Appendix M

Propeller Scour Study

Note: The Section 508 amendment of the Rehabilitation Act of 1973 requires that the information in Federal documents be accessible to individuals with disabilities. The USACE has made every effort to ensure that the information in this appendix is accessible. However, this appendix is not fully compliant with Section 508, and readers with disabilities are encouraged to contact Mr. Jayson Hudson at the USACE at (409) 766-3108 or at SWG201900067@usace.army.mil if they would like access to the information.

Port Corpus Christi Access Channel

Propeller Scour Study

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Port Corpus Christi Access Channel

Propeller Scour Study

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Revision	Date	Status	Comments	Prepared	Reviewed	Approved
A	05/10/2021	Draft	Issued for Client Comments	PJJ	SBV	LAW

Executive Summary

Freese and Nichols, Inc. (FNI) has engaged W.F. Baird & Associates Ltd. to provide coastal engineering and modeling services for the Corpus Christi Channel Deepening project. The project will comprise deepening of the Outer and Approach Channels to 77 ft, and the Jetty Channel and seaward-most portion of the Corpus Christi Ship Channel to 75 ft. The channel will be used by vessels including laden VLCC's at a maximum draft of 68 ft departing from the planned Axis and Harbor Island terminals. A propeller scour assessment as described in this Report was part of these studies developed for the purposes of assessing project adequacy for the Environmental Impact Statement. The study included navigation simulation assessment, model calibration to analytical methods, modeling of the propeller wash, and determination of scour potential.

The maneuvers modelled were based on simplifying assumptions of vessel position and time, which were developed from the navigation simulations for both Axis and Harbor Island terminals and validated with the Aransas Corpus Christi Pilots. From the numerical modelling results the following maneuvers were determined to be the most concerning for propeller induced scour:

- Laden VLCC's directing their wash towards the shoreline, structures, or slopes.
- Tugs that are close to the shoreline for an extended period of time.

The maximum scour potential was determined for each of the six simulations and their potential to influence structures was also commented on. These results are summarized as:

- Area 2 resulted in a maximum scour potential of 14.45 mm (0.57 in) and is unlikely to cause scour issues along the revetment at the shoreline.
- Area 3a (Tug) resulted in a maximum scour potential of 747.78 mm (2.45 ft) and may be a concern for slope stability and undermining of the wall located on the shoreline.
- Area 3b (VLCC) resulted in a maximum scour potential of 3787.15 mm (12.43 ft) and may be a concern for slope stability and underkeel clearance due to sediment deposition.
- Area 5 resulted in a maximum scour potential of 29.38 mm (1.16 in) and is unlikely to cause scour issues along the revetment at the shoreline.
- Alternative Area 1 resulted in a maximum scour potential of 69.99 mm (2.76 in) and is unlikely to be a concern for scour potential.
- Alternative Area 2 resulted in a maximum scour potential of 10.82 mm (0.43 in) and is unlikely to cause scour issues along the breakwater at the shoreline.

Baird recommends that as Area 3 developed the largest scour potential, a monitoring program be put in place to monitor scour adjacent to the wall at the shoreline and slope stability at the toe of slope. Furthermore, the potential for propeller scour to uncover buried pipelines and cables should also be analyzed.

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1. Introduction

1.1 Project Background

W.F. Baird & Associates Ltd. (Baird) was engaged by Freese & Nichols, Inc. (FNI) to provide coastal engineering and modeling services for the Corpus Christi Ship Channel Deepening Project (CDP). The project is the proposed deepening the Offshore Channel to a nominal depth of 77 ft (Segments 1 and 2 in Figure 1.1), and the Entrance Channel and seaward-most portion of the Corpus Christi Ship Channel to 75 ft (Segments 3 to 6 in Figure 1.1). The channel will service the planned Harbor Island and Axis terminals with laden VLCC's departing from these terminals.

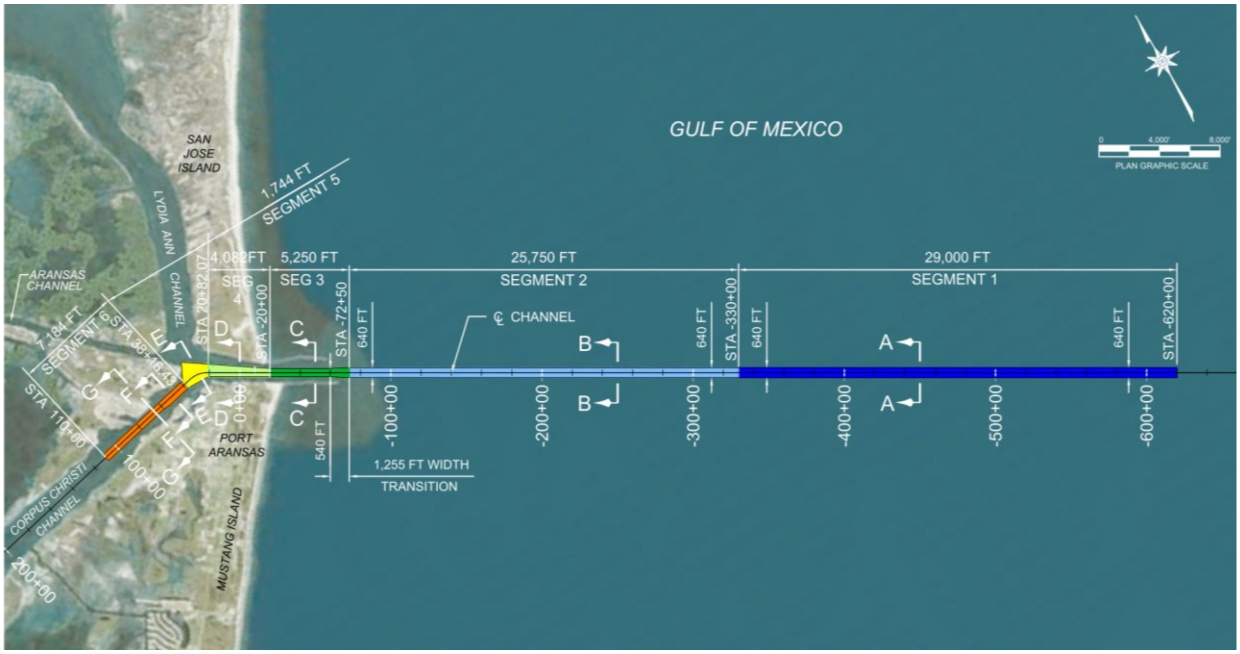

Figure 1.1: Dredging plan for the Corpus Christi Ship Channel Deepening Project

Baird's services include the following tasks:

- Vessel wake analysis
- Dynamic underkeel clearance (UKC) study
- Propeller scour study
- Tidal and hydrodynamic modeling
- Storm surge analysis
- Sediment transport modeling

The propeller scour study is addressed in this Report.

1.2 Study Objectives

The dredged depths for all channel segments have been proposed by PCCA for the present phase of the channel design. The objective of the propeller scour study is to assess the scour potential around the channel improvement areas and existing structures. The potential for scouring is derived from the propeller wash of the project vessel and supporting tug thrusters. The results of the propeller scour modeling will provide insight into areas that may be a concern for scouring and undermining of structures.

1.3 Report Outline

The outline of the report is as follows:

- Section 2 provides a brief description of the numerical model that is used to determine the velocity fields generated by the propeller wash. The input data used for the propeller wash assessment is also presented.
- Section 3 describes the model calibration phase.
- Section 4 presents the results of the modeling and the erosion potential due to propeller wash.
- Section 5 outlines the conclusions and recommendations of the study.

2. Model Description

2.1 General

Baird has completed a numerical modeling study that used FLOW-3D® to model the hydrodynamics induced by propeller generated flow (i.e., propeller wash). The model used is a Computational Fluid Dynamics (CFD) model that solves the three-dimensional incompressible Navier-Stokes equations and uses a fan/impeller model to simulate propellers.

The FLOW-3D® fan/impeller model is capable of replicating the axial and swirl components of a propeller by introducing a 'phantom' obstacle. The phantom obstacles are right-circular cylinders with a specified radius and thickness, which defines the region swept out by the rotating blades. The propeller model is characterized by a linear pressure drop across the cylinder length versus the net flow rate passing through it. Additionally, the performance of the fan/impeller is defined by its rotation rate, an accommodation coefficient (A_d) that controls how effective the blades are in setting fluid into motion, and a coefficient (B_d) that controls the amount of axial flow induced (Flow Science, 2018).

2.2 Bathymetry

The bathymetry for the proposed channels and terminals was obtain from FNI and was combined with bathymetry from the NOAA NCEI CUDEM grid to produce the bathymetry for the CFD model. The bathymetry used as input into the propeller wash modeling is presented in Figure 2.1.

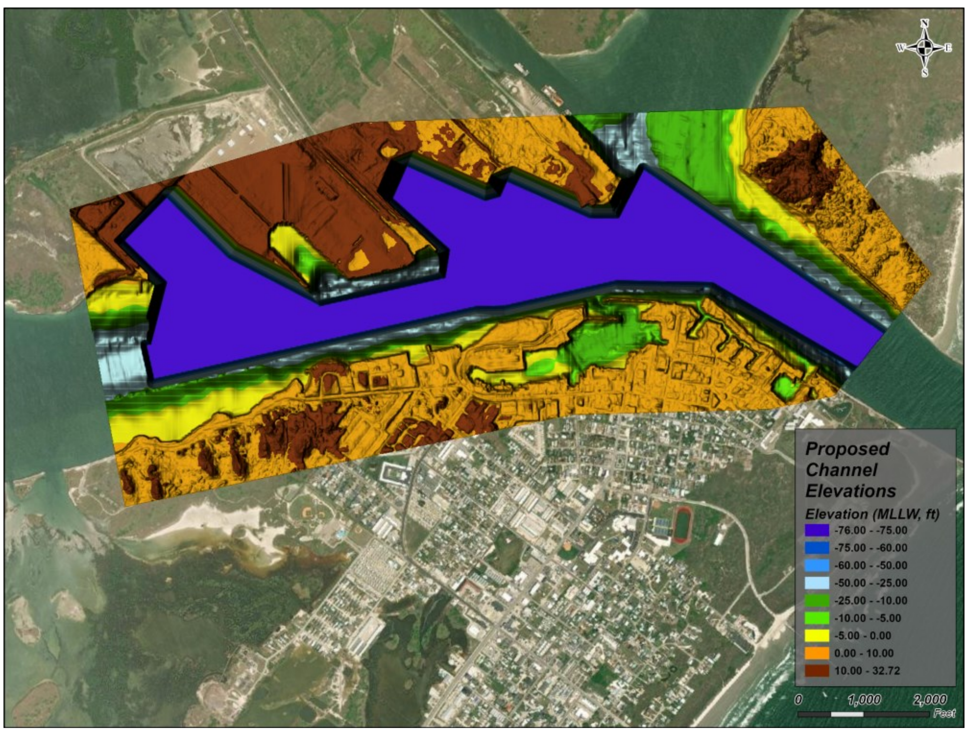

Figure 2.1: Model Bathymetry

2.3 Vessels

The design vessel for the project is a 306k DWT VLCC. The VLCC has one 10 m (32.8 ft) propeller located at the stern of the vessel at approximately 1 m (3.3 ft) above the keel. The tug simulated in the model is based off the Preliminary Design Summary Report for the terminal / escort tug ART 110-35 designed by Robert Allan Ltd. (Robert Allan Ltd., 2021). The tug designed by Robert Allan Ltd. is a rotor tug with three 2.8 m (9.2 ft) ducted propellers. The two propellers located at the bow of the tug are separated by 6.1 m (20 ft) and the propeller at the stern of the tug is located at approximately 20.1 m (66 ft) away from the forward propellers. These three propellers were assumed to have the same draft at approximately 5.2 m (17 ft).

2.4 Model Domains and Scenarios

The model domains are broken down into key areas presented in Figure 2.2. These domains were derived from the Harbor Island and Axis terminal navigation simulations and a summary of the modeling scenarios for each area is presented in the following sections. The scenarios were developed in conjunction with the Aransas Corpus Christi Pilots. All models were run only for the mean lower low water (MLLW) level as this represents a conservative estimate of the scour potential. Areas 1 and 4 which were initially identified in the scope of work were not seen to have significant propeller scour potential from review of the simulations and were therefore replaced with Alternative Areas 1 and 2.

Figure 2.2: Model Domains

2.4.1 Area 2

The propeller wash modeling scenario for area two is shown in Figure 2.3. The vessel being modeled is an inbound unladen VLCC transiting at full ahead, which is at a propeller spin rate of approximately 57 rpm. This scenario is based off Axis Run 4 at time stamp 0:16:08 and was modeled for two minutes of time.

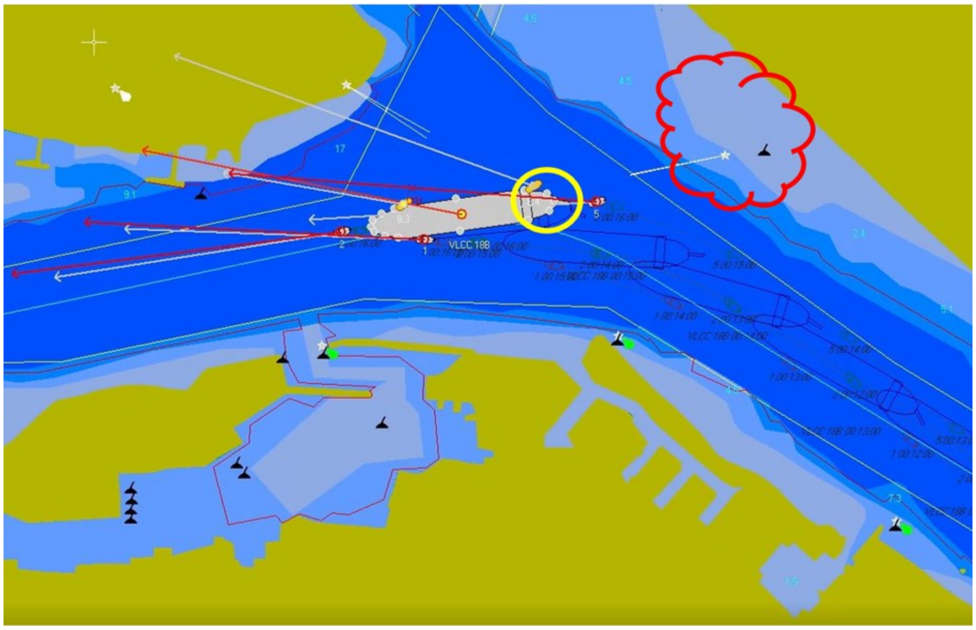

Figure 2.3: Area 2 Propeller Wash Modeling Scenario

2.4.2 Area 3a

The propeller wash modeling scenario for area three is shown in Figure 2.4. The vessel being modeled is the starboard bow tug at full power, which is at a propeller spin rate of approximately 240 rpm. This scenario is based off HICT Run 1 at time stamp 0:26:48 and was modeled for three minutes of time.

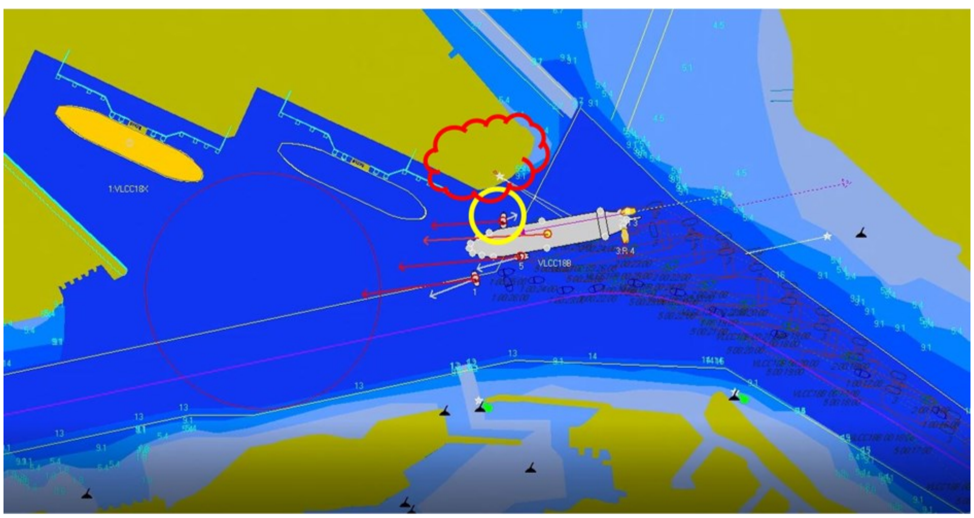

Figure 2.4: Area 3a (Tug) Propeller Wash Modeling Scenario

2.4.3 Area 3b

The propeller wash modeling scenario for area three is shown in Figure 2.5. The vessel being modeled is a laden VLCC transiting at full ahead, which is at a propeller spin rate of approximately 57 rpm. This scenario is based off Axis Run 11 at time stamp 0:17:44 and was modeled for two minutes of time.

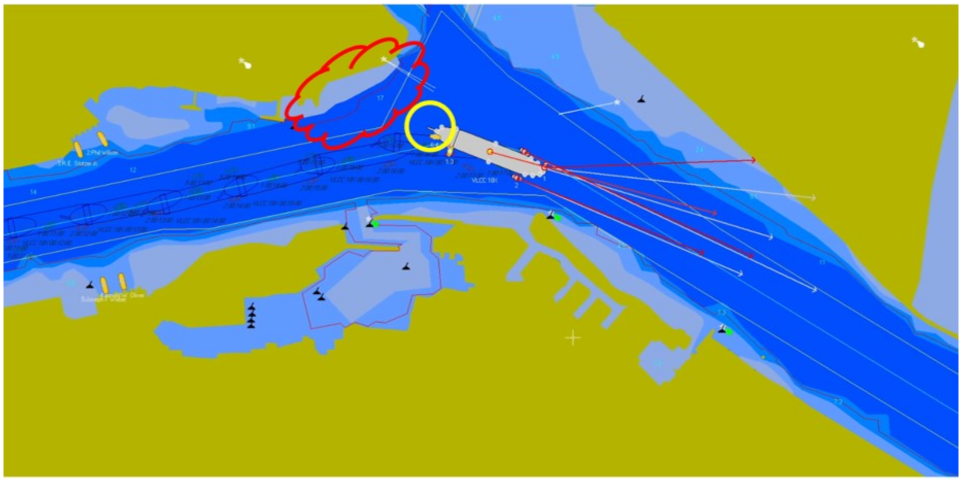

Figure 2.5: Area 3b (VLCC) Propeller Wash Modeling Scenario

2.4.4 Area 5

The propeller wash modeling scenario for area five is shown in Figure 2.6. The vessel being modeled is the starboard bow tug at full power, which is at a propeller spin rate of approximately 240 rpm. This scenario is based off HICT Run 1 at time stamp 0:37:54 and was modeled for four minutes of time.

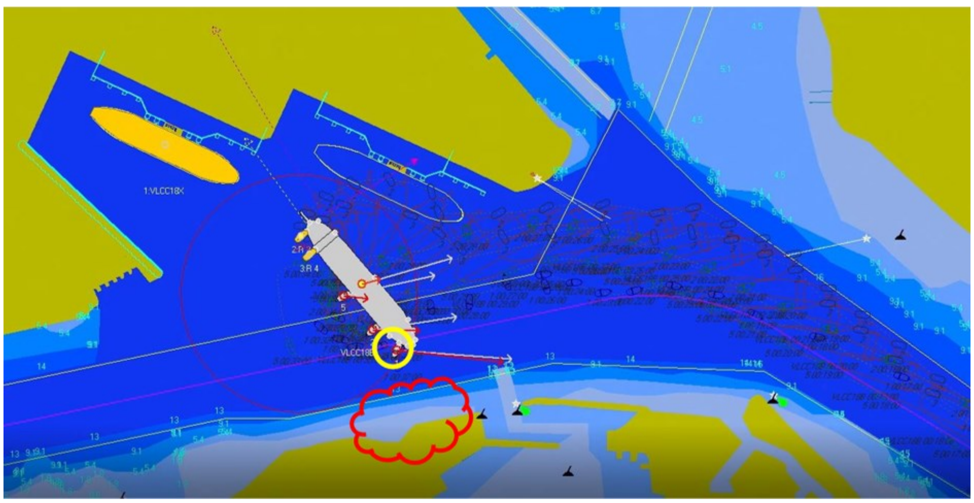

Figure 2.6: Area 5 Propeller Wash Modeling Scenario

2.4.5 Alternative Area 1

The propeller wash modeling scenario for alternative area one is shown in Figure 2.7. The vessels being modeled are the port bow tugs at full power, which is at a propeller spin rate of approximately 240 rpm. This scenario is based off Axis Run 10 at time stamp 0:11:42 and was modeled for four minutes of time.

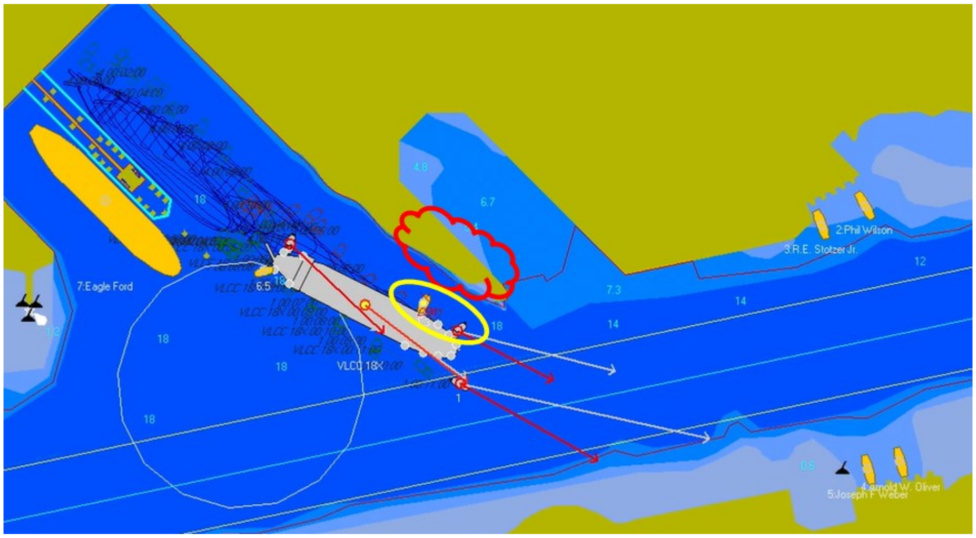

Figure 2.7: Alternative Area 1 Propeller Wash Modeling Scenario

2.4.6 Alternative Area 2

The propeller wash modeling scenario for alternative area two is shown in Figure 2.8. The vessel being modeled is the starboard bow tug at full power, which is at a propeller spin rate of approximately 240 rpm. This scenario is based off Axis Run 9.2 at time stamp 0:14:06 and was modeled for three minutes of time.

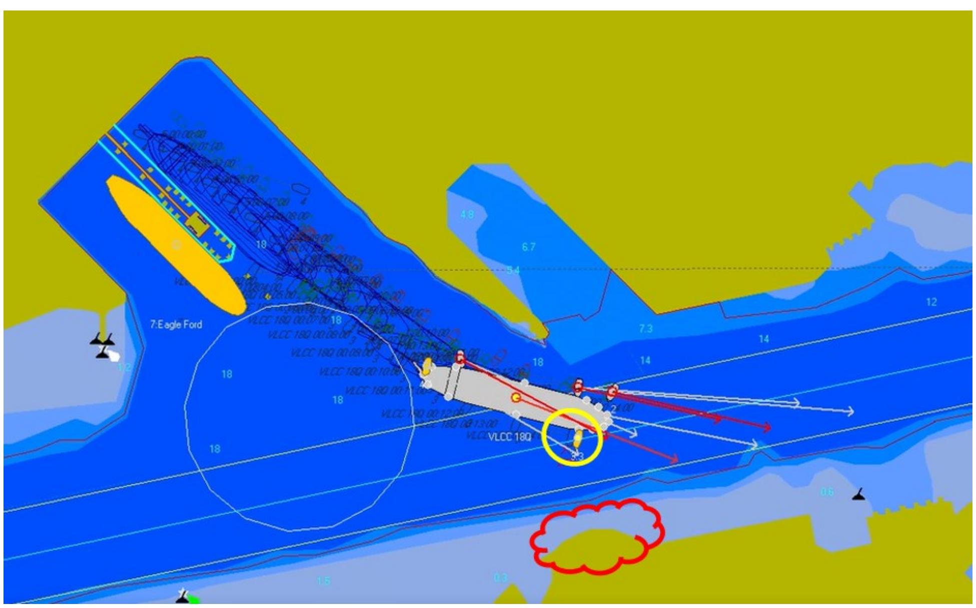

Figure 2.8: Alternative Area 2 Propeller Wash Modeling Scenario

3. Model Calibration

3.1 Calibration Parameters

FLOW-3D® provides two calibration parameters for the fan/impeller model, these two parameters are the accommodation coefficient *(A_d)* and the coefficient to account for axial flow (B_d). For this study these two coefficients were iterated until the propeller centerline velocities for the VLCC and tug approximated an analytical solution. The analytical solution for propeller centerline velocities was taken from Blaauw & van de Kaa (1978), who derived their formulas from physical experiments of a jet in a flume. One key difference between the analytical method and a spinning propeller is that the analytical method assumes the maximum velocity of the propeller occurs at the centerline and radially decreases away from the center. This differs from a spinning propeller, where the velocity is maximum at the blade tips close to the propeller and converges to the velocity at the centerline as you move further away from the propeller.

3.2 VLCC Model Calibration

As described in Section 3.1, the VLCC propeller model was calibrated to the analytical solution for the propeller centerline velocity for non-ducted propellers (Blaauw & van de Kaa, 1978). The calibration runs resulted in an A_d coefficient equal to 0.8 and a B_d coefficient equal to 1.5. Figure 3.1 presents the calibrated propeller centerline velocity curves.

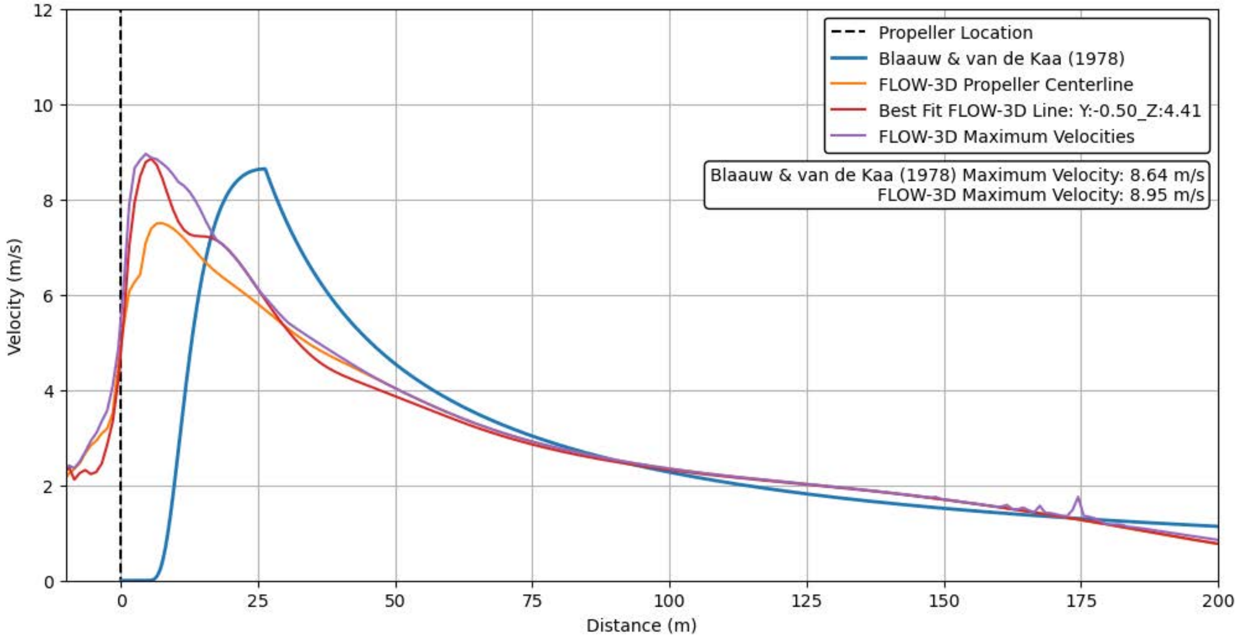

Figure 3.1: Velocity Profile Calibration Along VLCC Propeller Centerline

Four curves are presented on Figure 3.1, the first curve is the analytical solution provided by Blaauw and van de Kaa (1978), while all other curves are results from the FLOW-3D® simulation. As described in Section 3.1, Blaauw and van de Kaa (1978) provided a solution along the propeller centerline which is assumed to be the maximum velocity. The orange curve outlines the propeller centerline velocity from FLOW-3D® and compared to Blaauw and van de Kaa (1978), the FLOW-3D® simulation approximates the analytical solution well in the far-field but not in the near-field. This is expected behavior as the FLOW-3D® simulation does not assume that the maximum velocity occurs at the propeller centerline near the propeller. The red curve represents the grid line in the FLOW-3D® simulation that best represents analytical curve, which from the plot legend is not located directly at the propeller centerline at (Y:0, Z:0). The line that best represents the analytical curve is located 0.50 m horizontally and 4.41 m vertically away from the propeller center. Since, the analytical curve represents the maximum velocities generated by the propeller it is best to compare it to the maximum velocities generated by the propeller in the FLOW-3D® simulation. The purple curve represents the maximum velocities generated by the propeller in the FLOW-3D® simulation and it is clear that the simulation represents both the magnitude and shape of the analytical curve well. The simulation slightly overestimates the maximum velocity as predicted by the analytical solution while bounding the far-field velocity. The simulation overestimates the maximum velocity by 0.31 m/s (1.01 ft/s). The shift in the x-coordinate between the FLOW-3D® simulation results and the analytical curve is due to the analytical curve assuming it takes a distance of approximately 2.6 times the propeller diameter to establish the flow (Blaauw & van de Kaa, 1978). Whereas FLOW-3D® establishes the flow directly at the propeller along the length of the propeller.

3.3 Tug Single Propeller Model Calibration

As described in Section 3.1, the tug propeller model was calibrated to the analytical solution of the propeller centerline velocity for ducted propellers (Blaauw & van de Kaa, 1978). For the calibration runs only a single tug propeller was used as Blaauw & van de Kaa (1978) is only applicable for a single propeller. The calibration runs resulted in an A_d coefficient equal to 0.7 and a B_d coefficient equal to 1.25. Figure 3.2 presents the calibrated propeller centerline velocity curves.

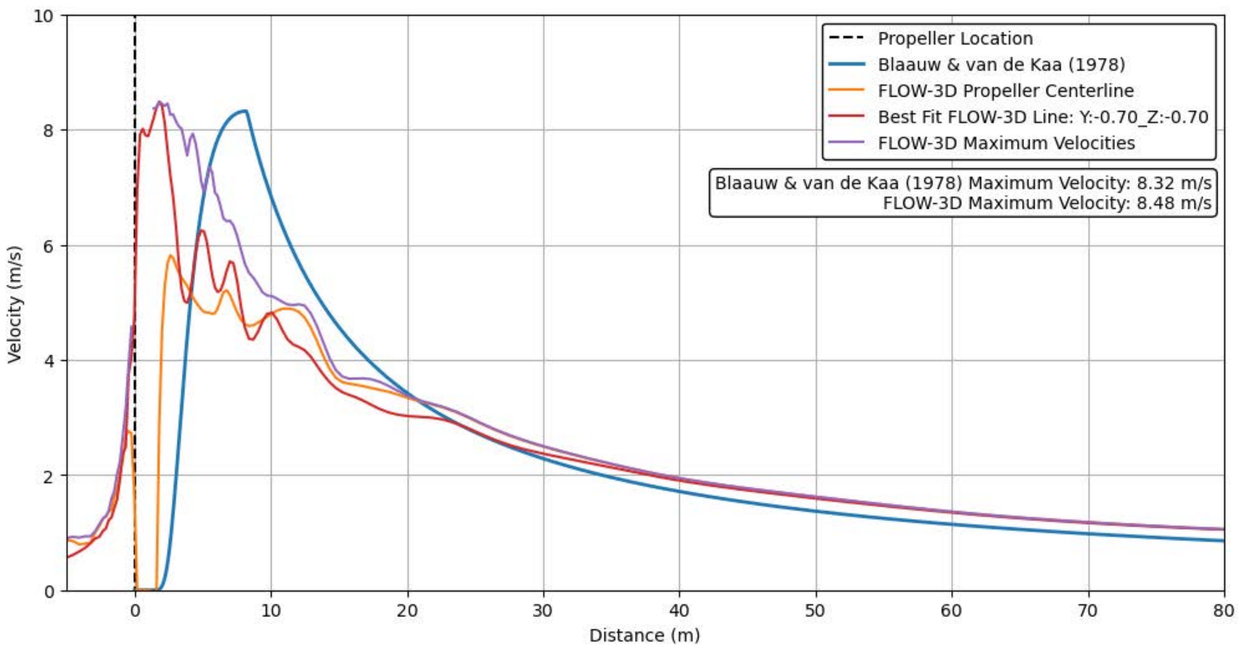

Figure 3.2: Velocity Profile Calibration Along Tug Propeller Centerline

Four curves are presented on Figure 3.2, the first curve is the analytical solution provided by Blaauw and van de Kaa (1978), while all other curves are results from the FLOW-3D® simulation. As described in Section 3.1, Blaauw and van de Kaa (1978) provided a solution along the propeller centerline which is assumed to be the maximum velocity. The orange curve outlines the propeller centerline velocity from FLOW-3D® and compared to Blaauw and van de Kaa (1978), the FLOW-3D® simulation approximates the analytical solution well in the far-field but not in the near-field. This is expected behavior as the FLOW-3D® simulation does not assume that the maximum velocity occurs at the propeller centerline near the propeller. The red curve represents the grid line in the FLOW-3D® simulation that best represents analytical curve, which from the plot legend is not located directly at the propeller centerline at (Y:0, Z:0). The line that best represents the analytical curve is located 0.70 m horizontally and 0.70 m vertically away from the propeller center. The purple curve represents the maximum velocities generated by the propeller in the FLOW-3D® simulation and it is clear that the simulation represents both the magnitude and shape of the analytical curve well. The simulation slightly overestimates the maximum velocity as predicted by the analytical solution while also slightly overestimating the far-field velocity. The maximum velocity is overestimated by 0.16 m/s (0.52 ft/s) whereas the far-field velocity is overestimated by approximately 0.19 m/s (0.62 ft/s). The shift in the x-coordinate between the FLOW-3D® simulation results and the analytical curve is due to the analytical curve assuming it takes a distance of approximately 2.6 times the propeller diameter to establish the flow (Blaauw & van de Kaa, 1978). Whereas FLOW-3D® establishes the flow directly along the length of the propeller.

4. Model Results

The results of the six scenarios for the propeller wash modeling are presented in this section.

4.1 Erosion and Scour Potential

The erosion potential was approximated based upon the sediment characteristics within each of the model domains and the bed shear stress / bed shear velocities developed during the simulations. The sediment sizes for each of the model domains was determined from the borehole logs presented in Terracon Consultants Inc. (2018) and summarized in Table 4.1. Based on Table 4.1, a very fine sand of grain size 0.12 mm (0.005 in) was chosen to represent the sediment in each of the domains. For this analysis the dry density of the very fine sand is assumed to be 1600 kg/m^3 (100 lb/ft^3). Following Soulsby (1997), the dimensionless sediment size for this sediment is 3.00 with a critical bed shear stress of 0.13 Pa (0.0027 psf) and a critical bed shear velocity of 0.011 m/s (0.037 ft/s).

Table 4.1: Grain Size in Each Model Domain

Area	Bore Hole Number	Depth Below Seabed (m) [ft]	D_{50} (mm) [in]
2	BH-34	1.1 [3.5]	0.11 [0.004]
2	BH-34	5.9 [19.5]	0.13 [0.005]
3	BH-37	2.3 [7.5]	0.10 [0.004]
5	BH-36	0.6 [2]	0.13 [0.005]
Alternative Area 1	CB-3	1.6 [5.15]	0.13 [0.005]
Alternative Area 1	CB-3	10.7 [35.15]	0.11 [0.004]
Alternative Area 2	CB-2	2.8 [9.05]	0.13 [0.005]

The scour potential was approximated based upon the analytical formula for the erosion rate (Partheniades, 1965):

$$S_E = E\left(\frac{\tau_b}{\tau_{ce}} - 1\right)^n \qquad \tau_b > \tau_{ce}$$

Where S_E is the erosion rate (mm/hr), E is the erodibility coefficient (mm/hr), τ_b is the bed shear stress (Pa), τ_{ce} is the critical shear stress (Pa), and n is the power of erosion (-). For this study the power of erosion (n) was assumed to be a value of 1.5 for sand. The erodibility coefficient (E) is typically determined from lab experiments which are not available for this study. Utilizing previous Baird studies, the erodibility coefficient for silty sand with a critical shear stress of approximately 0.10 Pa can range from 1.67 to 4.73 mm/hr. To obtain an estimate for the erodibility coefficient for this project, a FLOW-3D® sediment transport model was run for Area 3b (VLCC). The maximum scour hole depth from the numerical simulation was then used as the calibration value for the erodibility coefficient. The erodibility coefficient was iterated between 1.67 to 4.73 mm/hr until the maximum scour hole depth approximated by the analytical formula matched the depth predicted by the numerical model. For Area 3b (VLCC) the numerical model developed a maximum scour hole depth of 3.79 m

(12.43 ft), which resulted in an erodibility coefficient of 3.22. An erodibility coefficient of 3.22 and a power of erosion of 1.5 was used for all other model domains to approximate the scour potential.

4.1.1 Limitations and Simplifications to the Hydrodynamic Modeling and Analytical Approximation of Scour Potential

The approach taken for modeling the propeller wash and analytically calculating the scour potential has certain limitations, some of these limitations are outlined below:

- The vessel is moving with time which would result in eroding new areas and potentially backfilling previous areas. For this study the propeller was modelled as stationary, which is a conservative assumption with respect to scour depth potential. However, with a moving vessel the scour area potential would be larger due to the constant movement of the velocity plume.
- The analytical approach for approximating scour potential only accounts for erosion and not deposition.
  - Bed forms generated by the sediment transport are not captured, which may result in an overestimation of the scour potential area. Based on preliminary coupled hydrodynamic and sediment transport simulations, the propeller wash tends to follow the scour hole path leading to a velocity plume that does not disperse laterally as much when compared to fixed bed simulations.
- The bed shear stress and bed shear velocities are assumed to not be influenced by the development of the scour hole (i.e., not a coupled simulation).
- There is a lack of physical data to calibrate to for propeller velocities and associated scour potential for the vessels being used in this study and in the Corpus Christi area.

4.1.2 Area 2

Figure 4.1 presents the bed shear stress and bed shear velocities maximized over all time steps within the Area 2 model domain. From Figure 4.1, it is apparent that both the bed shear stresses and bed shear velocities result in plots that are very similar. This is due to the bed shear stress (τ_b) being related to the bed shear velocity (u_*) and the density of water (ρ_w) by the following formula:

$$\tau_b = \rho_w u_*^2$$

From Figure 4.1, it is apparent that the areas of highest shear stress are located near the propeller and develop in a cone shape away from the propeller. The areas of the highest shear stress will result in the areas with the highest erosion potential.

For this simulation there is a submerged groin that is currently buried by sediment, which is outlined in Figure 4.1 and Figure 4.2. Observing the potential scour areas in Figure 4.2, it appears that the scour for this simulation will not uncover the submerged groin. Additionally, for this simulation the propeller wash and scour potential did not reach the shoreline which will not result in undermining of the armor stone located on the shore. From Figure 4.2, the maximum scour potential is estimated to be 14.45 mm (0.57 in) and the total scour potential area is approximately 45879 m^2 (11.34 ac).

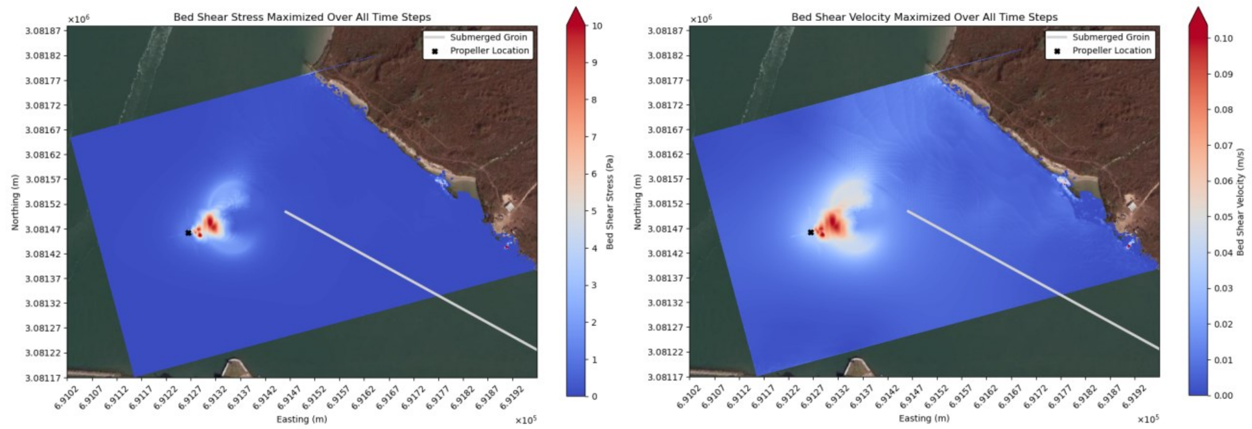

Figure 4.1: Area 2 Bed Shear Stress (Left) and Bed Shear Velocity (Right) Maximized Over All Time Steps

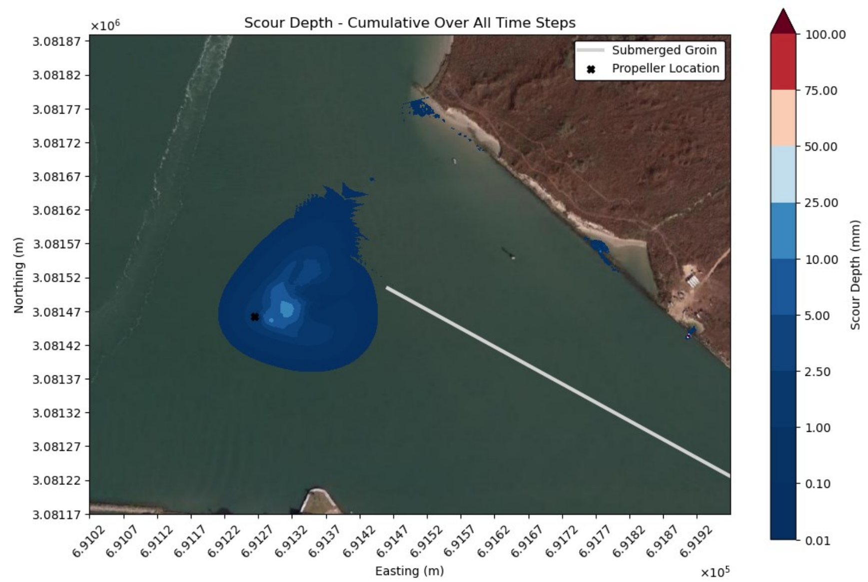

Figure 4.2: Potential Scour Area for Area 2

4.1.3 Area 3a (Tug)

From Figure 4.3, it is apparent that the areas of highest shear stress are located near the propellers and at the shoreline. The propeller wash initial is conical in shape but once it reaches the shoreline it splits to either side. For this simulation there is a wall located at the shoreline, where potential undermining could occur.

Figure 4.4 presents the potential scour areas for this simulation. From Figure 4.4, the maximum scour potential is estimated to be 747.78 mm (2.45 ft) and the total scour potential area is approximately 13028 m^2 (3.22 ac). Furthermore, from Figure 4.4 the scouring starts at the toe of slope and increases as the water depth decreases which may be problematic for slope stability.

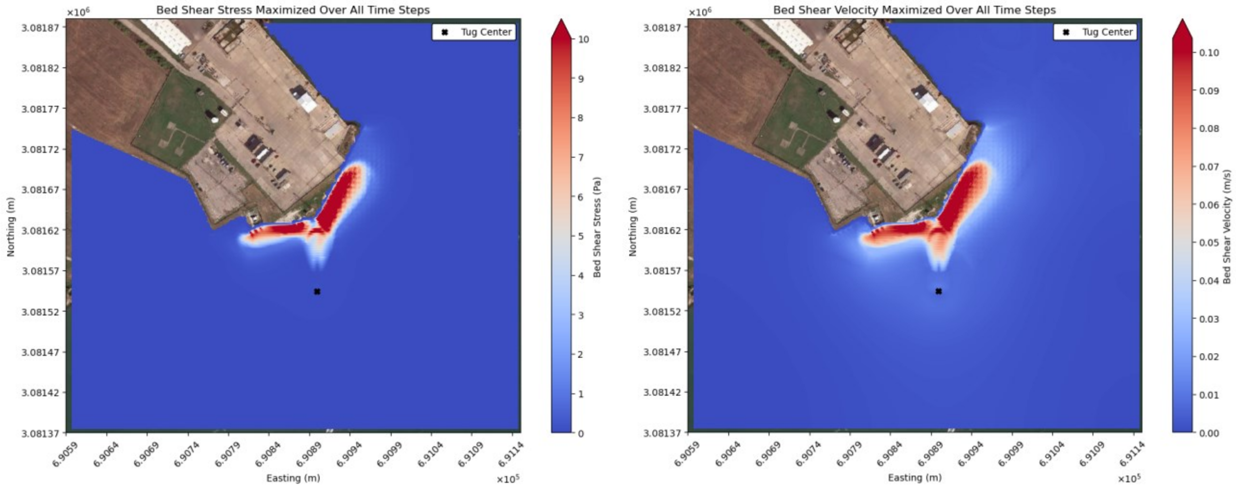

Figure 4.3: Area 3a (Tug) Bed Shear Stress (Left) and Bed Shear Velocity (Right) Maximized Over All Time Steps [Note: maximum bed shear stress and velocity are 47 Pa and 0.2 m/s respectively]

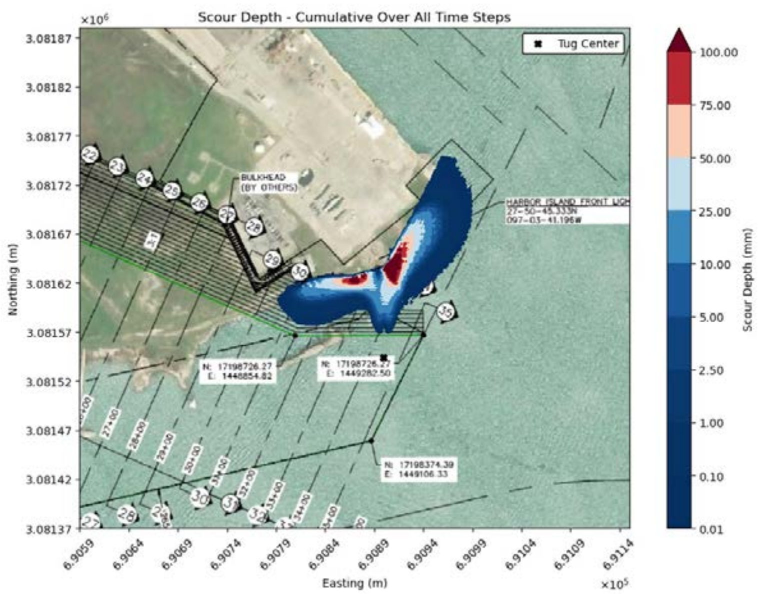

Figure 4.4: Potential Scour Area for Area 3a (Tug)

4.1.4 Area 3b (VLCC)

From Figure 4.5, it is apparent that the areas of highest shear stress are located near the propeller. This simulation represents the worst case for sediment scour potential as the VLCC propeller is located just above the seabed due to the vessel being laden. For this simulation the propeller wash does not reach the shoreline and is contained within the dredged channel and harbor.

Figure 4.6 presents the potential scour areas for this simulation. From Figure 4.6, the maximum scour potential is estimated to be 3787.15 mm (12.43 ft) and the total scour potential area is approximately 37764 m^2 (9.33 ac). Furthermore, as shown in Figure 4.6, the scour potential reaches the toe of slope which may be problematic for slope stability.

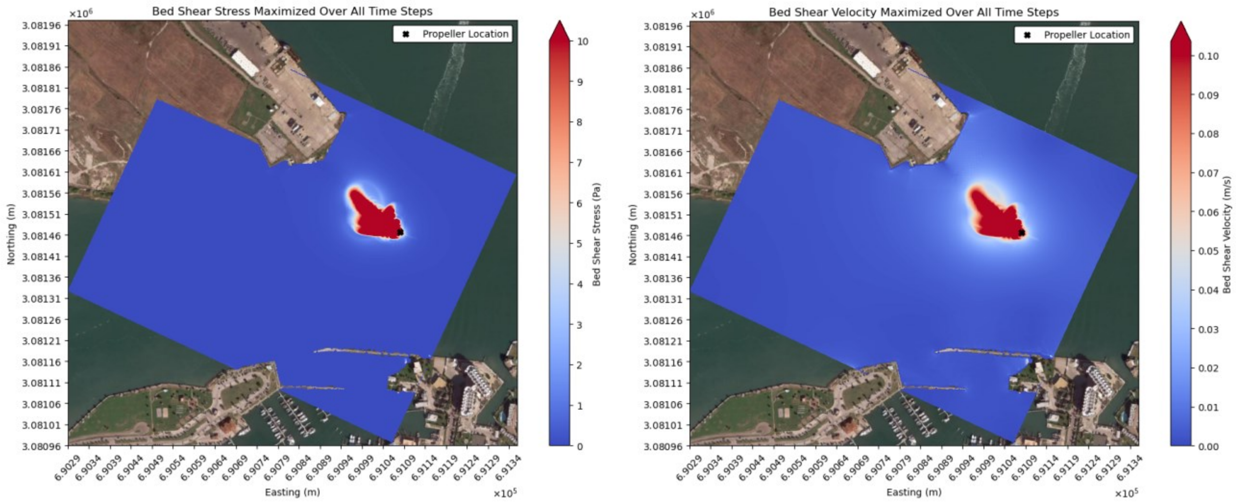

Figure 4.5: Area 3b (VLCC) Bed Shear Stress (Left) and Bed Shear Velocity (Right) Maximized Over All Time Steps [Note: maximum bed shear stress and velocity are 230 Pa and 0.5 m/s respectively]

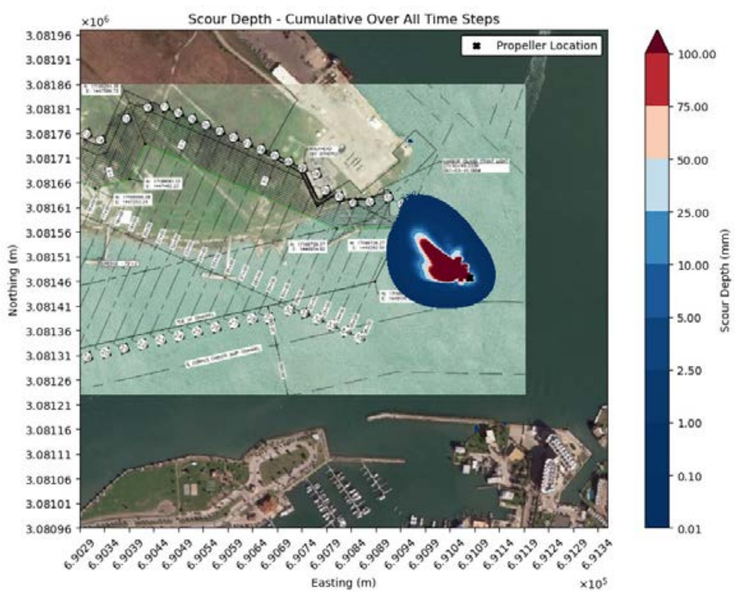

Figure 4.6: Potential Scour Area for Area 3b (VLCC)

4.1.5 Area 5

From Figure 4.7, it is apparent that the areas of highest shear stress are located near the shoreline. The propeller wash is initially conical in shape but once it reaches the shoreline it splits to either side, similar to the results of Area 3a (tug) in Section 4.1.3. There is a revetment located along the shoreline, however, the estimated scour potential is small and likely not a concern for undermining of the structure.

Figure 4.8 presents the potential scour areas for this simulation. From Figure 4.8, the maximum scour potential is estimated to be 29.38 mm (1.16 in) and the total scour potential area is approximately 19391 m^2 (4.79 ac).

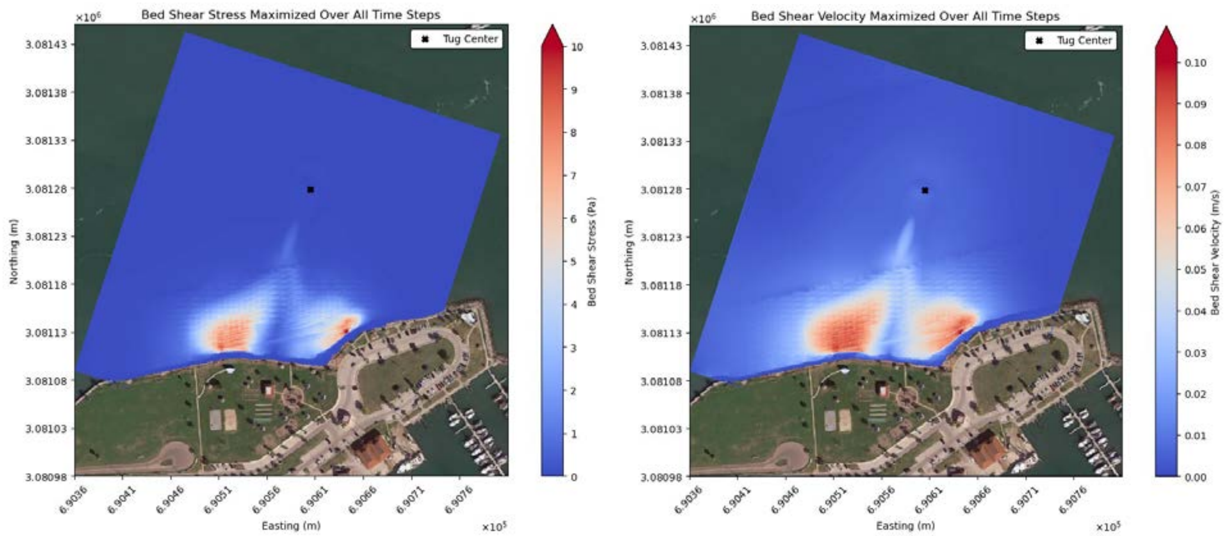

Figure 4.7: Area 5 Bed Shear Stress (Left) and Bed Shear Velocity (Right) Maximized Over All Time Steps

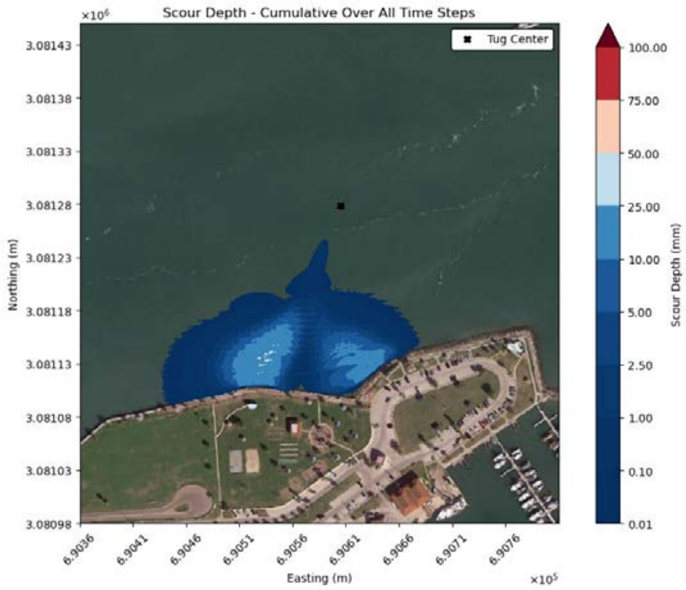

Figure 4.8: Potential Scour Area for Area 5

4.1.6 Alternative Area 1

From Figure 4.9, it is apparent that the areas of highest shear stress are located near the shoreline. This simulation was composed of two tugboats and resulted in the two plumes combining in between the tugs and extending along the shoreline.

Figure 4.10 presents the potential scour areas for this simulation. From Figure 4.10, the maximum scour potential is estimated to be 69.99 mm (2.76 in) and the total scour potential area is approximately 27213 m^2 (6.72 ac). Furthermore, from Figure 4.10 the scouring starts at the toe of slope and increases as the water depth decreases. However, the magnitude of the scour potential is small and likely not a concern for slope stability.

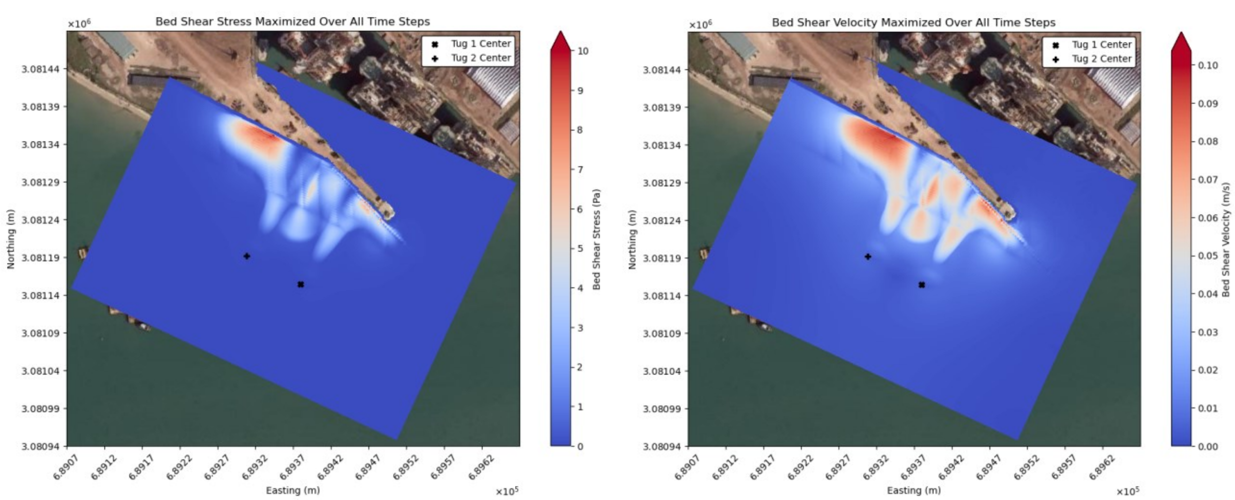

Figure 4.9: Alternative Area 1 Bed Shear Stress (Left) and Bed Shear Velocity (Right) Maximized Over All Time Steps

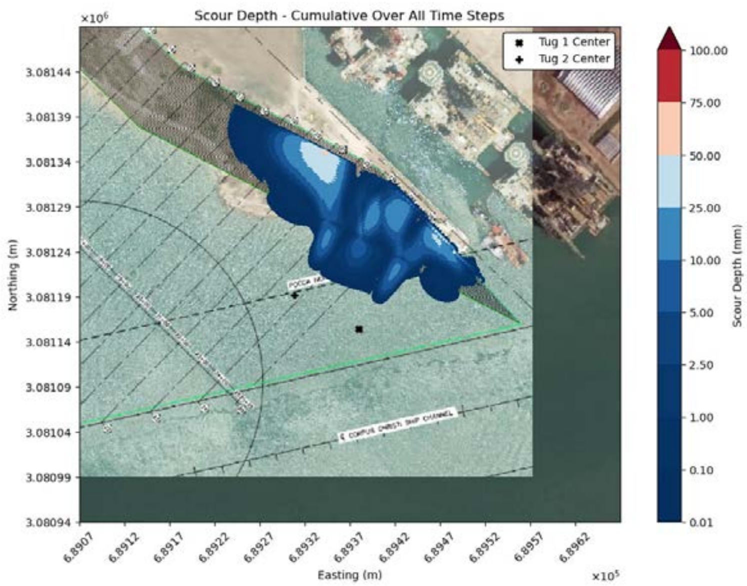

Figure 4.10: Potential Scour Area for Alternative Area 1

4.1.7 Alternative Area 2

From Figure 4.11, it is apparent that the areas of highest shear stress are located near the shoreline. The propeller wash is initially conical in shape but once it reaches the shoreline it splits to either side, similar to the other tug simulations. There is a breakwater located along the shoreline, however, the estimated scour potential is small and likely not a concern for undermining of the structure.

Figure 4.12 presents the potential scour areas for this simulation. From Figure 4.12, the maximum scour potential is estimated to be 10.82 mm (0.43 in) and the total scour potential area is approximately 15501 m^2 (3.83 ac).

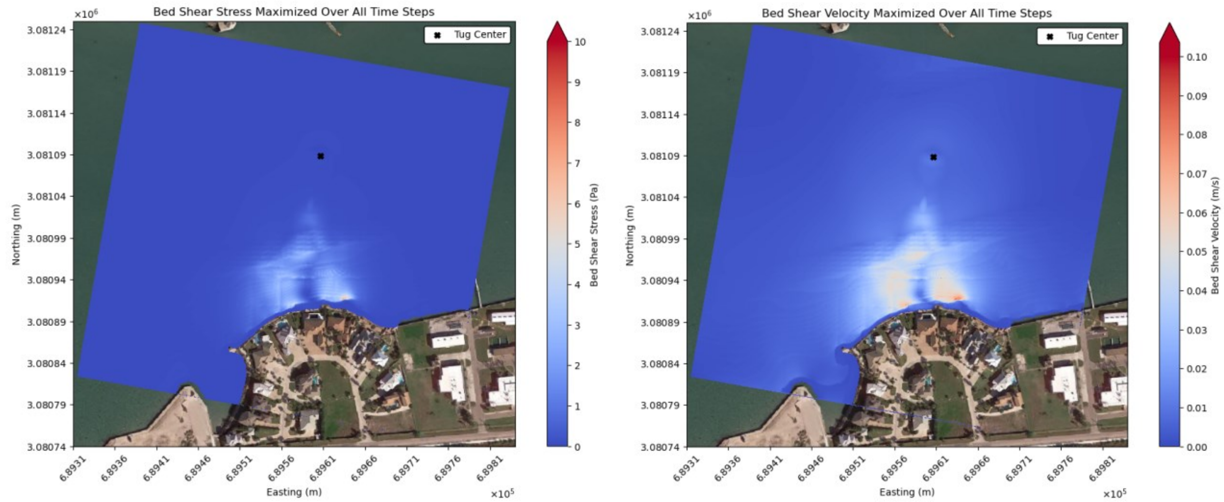

Figure 4.11: Alternative Area 2 Bed Shear Stress (Left) and Bed Shear Velocity (Right) Maximized Over All Time Steps

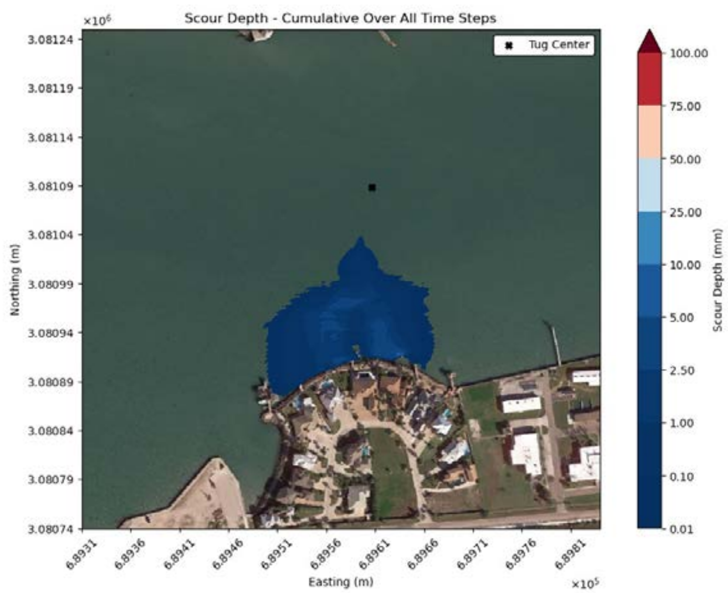

Figure 4.12: Potential Scour Area for Alternative Area 2

5. Conclusions and Recommendations

Baird has conducted a propeller scour study as part of the modeling services for the Corpus Christi Channel Deepening project. The project will be comprised of deepening the Outer and Approach Channels to 77 ft, and the Jetty Channel and seaward-most portion of the Corpus Christi Ship Channel to 75 ft. The channel will be used by vessels including laden VLCC's at a maximum draft of 68 ft departing from the planned Axis and Harbor Island terminals.

The propeller scour study consisted of the following tasks:

- Assessment of vessel maneuvers in the channel
- Model calibration of the VLCC and tug propellers
- Modeling propeller wash hydrodynamics
- Analytically assessing scour potential due to propeller wash

The vessel maneuvers modelled were based on simplified assumptions of vessel position and time, which were developed from the navigation simulations for both Harbor Island and Axis terminals. The presented maneuvers represent the likely scenarios where propeller induced scour might be an issue. If more navigation simulations are completed for these terminals, it is recommended to re-evaluate any new maneuvers that might cause propeller induced scour. Specifically maneuvers that result in a laden VLCC directing its wash towards the shore or structures and maneuvers where tugs are relatively close to the shore for an extended period of time are concerning for propeller induced scour.

The numerical model was calibrated to the analytical solution for propeller centerline velocities developed by Blaauw & van de Kaa (1978) and presented in PIANC (2015). As presented in Section 3, the VLCC propeller and a single tug propeller were both calibrated to the analytical formula in FLOW-3D®. However, Baird is not aware of any physical model data to validate the propeller centerline velocities for these specific propellers.

The propeller wash hydrodynamics was modelled with FLOW-3D® and the scour potential was quantified using an analytical approach. The analytical approach for quantifying scour potential was calibrated to the maximum scour hole depth achieved by a coupled sediment transport and hydrodynamic simulation of Area 3b (VLCC). Using the maximum scour hole depth from the coupled numerical model, the erodibility coefficient was changed in the analytical approach until it resulted in a similar maximum scour hole depth. For the sediment properties assumed in this study, the erodibility coefficient was determined to be 3.22 and the power of erosion was determined to be 1.5. The conclusions drawn for each area are as follows:

- Area 2:
  - For this maneuver, the submerged groin is unlikely to be uncovered due to propeller induced scour.
  - The maximum scour potential is 14.45 mm (0.57 in) and does not reach the shoreline. As such, this maneuver is unlikely to cause scour issues along the revetment at the shoreline.
- Area 3a (tug):
  - This maneuver resulted in scour at the wall located along the shoreline.
  - The maximum scour potential is 747.78 mm (2.45 ft) and is largest at the wall located along the shoreline.
  - This maneuver could result in undermining of the wall.
  - This maneuver may be a concern for slope stability as it scours the toe of slope and increases in scour potential as the water depth decreases.

- Area 3b (VLCC):
  - This maneuver resulted in the largest scour potential due to this simulation being a laden VLCC.
  - The maximum scour potential is 3787.15 mm (12.43 ft) and is largest near the propeller and in the dredged channel.
  - While there doesn't appear to be any risk for structures located along the shore, there could be additional risk for underkeel clearance depending on where the suspended sediment deposits.
  - Additionally, scour near the toe of slope for the dredged channel could be a concern for slope stability.
- Area 5
  - This maneuver resulted in scour at the revetment located along the shoreline.
  - The maximum scour potential is 29.38 mm (1.16 in) and is largest at the revetment.
  - Due to the scour potential being small it is not likely to be a concern for undermining of the revetment.
- Alternative Area 1
  - This maneuver resulted in scour along the shoreline.
  - The maximum scour potential is 69.99 mm (2.76 in) and is largest at the shoreline.
  - Due to the scour potential being small and there being no structures located at the shoreline, this maneuver is not a concern for scour potential.
- Alternative Area 2
  - This maneuver resulted in scour along the shoreline.
  - The maximum scour potential is 10.82 mm (0.43 in) and is largest at the shoreline.
  - There is a breakwater located along the shoreline, however, the estimated scour potential is small and unlikely to cause undermining of the breakwater.

Based on the results of the propeller scour study, the following conclusions can be made about the maneuvers that appear to cause the most scour potential. Additionally, general recommendations are also presented:

- Maneuvers associated with a laden VLCC could result in significant scour potential and sediment transport which may be problematic for underkeel clearance in the dredged channel, structures along the shoreline if the propeller is close to the shoreline (10 propeller diameters away), or slope stability.
- Maneuvers associated with a tug near the shoreline for an extending period of time (> 2mins) could result in significant scour potential and undermining of structures along the shoreline if these events occur frequently. They may also be a concern for slope stability.
- Baird recommends investigating the depth that pipelines and cables are buried to ensure they are not uncovered due to propeller scour.
- As Area 3 developed the largest scour potential, Baird recommends a monitoring program be put in place to monitor wall undermining at the shoreline and slope stability at the toe of slope. If scour is determined to be a potential issue for slope or structure stability, then bed armoring should be investigated as a mitigative solution.

6. References

Blaauw, H., & van de Kaa, E. (1978). Erosion of Bottom and Sloping Banks Caused by the Screw Race of Manoeuvring Ships. *7th International Harbour Congress.* Antwerp, Belgium.

Flow Science. (2018). *FLOW-3D® Version 12.0 Users Manual.* Santa Fe, NM.

Partheniades, E. (1965). Erosion and deposition of cohesive soils. *Journal of the hydraulics division Proceedings of the ASCE 91 (HY1)*, 105-139.

PIANC. (2015). *Guidelines for Protecting Berthing Structures from Scour Caused by Ships Report N° 180.*

Robert Allan Ltd. (2021). *Preliminary Design Summary Report.*

Soulsby, R. (1997). *Dynamics of marine sands a manual for practical applications.* London : Thomas Telford.

Terracon Consultants Inc. (2018). *Geotechnical Data Report Corpus Christi Ship Channel - Lower Bay Reach.* Corpus Christi, TX.