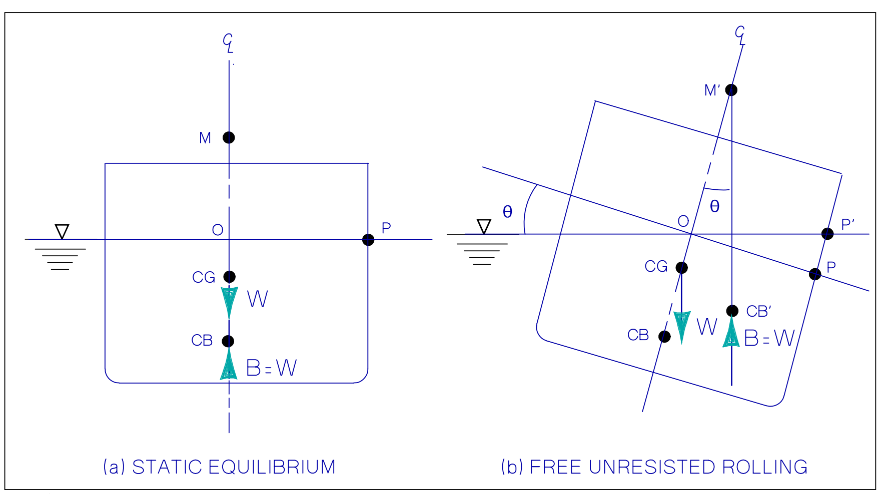


Figure 8. Equilibrium conditions for a ship.

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. The longitudinal center of buoyancy (as shown in the calculated hydrostatics in Figure 7) can be used as a good estimate of the L_{CG}, which is measured positive, aft of the forward perpendicular. The vertical center of gravity K_G is usually located along the vertical axis of the ship, approximately midway in the cargo as measured from the keel. In CADET the K_G is measured positive up from the waterline and varies with the type of ship. Tankers typically have negative values around -5 to -20 ft since their 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.

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 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 requires only the roll damping factor to account for the ship's roll characteristics. This factor is the fraction of critical damping and typically is 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

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

2.4.1.3 Motion risk parameter α

The motion risk parameter α typically has a value of 0.01 for most design applications.

2.4.1.4 CADET sinkage and trim

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

2.4.1.5 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.

2.4.1.6 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 matches the highest frequency with significant wave energy to insure the highest accuracy in the RAOs. These RAOs are used in Equation 3 to determine the CADET predictions.

2.4.1.7 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 Equation 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.

2.5 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.

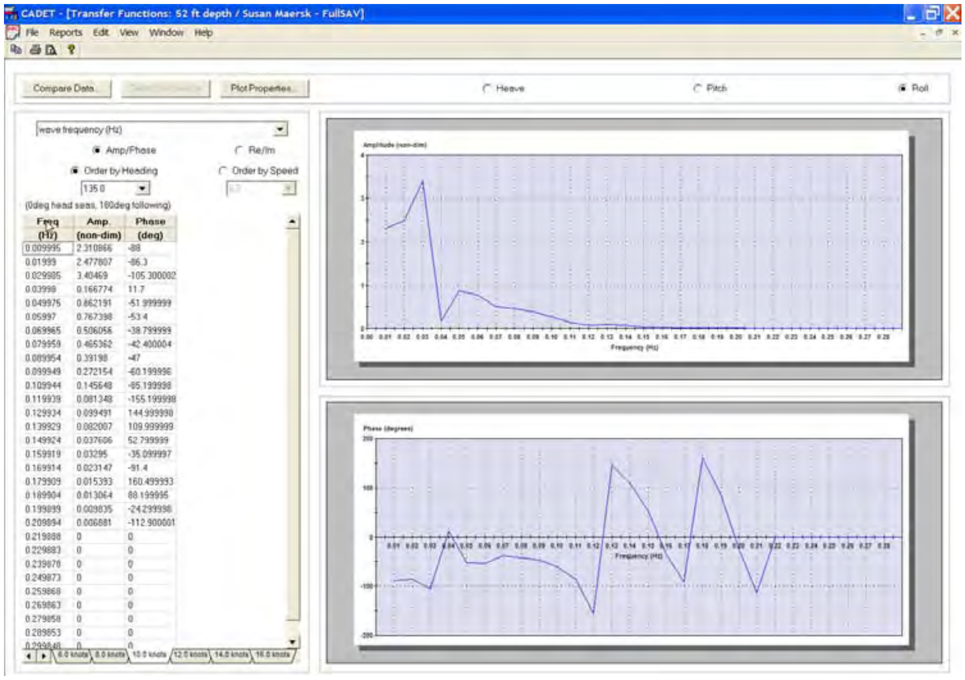


Figure 9. Example CADET roll ship motion transfer function.

2.5.1.1 Reaches

Reaches should be defined whenever the depth, width, cross-section, or alignment of the channel changes. 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 increased automatically 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°, south 180°, and west 270°. 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

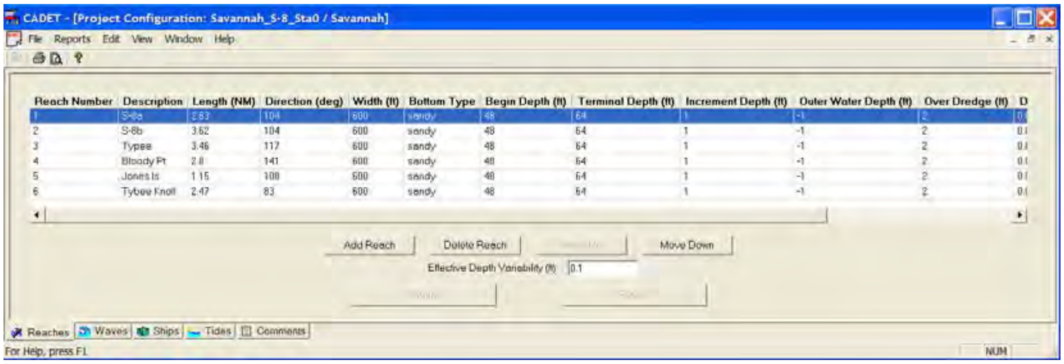


Figure 10. CADET reach example.

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. A typical value is 0.85 ft. The wave coefficient of variation is an indication of the reliability of the waves with a typical value of 0.4.

2.5.1.2 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 typically are 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 θ_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 entered manually after importing the wave file(s). The days/yr field is populated automatically 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 12 is an example of a directional spectrum in CADET. Individual spectral ordinates are listed in ft^2/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.

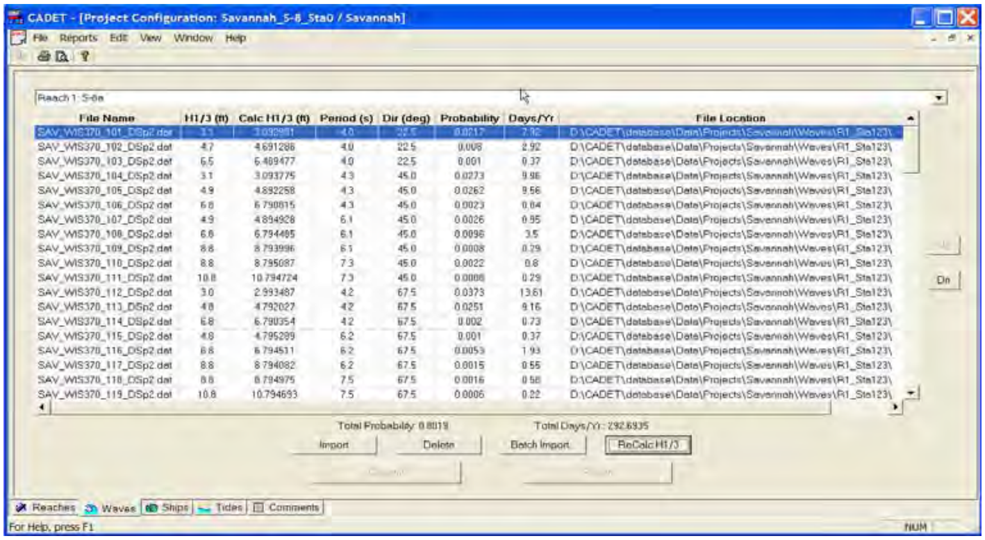


Figure 11. Example CADET wave record.

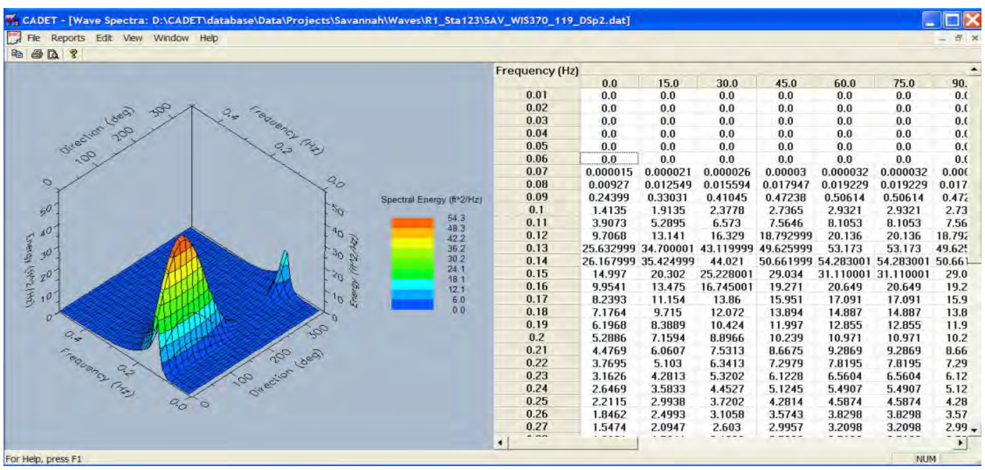


Figure 12. Example CADET directional spectrum.

Empirical directional wave spectrum. The directional wave spectrum S(f,θ) is created typically 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

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

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

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

where:

α = 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

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

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

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

where f_p = peak spectral frequency and σ is given by

$$a=\sigma\begin{cases}0.07 & f\le f_p\\ 0.09 & f>f_p\end{cases} \qquad (11)$$

Procedures for estimating α and γ 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 α is calculated using an iterative procedure that compares the target wave height to the calculated value for a required tolerance. The γ controls the width of the frequency spectrum (small values give broad frequency peaks and large values give narrow peaks). Considering sea and swell wave components, spectra with short (long) wave periods are generally broader (narrower) in frequency space. Table 3 provides some guidance in the selection of γ based on wave period (Thompson et al. 1996).

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

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 Equation 7 is satisfied
θ = direction of the spectral component
θ_m = peak or dominant direction of the spectral component

The SCORES module requires that θ 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.

2.5.1.3 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 Chapter 3, CADET sinkage and trim).

2.5.1.4 Tides

CADET has an optional program that calculates the tidal duration for a project and includes the effect of the extra water depth in the calculated accessibility. 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 and a tide prediction program 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 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 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 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 transit safely 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 transit safely 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 transit the channel safely. 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 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 for 2 to 4 hours at 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

2.5.2 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.

2.5.2.1 Motion transfer analysis module 1

The first analysis module uses the previously computed motion transfer functions for each selected ship and loading condition and the wave spectra data files defined for each project reach. From these input data files, the vertical motion variances (displacement σ_j and velocity σ_{Vj} according to Equation 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.

2.5.2.2 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 Equation 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.

2.5.2.3 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 whether the risk of grounding is equal or less than $\alpha = 0.01$ (or corresponding value of the risk factor α) for each reach and water depth. Accessibility data is provided for primary and alternative control points for each ship loading condition, ship speed, inbound or outbound ship heading, and each channel reach.

2.5.3 Results module

Multiple set of analysis results may be associated logically 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.

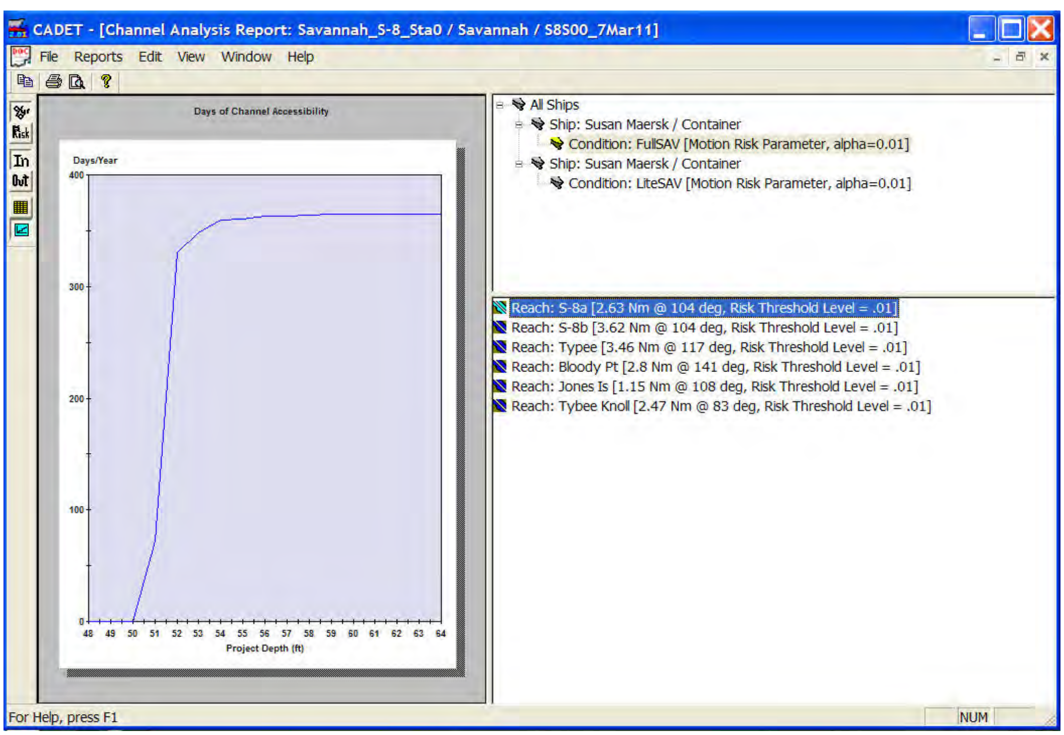


Figure 13. CADET analysis results plots.

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 always can 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.

2.6 CADET inputs

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

2.6.1 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 typically is proprietary and not available to the public. Best judgment is used as necessary in these cases.

2.6.2 Project module parameters

2.6.2.1 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.

Table 5. Input parameters for *Susan Maersk* containership in 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)	K_G	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)	α	–	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

Parameter description	Symbol	Units	Light-loaded	Fully-loaded
Final	f_{Final}	Hz	0.30	0.30
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

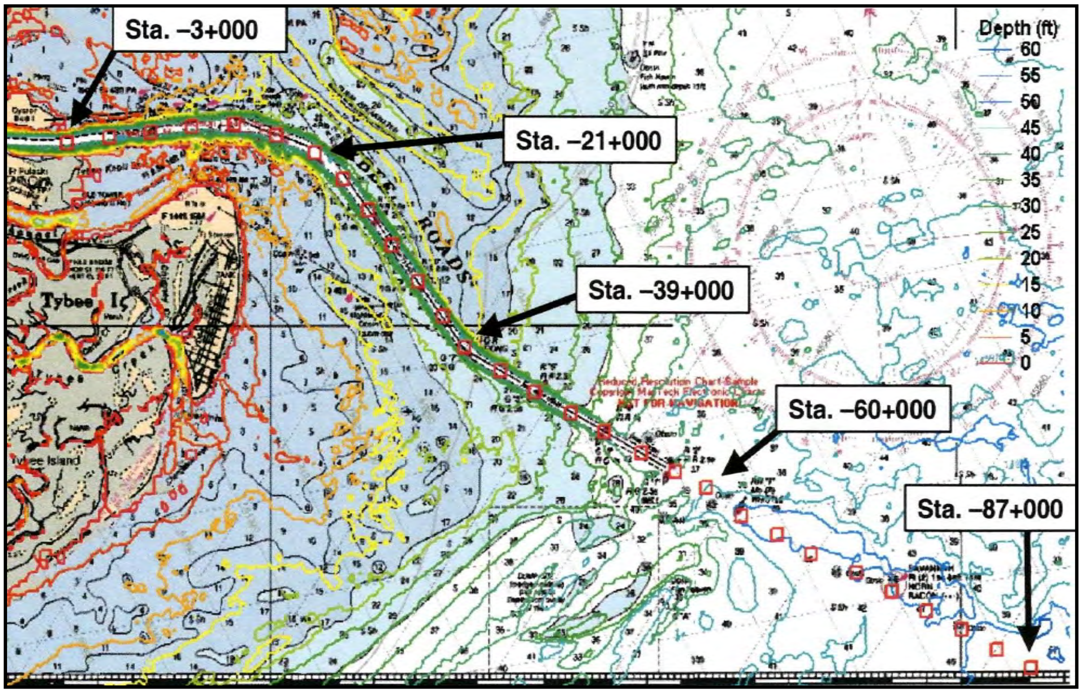


Figure 14. Station numbers for Savannah Outer Channel.

Table 6 lists the channel particulars for these three options and the existing channel. Included are group ID, reach 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). Groups 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).

2.6.2.2 Wave input

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

Table 6. Savannah Outer Channel parameters.

Group ID	Reach 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.

2.6.2.3 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 (**B**eck, **N**ewman, and **T**uck) ship squat module. A description of this program is contained in Chapter 3.

2.6.2.4 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 the 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 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 is compared for PIANC, Ankudinov, and CADET 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.

3.1 PIANC squat formulas

PIANC (1997, 2011) 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. 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.

3.1.1 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

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

where:

U = Unrestricted or open channel
C = Canal channel.
R = Restricted 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 that the ship will squat by the bow, then this formula will give the squat at the stern, and vice versa.

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

3.1.2 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.

3.1.3 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 used typically 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 ∇ is given by

$$\nabla = C_B L_{pp} BT \tag{23}$$

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

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

where the corrected blockage factor s_1 is given by

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

Note that K_s goes to 1.0 when s_1=0.03 for both ranges of s_1 in Equation 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 $h_T=h$.

3.1.4 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

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

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

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

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

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

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

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

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

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

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

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

3.1.5 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

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

where the enhanced ship speed term V_e is given by

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

3.2 Ankudinov squat formula

The Ankudinov squat formulas are much more complicated than the PIANC squat formulas and were used originally 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), McCollum and Ankudinov (2000), and Ankudinov et al. (1996, 2000) proposed the MARSIM 2000 formula for maximum squat based on a midpoint 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)[1] are contained in the FORTRAN programs.

1 Per discussions via telcons and e-mails with Briggs.

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 midpoint 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.

3.2.1 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

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

which is a numerical approximation to the term "$F_{nh}^2 \big/ \sqrt{1-F_{nh}^2}$" 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

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

The Channel effects parameter P_{Ch1} is given by

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

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

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

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 midship cross-section A_S.

3.2.2 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) [1] as

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

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

[1] Per discussions via telcons and e-mails with Briggs.

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

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

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

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

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

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

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

3.3 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.

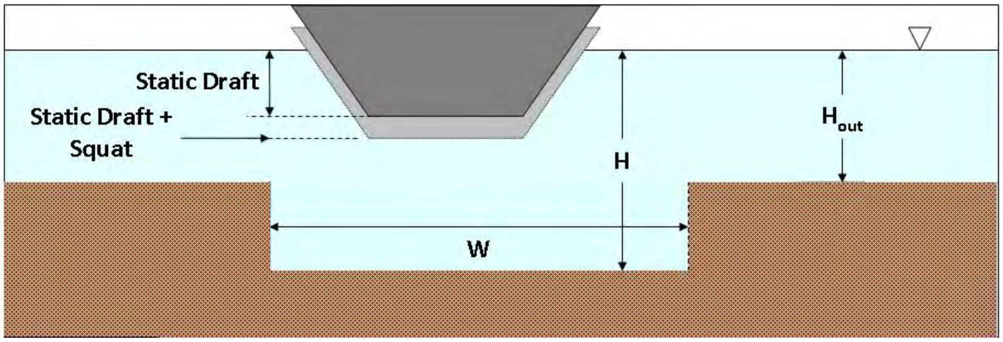


Figure 15. BNT channel geometry variables.

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.

4.1 CADET waves

4.1.1 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 θ_p. The θ_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 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,

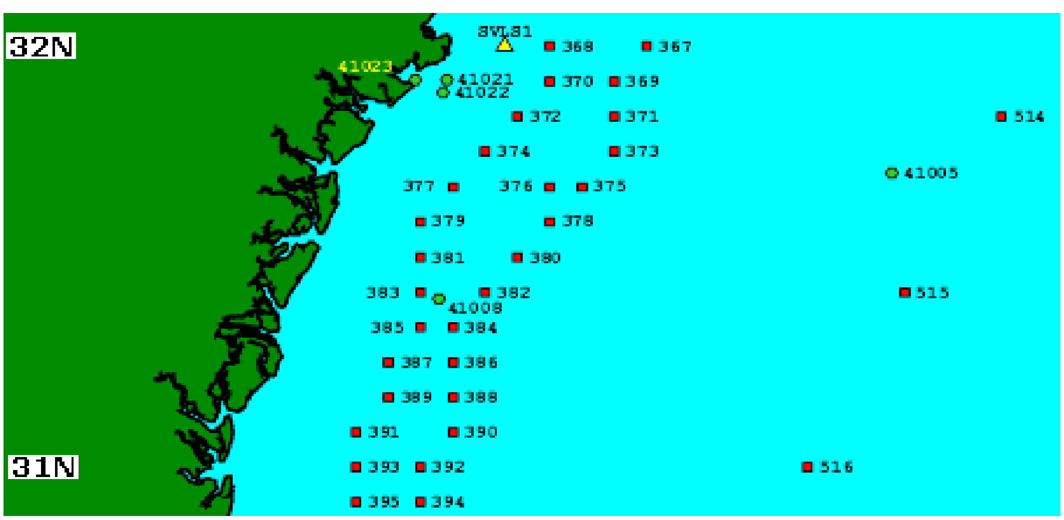


Figure 16. Location of WIS370 hindcast wave station.

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

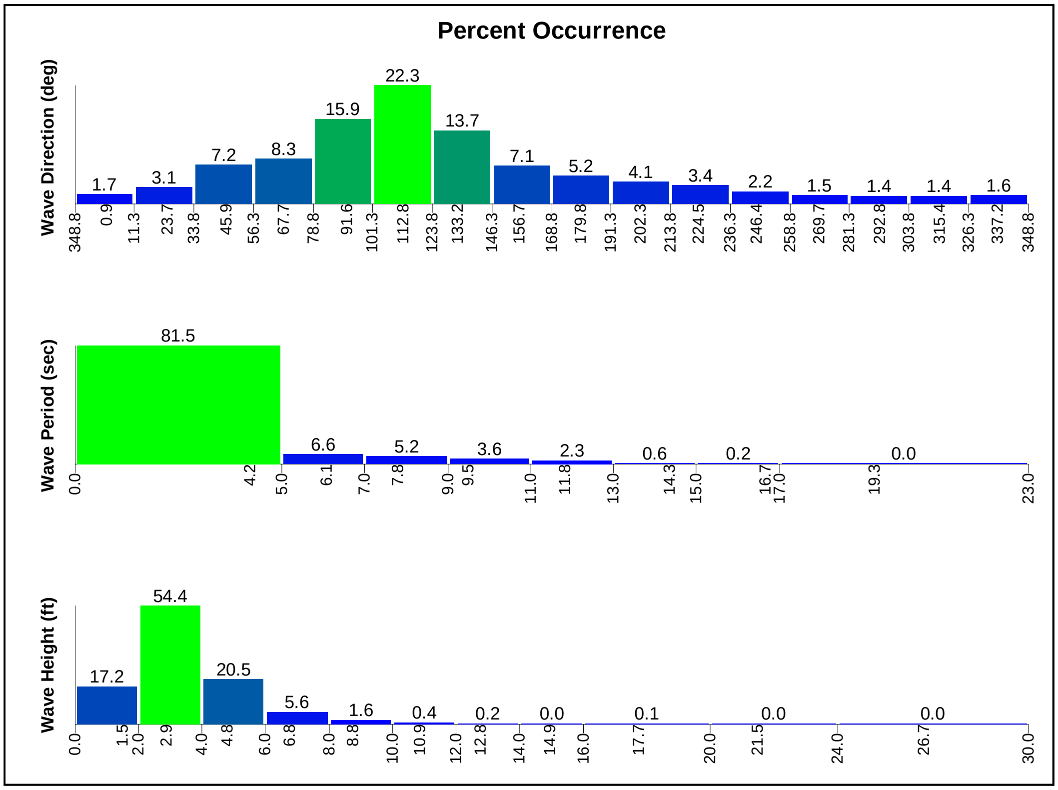


Figure 17. WIS370 percent occurrence histogram of wave direction, period, and height, 1980 to 1999.

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 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.

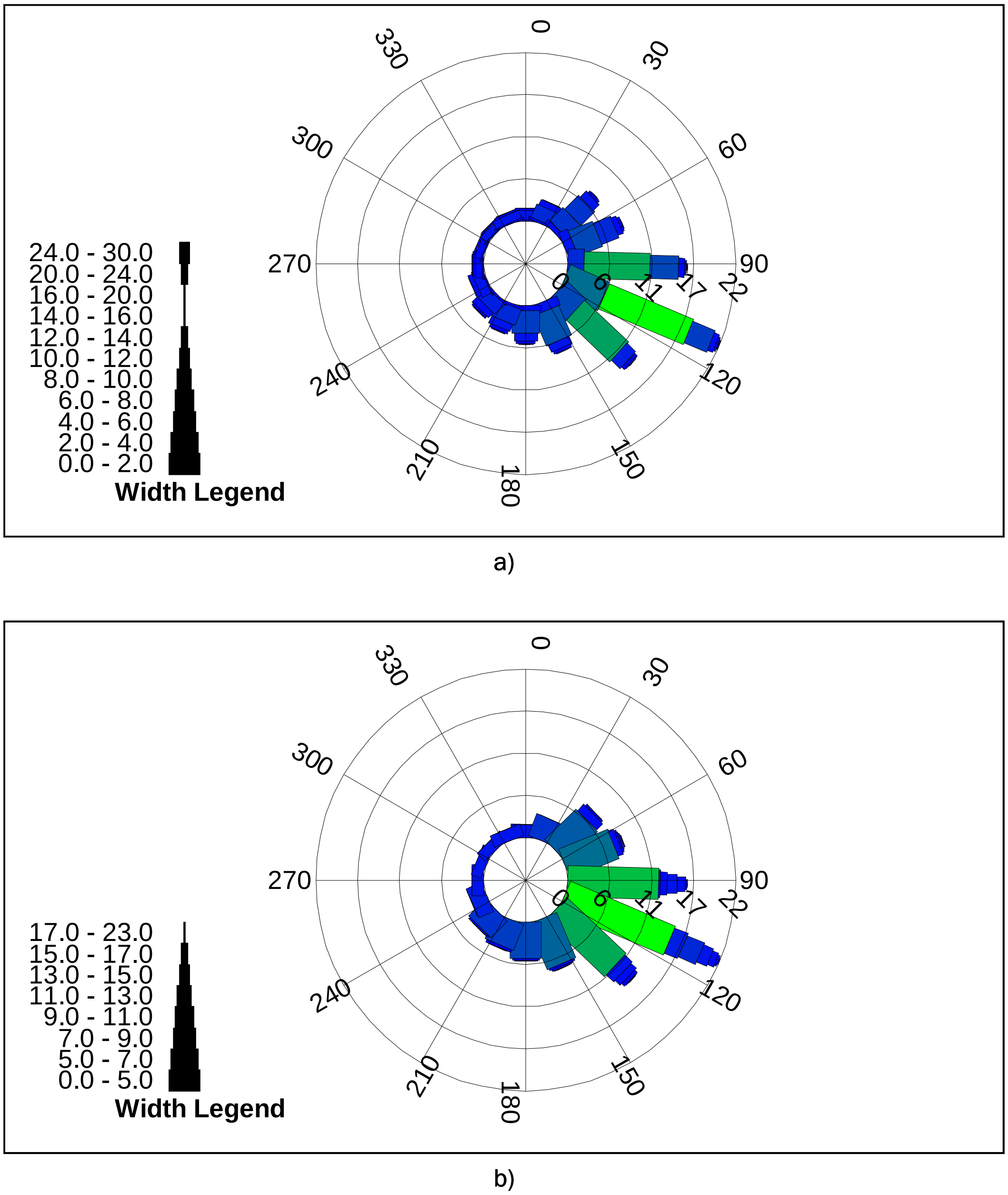


Figure 18. WIS370 wave roses for 1980 to 1999 (a) wave height and (b) peak wave period.

4.1.2 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 θ_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.

4.1.3 Directional wave spectra

The directional wave spectra were then generated using a TMA frequency spectrum and a 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 γ parameter that varied between 3.3 (broad) to 8 (narrow). For the directional 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.

4.1.4 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

4.1.5 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).

4.2 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 was 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 θ_p were calculated at every third station along the channel from Station 0 to Station 99 for simulating waves in the STS.

4.2.1 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 increase the wave heights significantly 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 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 were 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.

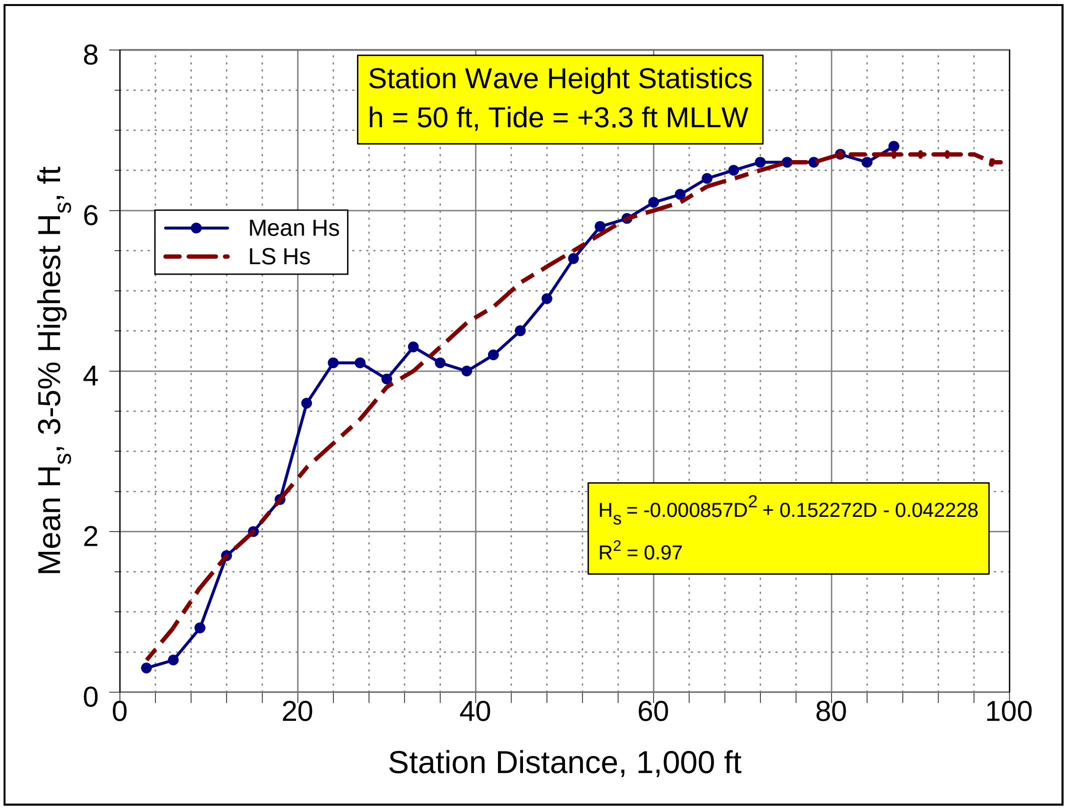


Figure 19. Mean H_s along channel, 3-5 percent highest H_s, h=50 ft, tide=+3.3 ft MLLW.

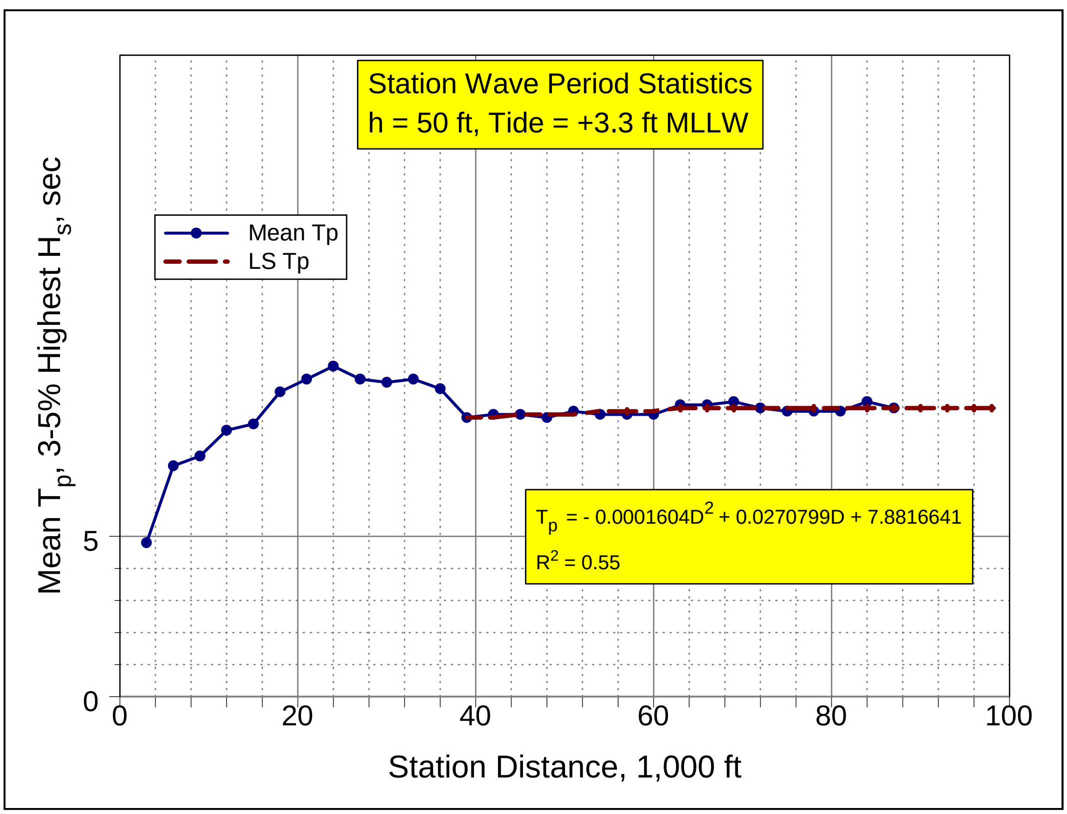


Figure 20. Mean of T_p along channel, 3-5 percent highest H_s, h=50 ft, tide=+3.3 ft MLLW.

The corresponding mean θ_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 θ_p = 107 to 113 deg. Again, goodness-of-fit is demonstrated by typical differences between STWAVE θ_p and predicted θ_p between Stations 60 to 87 being less than 3.5 deg. Finally, this compares favorably with the overall mean θ_p = 106 deg for the 3-5 percent highest waves at WIS33.

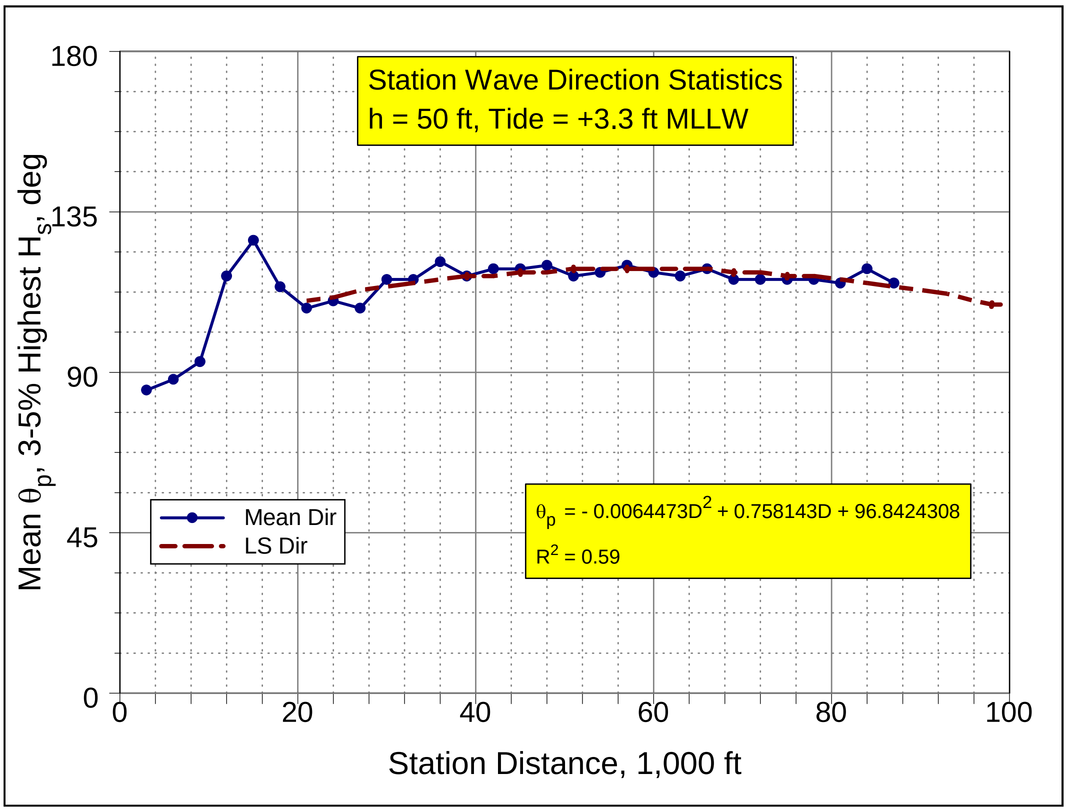


Figure 21. Mean of θ_p along channel, 3-5 percent highest H_s, h=50 ft, tide=+3.3 ft MLLW.

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.

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 θ_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

4.2.2 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.

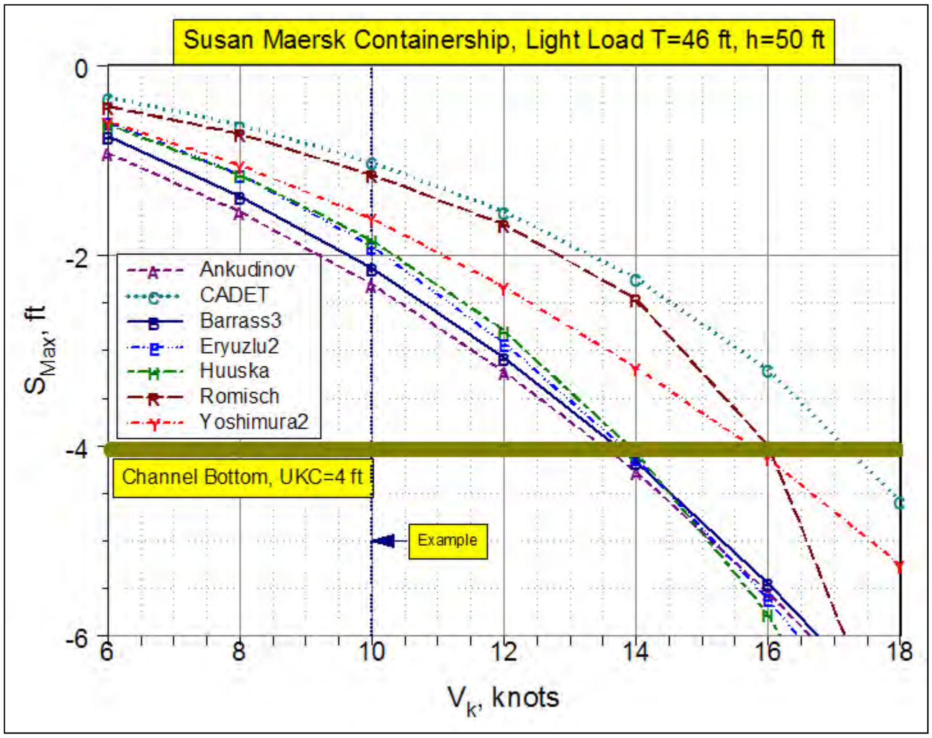
5 Ship Squat Results

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

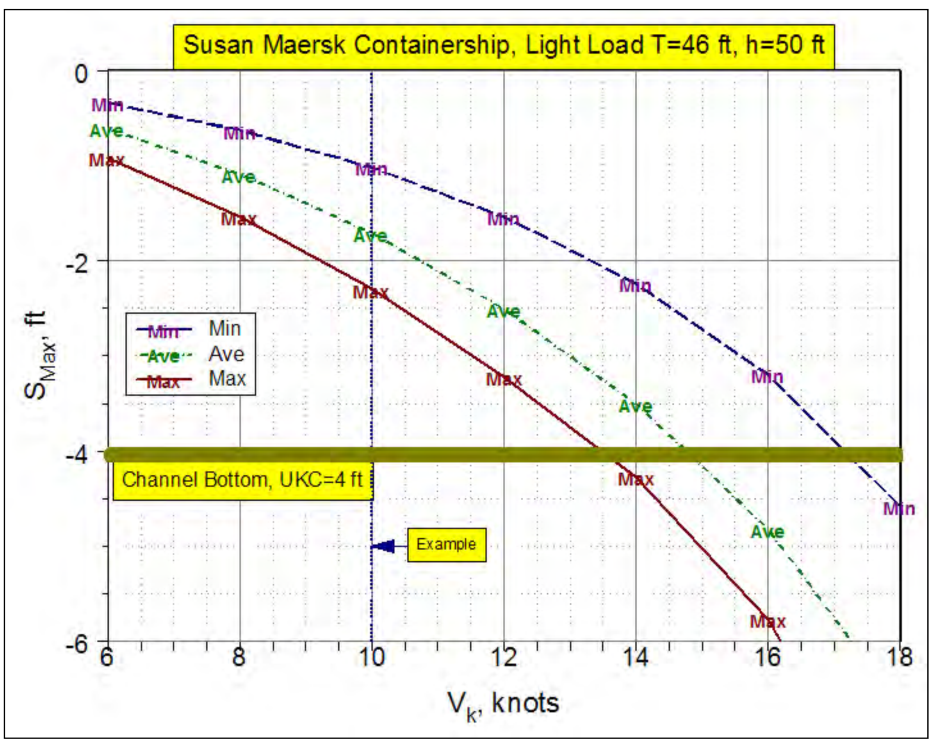
5.1 Light-loaded conditions

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.

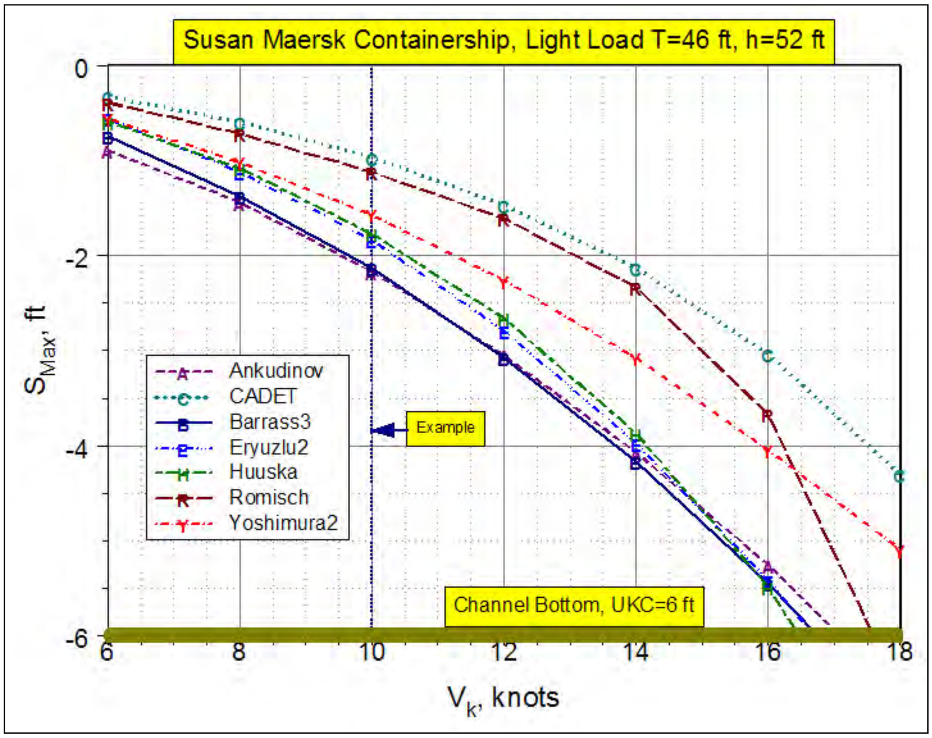


a)

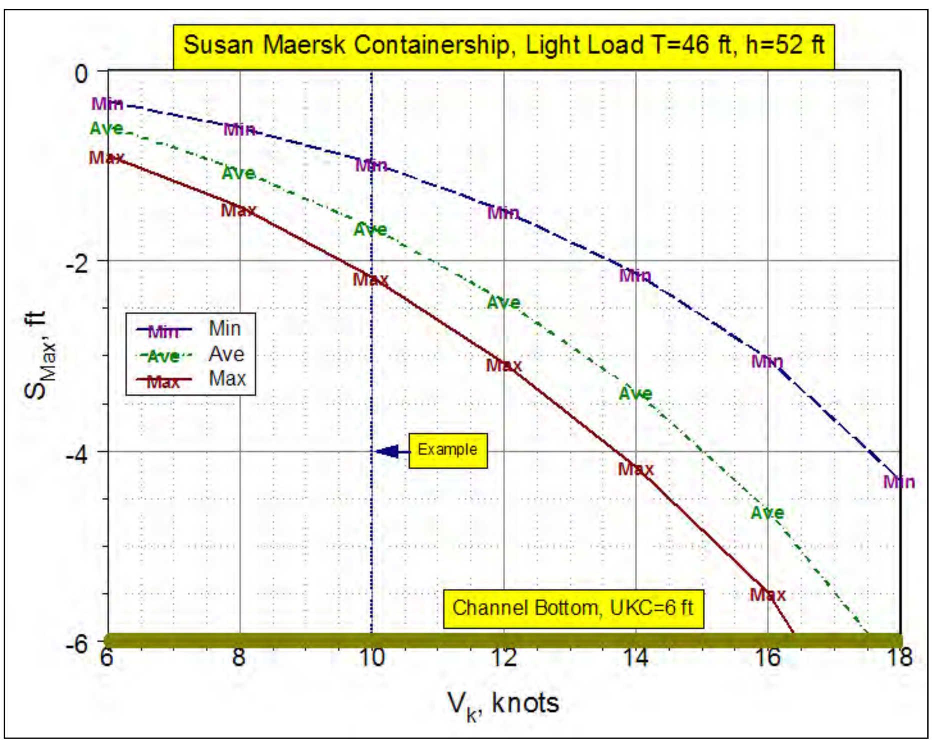


b)

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.

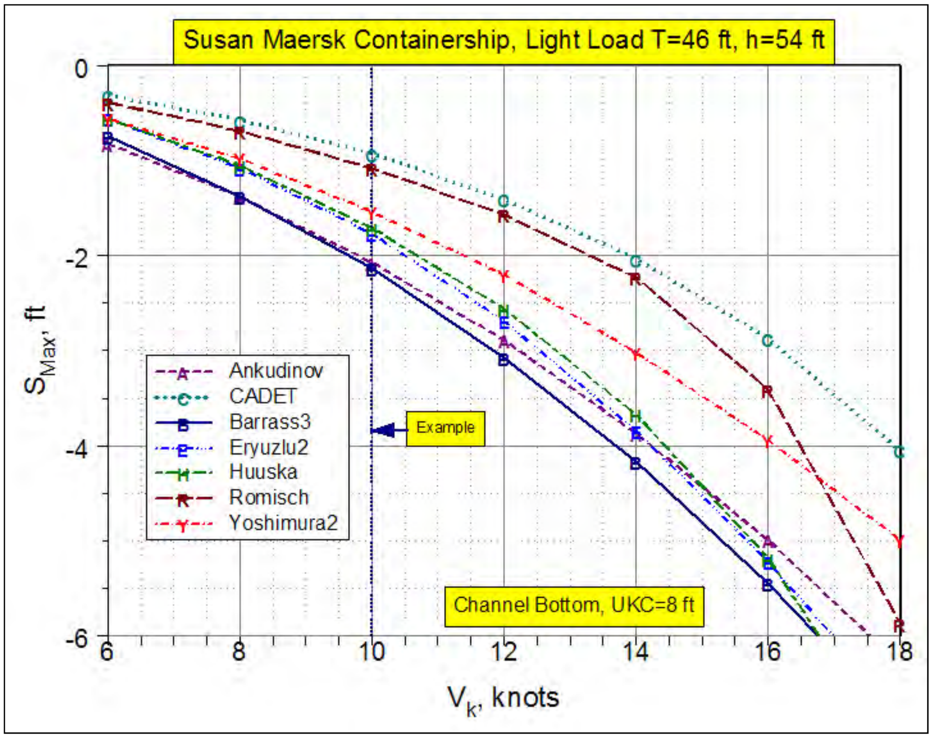


a)



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.



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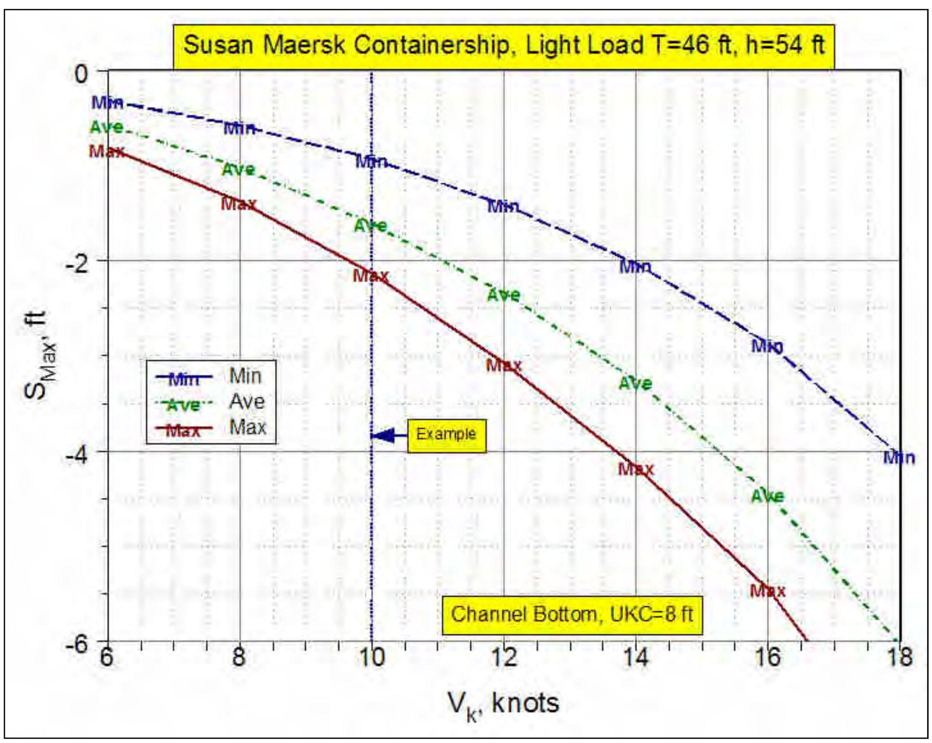


b)

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) with a 1-ft tidal increase 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.

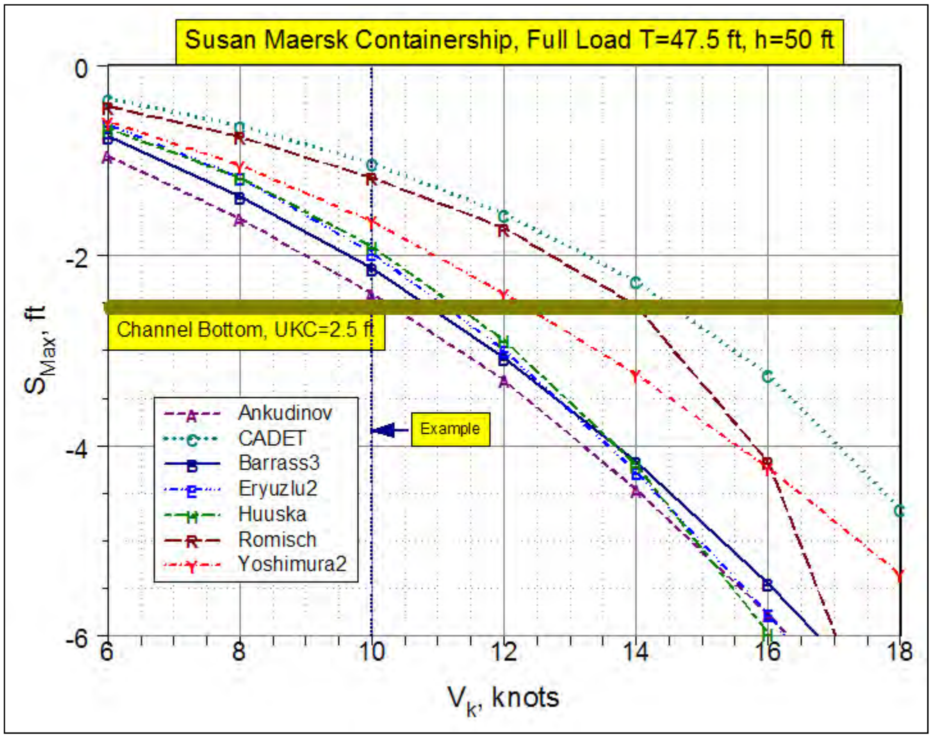
In the second scenario of h=52 ft (h/T=1.13) with a 3-ft tidal increase (Figure 23), the available UKC is 6 ft. With this water depth, the ship is not in danger of touching bottom (i.e., exceeding the available UKC of 6 ft) due to squat except for the fastest speed of V_k =18 kt. Again, these values 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 5-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.

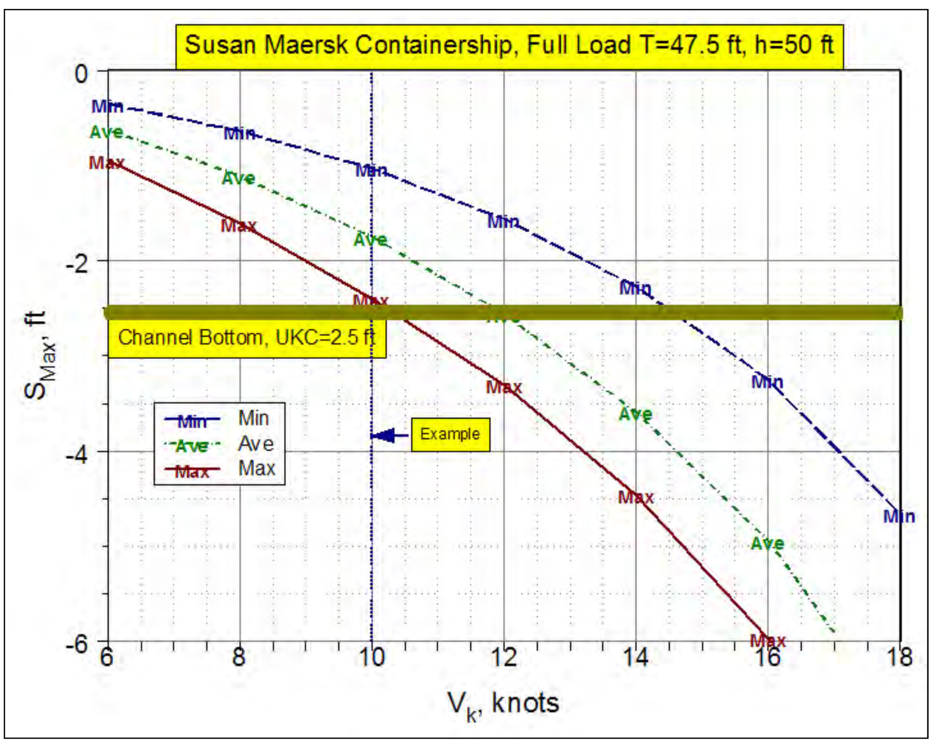
5.2 Fully-loaded conditions

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

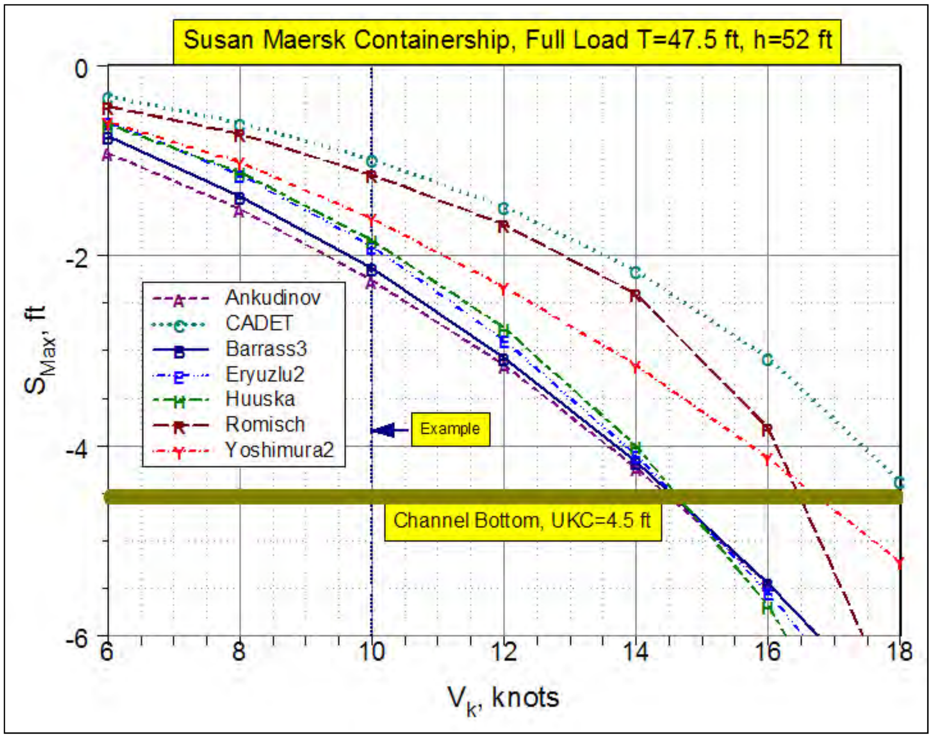


a)



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.



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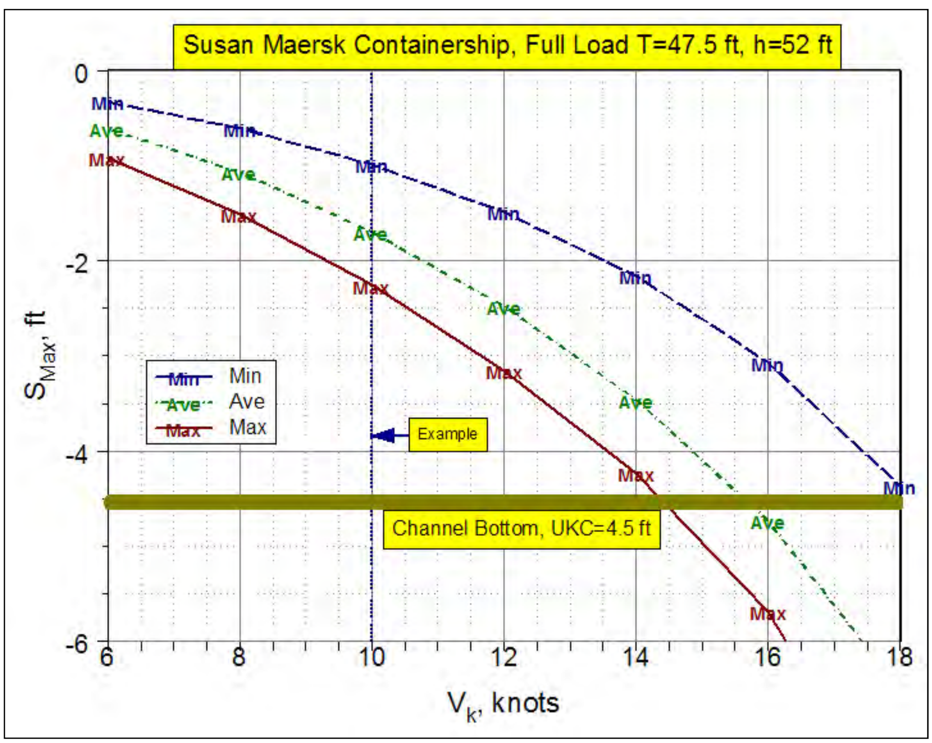
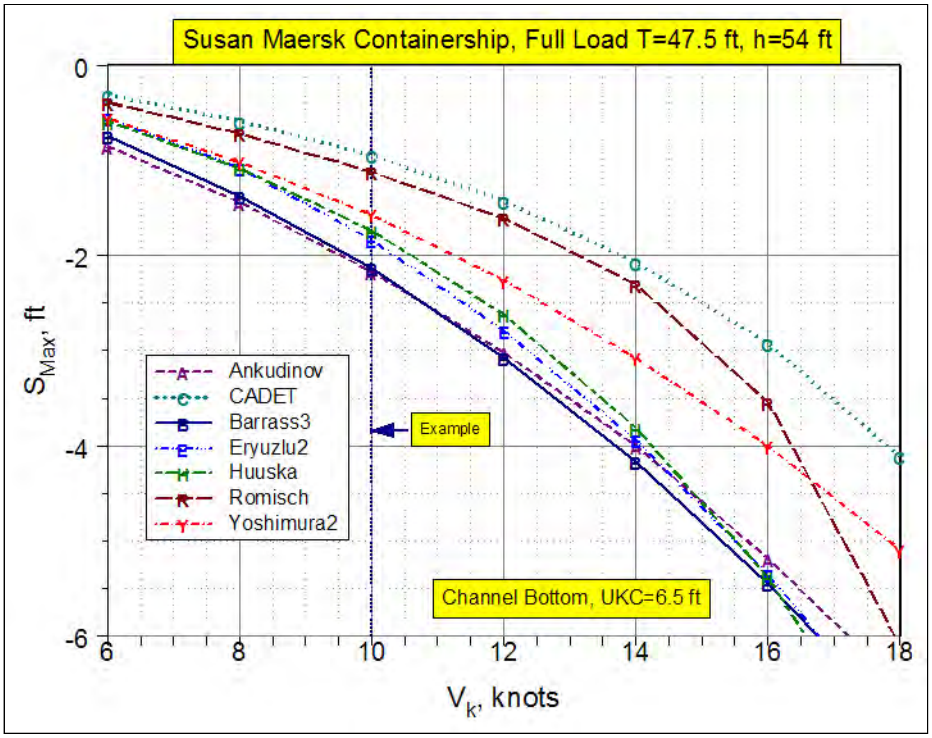
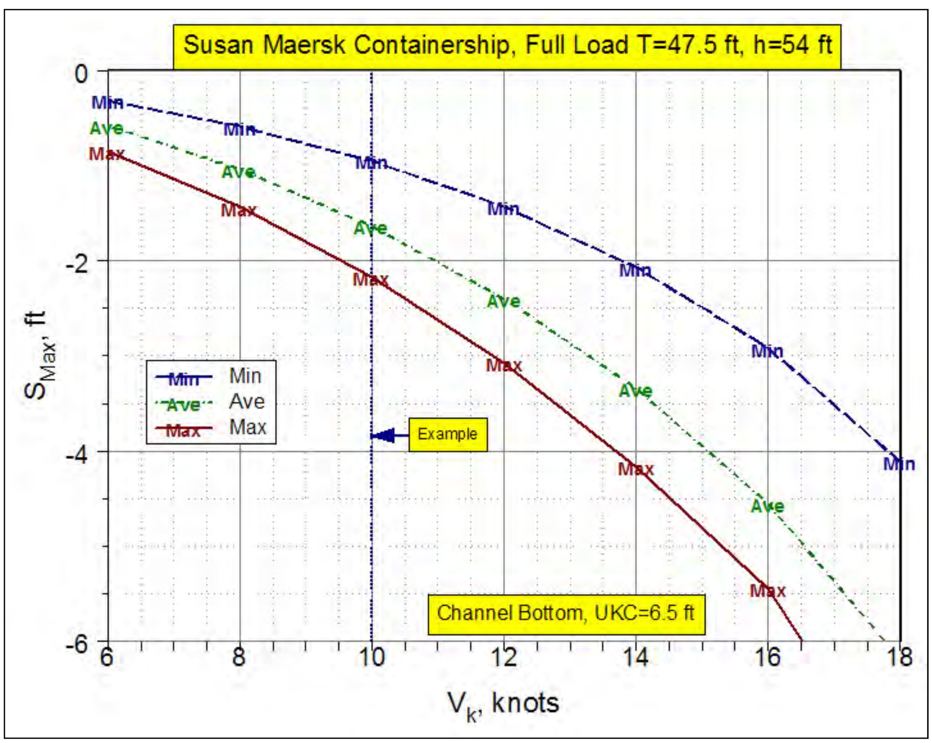


b)

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 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 3-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 5-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.

5.3 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, 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 (requiring an additional 1 ft of tidal depth to the shallowest depth of h=49 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:

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.

6.1 Absolute water levels

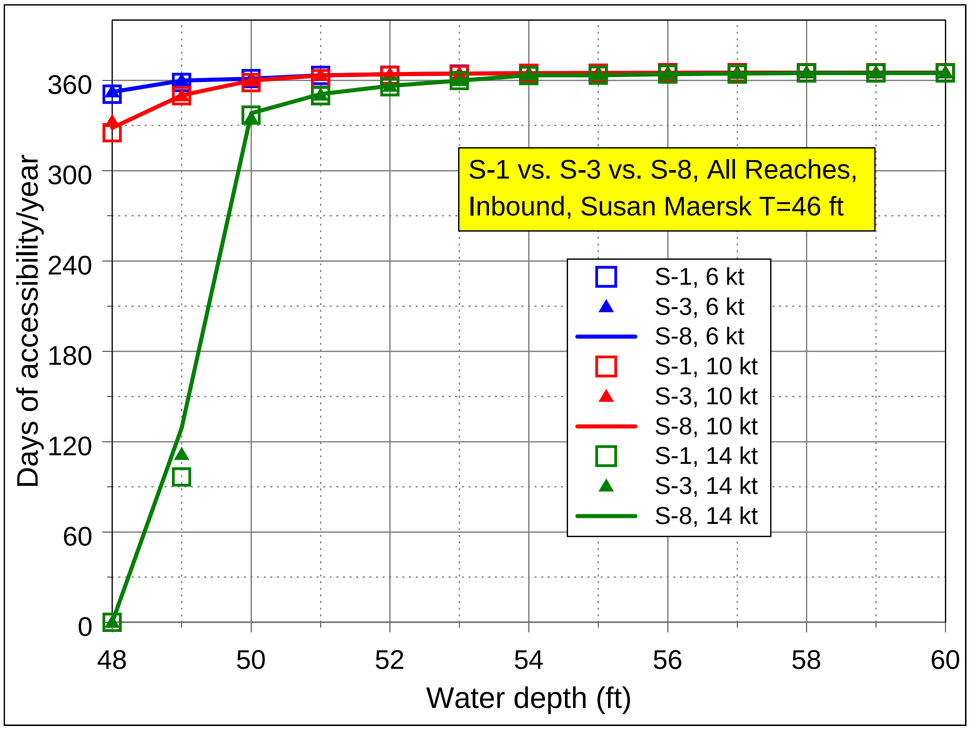
This section presents results for the light- and fully-loaded *Susan Maersk* for absolute water levels. These water levels represent a combined water depth that includes tides and/or future dredging. For instance, a depth of 52 ft represents either a dredged depth of 52 ft or a depth of 49 ft plus a tide level of +3 ft. The effect of the tides on the actual water depths is discussed later in this chapter.

6.1.1 Light-loaded conditions

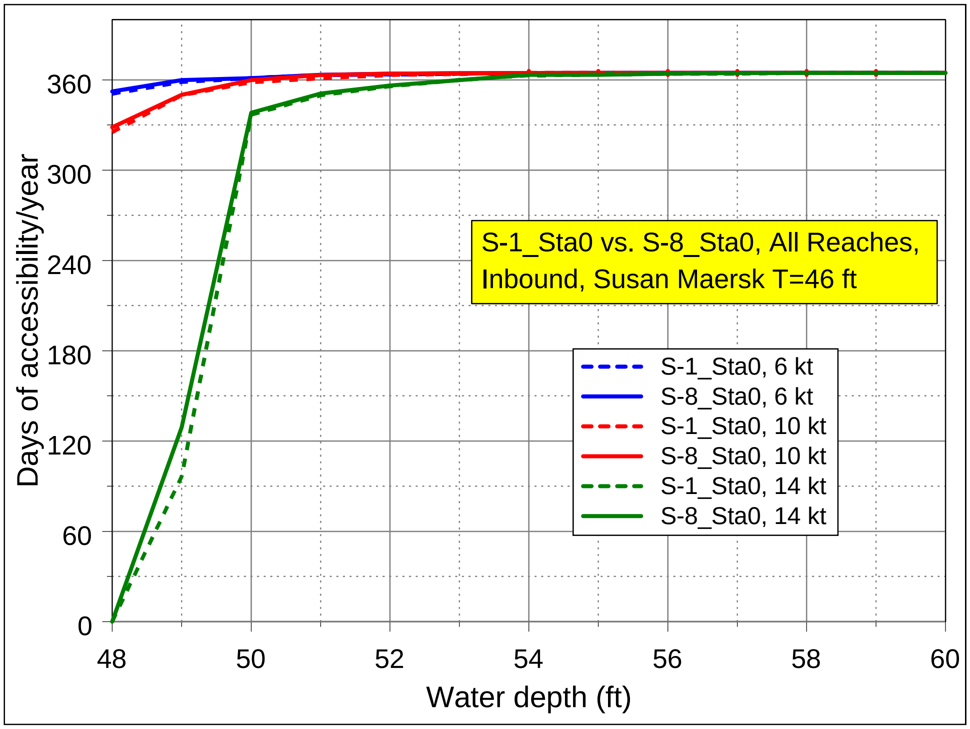
This section discusses the effects of inbound, outbound, and combined transit directions on days of accessibility for the light-loaded *Susan Maersk*. Appendix C contains tables with the days of accessibility for each of the channel option configurations. A comparison between Reach 1 and Reach 6 in the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

6.1.1.1 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.



a)



b)

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.

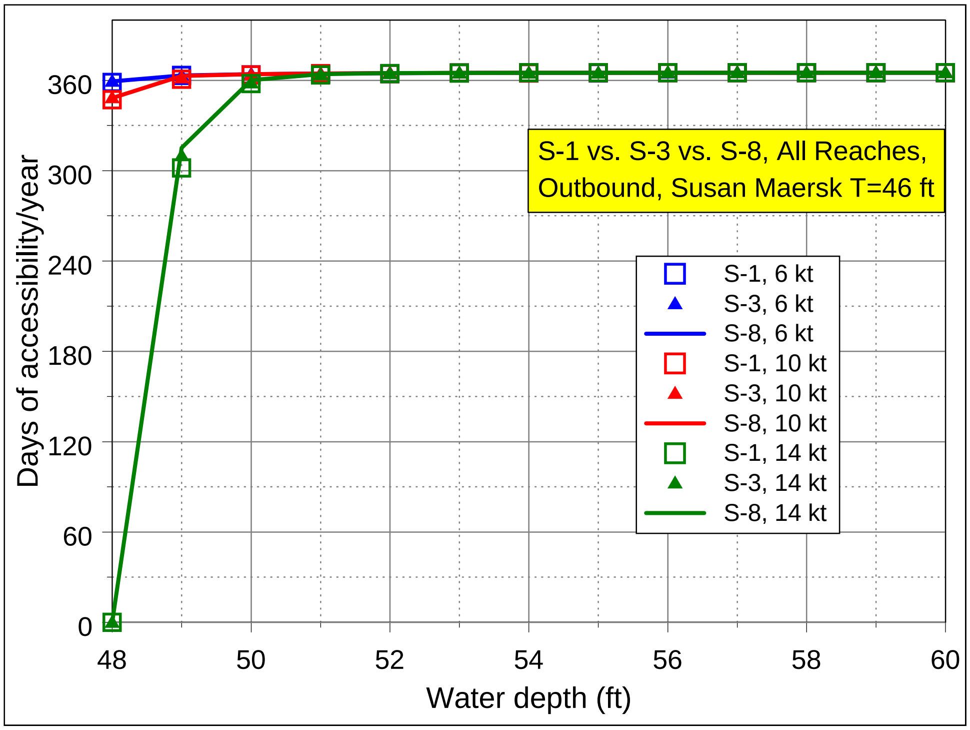
These plots represent the worst case combinations for all three reaches in a group for inbound transits. The left-most curves in these accessibility figures represent the best results since they indicate the most number of days of accessibility for the shallowest channel depth. In general, the slower 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.

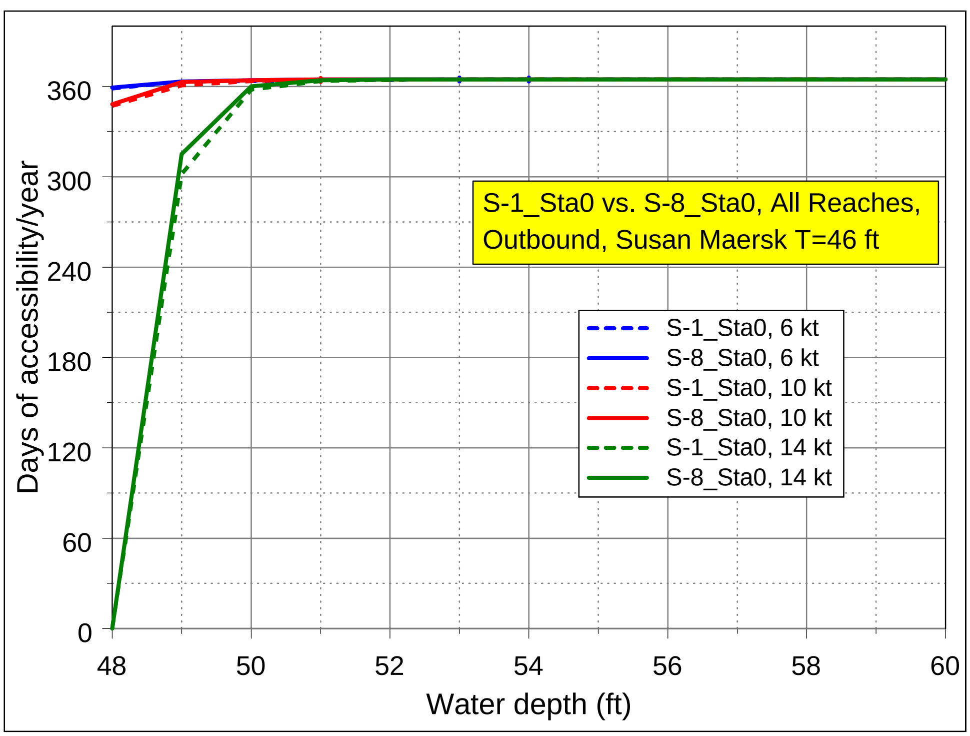
6.1.1.2 Outbound transits

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 of 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 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 are 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.



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.

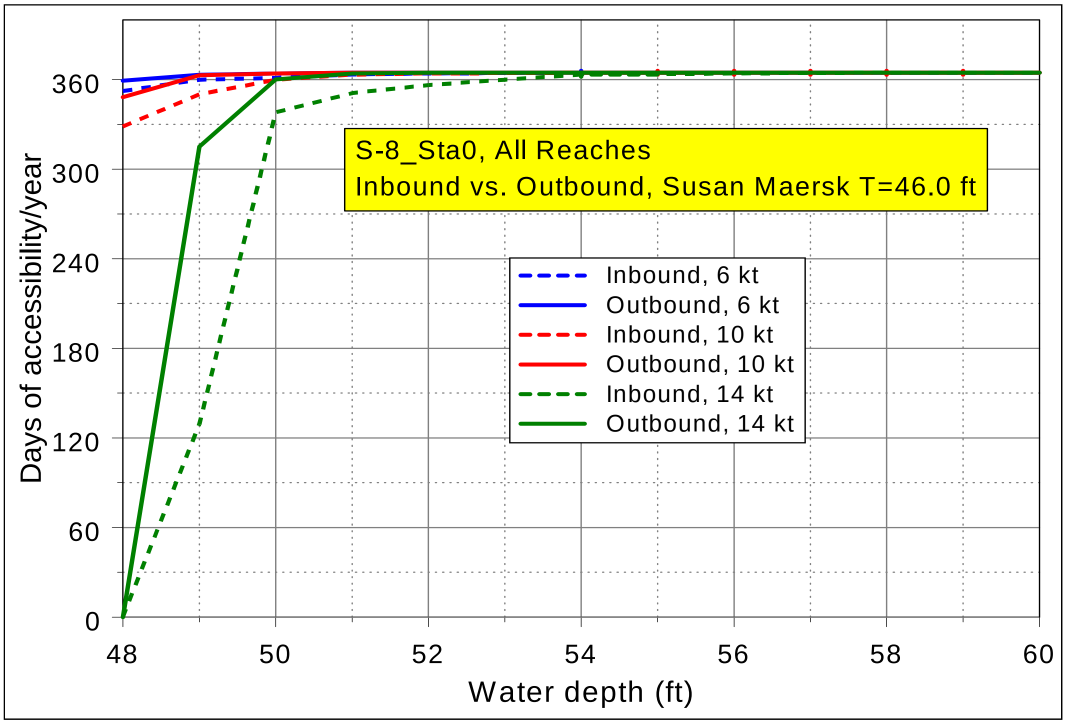


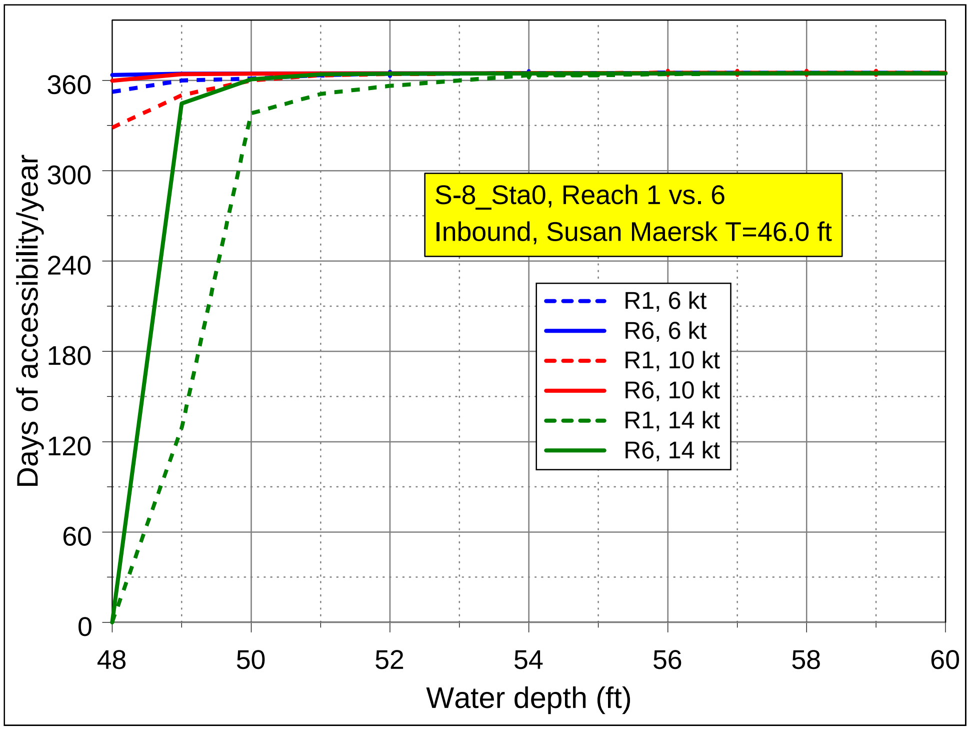
Figure 30. CADET predictions of days of accessibility for inbound vs. outbound light-loaded *Susan Maersk* as a function of channel depth and ship speed for all six reaches in S-8_Sta0 group.

6.1.1.3 Combined transits

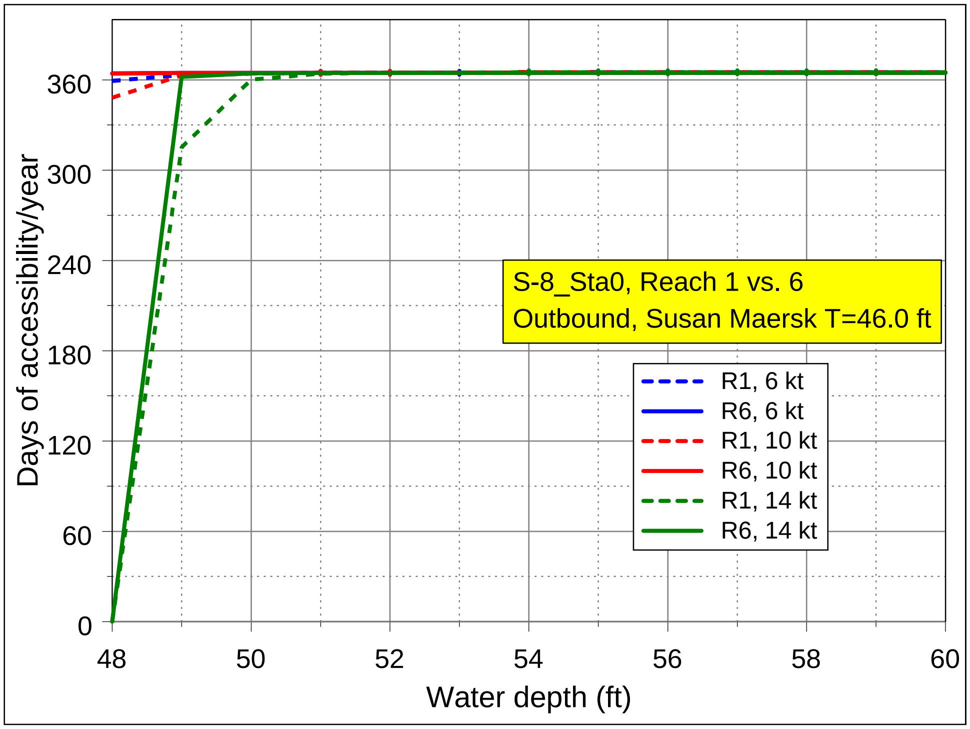
The combined transit results include the grouping of all results for inbound and outbound transits and all reaches in each channel option. Since the inbound transit presents the worst conditions for vertical ship motions, the combined transit cases are identical to the inbound results. Typically, these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

6.1.1.4 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.



a)



b)

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.

6.1.1.5 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

6.1.2 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.

6.1.2.1 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).

6.1.2.2 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).

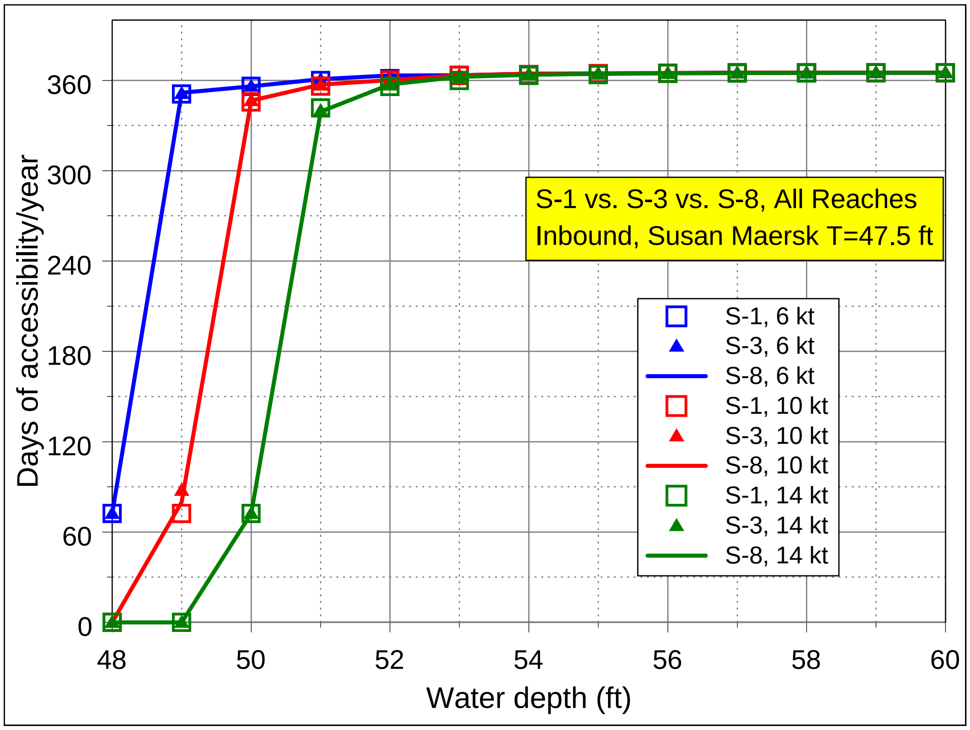
Figure 34 compares the inbound and outbound transits for the fully-loaded *Susan Maersk* for all six reaches in the S-8_Sta0 group. Again, these are the same values shown in Figures 32 and 33, but re-plotted to facilitate comparison of the effect of inbound and outbound transits on the days of accessibility. 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.

6.1.2.3 Combined transits

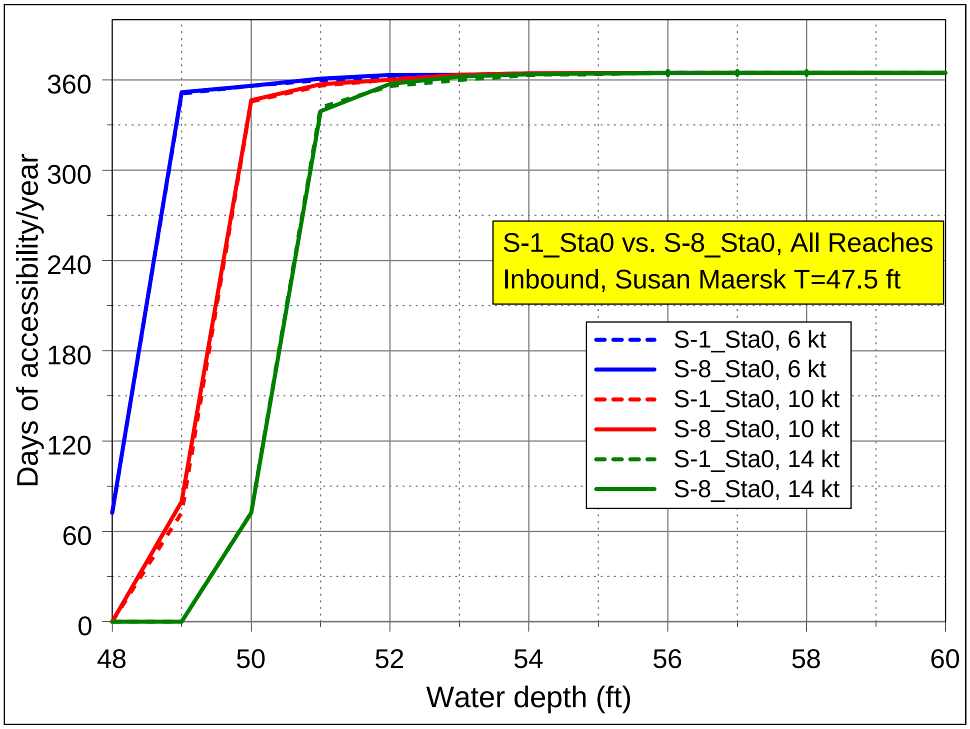
Again, the combined transits are not shown since they are equivalent to the inbound transits.

6.1.2.4 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 to 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.

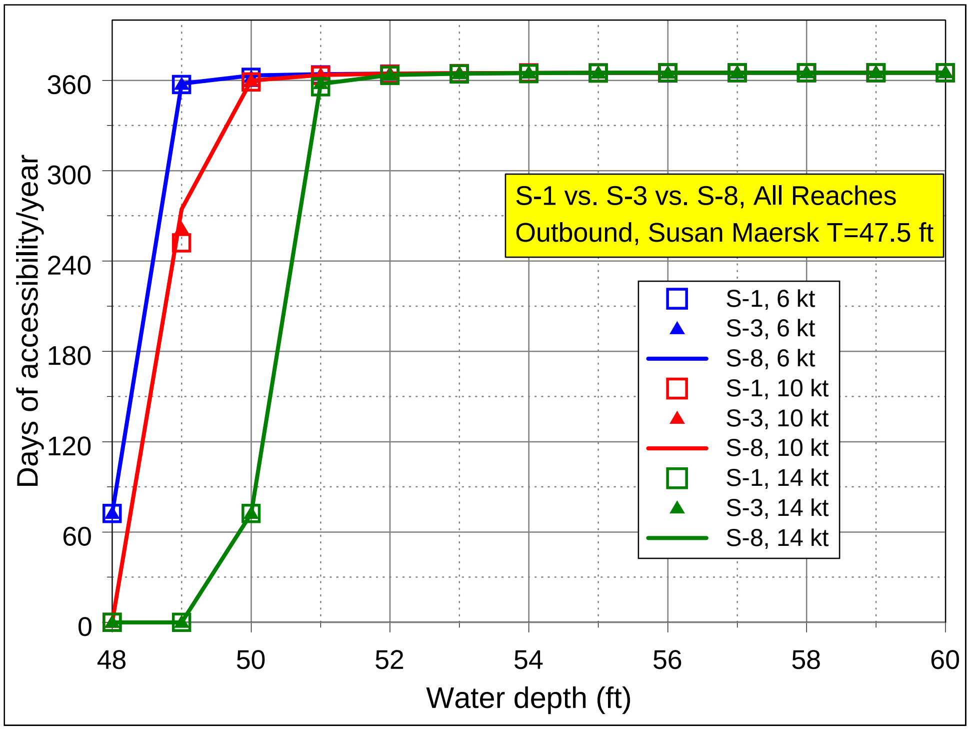


a)

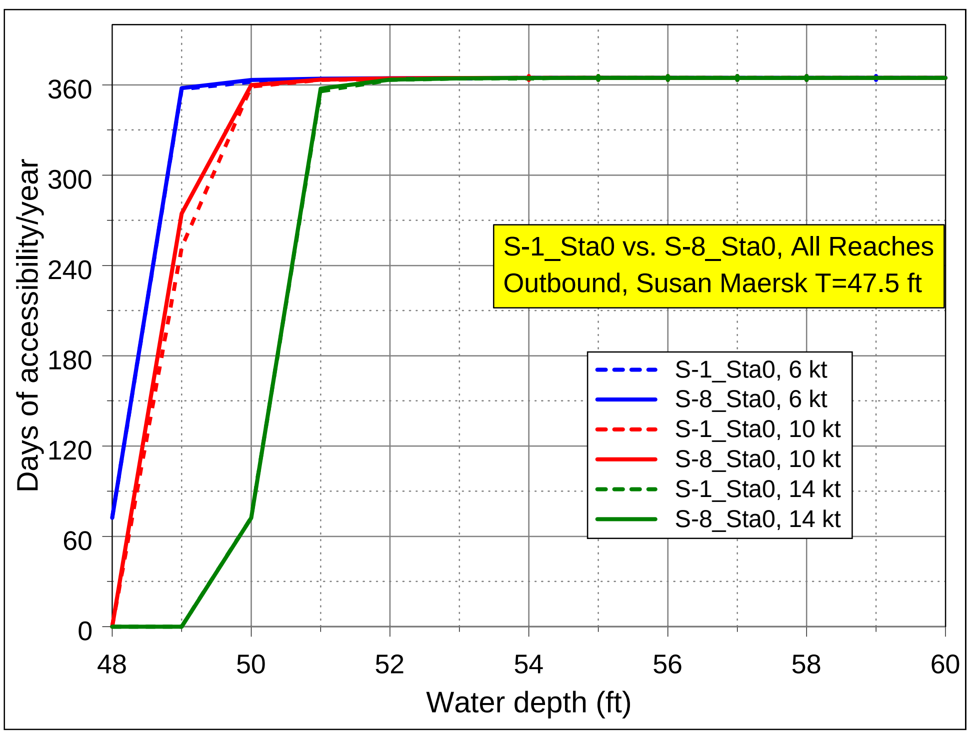


b)

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.

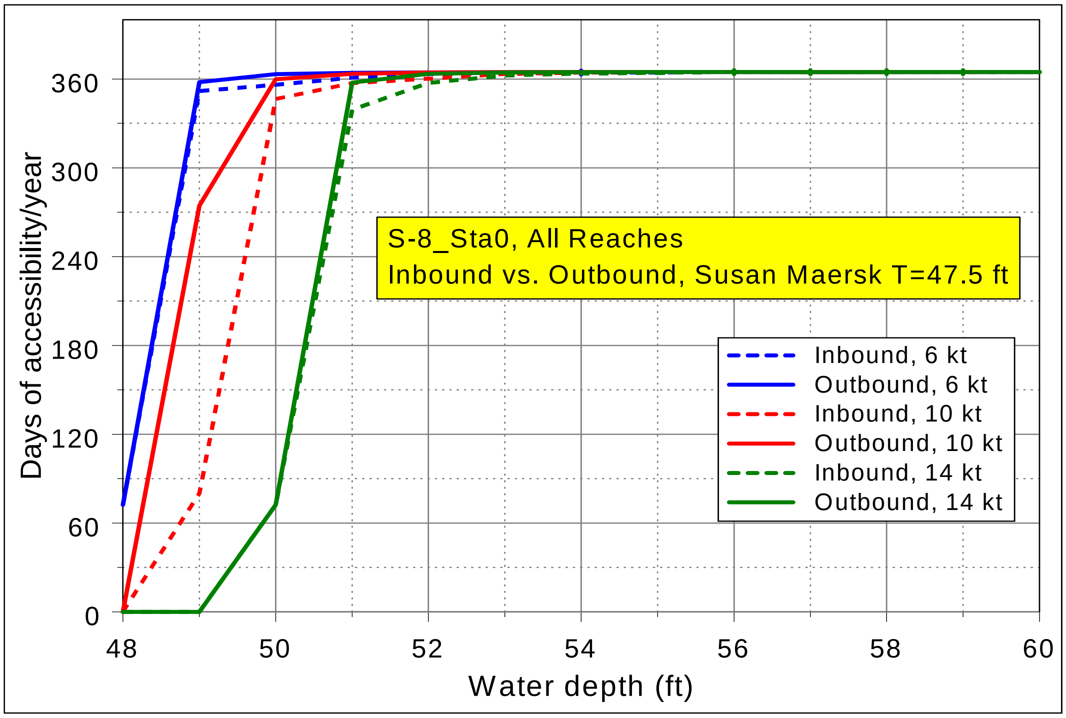


Figure 34. CADET predictions of days of accessibility for inbound vs. outbound fully-loaded *Susan Maersk* as a function of channel depth and ship speed for all six reaches in S-8_Sta0 group.

6.1.2.5 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.

6.1.3 Light- versus fully-loaded ship

To facilitate comparison between the light- and fully-loaded *Susan Maersk*, Figure 36 shows days of accessibility for inbound (Figure 36a) and outbound (Figure 36b) transits. These are the same data shown in previous figures, but re-plotted to facilitate comparisons between ship

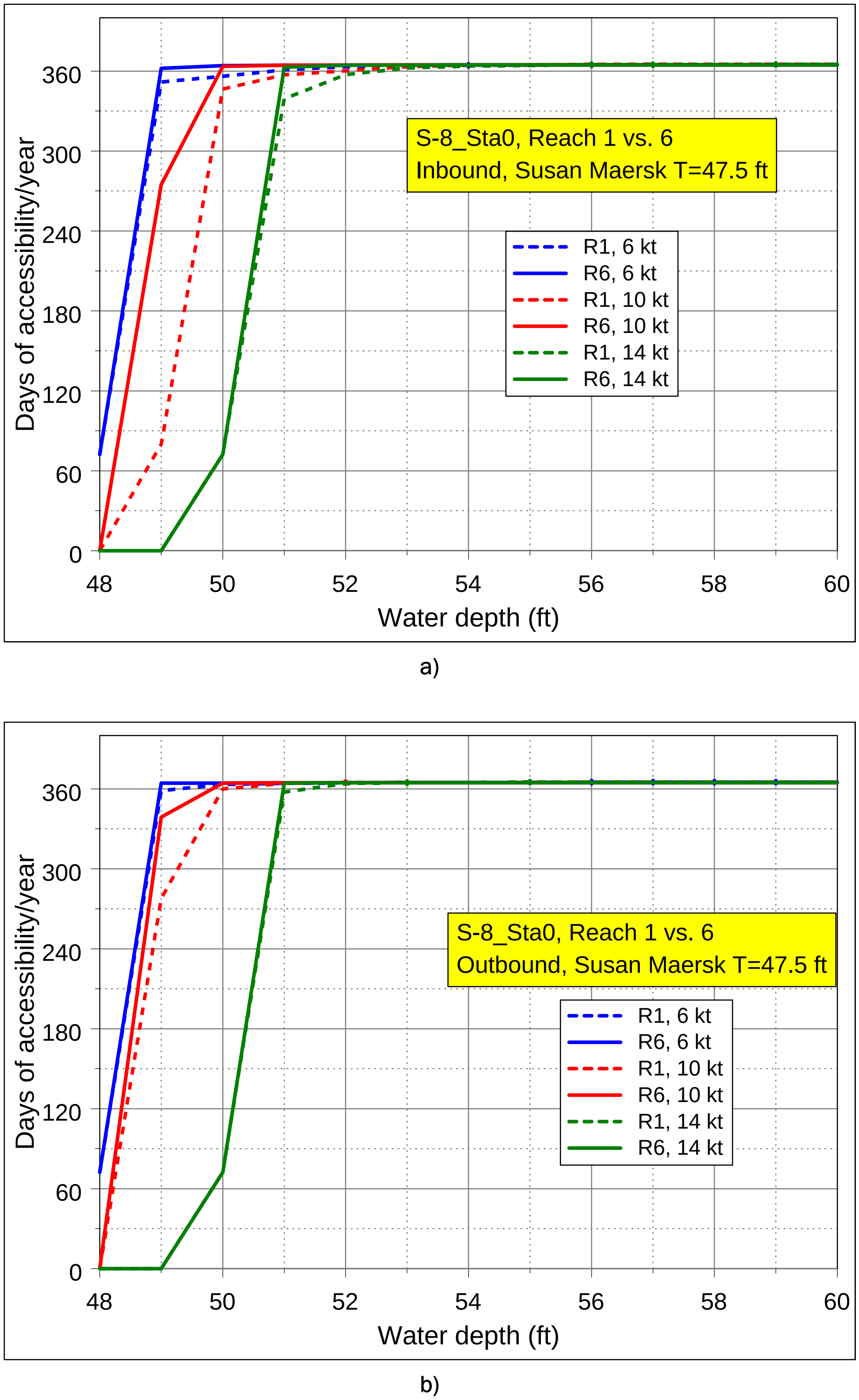
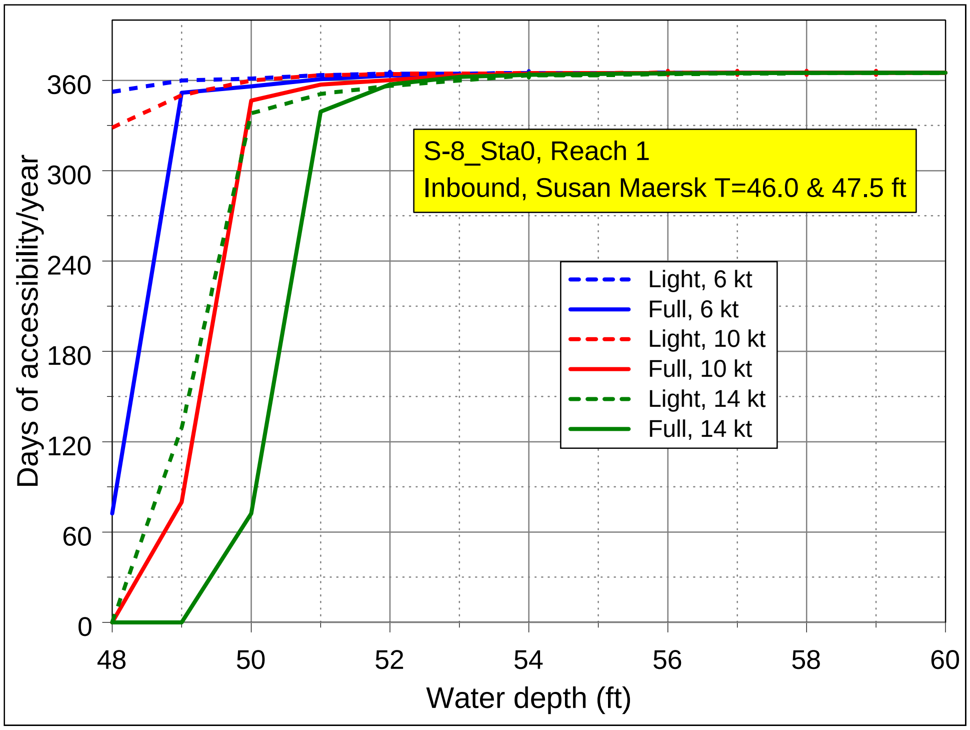
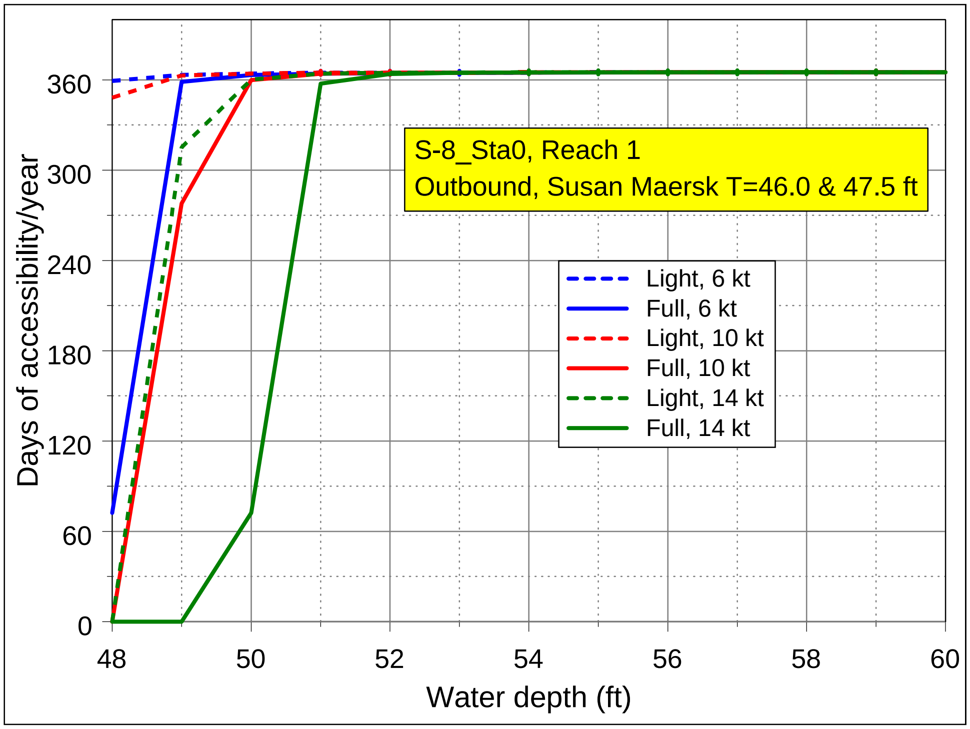


Figure 35. CADET predictions of days of accessibility in Reaches 1 (R1) and 6 (R6) in S-8_Sta0 for fully-loaded *Susan Maersk* as a function of channel depth and ship speed for (a) inbound and (b) outbound transits.



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.

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

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.

6.1.3.1 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 ft (+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.

6.2 Effect of tides

The output from the tide 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.

6.2.1.1 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.

	Distance		Ship speed (kt)		
Channel option	(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)

6.2.1.2 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

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

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.

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.

6.2.1.3 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 the tide to accommodate safe transits for light-loaded ships. Of course, the tides will provide additional safety margins.

6.2.1.4 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 accessibility 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 shows that the *Susan Maersk* would have approximately 360 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 360 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., 360 ≤ 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 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 Table C9, 338 days per year are predicted for in-bound 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 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 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. 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).

6.2.2 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).

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.

7.1 Wave-induced vertical ship motions

7.1.1 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.

7.1.1.1 Maximum ship displacements

Table 19 lists the maximum ship displacements that each water depth can accommodate safely 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.

7.1.1.2 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 Equation 4 and are output for each

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:

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

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 sec 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 sec and height of 8.9 ft. Both waves are from 112.5 deg, which is the most frequently occurring wave direction for Savannah.

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, so the maximum ship motions are limited to 4 ft at this depth.

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:

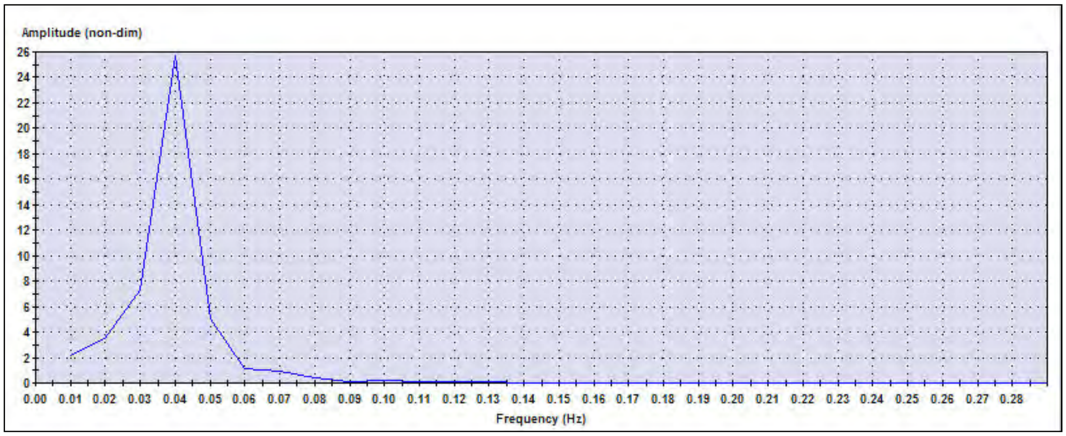
1. Gross UKC = 4.0 ft for h=50 ft.

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 and roll for different angles of rotation.

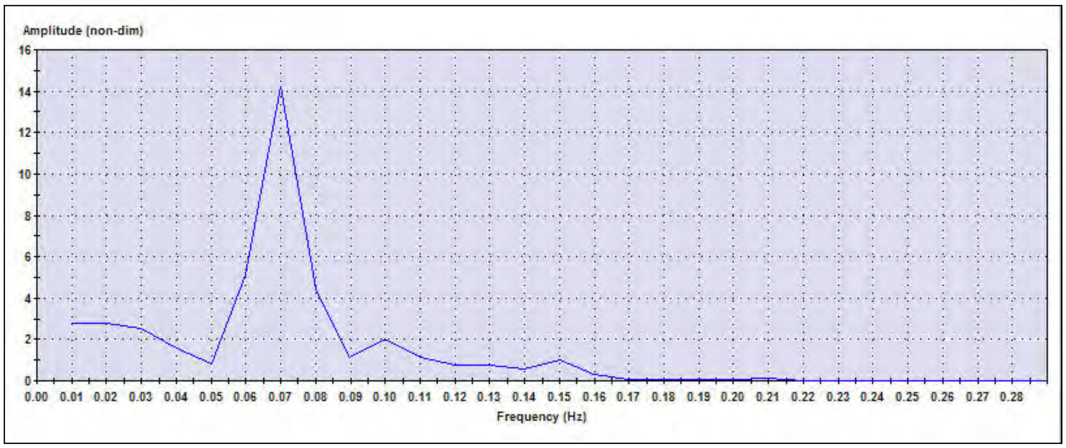
Table 21. Vertical ship motions due to pitch and roll.

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

Also, a wave with a 112.5 deg 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, especially roll. Figures 37a and 37b illustrate the roll RAO transfer function at a depth of



a)



b)

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.

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 sec 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.

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).

7.1.1.3 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.

7.1.2 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.

7.1.2.1 Maximum ship displacements

Table 23 lists the maximum ship displacements that each water depth can accommodate safely 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 shown again 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.

7.1.2.2 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

Table 22. Vertical motion allowance 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	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.

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:

1. Gross UKC=2.5, 4.5, and 6.5 ft for h=50, 52, and 54 ft, respectively.

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:

1. Gross UKC = 4.5 ft for h=52 ft.

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.

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 decrease monotonically 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.

7.1.2.3 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

7.2 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).

7.2.1 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.

7.2.1.1 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).

7.2.1.2 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

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.

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

Table 28. 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-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.

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.

7.2.1.3 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 sec, 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.

Table 29. 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

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.

7.2.2 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.

7.2.2.1 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.

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).

7.2.2.2 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 (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:

1. Gross UKC = 4.5 ft for h=52 ft.

7.2.2.3 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.

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 sec, 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.

Table 31. 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.

Table 32. 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

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.

The *Susan Maersk* was selected as the design ship for this study. It has a light-loaded draft of 46 ft and a fully-loaded draft of 47.5 ft. Of course, these drafts represent "worst" case scenario as ships rarely are loaded to their full design drafts due to differences in cargo density and scheduling. Also, traffic congestion and two-way traffic are not a factor for the Savannah channel as ships of this size are expected to call on this port on only a weekly basis.

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 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 predictions. The five PIANC empirical squat formulas included those of Barrass, Eryuzlu, Huuska, Römisch, and Yoshimura. The Ankudinov formula was used originally 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 (+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.

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 optimum depths are 50 (+1 ft) 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 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 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 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 7 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 1 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. Increasing the depth by 5 ft to 54 ft would provide 364 days per year accessibility, but only for 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 keel of the ship. CADET calculates these vertical motion allowances for each ship loading condition, channel reach, and water depth. The allowances are based on Equation 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 sec, 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 sec, 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 sec, 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

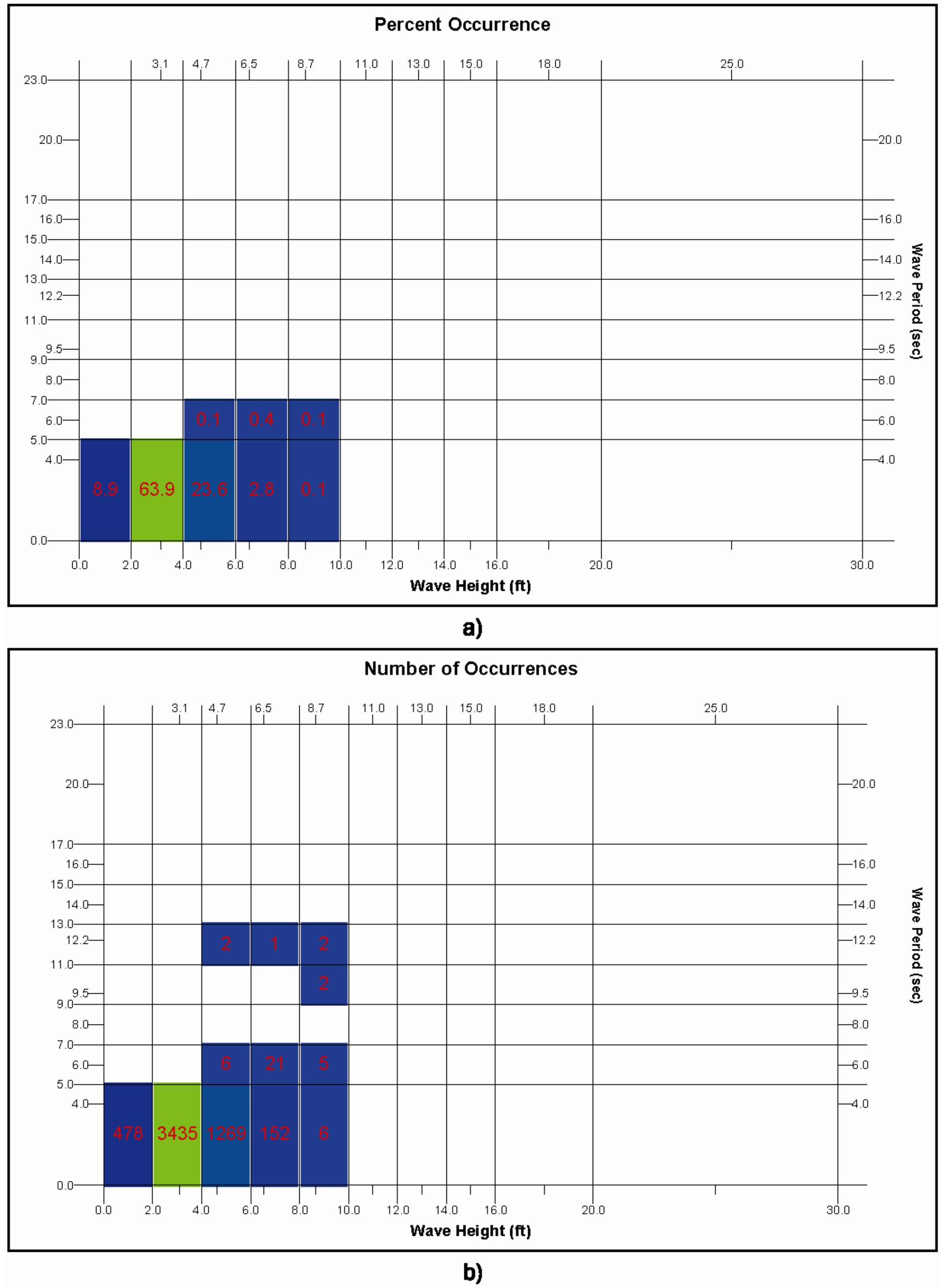
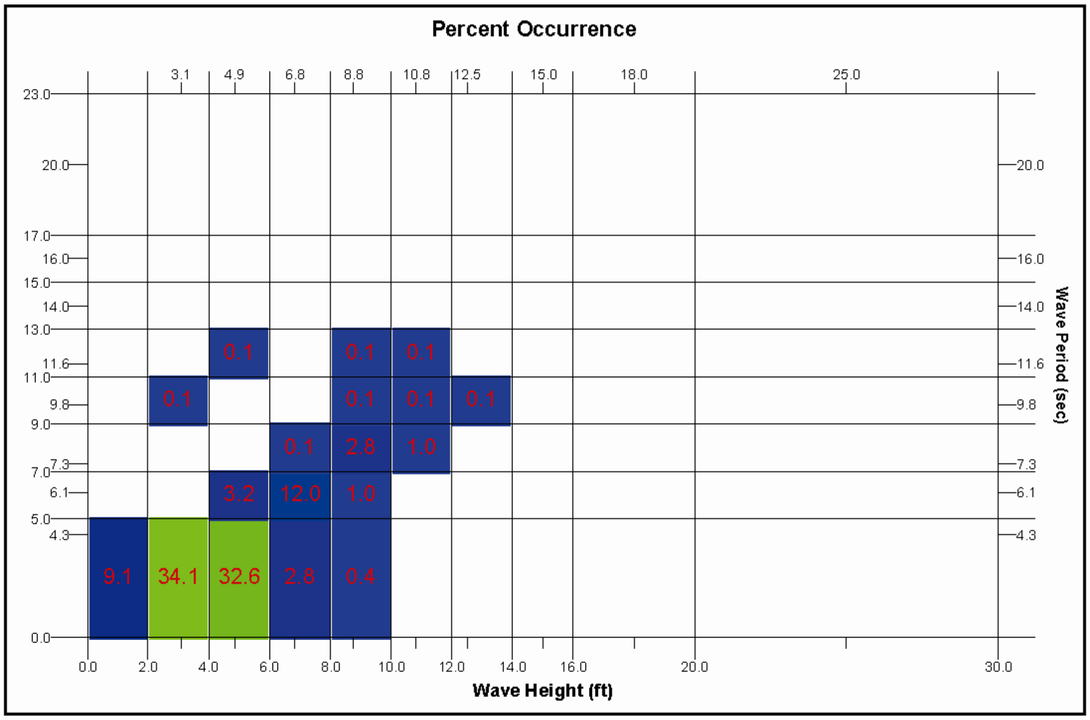
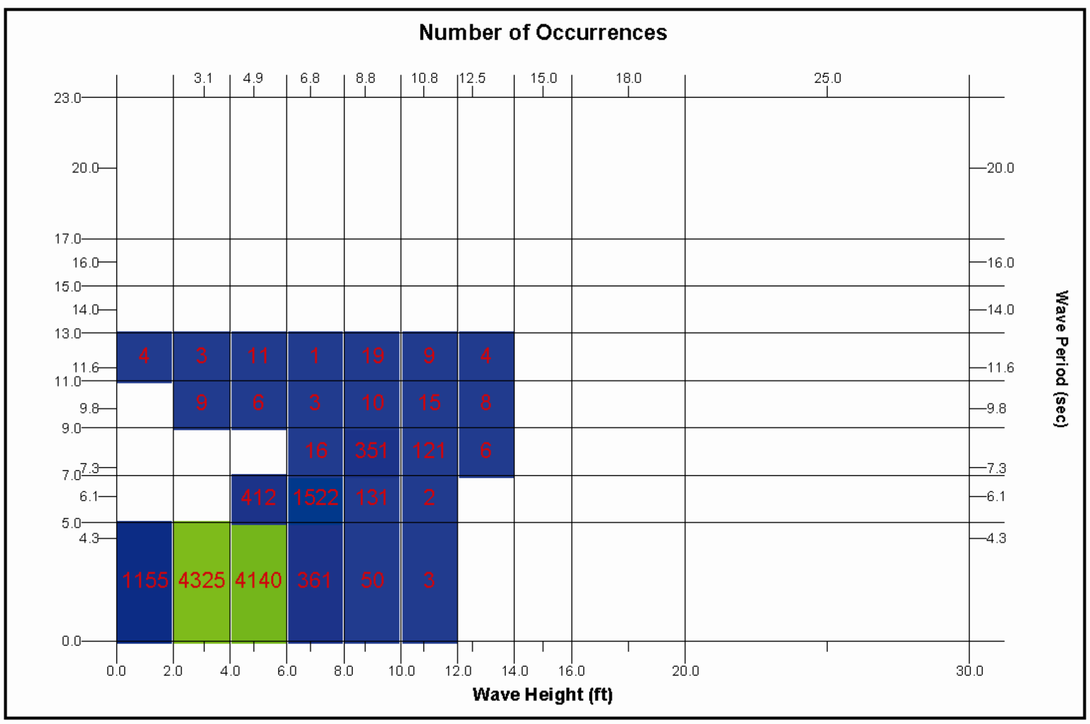


Figure A1. WIS370 T_p vs. H_s percent occurrence table for direction band centered at θ_p =22.5 deg (a) percent and (b) number of observations.



a)



b)

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

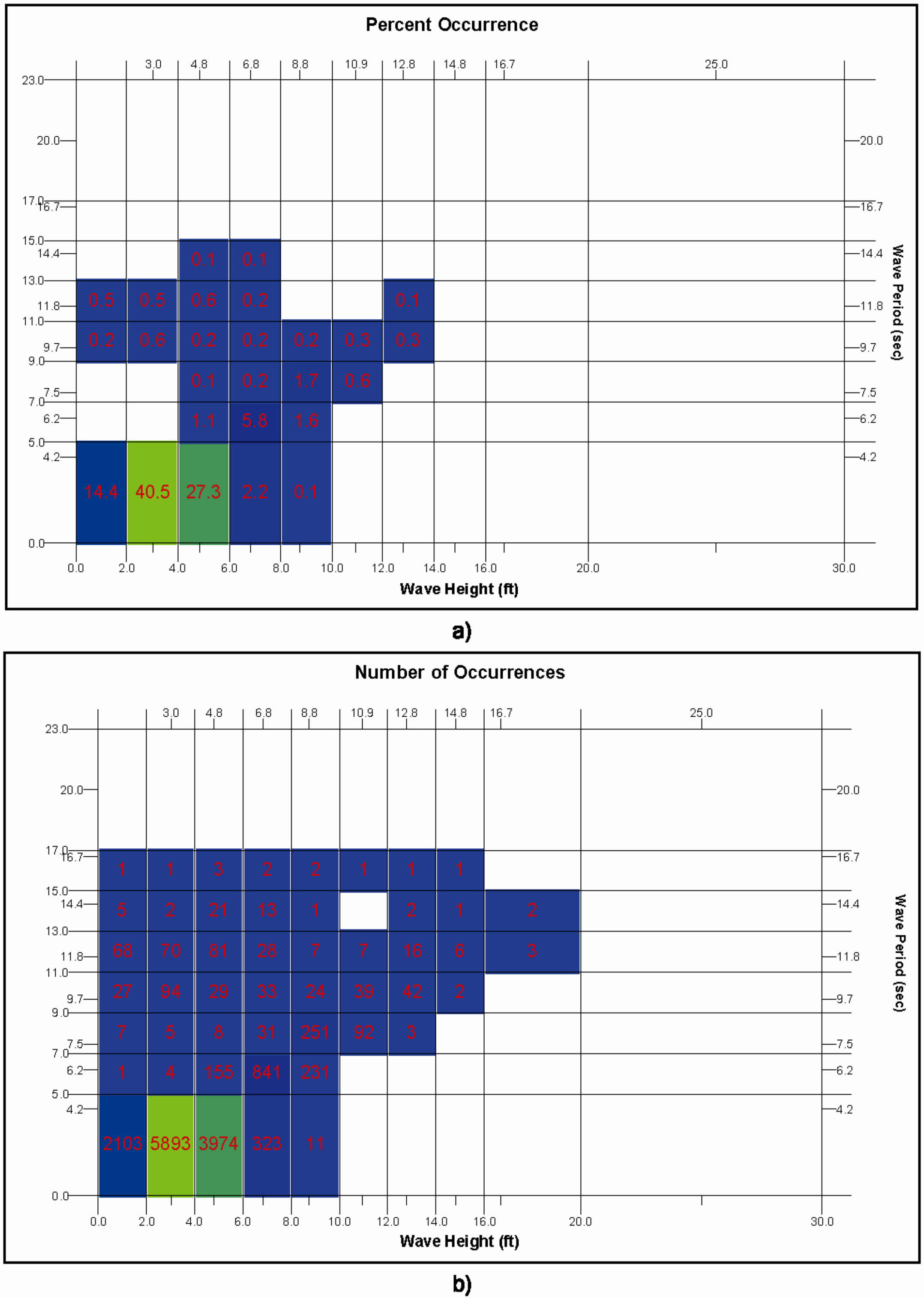
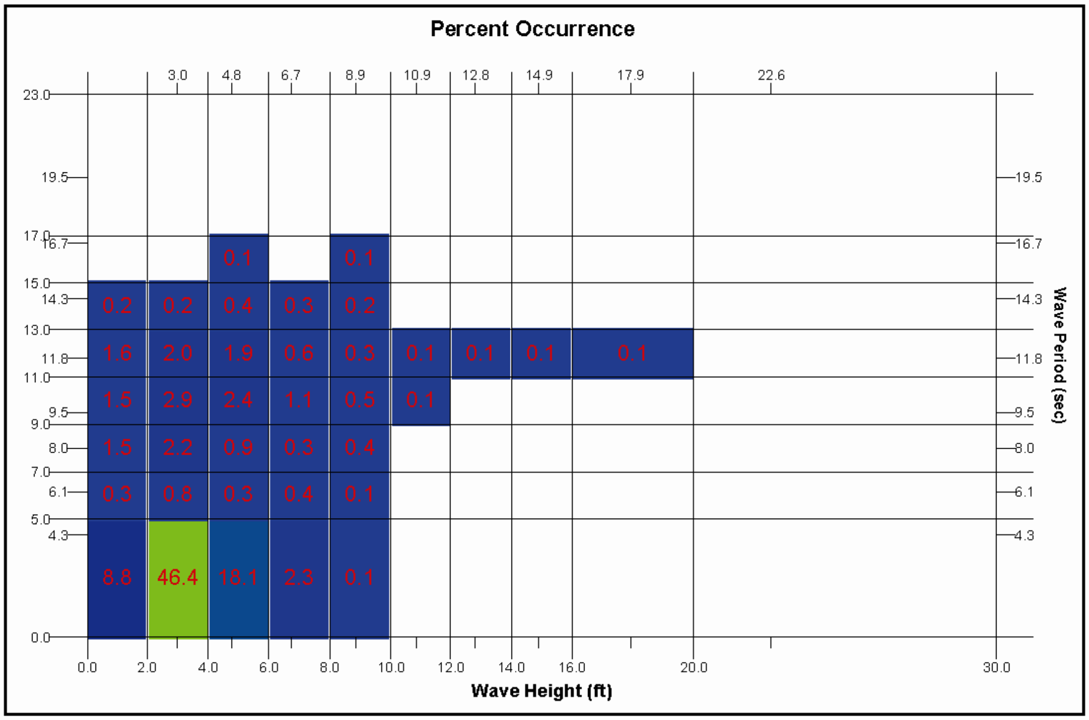
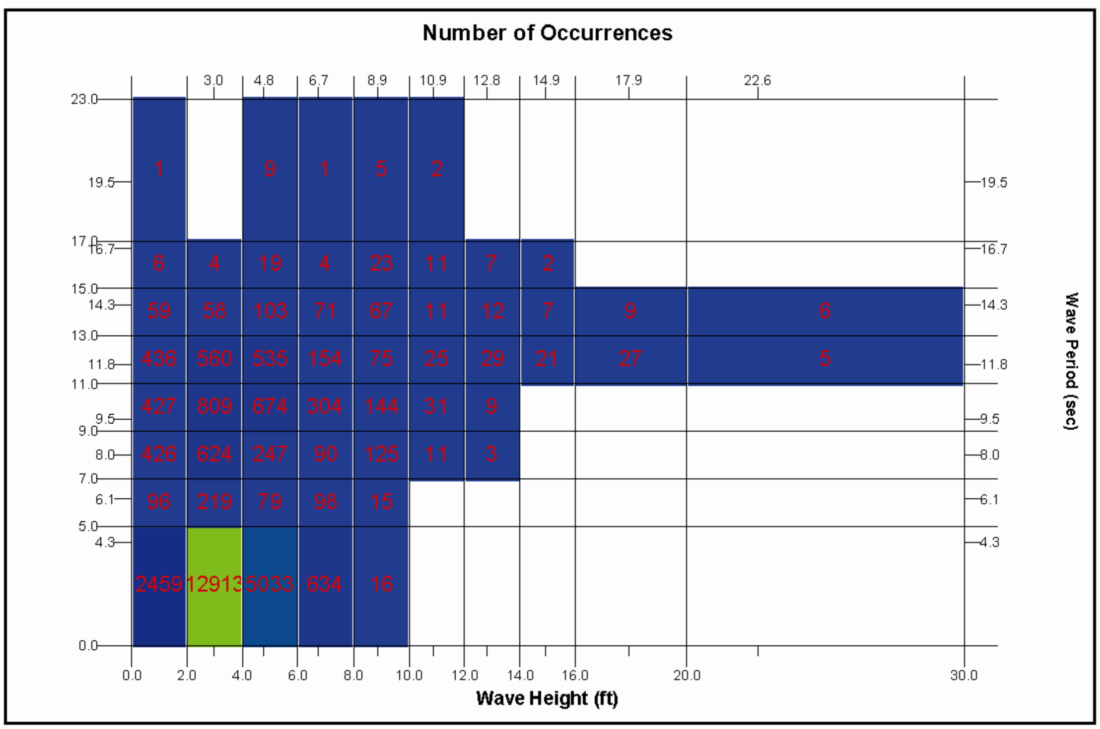


Figure A3. WIS370 T_p vs. H_s percent occurrence table for direction band centered at θ_p =67.5 deg (a) percent and (b) number of observations.

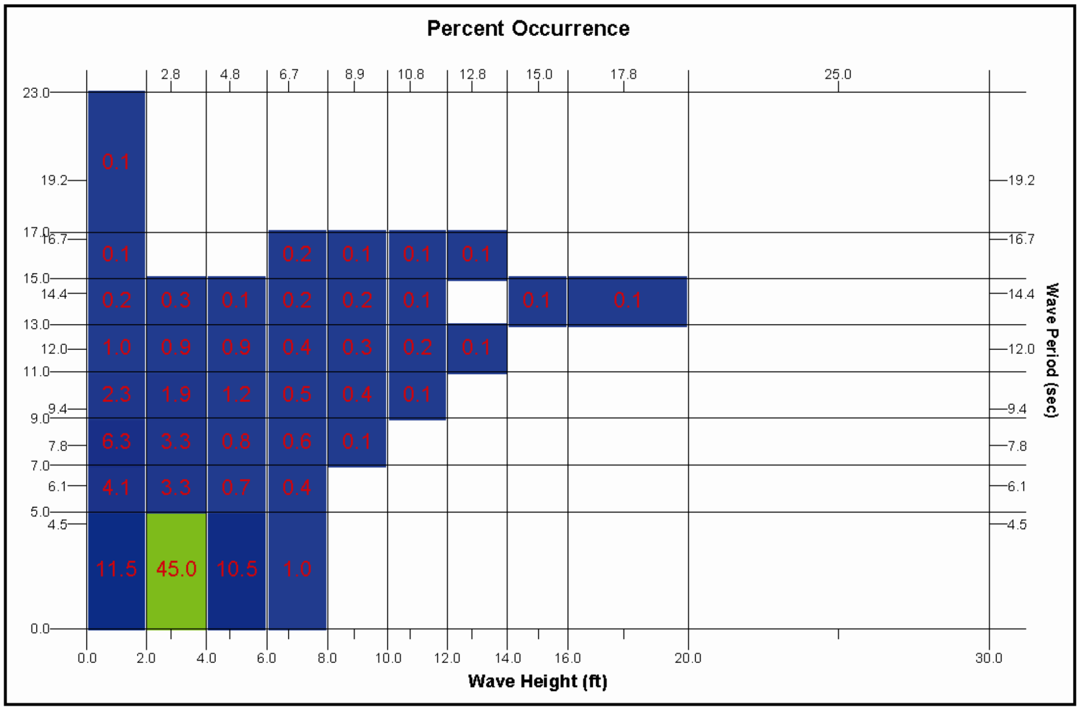


a)

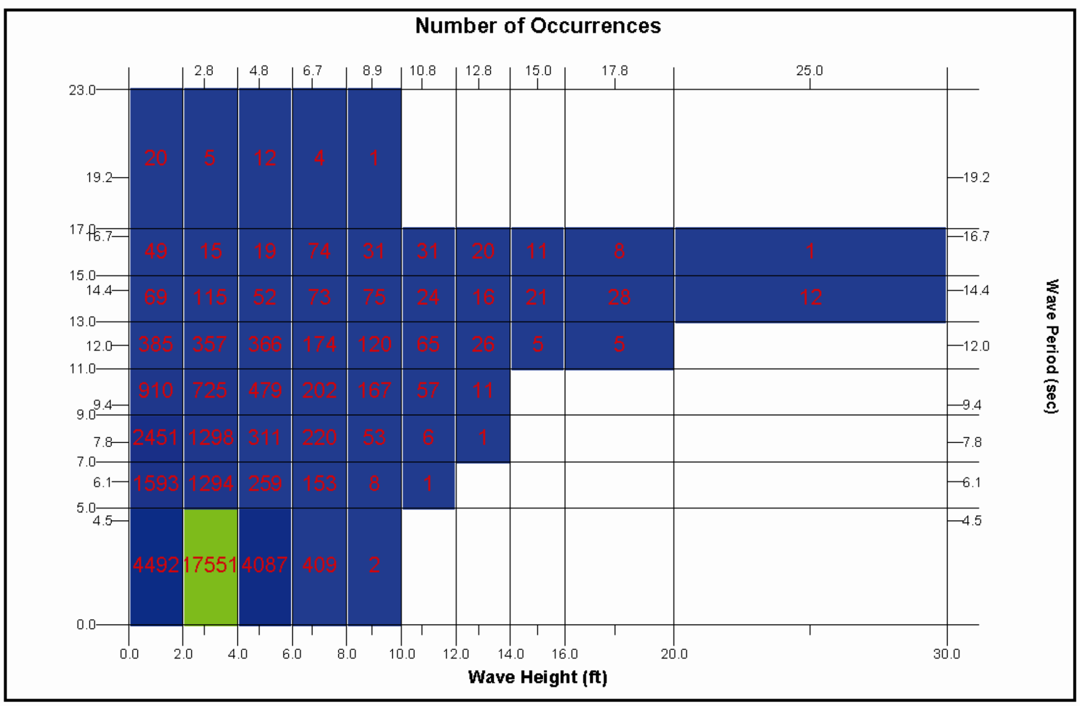


b)

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



a)



b)

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

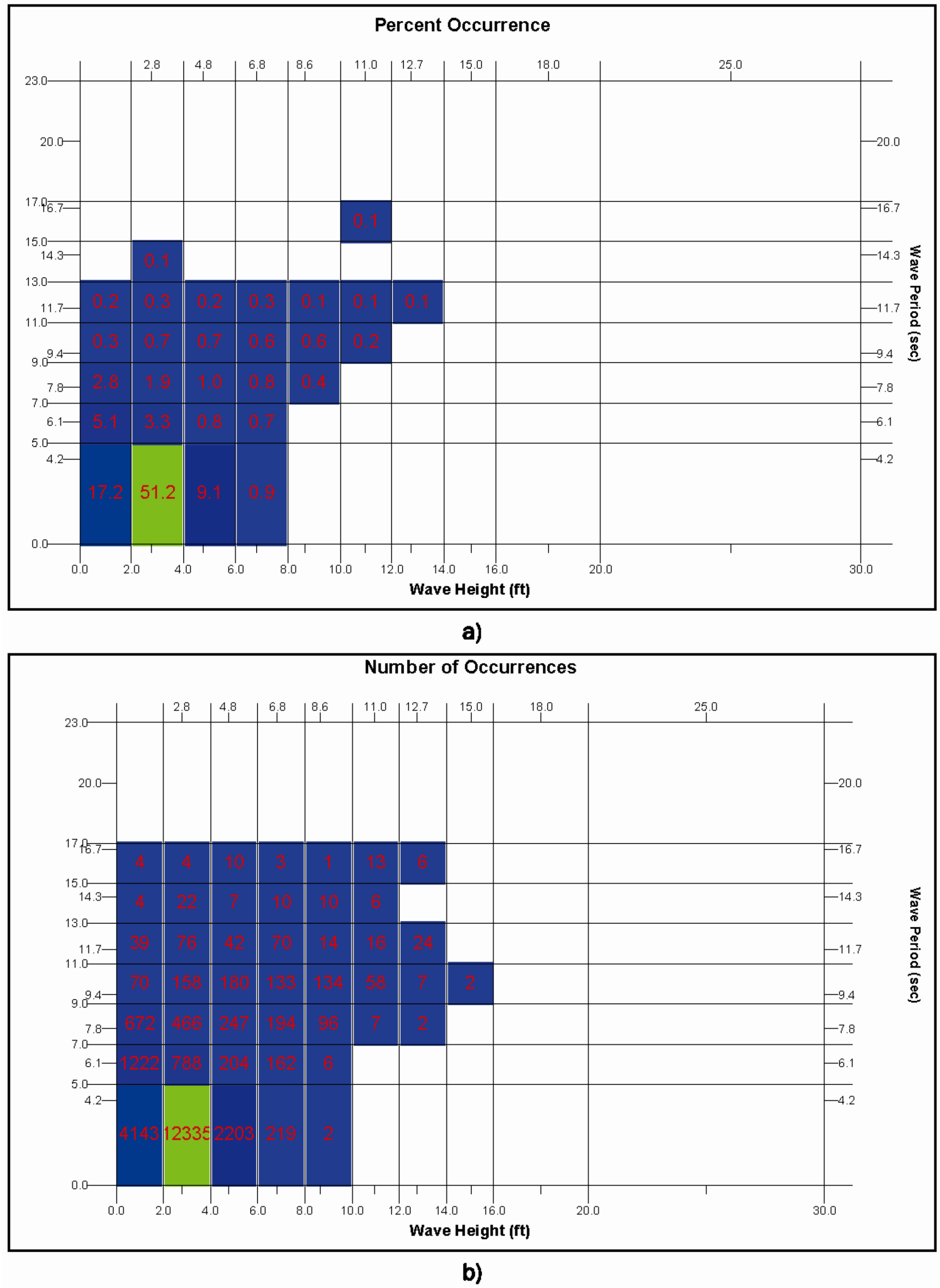
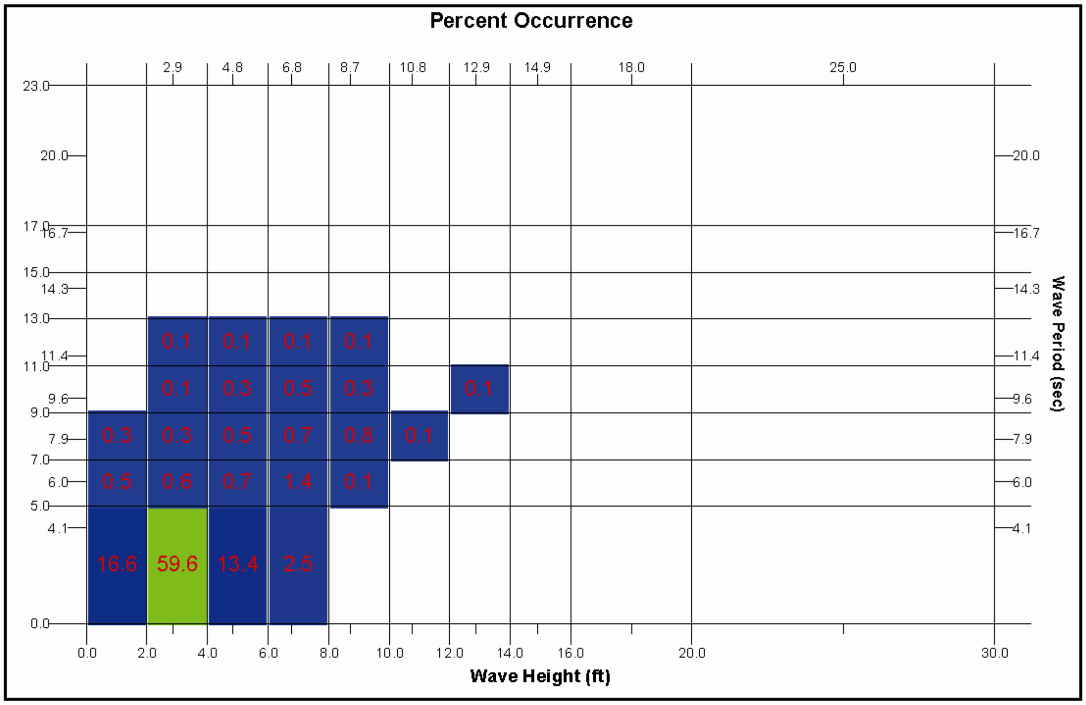
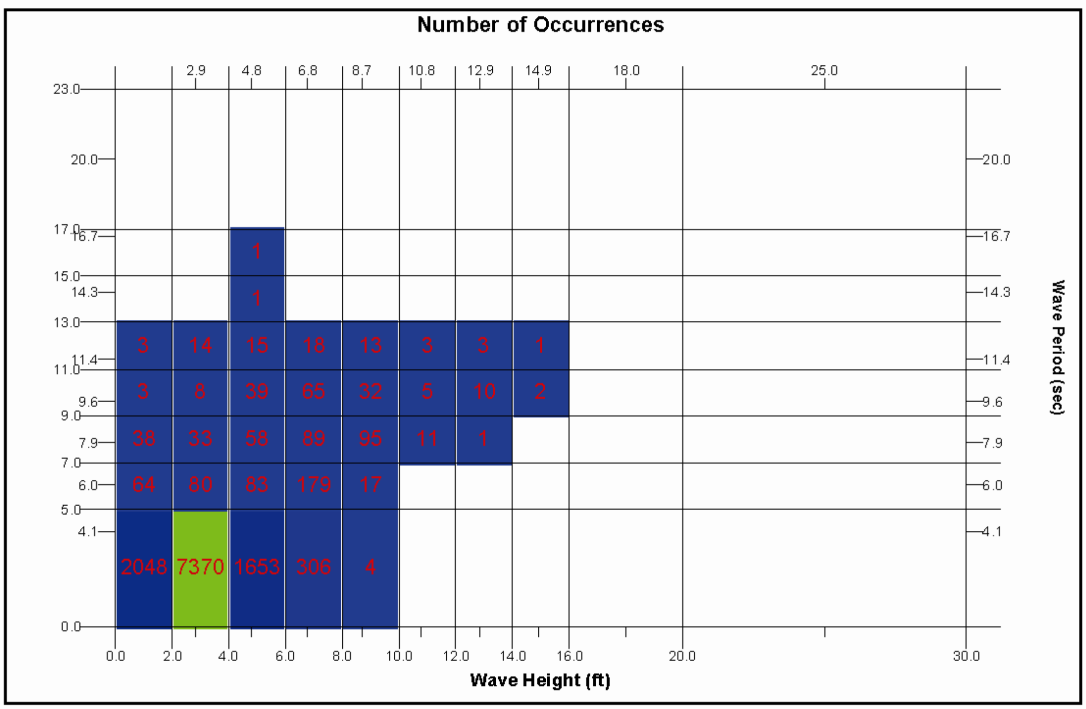


Figure A6. WIS370 T_p vs. H_s percent occurrence table for direction band centered at θ_p =135 deg (a) percent and (b) number of observations.



a)



b)

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

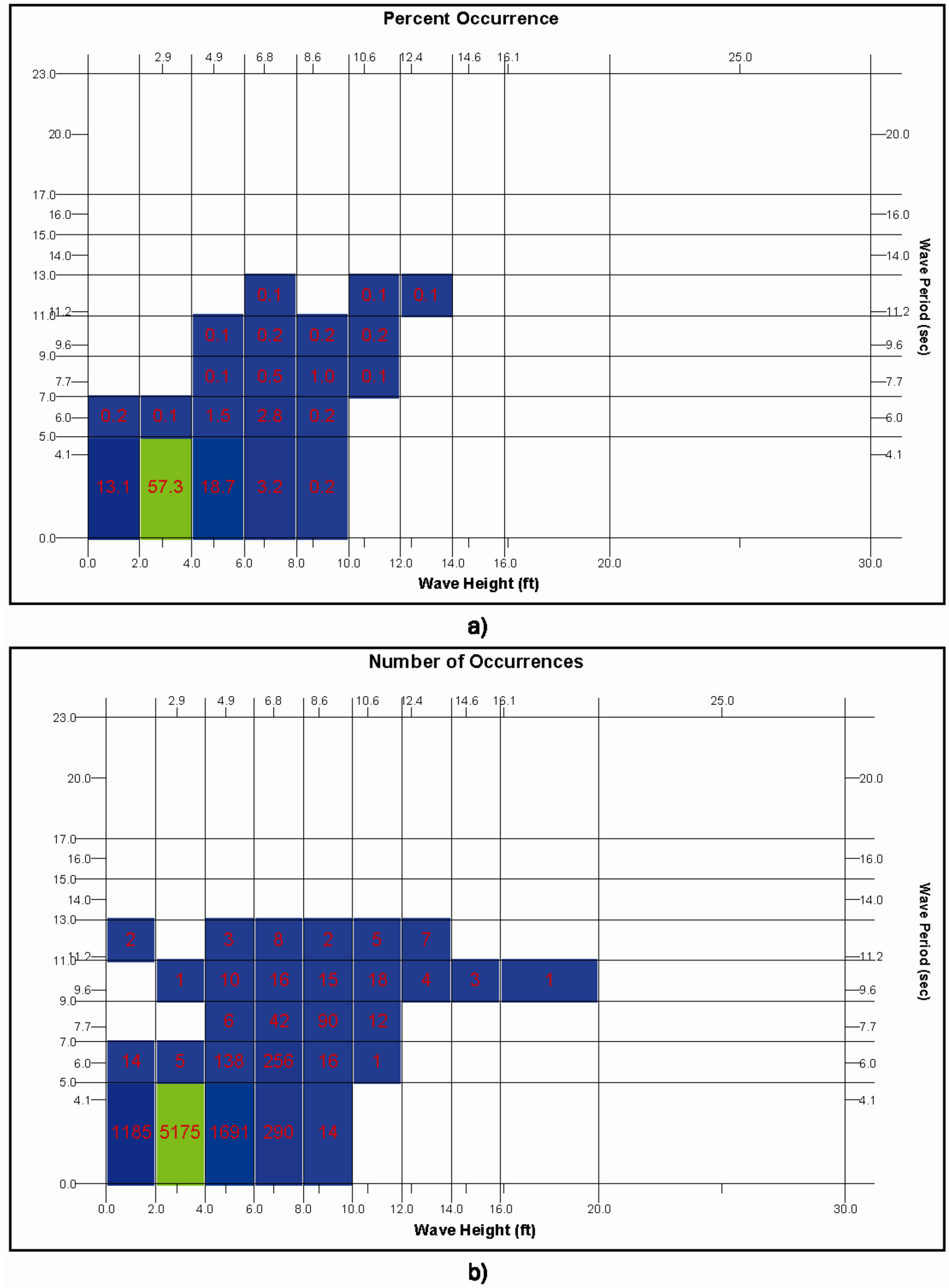


Figure A8. WIS370 T_p vs. H_s percent occurrence table for direction band centered at θ_p =180 deg (a) percent and (b) number of observations.

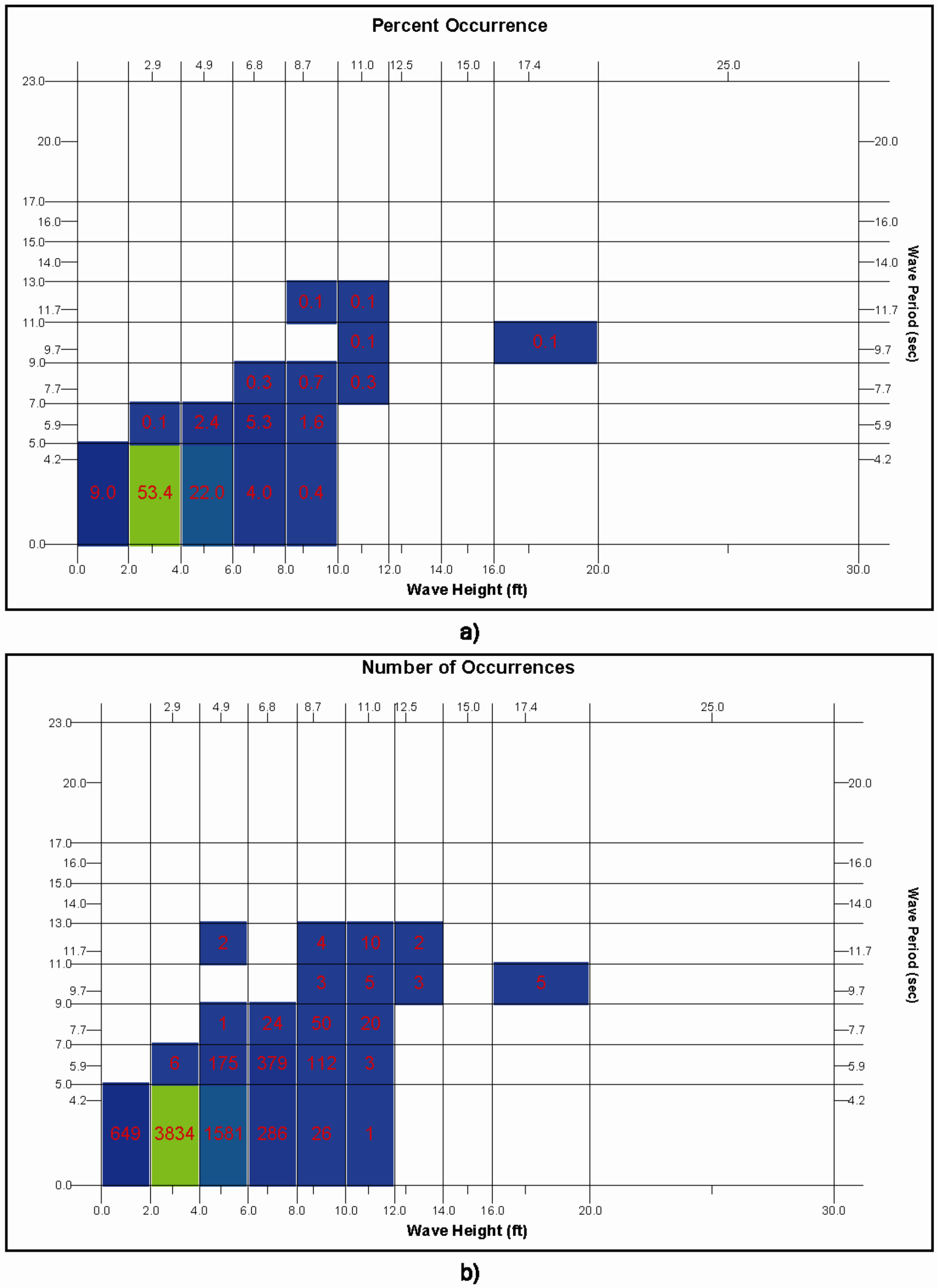
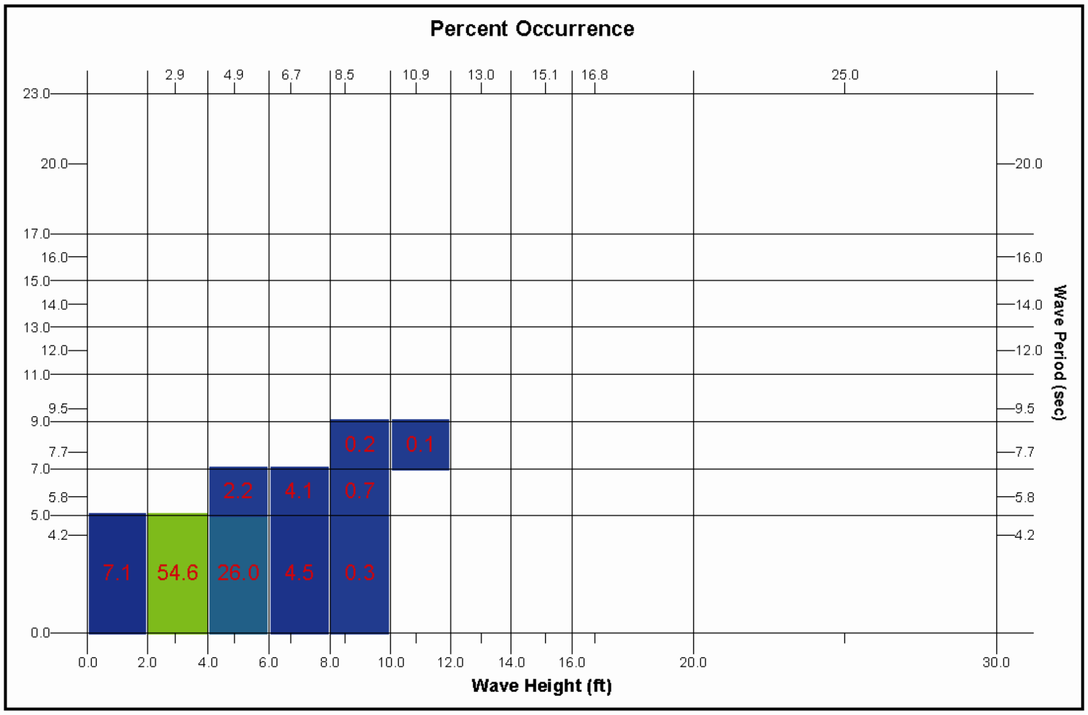
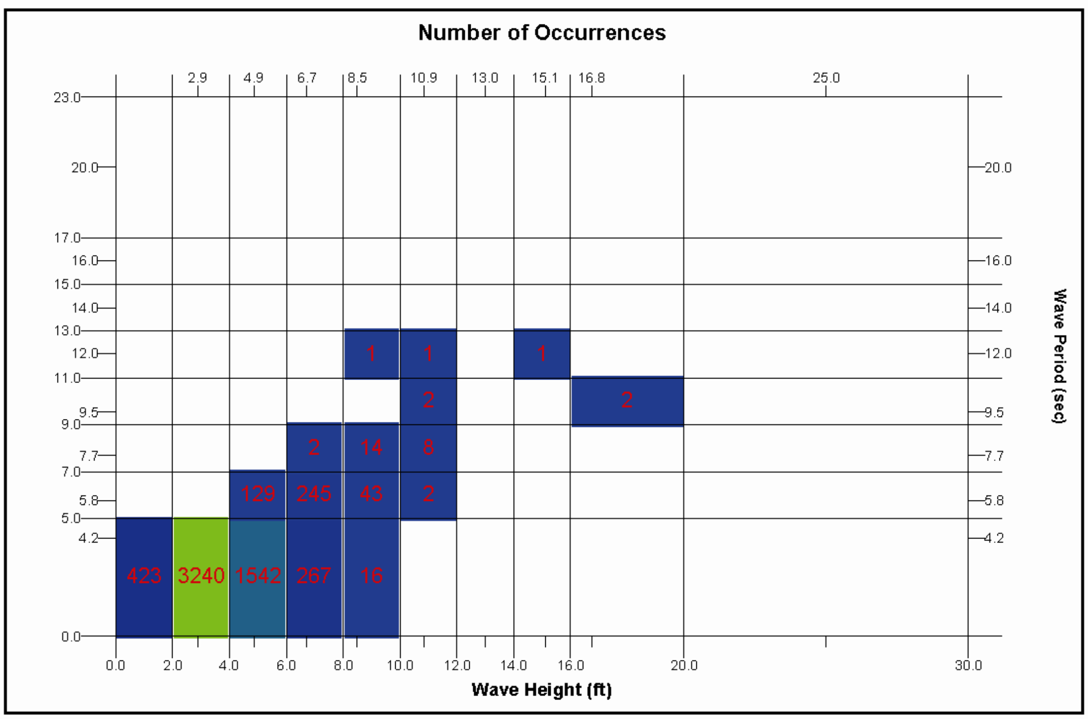


Figure A9. WIS370 T_p vs. H_s percent occurrence table for direction band centered at θ_p =202.5 deg (a) percent and (b) number of observations.



a)



b)

Figure A10. WIS370 T_p vs. H_s percent occurrence table for direction band centered at θ_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

ID	H_s (ft)	T_p (sec)	Direction (deg)	α	γ	n	Probability	Days/yr
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
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

ID	H_s (ft)	T_p (sec)	Direction (deg)	α	γ	n	Probability	Days/yr
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
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

ID	H_s (ft)	T_p (sec)	Direction (deg)	α	γ	n	Probability	Days/yr
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
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

ID	H_s (ft)	T_p (sec)	Direction (deg)	α	γ	n	Probability	Days/yr
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
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

ID	H_s (ft)	T_p (sec)	Direction (deg)	α	γ	n	Probability	Days/yr
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

ID	H_s (ft)	T_p (sec)	Direction (deg)	α	γ	n	Probability	Days/yr
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
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

ID	H_s (ft)	T_p (sec)	Direction (deg)	α	γ	n	Probability	Days/yr
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
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

ID	H_s (ft)	T_p (sec)	Direction (deg)	α	γ	n	Probability	Days/yr
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
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

ID	H_s (ft)	T_p (sec)	Direction (deg)	α	γ	n	Probability	Days/yr
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
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

ID	H_s (ft)	T_p (sec)	Direction (deg)	α	γ	n	Probability	Days/yr
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

ID	H_s (ft)	T_p (sec)	Direction (deg)	α	γ	n	Probability	Days/yr
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
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

ID	H_s (ft)	T_p (sec)	Direction (deg)	α	γ	n	Probability	Days/yr
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
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

Depth (ft)	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
	6	8	10	12	14	16	6	8	10	12	14	16
Reach R3: Tybee												
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

Depth (ft)	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
	6	8	10	12	14	16	6	8	10	12	14	16
Reach R3: Tybee												
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	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	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

Depth (ft)	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
	6	8	10	12	14	16	6	8	10	12	14	16
Reach R3: Tybee												
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 (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	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

Depth (ft)	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
	6	8	10	12	14	16	6	8	10	12	14	16
Reach R3: Tybee												
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

Depth (ft)	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
	6	8	10	12	14	16	6	8	10	12	14	16
Reach R3: Tybee												
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

Depth (ft)	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
	6	8	10	12	14	16	6	8	10	12	14	16
Reach R3: Tybee												
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 (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

Depth (ft)	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
	6	8	10	12	14	16	6	8	10	12	14	16
Reach R3: Tybee												
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

Depth (ft)	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
	6	8	10	12	14	16	6	8	10	12	14	16
50	364	364	364	363	354	319	365	365	365	365	365	348
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

Depth (ft)	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
	6	8	10	12	14	16	6	8	10	12	14	16
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 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

Depth (ft)	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
	6	8	10	12	14	16	6	8	10	12	14	16
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												
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

Depth (ft)	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
	6	8	10	12	14	16	6	8	10	12	14	16
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
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

Depth (ft)	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
	6	8	10	12	14	16	6	8	10	12	14	16
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
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 (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

Depth (ft)	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
	6	8	10	12	14	16	6	8	10	12	14	16
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												
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

Depth (ft)	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
	6	8	10	12	14	16	6	8	10	12	14	16
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
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

Depth (ft)	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
	6	8	10	12	14	16	6	8	10	12	14	16
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
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	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	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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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		Inbound Ship speed (kt)						Outbound Ship speed (kt)					
ID	Days/yr	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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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		Inbound Ship speed (kt)						Outbound Ship speed (kt)					
ID	Days/yr	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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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		Inbound Ship speed (kt)						Outbound Ship speed (kt)					
ID	Days/yr	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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave		Inbound Ship speed (kt)						Outbound Ship speed (kt)					
ID	Days/yr	6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave		Inbound Ship speed (kt)						Outbound Ship speed (kt)					
ID	Days/yr	6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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

Wave ID	Days/yr	Inbound Ship speed (kt)						Outbound Ship speed (kt)					
		6	8	10	12	14	16	6	8	10	12	14	16
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
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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14. ABSTRACT

The Savannah District (SAS) is preparing a Final Engineering Appendix for the Savannah Harbor Expansion project. Initial vertical motion studies addressed extension of the entrance channel to deeper water along the existing alignment. After initial channel design, shallower offshore shoals were identified that could influence the safety and efficiency of navigation on the proposed channel alignment. 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 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.

15. SUBJECT TERMS

CADET model	Deep draft channel design	Ship squat
Containerships	Design ship	Underkeel clearance
	Numerical models	Vertical ship motions

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