MOTT MACDONALD

PORT CORPUS CHRISTI®

Passing Vessel Hydrodynamic Study

in the vicinity of Ingleside Cove and Ingleside-on-the-Bay, Texas

April 3, 2019

Port of Corpus Christi Authority
18-006A

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Table of Acronyms

Port of Corpus Christi Authority (PCCA)
Vessel Hydrodynamics Long-Unsteady (VH-LU) Numerical Model
Water Surface Elevation (WSE)
Mean Low Tide (MLT)
Mean Sea Level (MSL)
Beneficial Use/Dredged Material Placement Area (BU/DMPA) or Site (BUS)
Corpus Christi Ship Channel (CCSC)
La Quinta Channel (LQC)
Relative Sea Level Rise (RSLR)
Central Standard Time (CST)
Automatic Identification System (AIS)
Liquid Natural Gas (LNG) Tanker
Length Overall (LOA)
Existing Conditions (EC)

Executive summary

This Technical Memorandum was prepared for use by the Port of Corpus Christi Authority (PCCA) and summarizes the work performed by Mott MacDonald under Service Order No. 2 of PCCA Master Services Agreement No. 18-03. The purpose of this study was to investigate the hydrodynamic effects of existing conditions and potential impacts or changes due to proposed modifications to the Corpus Christi and La Quinta ship channels, including the widening of the Corpus Christi Ship Channel (CCSC), construction of a Beneficial Use/Dredged Material Placement Area (BU/DMPA) near the intersection (junction) of the La Quinta and Corpus Christi Ship Channels (BU Site C-Q), and the construction of a future BU/DMPA within Ingleside Cove (BU Site I-C).

The study was conducted using the two-dimensional (2D) Vessel Hydrodynamics Long-Unsteady wave (VH-LU) numerical model. VH-LU is a proprietary Mott MacDonald model, which simulates the pressure field wave in the form of variations in the water surface elevation and velocities in the modeling domain during passage of a vessel through a channel. An expansive set of model runs was developed to evaluate the impacts from a range of large vessels underling varying channel conditions (existing and proposed). For the purpose of this study, all ships were modeled during loaded conditions for conservatism. The worst-case scenario was identified from the list of simulations and was used as a representative case to further evaluate impacts from other and future water level conditions and test several mitigation concepts. Several key objectives and findings from the study are listed below:

- How well can the VH-LU model using available bathymetric datasets replicate passing vessel conditions at the site?
    - A validation model run was performed to replicate a recorded overtopping event at a property adjacent to the La Quinta Channel (LQC) in Ingleside-on-the-Bay. The model was found to successfully simulate the observed overtopping event.
- How will passing vessel effects be changed by the proposed future channel conditions?
    - The existing and proposed conditions were evaluated using a range of vessel types and scenarios. The impacts of the proposed conditions were evaluated by comparing resulting maximum instantaneous water surface elevation (WSE) values along transects throughout the project area and comparing them to the results of the same vessel simulation but under existing conditions. The proposed conditions were found to increase WSEs by a maximum of 6 inches at the transects of interest. This report documents the increases in instantaneous max WSE caused by each proposed condition.
    - The proposed future channel conditions do not increase the overtopping that is currently experienced under present-day/existing conditions at the waterfront property on Bayshore Drive (Region 2).
- How will higher water levels and relative sea level rise (RSLR) affect the impacts from passing vessel?
    - Water level tests were performed to evaluate how a range of future water level scenarios would impact resulting max WSE values due to passing vessel activities. The tested water levels include: (1) an increment for

RSLR; and (2) a 5-yr elevated tidal event. These water level scenarios were tested separately. The results show that in general, an increase in initial water levels due to the simulated RSLR and the simulated 5-yr elevated tidal event, does result in an increase in max WSE values caused by passing vessels, but does not increase the number of bulkheads overtopped in Region 2.

- What structural or operational measures can be used to mitigate the passing vessel impacts along the shoreline, such as constructing a breakwater or reducing vessel speeds?
    - Three mitigation measures were developed and tested using the VH-LU model. The model simulation results indicate that, of the three mitigation measures developed and tested in this study, the following two measures may be feasible for reducing passing vessel impacts and are recommended for further evaluation: (1) installing retaining walls or increasing the bulkhead cap elevations along Bayshore Drive waterfront properties where overtopping occurs, to the elevation of existing bulkhead/retaining wall structures that are not overtopped; a preliminary estimate for a minimum elevation is provided in this study; or (2) extend the existing offshore breakwater towards the north, up to the bulkheads of the Bayshore Drive waterfront properties. Note that the purpose of this study was to evaluate the potential impacts to passing vessel hydrodynamic conditions of the mitigation measures tested, the actual feasibility of these measures was not evaluated under this study. Furthermore, this study does not determine or assess additional impacts that may result from the construction of these mitigation measures.

1 Introduction

1.1 Background

This technical memorandum summarizes the work and results of a numerical modeling study of vessel hydrodynamics conducted by Mott MacDonald at the request of the Port of Corpus Christi Authority (PCCA) under Service Order NO. 2 of PCCA Master Services Agreement NO.18-03. The purpose of this study was to investigate the hydrodynamic effects of existing conditions and due to proposed modifications to the Corpus Christi and La Quinta Ship Channels including the widening of the Corpus Christi Ship Channel, construction of a beneficial use (BU) Dredged Material Placement Area (DMPA) near the intersection of the La Quinta and Corpus Christi Ship Channels (BU Site C-Q), and the construction of an additional beneficial use DMPA within Ingleside Cove (BU Site I-C). The goals of this project were as follows:

1. Quantify changes in passing vessel impacts by analyzing water level fluctuations along the shoreline between existing and proposed conditions.
2. Determine potential passing vessel-induced hydrodynamic impacts (i.e., overtopping) to the Ingleside On-the-Bay bulkheads and shoreline along the La Quinta Channel (LQC) and along the Corpus Christi Ship Channel (CCSC), including the full length of Bayshore Drive, Ingleside Marina, Ingleside Cove shoreline, and PCCA Island for existing and potential future channel improvement conditions.
3. Evaluate potential effects of relative sea level rise (RSLR) and various tide/water levels on passing vessel hydrodynamic effects.
4. Identify and test potential structural and non-structural mitigation measures for reducing impacts to the shoreline due to hydrodynamic conditions created by passing vessels.

1.2 Project Site of Interest

The project is located at Ingleside, Texas, at the northern end of the Corpus Christi Bay. See Figure 1 for an aerial of the project area and locations of the LQC and CCSC. To best evaluate the analysis results and assess potential impacts to the relevant shorelines, the project site was divided into three regions. Areas of interest and similar shoreline types were identified to help define each region's extents. Region 1 encompasses Ingleside Cove; this area features a mix of bulkheading and natural shoreline. Region 2 encompasses the area of shoreline with only bulkheading (i.e., no natural shoreline) along Bayshore Drive that parallels the LQC. Region 3 covers the section of shoreline along Bayshore Drive that faces southwest, has a revetment, and is landward of the existing offshore breakwater. An aerial image of these three regions and their coverages is provided in Figure 2. Note that this figure also shows transect lines within each region. These transect lines identify detailed locations of interest and are further discussed in Section 5.

It should also be noted that while the purpose of this analysis is to investigate the potential impacts within the whole project area (i.e., all three regions), focus is placed on the section of shoreline along Bayshore Drive that is adjacent to the LQC (i.e., Region 2), because this location is known to be most vulnerable to impacts from passing vessel activities during

present day conditions due to the close proximity of private homes and bulkheads to the channel.

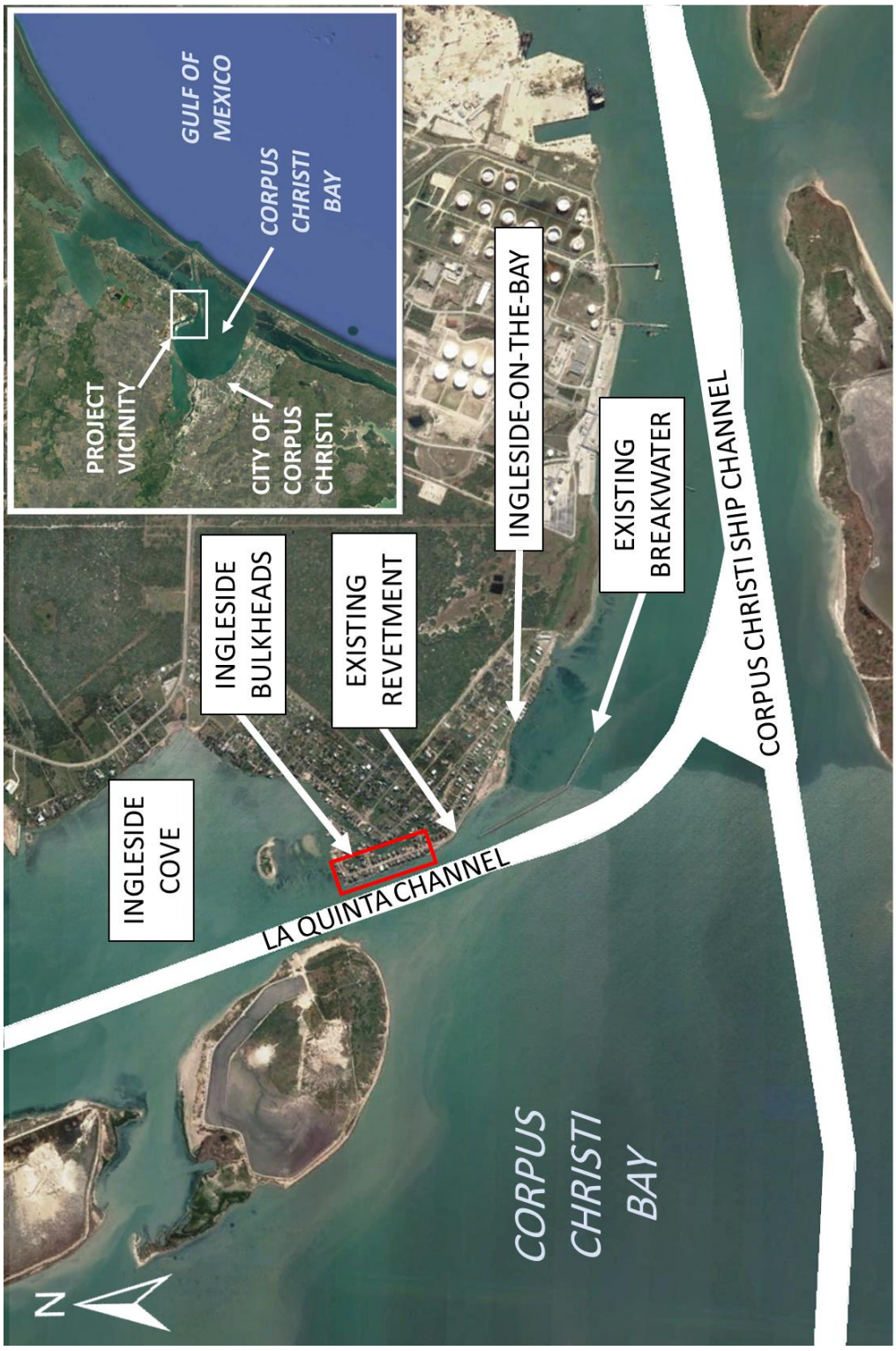

Figure 1. Project location overview.

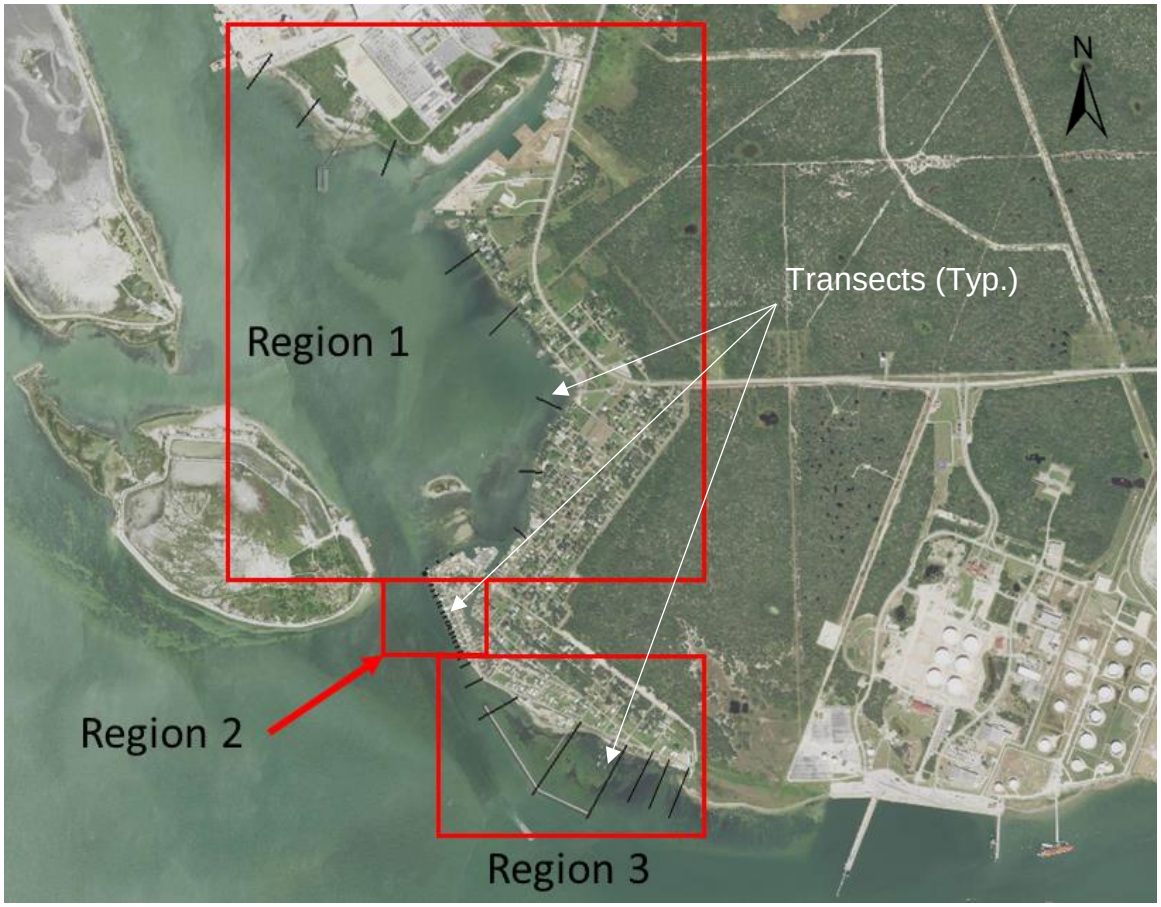

Figure 2. Aerial image of the project site and the three regional coverages developed for analyzing results.

1.3 Proposed Channel Developments

The potential impacts of vessel-induced hydrodynamics within the project area due to three different proposed conditions are evaluated in this study. The three proposed conditions, along with a description of each, are listed below:

- Proposed Condition A: CCSC deepening/widening from its existing condition depth of -45 ft MLT and bottom channel width of 400 ft.
  - The CCSC is deepened to a total depth of 55 ft (i.e., 55 ft below MLT). This depth includes a 54 ft design dredge depth plus 1 ft of overdredge (which is half of the 2 ft overdredge tolerance). The CCSC is also widened to a channel bottom width of 530 ft. In addition to the channel bottom widening, 200 ft barge channels are added to both sides of the CCSC channel at an elevation of -12 ft MLT beginning at the LQC junction and extending westerly.

- Proposed Condition B: CCSC deepening/widening with BUS C-Q
  - In addition to the CCSC deepening/widening, the beneficial use site (BUS) C-Q is constructed in the bay area that is west of the LQC and CCSC intersection point. The constructed BUS C-Q consists of a U-shaped outer protection berm and an interior backfill area. For the purpose of this study, the analysis was performed using a protection berm crest elevation above +9.0 ft

MLT, and an interior backfill area that is uniformly set to elevation -1.0 ft MLT. The crest elevation was set to eliminate any potential overtopping of the structure for this analysis. Since the exact location of the proposed BUS C-Q is yet to be determined, the location used in this study is approximate.

- Proposed Condition C: CCSC deepening/widening with BUS C-Q and BUS I-C
  - In addition to the CCSC deepening/widening and the BUS C-Q, a second beneficial use site, BUS I-C, is constructed in Ingleside Cove, west of the LQC. BUS I-C is also constructed in a U-shape, with an outer protection berm and an interior backfill area. For the purpose of this study, the analysis will be performed using a protection berm crest elevation of +5.5 ft MLT, and a uniform interior backfill area elevation of -1.0 ft MLT. Similar to BUS C-Q, the exact location of BUS I-C is yet to be determined, thus the location used in this analysis is approximate.

1.4 Additional Analysis

In addition to evaluating the potential impacts on vessel-induced hydrodynamics within the project area due to the three proposed conditions, further analysis was performed to evaluate: (1) how future water level conditions will impact the observed results; and (2) how mitigation measures may impact the observed results.

1.4.1 Future Water Levels

To evaluate impacts due to future water level conditions, hydrodynamic modeling runs were performed for the two following scenarios:

- Future Water Level Condition A: an elevated tidal event
- Future Water Level Condition B: a water level that incorporates sea level rise for the year 2040.

Specific water level values for both of these scenarios are investigated and determined in Section 2. Note that properties adjacent to the Ingleside-on-the-bay shoreline may be vulnerable to flooding due to projected relative sea level rise, normal astronomical tides, and other meteorological events. This study only focused on the possible flooding and impacts due to passing vessels at future water levels but does not assess coastal impacts from wind waves and high tides which may result in similar or greater impacts to the shoreline than the results from passing vessels under the modeled conditions.

1.4.2 Mitigation Measures

Since specific areas within the project site are known to be vulnerable to passing vessel activities under normal/present-day conditions, mitigation measures were developed to test if the passing vessel impacts could be reduced. A total of three mitigation measures were developed for investigation. Note that the purpose of this study was to evaluate the potential impacts to passing vessel hydrodynamic conditions of the mitigation measures tested, the actual feasibility of these measures was not evaluated under this study. These potential mitigation measures are listed and discussed below:

- Potential Mitigation Measure A: Increase cap elevations of Bayshore Drive bulkheads/retaining walls
  - The purpose of this mitigation measure would be to prevent overtopping at the bulkheads/retaining walls along the waterfront properties along Bayshore Drive caused by passing vessel scenarios evaluated during this study. The

proposed new cap elevation for the bulkheads/retaining wall shall exceed the highest water surface elevation that results within this area (referred to as Region 2) from the passing vessel simulations with proposed conditions.

- Potential Mitigation Measure B: Reduce vessel speeds to 4 knots
  - It was anticipated that the intensity of the vessel-induced hydrodynamics can be dampened by reducing the vessel's speed, thus reducing the risk of overtopping at the waterfront properties adjacent to the shipping channel. As such, a reduced speed of 4 knots will be evaluated. Note, that reduced speeds hinder the maneuverability of the vessels which may not be feasible or may require the use of tug boats for the safe transit of vessels along the area. However, note that even the use of tug boats may not be feasible due to limited navigation room. The purpose of this analysis is only to assess the effects on vessel hydrodynamics and does not assess the feasibility of this measure based on vessel maneuverability and operation.

- Potential Mitigation Measure C: Install protection structure seaward of Bayshore Drive bulkheads
  - This mitigation measure involves extending/elongating the existing breakwater structure towards the northwest. The structure would extend up to the northern-most end of Bayshore Drive. The purpose of the emergent breakwater would be to intercept the passing vessel wakes and reduce the wave and surge energy experienced at the shoreline. The proposed breakwater could be constructed of sheet piling and batter piles, but this would be evaluated at a later point in time. The crest elevation of the structure would also be determined during the future detailed analysis, but it is expected that the crest would be similar to the existing breakwater (+6 ft MLT). It is important to note that this mitigation measure may result in additional impacts to the channel, environment (such as circulation and seagrass), and adjacent residential properties and recreational access to the channel, which are not assessed in this study. These impacts should be fully evaluated in the next phase of the project.

2 Water Level Conditions Analysis

The purpose of performing a water level conditions analysis was to evaluate current and future water level scenarios for use in the vessel hydrodynamics modeling runs. This section discusses the water level analyses and conditions; more details on which water level values are used in each specific model run is discussed later in Section 4.

2.1 Tidal Datum

The local tidal datum for this project area was established during one of the PCCA's previous projects within the same location and is documented in CHE (2014). The local tidal datum established in CHE (2014), which utilizes the local NOAA tidal station at Port Ingleside, is provided in Table 1 below. As noted in the table, the mean sea level (MSL) for is this site is 1.7 ft MLT, so all the vessel hydrodynamic modeling runs (expect for those used for evaluating impacts of future water level conditions) were simulated with an initial water level of 1.7 ft MLT. Furthermore, knowing the tidal datum at the site enables us to properly evaluate potential impacts of the vessel induced hydrodynamics because it provides a basis of comparison against normal (daily observed) water elevations.

Table 1. Local tidal datum for the project site in Corpus Christi Bay (obtained from CHE (2014).

Water Datum	Elevation (ft MLT)
Mean Higher High Water (MHHW)	1.9
Mean Sea Level (MSL)	1.7
Mean Lower Low Water (MLLW)	1.3
NAVD88	1.0
USACE Mean Low Tide (MLT)	0.0

2.2 Extremal Water Levels

An extremal analysis of water levels was performed to identify a reasonable elevation to be used for testing the impacts of future water level conditions on the observed results from the vessel hydrodynamic modeling. The extremal analysis was performed with all available water level data at the site and for water levels exclusively during September and October months (as the highest water levels primarily occur during these months) and is shown in Table 2. This table provides a select number of return periods, and their resulting water levels from the extremal analysis. A return period corresponds to a percent likelihood of the resulting event to occur in any given year (i.e., a 1-year return period has a 1/1 or 100% likelihood of occurring in any given year, while a 100-year return period has a 1/100 or 1% probability of occurring in any given year). The results show very little difference in return periods between the complete dataset and the Sep-Oct period. For comparison purposes only, reported water levels at Port Aransas reached an elevation of

approximately 7.3 ft MLT during Hurricane Harvey (Zelinsky, 2018). Hurricane Harvey was a Category 4 storm of a magnitude far exceeding the 33-year return period reported for the area by NOAA (NOAA, 2018f).

Table 2. Extreme values of water levels for the entire available record and for September & October months at the project site.

Return Period (years)	Resulting Water Level (ft MLT)	
	All Record	September-October
1	3.3	3.2
2	3.6	3.5
5	3.9	3.8
7.5	4.0	4.0
10	4.1	4.1
15	4.3	4.3
20	4.5	4.4
25	4.6	4.6
30	4.6	4.8

Notably high tides have recently impacted the project area with measured water levels consistently above +3 ft MLT at the NOAA USS Lexington Station from October 5, 2018 through October 16, 2018. On October 13th, water levels peaked at approximately +4.3 ft MLT. Per the results shown in Table 2, the October 13th, event corresponds to a 15-year return period water level event. Considering this event and its associated return period, the 5-year return period water level was then chosen for use in the hydrodynamic model runs for evaluating impacts under future water levels (for Future Water Level Condition A). The 5-year return period value of 3.9 ft MLT represents a reasonable high water level event that may be experienced relatively frequently.

2.3 Relative Sea Level Rise

Relative Sea Level Rise (RSLR) at the project site is also evaluated to test its impact on the observed results from the vessel-induced hydrodynamic modeling runs. RSLR changes in the observed local water level elevations over time and is a combination of eustatic sea level rise and local land subsidence. Long-term variations in sea level occur over various time scales, from years to centuries, and is a result of several factors, such as global climate change, variations in coastal and ocean circulation and temperature, vertical land motion, and the El Niño Southern Oscillation. Anthropogenic influences, such as groundwater and petrochemical extraction also contribute to the subsidence component of these variations.

The report by Nueces River and Corpus Christi and Baffin Bay Basin and Bay Area Stakeholder Committee (Nueces BBASC, 2012) estimated low, intermediate and high estimates of the sea level rise rates as 5.16 mm/year, 7.65 mm/year and 12.096 mm/year, respectively as applicable to the Nueces delta. Assuming these rates continue over the next two decades, the sea level in year 2040 will be higher by about 0.33 ft for low, 0.50 ft for intermediate and 0.79 ft for high estimates; however, since the creation of this report, newer and more accurate projections for global sea level rise have been made.

More recently, NOAA has developed their own projections and estimates for regional RSLR within the United States. There are two NOAA stations close to the project site that provide sea level rise protections: (1) the NOAA Bob Hall Pier Station, and (2) the NOAA Rockport Station. While the Rockport and Bob Hall Pier stations are a similar distance from the project site and sea level rise conditions may be different at the site due to local subsidence trends, the projections for the Rockport gauge were used in this analysis because that location is more representative of the tidal dynamics and sea level conditions at the project site.

The NOAA Rockport station documents a sea level rise trend of 5.58 mm/year, as shown in Figure 3 (NOAA, 2018e). The NOAA Rockport station also provides projection estimates for low, intermediate, and high sea level rise magnitudes (among others) for future years, up to the year 2100 (NOAA, 2018c), (NOAA, 2018d); these projections are shown in Figure 4. By converting these each to an average rate, the low, medium and high estimates for Rockport are 8 mm/year, 14 mm/year, and 28 mm/year, respectively.

Due to the age of the Nueces BBASC document, it is recommended that the more recent NOAA projections be used for this analysis. Table 3 shows the list of relevant sea level estimates from the NOAA Rockport source in year 2040, which assumes that the rates continue over the next two decades.

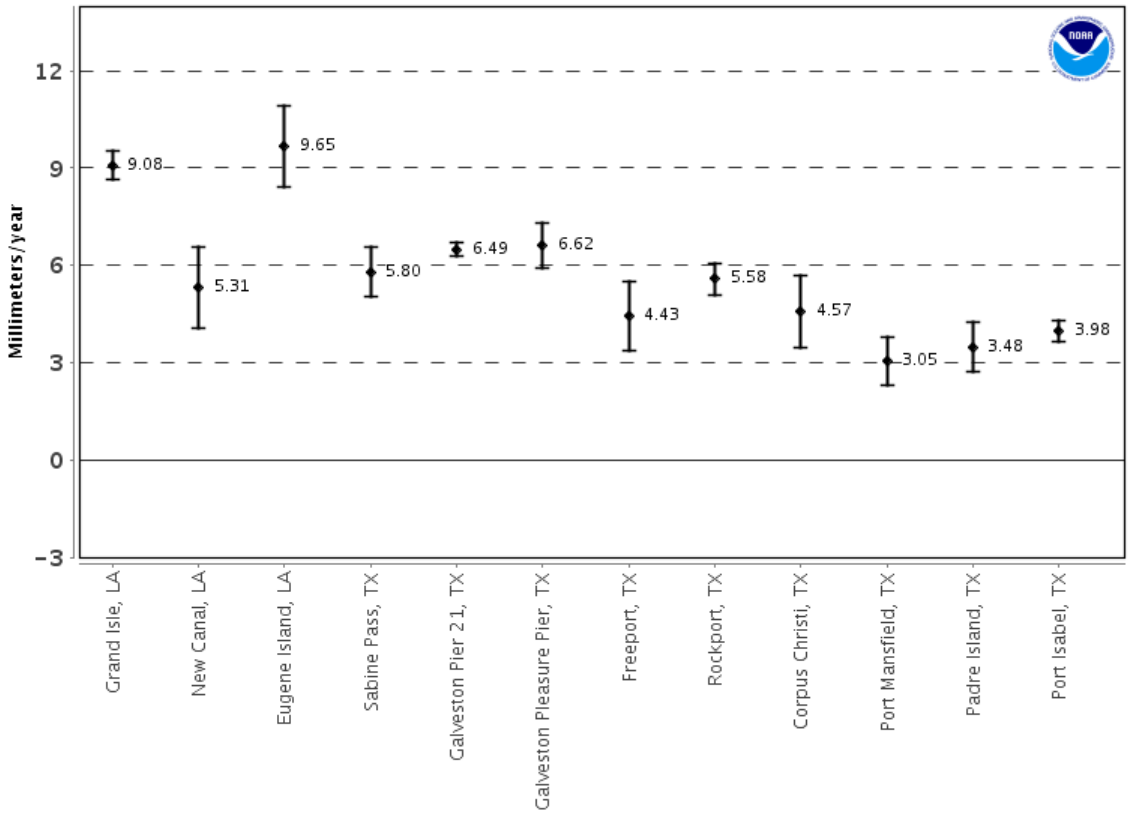

Figure 3. NOAA RSLR Trends for the Gulf of Mexico (NOAA, 2018e)

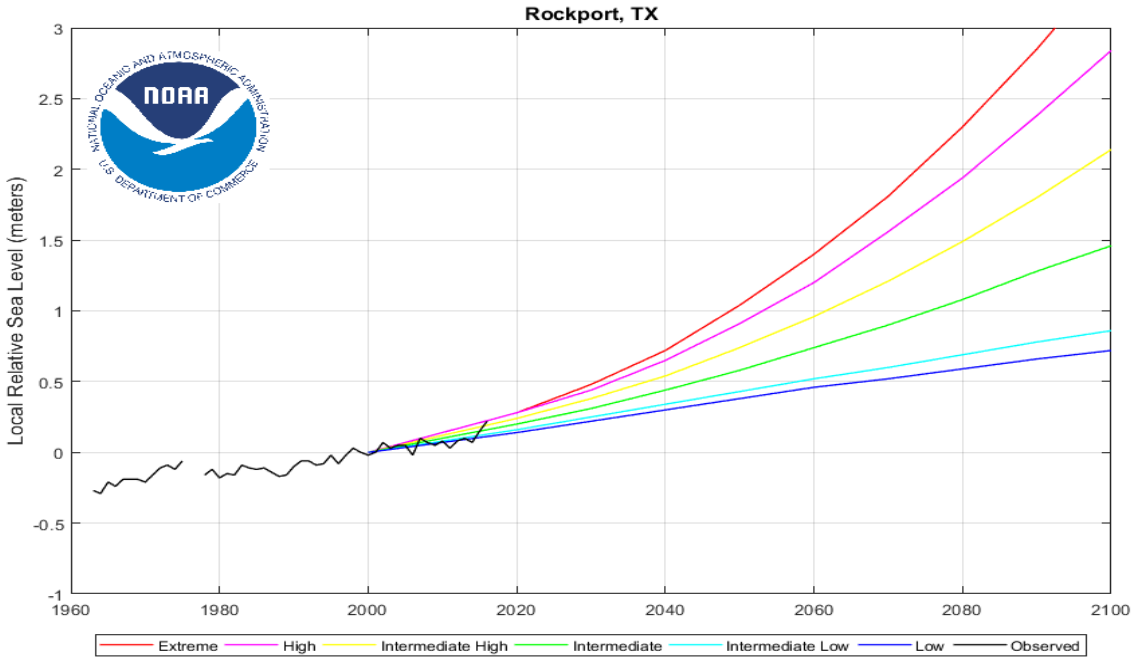

Figure 4. NOAA RSLR Projections for Rockport, TX (NOAA, 2018d)

Table 3. Estimated 20-year RSLR increments for the project site.

2040 Projection	NOAA Rockport
Low	0.52 ft
Intermediate	0.91 ft
High	1.83 ft

Since the goal of this study is not to predict actual sea level rise, but rather to identify the impacts to passing vessel conditions due to varying sea levels, which includes sea level rise, the intermediate 2040 value presented herein provides a sufficient value for this purpose. Thus, the hydrodynamic modeling run performed to test impacts of future water levels due to RLSR (Future Water Level Condition B) utilized a RSLR increment value of 0.91 ft in the simulation.

2.4 Water Level Conditions Summary

From the findings of the water level conditions analysis discussed above, the final three water level scenarios which were used in the vessel hydrodynamic modeling runs are as follows:

- Current Water Level Condition: Mean Sea Level (MSL)
  - Elevation = 1.7 ft MLT (or = 0.33 ft MLLW)

- Future Water Level Condition A: MSL + Relative Sea Level Rise (RSLR)
  - Elevation = 1.7 ft MLT + 0.91 ft = 2.61 ft MLT (or = 1.24 ft MLLW)

- Future Water Level Condition B: 5-yr Elevated Tide
  - Elevation = 3.9 ft MLT (or = 2.53 ft MLLW)

It is also important to understand the risk of overtopping at the Ingleside On-the-Bay properties due to environmental conditions only, such as elevated tides, storm events, wind driven waves, as these are events that occur regardless of passing vessel activity. Some of the waterfront properties within this location have bulkheads with a landward retaining wall; however, others only have a bulkhead (no retaining wall). See Figure 5 for an example of a bulkhead with a retaining wall versus just a bulkhead in Figure 6.

The properties at Ingleside On-the-Bay without retaining walls are more vulnerable to overtopping than those with bulkheads and retaining walls regardless of passing vessel effects. Of the properties with only bulkheads, the elevations of those bulkhead caps range from approximately 4 ft MLT to 6 ft MLT. As evident from the extreme water levels in Table 2, some of these properties will experience overtopping during 7.5-yr return period water level events and greater without the effects of any wind or passing vessel generated waves. At 4 ft MLT overtopping is likely for just a 1 ft wave at the shoreline for a 1-yr return period water level event (+3.3 ft MLT). Furthermore, the impact of RLSR will only increase the risk of overtopping under normal environmental conditions independent of passing vessels.

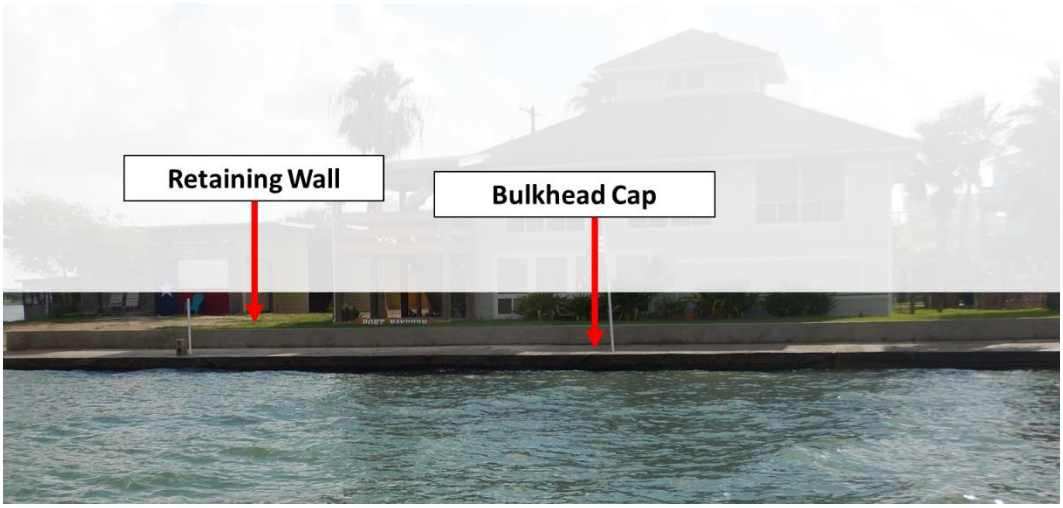

Figure 5. Example of a bulkhead with a retaining wall.

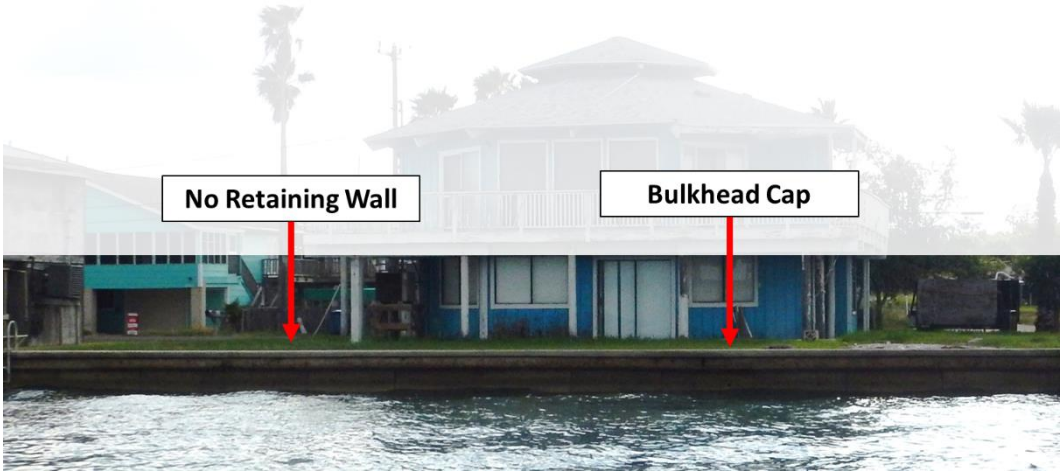

Figure 6. Example of a bulkhead only with no retaining wall.

3 Vessel Hydrodynamic Model

3.1 Description

This study was conducted using the two-dimensional (2D) Vessel Hydrodynamics Long-Unsteady wave (VH-LU) numerical model. VH-LU is a proprietary of Mott MacDonald. The VH-LU model is an advanced engineering tool that has been successfully applied for various projects in Gulf of Mexico, other regions of the U.S., and overseas. This model calculates the pressure field effects (i.e. drawdown) as deep draft vessels move through narrow waterways. As a ship moves through the channel, water rushes along its sides at relatively high velocities. The high current velocities cause low pressure along the side of the ship and high pressures at the bow and stern (Bernoulli Effect). The differences between water surface elevations at the bow (relatively high elevation), mid-ship (relatively low elevation), and stern (relatively high elevation) generates a long period wave (pressure field wave) that travels with the moving vessel.

The VH-LU model simulates the pressure field wave in the form of variations in the water surface elevation and velocities in the modeling domain during passage of a vessel through a channel. The vessel hydrodynamics modeling procedure consists of constructing a rectilinear modeling grid, developing of boundary and vessel input parameters, developing of modeling scenarios, actual modeling, and analysis of the output parameters.

3.2 Setup & Domains

Modeling vessel hydrodynamics with VH-LU requires a modeling grid that describes the bathymetry and ambient flow characteristics (where required) within the project vicinity (modeling domain). For this analysis, grid development utilized bathymetric data obtained by Mott MacDonald on August 27 through 29, 2018, which was combined with several publicly available bathymetric data sources including the latest navigation channel surveys from the US Army Corps of Engineers (USACE, 2018) and NOAA Digital Elevation Model data sets for the Corpus Christi area (NOAA, 2018g). These bathymetry sources provide the best available representation of the existing conditions at the site.

The compiled existing conditions bathymetry at the project site is shown in Figure 7. The elevation legend provides a color key for the shown contours. Note that while the legend indicates different colors shown for different depths up to 20 ft, this does not indicate that the max depth is 20 ft. Instead, this indicates that all depths exceeding 20 ft are shown as the same color – dark blue. The CCSC and LQC are in fact a minimum depth of 45 ft, at time of writing. It's also important to note that the existing breakwater structure, which is located on the eastern side of the LQC, is an important feature and is incorporated into the modeling grids. This breakwater has a crest elevation of +6 ft MLT; thus, it is always emergent (under normal conditions).

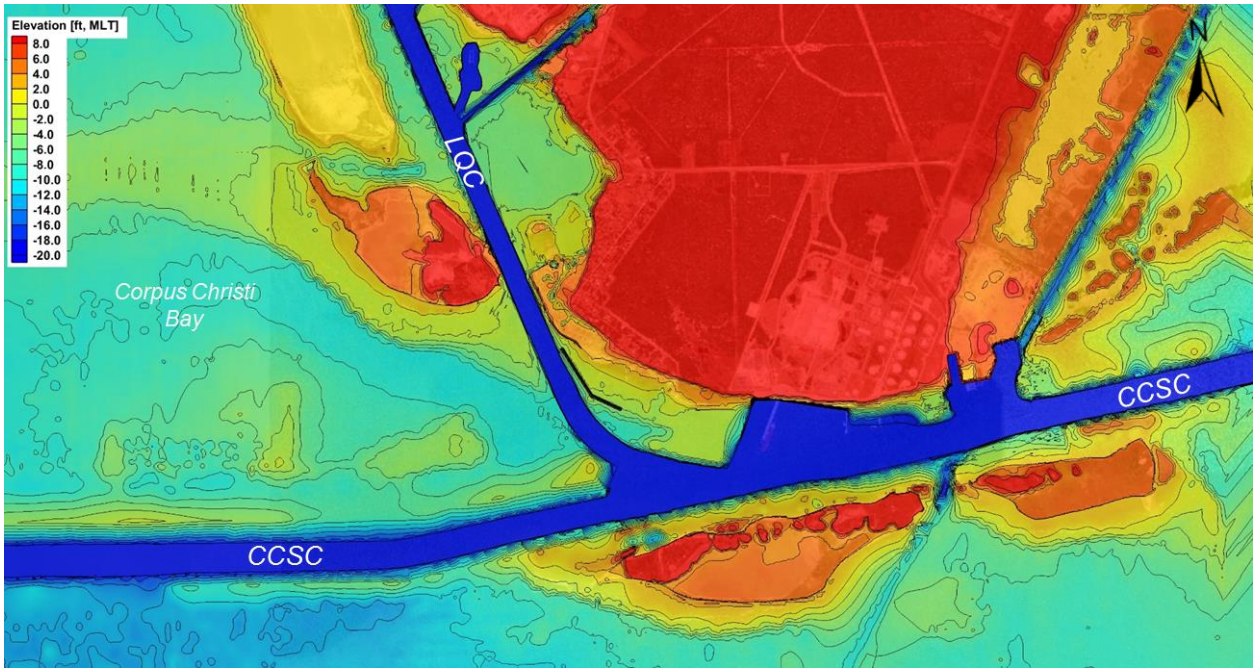

Figure 7. Compiled existing conditions bathymetry at the project site.

To perform the vessel hydrodynamic analysis in an efficient manner, vessel simulations through the LQC and through the CCSC were modeled separately. In other words, different modeling grids were developed and used for the LQC and CCSC simulations. Each LQC grid is a 2.5 m (8.2 ft) resolution grid with 617 cells in the x-direction and 2133 cells in the y-direction. Each CCSC grid has a 3.0 m (9.8 ft) resolution with 1865 cells in the x-direction and 890 cells in the y-direction. The size, extents, and resolution of these grids were selected to best optimize data size and processing, required model run time, and quality of results. The total list of modeling grids developed for the analysis is provided in the next section.

3.3 Individual Modeling Grids

Recall the project goals listed in Section 1.1. To evaluate each scenario identified in the project goals, modeling grids were developed separately for each. In summary, grids were developed for existing conditions, each of the three proposed conditions, future water level conditions, and for potential mitigation measures. This section describes each individual grid that was developed for the vessel hydrodynamic modeling runs. A total list of modeling runs is later provided in Section 4.

3.3.1 Existing Conditions

The LQC grid developed for existing conditions is shown in Figure 8, and the CCSC grid developed for existing conditions is shown in Figure 9. In these figures, the grids are overlaid onto an aerial image, the grid elevations are shown in colored contours, and the navigation channels are visually evident in dark blue. These grids were developed using the bathymetry shown in Figure 7 with no modifications to properly represent the existing conditions at the project site. Channel dimensions shown in the figures are approximate.

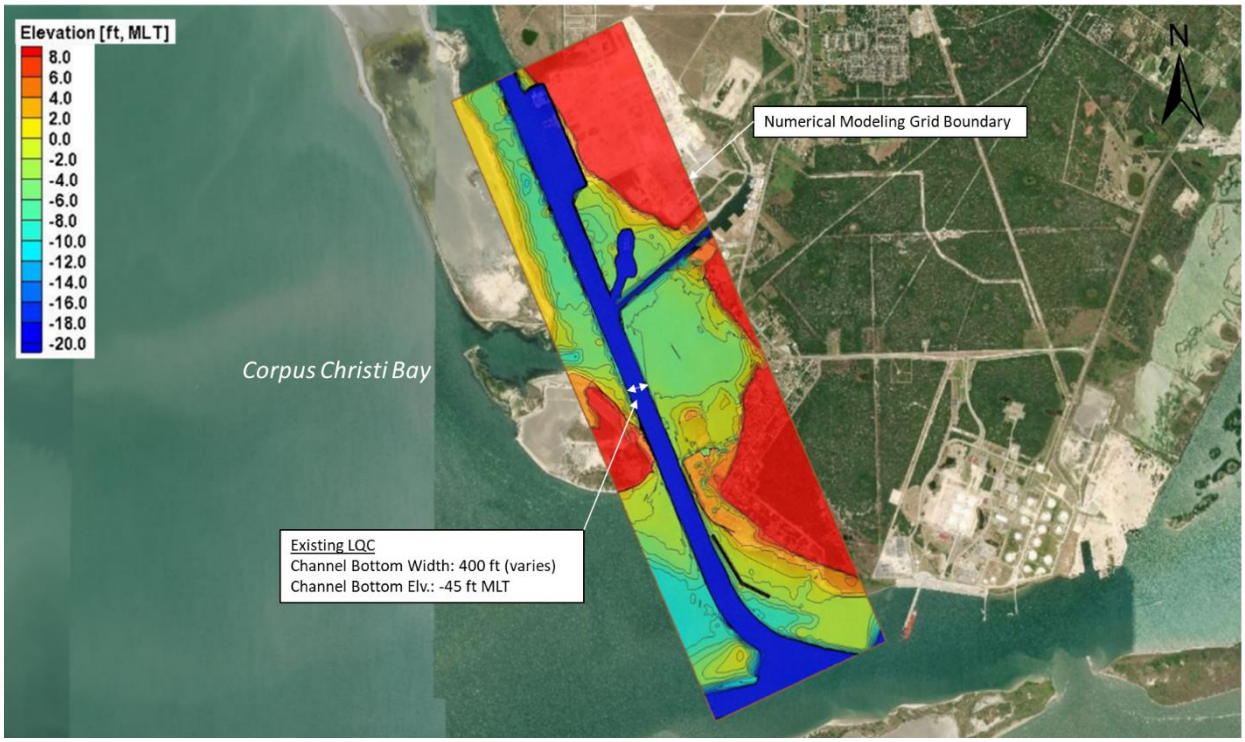

Figure 8. La Quinta Channel existing bathymetry grid.

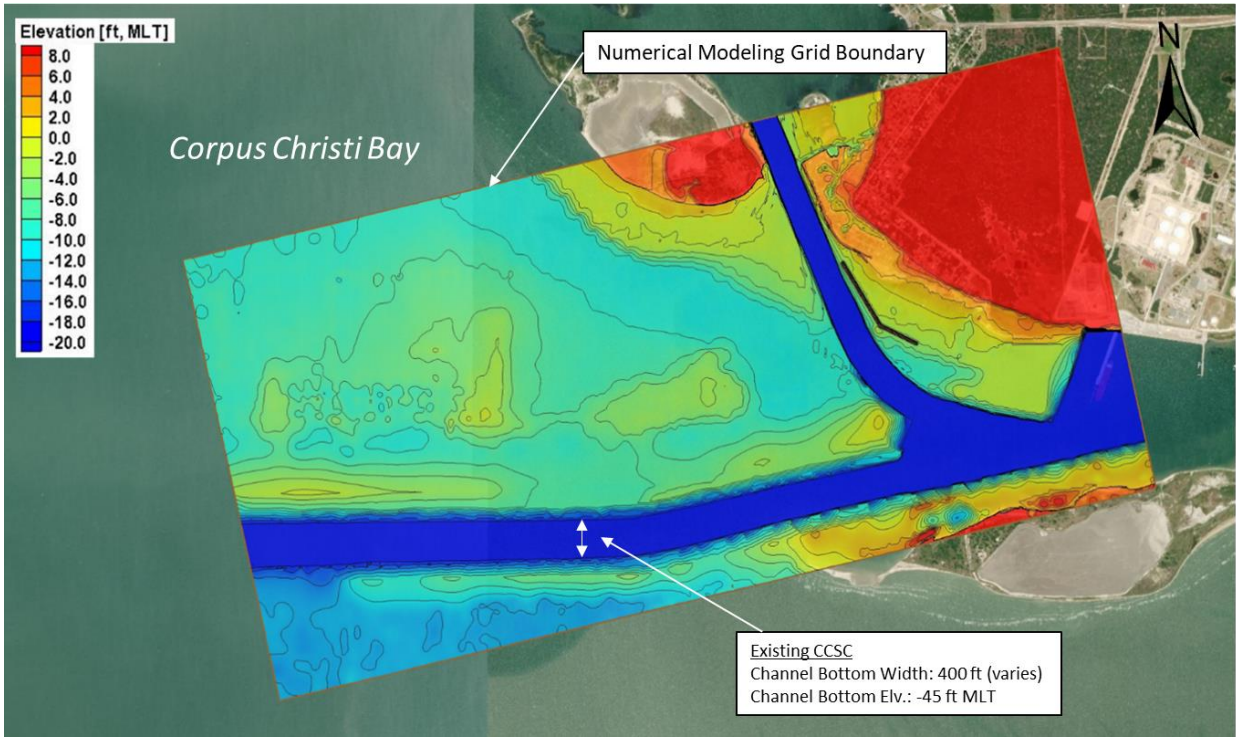

Figure 9. Corpus Christi Ship Channel existing bathymetry grid.

3.3.2 Proposed Condition A

The LQC and CCSC grids were developed to represent Proposed Condition A: CCSC widening/deepening. To develop these grids, the modifications were first applied to the existing bathymetry dataset and then interpolated onto the VH-LU grids. The grids for this condition are shown for the LQC and CCSC in Figure 10 and Figure 11, respectively. Note that the proposed CCSC depth of 55 ft below MLW includes the proposed required depth plus half of the overdredge tolerance.

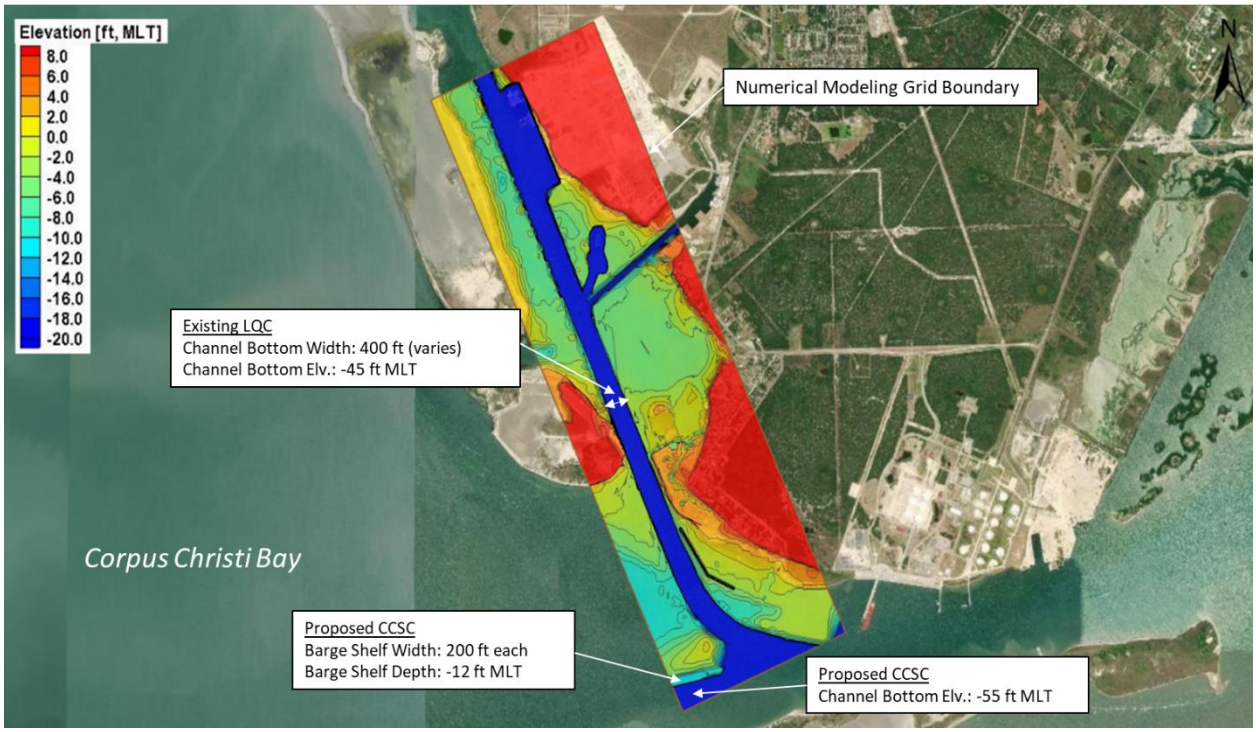

Figure 10. La Quinta Channel bathymetry grid including the proposed CCSC widening/deepening.

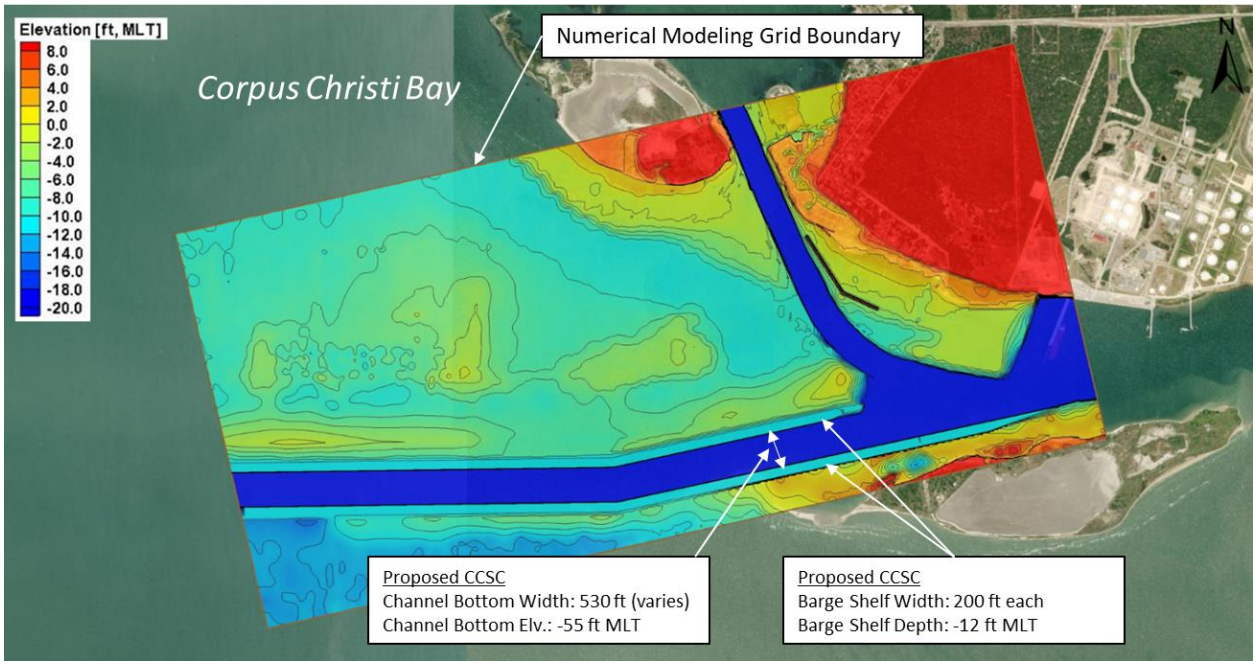

Figure 11. Corpus Christi Ship Channel bathymetry grid including the proposed CCSC widening/deepening, which includes barge shelves.

3.3.3 Proposed Condition B

The grids representing Proposed Condition B: CCSC widening/deepening with BUS C-Q, are shown for the LQC and CCSC in Figure 12 and Figure 13, respectively. The BUS C-Q is modeled as an impervious structure. Note that the location of BUS C-Q is approximate and subject to change throughout the development of final placement area design by others.

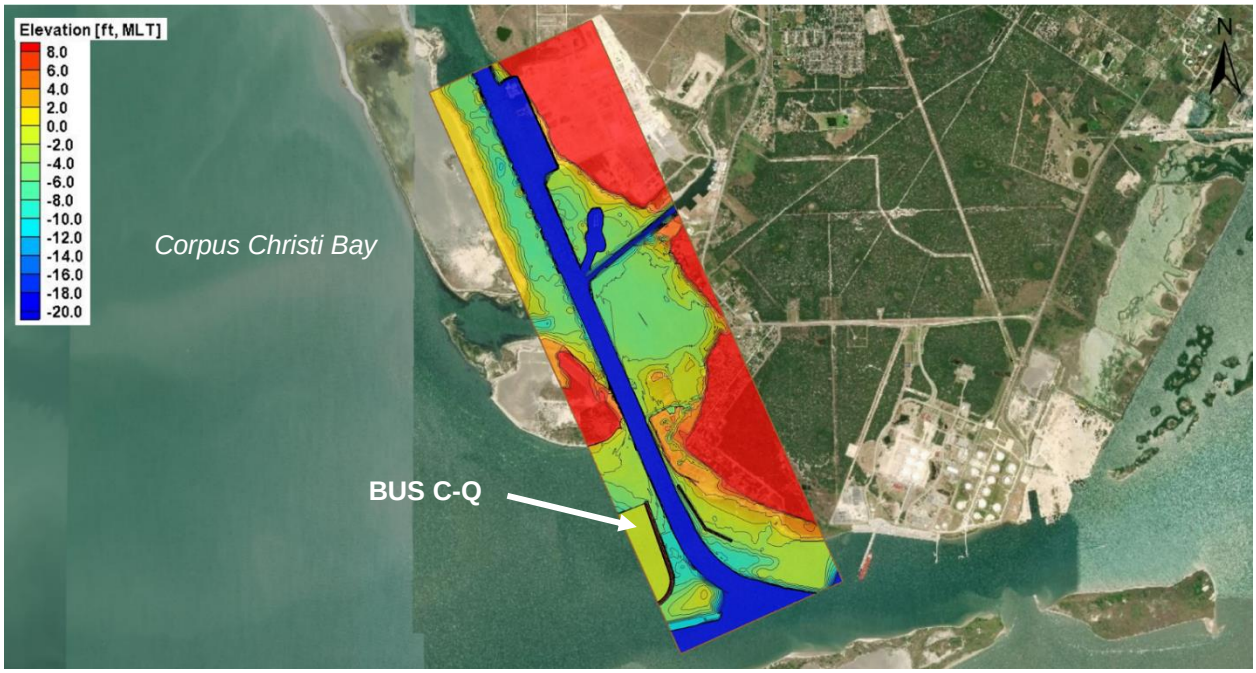

Figure 12. La Quinta Channel bathymetry grid including the proposed CCSC widening/deepening and the BUS C-Q.

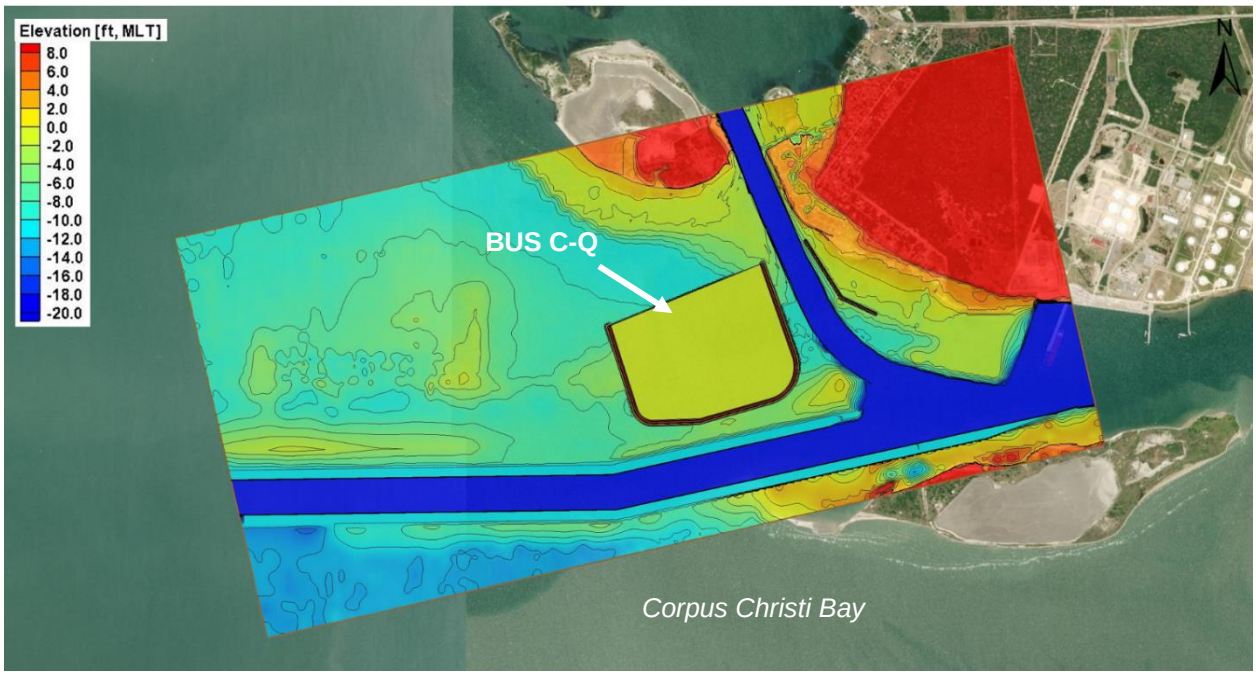

Figure 13. Corpus Christi Ship Channel bathymetry grid including the proposed CCSC widening/deepening and the BUS C-Q.

3.3.4 Proposed Condition C

Proposed Condition C: CCSC widening/deepening with BUS C-Q and BUS I-C, only affects the LQC grid, since the location of the BUS I-C is outside the extents of the CCSC grid. Thus, the LQC grid representing these proposed conditions is provided in Figure 14. The BUS I-C is modeled as an impervious structure. Note that the location of BUS I-C is approximate and subject to change throughout the development of final placement area design.

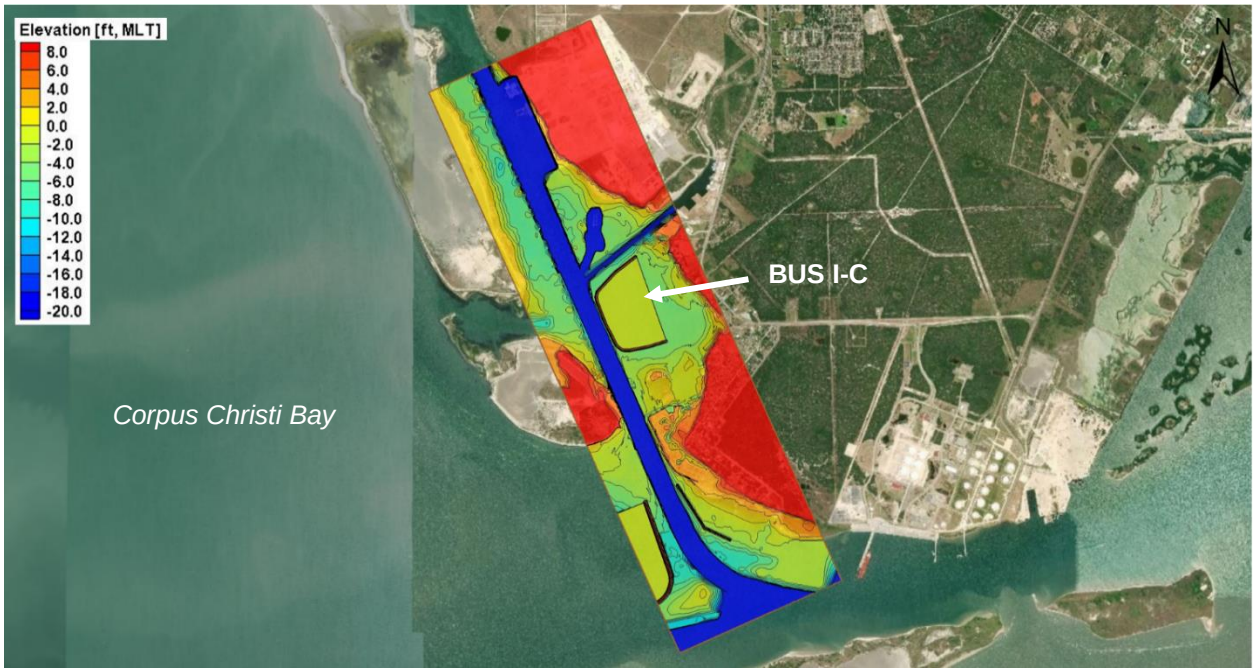

Figure 14. La Quinta Channel bathymetry grid including the proposed CCSC widening, the BUS C-Q, and the BUS I-C.

3.3.5 Future Water Level Condition A

The hydrodynamic modeling run performed to evaluate impacts due to Future Water Level Condition A (MSL + RSLR) does not require a new grid. Instead, this model run utilized the grid shown in Figure 14, which is the LQC grid for Proposed Condition C: CCSC widening/deepening with BUS C-Q and BUS I-C. As discussed later in Section 4, this grid is chosen for use in the future water level impact analysis runs since it best represents worst case scenario conditions for future years.

3.3.6 Future Water Level Condition B

Similar to the above-mentioned condition, analysis of Future Water Level Condition B (5-yr Elevated Tide) does not require a new grid, as this model run utilizes the LQC grid for Proposed Condition C: CCSC widening/deepening with BUS C-Q and BUS I-C.

3.3.7 Potential Mitigation Measure A

Potential Mitigation Measure A (increase bulkhead cap/retaining wall elevations of Region 2 bulkheads) does not need to be modeled in VH-LU since elevating the bulkhead caps does not impact the hydrodynamics of the passing vessels. To evaluate this mitigation measure, the results from proposed conditions model scenarios can simply be investigated

to determine the required bulkhead cap/retaining wall elevation to mitigate overtopping. Thus, no additional grid was created for this test.

3.3.8 Potential Mitigation Measure B

Potential Mitigation Measure B (reduce vessel speed to 4 knots) is simulated in VH-LU using the LQC grid for Proposed Condition C: CCSC widening/deepening with BUS C-Q and BUS I-C, which is discussed in Section 3.3.4; thus, no new grid was created for this simulation. This grid is chosen for use in the mitigation test runs since it best represents worst case scenario conditions for future years.

3.3.9 Potential Mitigation Measure C

Potential Mitigation Measure C (installation of protection structure seaward of Region 2 bulkheads), does require running VH-LU with a modified grid that includes the proposed breakwater structure; thus, a new grid was created for this simulation. An image of the grid developed for the breakwater mitigation measure test is provided in Figure 15; a zoomed in version at the extended breakwater is shown in Figure 16. The breakwater was integrated into the modeling grid as an emergent structure. The structure is modeled as a solid (non-porous) physical feature and was approximated as necessary within the model. Note that the grid also includes the CCSC channel widening/deepening, and the approximate locations of both BUS C-Q and I-C.

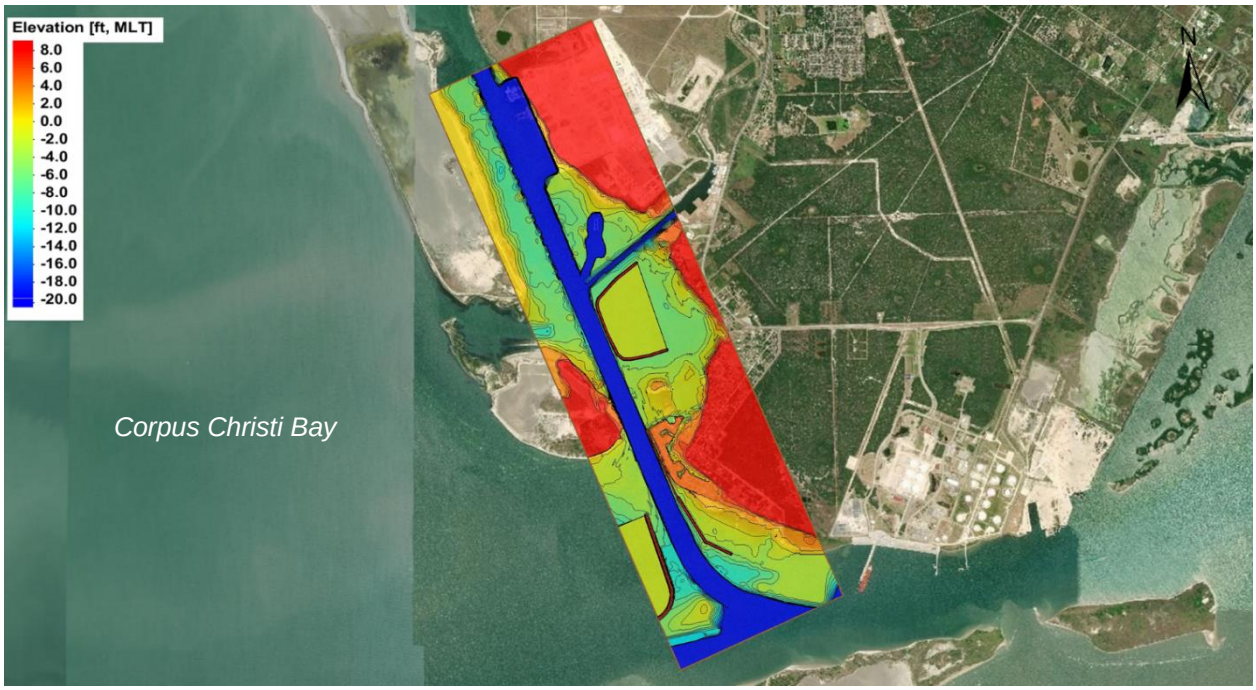

Figure 15. LQC grid developed for the breakwater extension mitigation test.

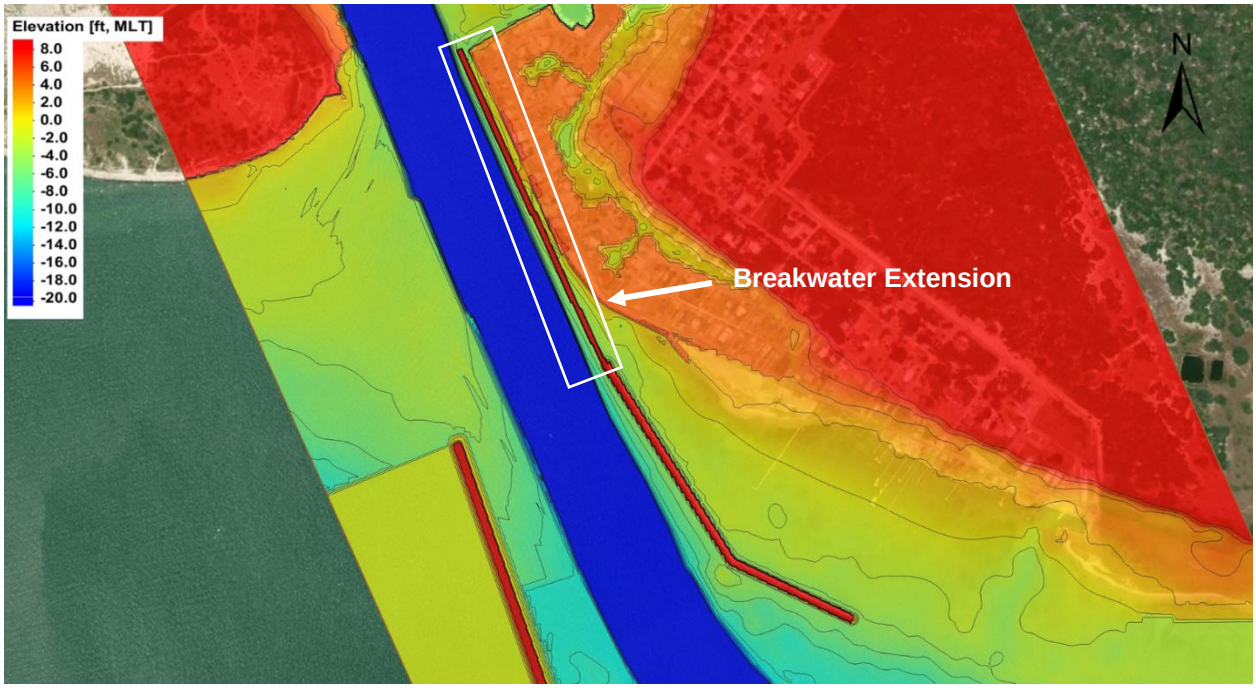

Figure 16. LQC grid developed for the breakwater extension mitigation test, zoomed into the location of the extended breakwater.

3.4 Validation

With any numerical model, validation is necessary to ensure the numerical model is accurately replicating real world conditions. While the VH-LU model has been well validated and applied hundreds of times, a validation model run was performed to replicate a recorded overtopping event at a property adjacent to the La Quinta Channel on Ingleside-on-the-Bay (see Figure 18 for the location). This overtopping event was captured on security camera footage as the vessel “Happy Albatross” passes within view of the camera. A still frame from the footage at the moment overtopping is observed is shown in Figure 17. The location of this camera relative to the property is shown in Figure 20. The footage provides critical information about the event including date, time, and the type of shipping vessel involved. Thus, the validation run was performed using parameter inputs determined from the available information that was documented by and/or could be inferred from, evidence within the video. Finally, the results of the model run were then visually compared to the observed overtopping recorded by the video.

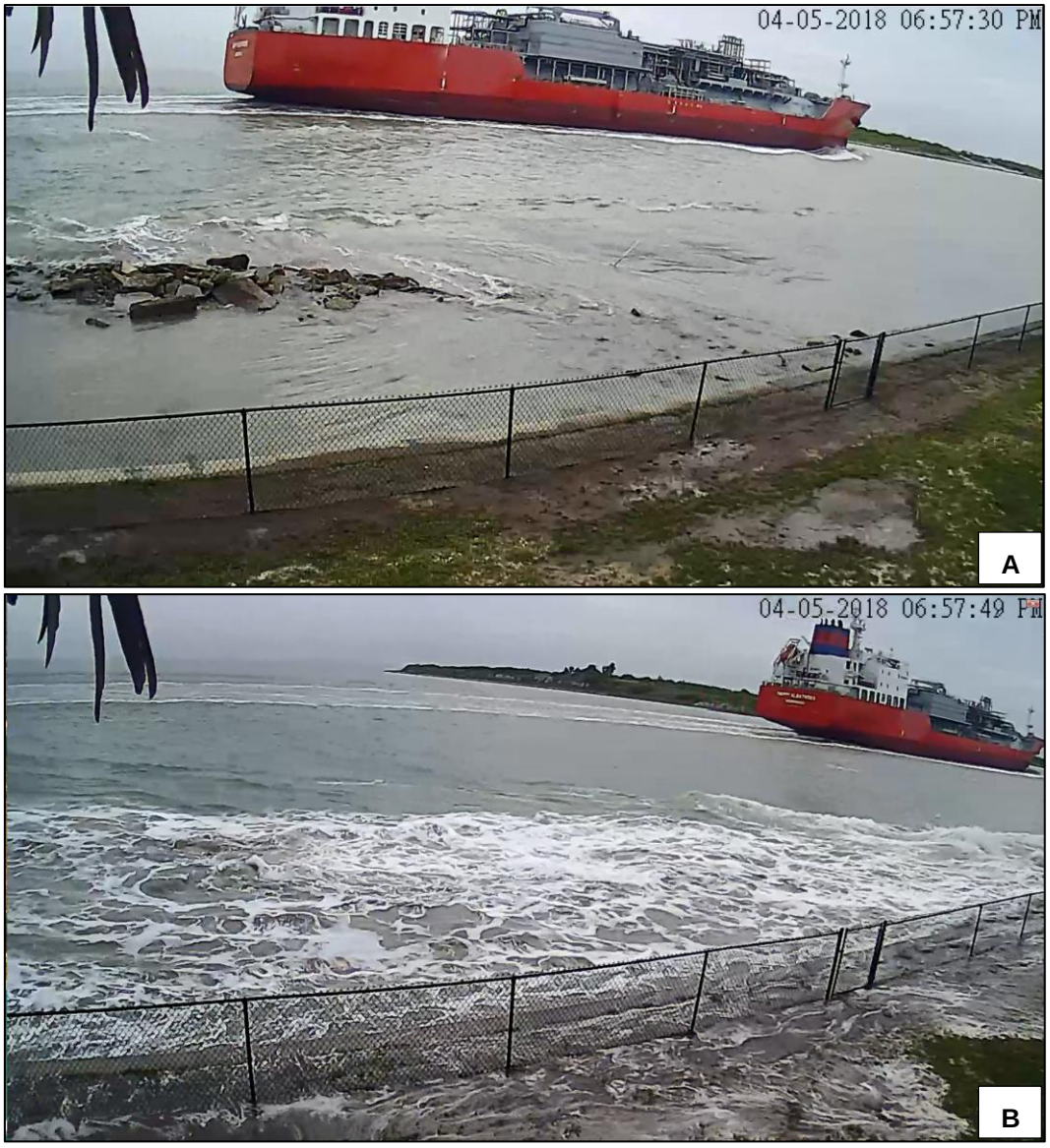

Figure 17. Still frame from the security camera (A) prior to and (B) at the point in time when overtopping is observed.

The security camera footage documents overtopping of the property's bulkhead as a ship passes through the channel. The video's date and timestamp showed that this event occurred on April 5, 2018 at 6:57 pm CST. Water levels were then obtained from adjacent tide stations and analyzed for the date and time of the vessel passing; it was determined that the water level was approximately +2.5 ft MLT (approximately 0.83 ft above MSL). The vessel name, type, dimensions, speed, and route of the passing ship were then collected from publicly available vessel Automatic Identification System (AIS) data. The AIS data showed that the vessel was travelling at an approximate speed of 9.5 knots as it is seen passing the property in the video. The route of the vessel is shown in Figure 18; as evident from this image, the route of the passing vessel (the Happy Albatross) was towards the eastern-most edge of the navigation channel. The video also showed that the ship was not fully loaded at the time of passing. Based on the AIS data it was determined that the

vessel draft was approximately 18.4 ft. A summary of these parameters, which were identified for the event from the video documentation is provided in Table 4.

Table 4. Overtopping event parameters used in the validation model run.

Ship Hull Type	Ship Name	LOA [ft]	Beam [ft]	Draft [ft]	Modeled Draft [ft]	Speed [kts]	Water Level [ft MLT]
LPG Tanker	Happy Albatross	480	74	31	18.4	~9.5	2.5

The validation run utilizes the LQC modeling grid with existing conditions. Figure 18 provides an aerial of the validation grid extents, with respect to the location of the overtopping event, channel, and vessel route. The topographical data implemented into the grid also includes elevations of the bulkhead caps and retaining walls along the local waterfront properties. The bulkhead at the specific property of interest, where the overtopping event occurred, has a cap elevation of 4.7 ft MLT. Figure 19 shows an image of this property, followed by an elevation profile view of the retaining wall and bulkhead cap elevations along all the waterfront properties within this area. This plot shows that the overtopped bulkhead (identified with the red circle) is relatively lower than the neighboring bulkhead caps and retaining wall elevations. These bulkhead survey datasets were collected by Mott Macdonald as part of this effort on August 27 through 29, 2018.

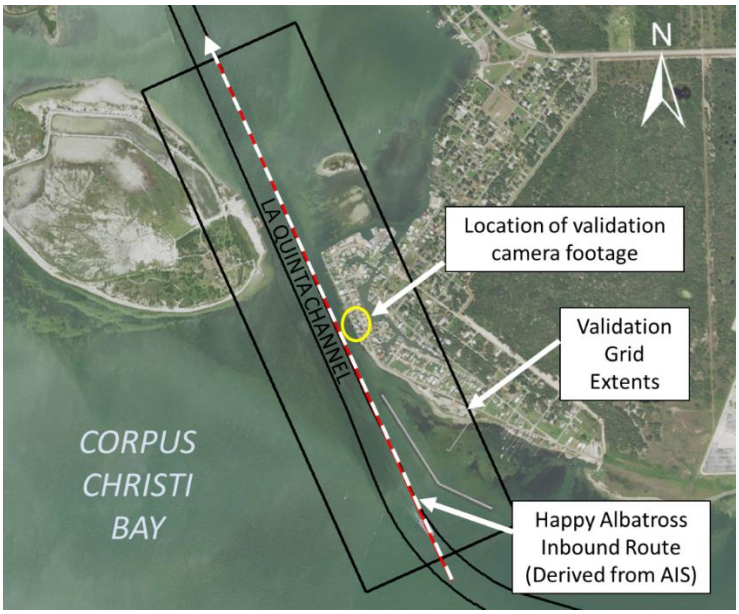

Figure 18. Validation model run grid extents, location of overtopping event (validation camera footage), and route of the passing vessel (the Happy Albatross).

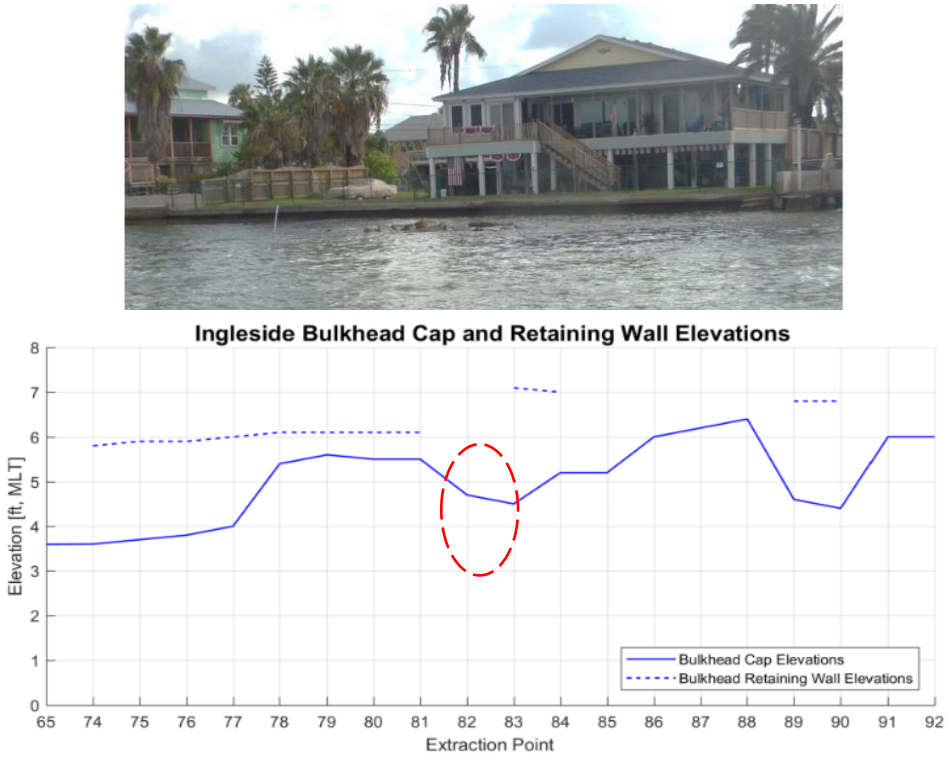

Figure 19. (Top) Image of the bulkhead at the property that was overtopped. (Bottom) Elevation profile view of the retaining wall and bulkhead caps along the local waterfront properties; the red, dashed circle identifies the elevation of the bulkhead cap at the property that was overtopped.

The VH-LU validation model run was simulated for approximately 11 minutes. This replicates the full duration over which the vessel passes the property; it also includes sufficient time before and after the overtopping incident, which properly simulates the water level starting from and return to normal conditions. Extraction points were located throughout the model's grid along the bulkheads and nearshore region of the waterfront properties. After running the model with the parameters identified in Table 4, the water surface elevation (WSE) timeseries results were inspected at each extraction point. At each extraction point, the WSE was compared to the associated bulkhead/retaining wall cap elevations in order to identify any evidence of overtopping.

After analyzing the results, it was found that the model simulated no overtopping at any of the waterfront properties except for the specific property of interest, where overtopping was recorded in the security camera video. These results properly represent what occurred in real-life, as the specific property of interest was the only location where overtopping was reported during this passing vessel event. The model results at Extraction Point 156, which is located at the bulkhead of the property of interest, is shown in Figure 20. In this figure, the left aerial image shows the locations of Point 156 and the property's camera. The right-hand plot shows the resulting timeseries of WSE at Point 156 and includes the bulkhead elevation. As evident from the plot, the model predicts overtopping at this location at around timestep 285 seconds.

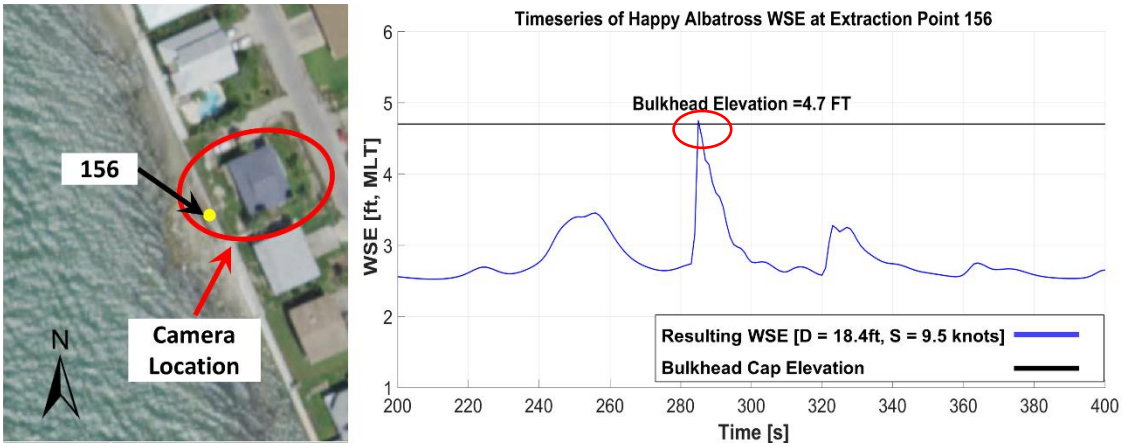

Figure 20. (Left) Aerial of the property that experienced overtopping at its bulkhead, and location of the data Extraction Point 156, where results were extracted from the validation model run. (Right) Validation model run results showing the timeseries of water surface elevation (WSE) at Point 156 as the vessel passed the property; overtopping is evident around timestep 285 s, where the WSE (blue line) surpasses the bulkhead cap elevation (black line).

The predicted overtopping at this property was further evaluated with aerial view model video simulations that were created using the resulting WSEs. A still-frame from the model simulation at the point in time when overtopping is predicted at the property's bulkhead is shown in Figure 21. The model video simulation was also evaluated against the video of the real-life overtopping that was captured in the security camera footage (refer to Figure 17). From the full analysis of the model run results, it was concluded that the predicted WSEs and overtopping event properly represented, and matched well with, the overtopping observed in the security camera footage. Thus, the results from this validation test further solidifies the accuracy of the VH-UL model and the relevant input parameters (i.e., bathymetry) for this project.

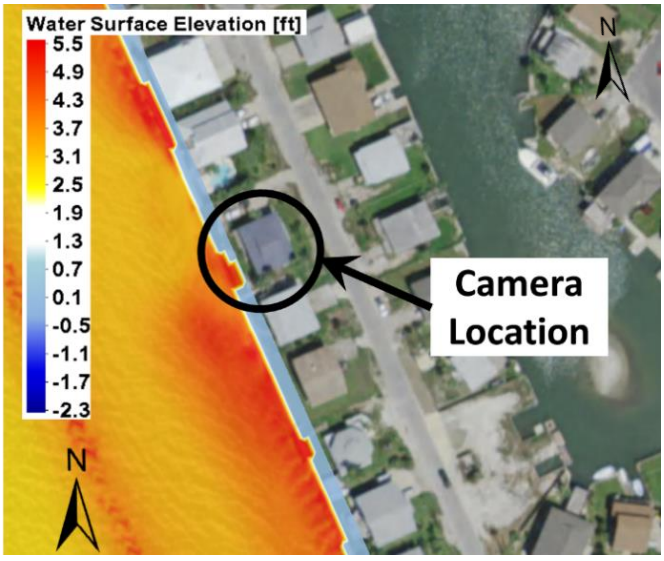

Figure 21. Still frame of model simulation water surface elevation as overtopping is experienced at the property's bulkhead.

4 Modeling Scenarios

4.1 Analysis Approach

To accurately evaluate the potential impacts of the three proposed conditions, future water level conditions, and potential mitigation measures within the project area, a comprehensive analysis approach has been developed. This approach is summarized in the following steps:

- Step 1. Develop a suite of testing vessels
  - Identify the largest vessels transiting through the La Quinta and Corpus Christi ship channels through analysis of AIS data and discussion with PCCA and pilots. These vessels are to be used in the VH-LU model runs.
- Step 2. Determine present-day level of impacts by vessel-induced hydrodynamics
  - Perform VH-LU model run using the suite of vessels with the existing conditions LQC and CCSC grids. Results from these model runs are to serve as a basis of comparison to understand and evaluate impacts from the proposed conditions, future water level conditions, and potential mitigation measures.
- Step 3. Determine vessel-induced impacts due to the proposed conditions
  - Perform VH-LU model runs using the suite of vessels with the LQC and CCSC grids for Proposed Conditions A, B and C. Compare results to those of the existing conditions model runs to assess changes and impacts.
- Step 4. Evaluate how future water level conditions will impact observed results
  - Perform VH-LU model runs using one representative vessel and conditions scenario* for Future Water Level Conditions A and B. Compare results to those of the exiting conditions model runs to assess changes and impacts.
- Step 5. Evaluate how mitigation measures impact results
  - Perform VH-LU model runs using one representative vessel and conditions scenario* for Potential Mitigation Measures A, B, and C. Compare results to those of the exiting conditions model runs to assess changes and impacts.

*The representative vessel and conditions scenario is determined after performing the VH-LU model runs with the proposed conditions (Step 3).

4.2 Vessel Suite

Three types of vessels were selected for modeling in VH-LU: (1) a Bulk Carrier; (2) a liquified natural gas tanker (LNG); and (3) a Suezmax Tanker. The Bulk Carrier and LNG Tanker are only to be simulated passing through the La Quinta Channel, while the Suezmax Tanker is to be simulated passing through both the La Quinta and Corpus Christi Ship Channels. The M/V Cap Pierre and M/V Castillo de Navia were identified as representative vessels that frequently navigate the Corpus Christi Ship Channel and La Quinta Channel for the Suezmax Tanker and Bulk Carrier, respectively. These vessels were selected based on discussions with the PCCA and Corpus Christi pilots and were determined to be representative of current and future vessels transiting within the vicinity of the project site.

Vessel speeds, routes, and drafts were determined using information derived from AIS data and as provided by the PCCA and Aransas-Corpus Christi Pilots. Speeds were held constant in the model, but it is important to know that vessel speeds are often variable in real-life conditions. LNG Tankers do not yet travel through the La Quinta Channel, and AIS data was not available for this vessel at the time of modeling. Therefore, the LNG Tanker parameters were determined using previous study results in coordination with the PCCA Project Manager and were based on assumptions that the route and speed would be similar to the Bulk Carrier and Suezmax Tankers. Shortly after the numerical modeling was completed, the LNG vessel FSRU Gola Tundra transited through the area in route to a new LNG facility near the San Patricio Turning Basin. This vessel has and LOA of approximately 960', beam of 143', which is generally consistent with the modeled vessel. Each vessel's parameters and speeds are listed in Table 5. This list represents the vessel suite which is to be used in the VH-LU modeling runs. Note that the vessel drafts used in this study are all based on loaded conditions. The study only utilizes the loaded conditions, for both inbound and outbound navigation, as this is representative of the worst-case scenario for passing vessel induced surges.

Table 5. Vessel parameters for VH-LU model runs.

Channel	Ship Hull Type	Ship Name	LOA [ft]	Beam [ft]	Draft [ft]	Modeled Draft [ft]	Speed [kts]
LQC	Bulk Carrier	Castillo De Navia	849	141	48	45	6
LQC	LNG Tanker	N/A	1000	150	40	40	6
LQC	Suezmax Tanker	Cap Pierre	900	157	50	45	6
CCSC	Suezmax Tanker – 45' Draft	Cap Pierre	900	157	50	45	11.5
CCSC	Suezmax Tanker – 52' Draft	Cap Pierre	900	157	50	52	11.5

This range of vessels identified for use in the VH-LU runs, represents the largest vessels that are expected to travel through this area, and therefore, represents the worst-case scenarios for passing vessel impacts. While each of these vessels do have different specific parameters, their speed and general dimensions are relatively similar; thus, similar results are expected among different vessel simulations (with the exception of the CCSC model runs, since those simulations utilize a much faster speed).

4.3 Modeling Scenarios

The following sections list each model run that was performed to evaluate the vessel-induced hydrodynamics within the project site under existing conditions, proposed conditions, future water level conditions, and potential mitigation measures.

4.3.1 Existing and Proposed Conditions

A list summarizing the total simulations performed with existing and proposed conditions provided in Table 6. This list of model runs is intended to be extensive. The full suite of vessels was simulated with each of the existing and varying proposed conditions to ensure that all possible worse-case events were evaluated. Performing such a comprehensive set of model runs helps to increase the level of confidence when identifying the controlling scenario, which was later used for testing future water level and mitigation measures.

Table 6. Existing and proposed condition runs analyzed with the VH-LU model.

Run ID	Run Direction	Channel	Ship Hull Type	Water Level [ft MLT]	CCSC Deepening/ Widening	Site C-Q	Site I-C
Existing Conditions Runs							
1	Inbound	LQC	Bulk Carrier	1.7’	Not present	Not present	Not present
2	Outbound	LQC	Bulk Carrier	1.7’	Not present	Not present	Not present
3	Inbound	LQC	LNG Tanker	1.7’	Not present	Not present	Not present
4	Outbound	LQC	LNG Tanker	1.7’	Not present	Not present	Not present
5	Inbound	LQC	Suezmax Tanker – 45’ Draft	1.7’	Not present	Not present	Not present
6	Outbound	LQC	Suezmax Tanker – 45’ Draft	1.7’	Not present	Not present	Not present
7	Inbound	CCSC	Suezmax Tanker – 45’ Draft	1.7’	Not present	Not present	Not present
8	Outbound	CCSC	Suezmax Tanker – 45’ Draft	1.7’	Not present	Not present	Not present
Proposed Condition A: CCSC Deepening/Widening Runs							
9	Inbound	LQC	Bulk Carrier	1.7’	Present	Not present	Not present
10	Outbound	LQC	Bulk Carrier	1.7’	Present	Not present	Not present
11	Inbound	LQC	LNG Tanker	1.7’	Present	Not present	Not present
12	Outbound	LQC	LNG Tanker	1.7’	Present	Not present	Not present
13	Inbound	LQC	Suezmax Tanker – 45’ Draft	1.7’	Present	Not present	Not present
14	Outbound	LQC	Suezmax Tanker – 45’ Draft	1.7’	Present	Not present	Not present
15	Inbound	CCSC	Suezmax Tanker – 45’ Draft	1.7’	Present	Not present	Not present
16	Outbound	CCSC	Suezmax Tanker – 45’ Draft	1.7’	Present	Not present	Not present
17	Inbound	CCSC	Suezmax Tanker – 52’ Draft	1.7’	Present	Not present	Not present
18	Outbound	CCSC	Suezmax Tanker – 52’ Draft	1.7’	Present	Not present	Not present
Proposed Condition B: CCSC Deepening/Widening with BUS C-Q							
19	Inbound	LQC	Bulk Carrier	1.7’	Present	Present	Not present
20	Outbound	LQC	Bulk Carrier	1.7’	Present	Present	Not present
21	Inbound	LQC	LNG Tanker	1.7’	Present	Present	Not present
22	Outbound	LQC	LNG Tanker	1.7’	Present	Present	Not present
23	Inbound	LQC	Suezmax Tanker – 45’ Draft	1.7’	Present	Present	Not present

Run ID	Run Direction	Channel	Ship Hull Type	Water Level [ft MLT]	CCSC Deepening/ Widening	Site C-Q	Site I-C
24	Outbound	LQC	Suezmax Tanker – 45' Draft	1.7'	Present	Present	Not present
25	Inbound	CCSC	Suezmax Tanker – 45' Draft	1.7'	Present	Present	Not present
26	Outbound	CCSC	Suezmax Tanker – 45' Draft	1.7'	Present	Present	Not present
27	Inbound	CCSC	Suezmax Tanker – 52' Draft	1.7'	Present	Present	Not present
28	Outbound	CCSC	Suezmax Tanker – 52' Draft	1.7'	Present	Present	Not present
Proposed Conditions C: CCSC Deepening/Widening with BUS C-Q and BUS I-C							
29	Inbound	LQC	Bulk Carrier	1.7'	Present	Present	Present
30	Outbound	LQC	Bulk Carrier	1.7'	Present	Present	Present
31	Inbound	LQC	LNG Tanker	1.7'	Present	Present	Present
32	Outbound	LQC	LNG Tanker	1.7'	Present	Present	Present
33	Inbound	LQC	Suezmax Tanker – 45' Draft	1.7'	Present	Present	Present
34	Outbound	LQC	Suezmax Tanker – 45' Draft	1.7'	Present	Present	Present
35	Inbound	CCSC	Suezmax Tanker – 45' Draft	1.7'	Present	Present	Present
36	Outbound	CCSC	Suezmax Tanker – 45' Draft	1.7'	Present	Present	Present

4.3.2 Future Water Level Conditions

The list of model runs performed to evaluate the identified future water level conditions is provided in Table 7. Note that Run No. 37 utilizes present day MSL as the input water level because this run is only used as a comparison tool to evaluate the results of Future Water Level Condition A: MSL + RSLR (Run No. 38), and Future Water Level Condition B: 5-yr return period Elevated Tide (Run No. 39). Note that the 5-yr return period Elevated Tide condition does not include RSLR.

As evident from the table, these model runs are only simulated with the LQC grid with Proposed Condition C: CCSC deepening/widening with BUS C-Q and BUS I-C and utilize the Bulk Carrier vessel heading inbound. This simulation serves as the representative scenario for all passing vessels studied in this analysis. Further discussed in Section 5, the results between different vessels are found to be relatively similar from the existing conditions and proposed conditions model runs, thus one scenario can be used for the future water level conditions and mitigation measure tests (rather than testing with the whole suite of vessels). However, when identifying this representative scenario, it should be noted that focus was placed on the section of shoreline along Bayshore Drive that is adjacent to the LQC (Region 2). In other words, this scenario was chosen to best evaluate

potential impacts within the project site, but specifically at the Bayshore Drive waterfront properties, because this location is known to be most vulnerable to impacts from passing vessel activities. Furthermore, by identifying one representative scenario, it was determined that future water level conditions and mitigation measure model runs with the remaining scenarios did not need to be simulated.

Table 7. Input parameters for the future water level conditions model runs.

Run ID	Run Direction	Channel / Grid	Ship Hull Type	Water Level	CCSC Deepening/ Widening	Site C-Q	Site I-C
37*	Inbound	LQC	Bulk Carrier	MSL (1.7 ft MLT)	Present	Present	Present
38	Inbound	LQC	Bulk Carrier	Future Water Level Condition A: MSL + RSLR (2.61 ft MLT)	Present	Present	Present
39	Inbound	LQC	Bulk Carrier	Future Water Level Condition B: Elevated Tide (3.9 ft MLT)	Present	Present	Present

*This simulation is the same as Run 29, and therefore, does not need to be simulated again. The results of this run are simply used as a basis of comparison for the following two runs.

4.3.3 Potential Mitigation Measures

The input parameters for three mitigation measure simulations are provided in Table 8. For descriptions of the potential mitigation measures, refer to Section 1.4.2. Similar to the future water level condition tests, the mitigation measure tests are only simulated with the representative vessel scenario (the LQC grid with the Proposed Condition C: CCSC deepening/widening with BUS C-Q and BUS I-C, with the Bulk Carrier vessel heading inbound). Each run was simulated with an initial water level at MSL (equivalent to 1.7 ft MLT).

Table 8. Input parameters for the three mitigation measure simulation tests.

Run ID	Run Direction	Channel / Grid	Ship Hull Type	Mitigation Measure	CCSC Deepening/ Widening	Site C-Q	Site I-C
40*	Inbound	LQC	Bulk Carrier	Mitigation Measure A: Elevate Bulkhead Caps in Region 2	Present	Present	Present
41	Inbound	LQC	Bulk Carrier	Mitigation Measure B: Reduce Vessel Speed to 4 knots	Present	Present	Present
42	Inbound	LQC	Bulk Carrier	Mitigation Measure C: Install Protection Structure (i.e., lengthen existing breakwater) Seaward of Region 2 Bulkheads	Present	Present	Present

*This simulation is the same as Run 29, and therefore, does not need to be simulated again. The results of this run are simply used as a basis for determining required bulkhead cap or retaining wall elevations above the existing elevations to prevent overtopping (Mitigation Measure A).

5 Results

To best evaluate the analysis results and assess potential impacts to the relevant shorelines, the project site was divided into three regions. Within each region, data extraction transects were overlaid on the grids at specific locations of interest. The transects were used to assess the bathymetry profile and resulting water surface elevations from each VH-LU simulation. The transect locations and numbering convention are shown for Regions 1, 2, and 3 in Figure 22. As visible in the figure, the transects extend from the offshore region to a sufficient distance onshore. This ensures that any potential overtopping is fully captured on the transects.

Following each VH-LU model run, the resulting water surface elevations (WSEs) along each transect were evaluated over the full timeseries. Profile simulation videos and snapshots were created for the transects to visually inspected how the WSEs change with time as the vessels pass. The maximum WSEs experienced at the shoreline over the full timeseries were extracted. The average maximum WSE value was then calculated for each region (using each region's total transects). These max WSE values for each modeled scenario are used to compare proposed conditions to the existing conditions and evaluate the potential impacts of the proposed conditions.

A summary of overall results from all the model runs is provided in the next section. More detailed discussions on the observed impacts from each of the proposed conditions, the future water level conditions, and the potential mitigation measures is then provided in the following sections.

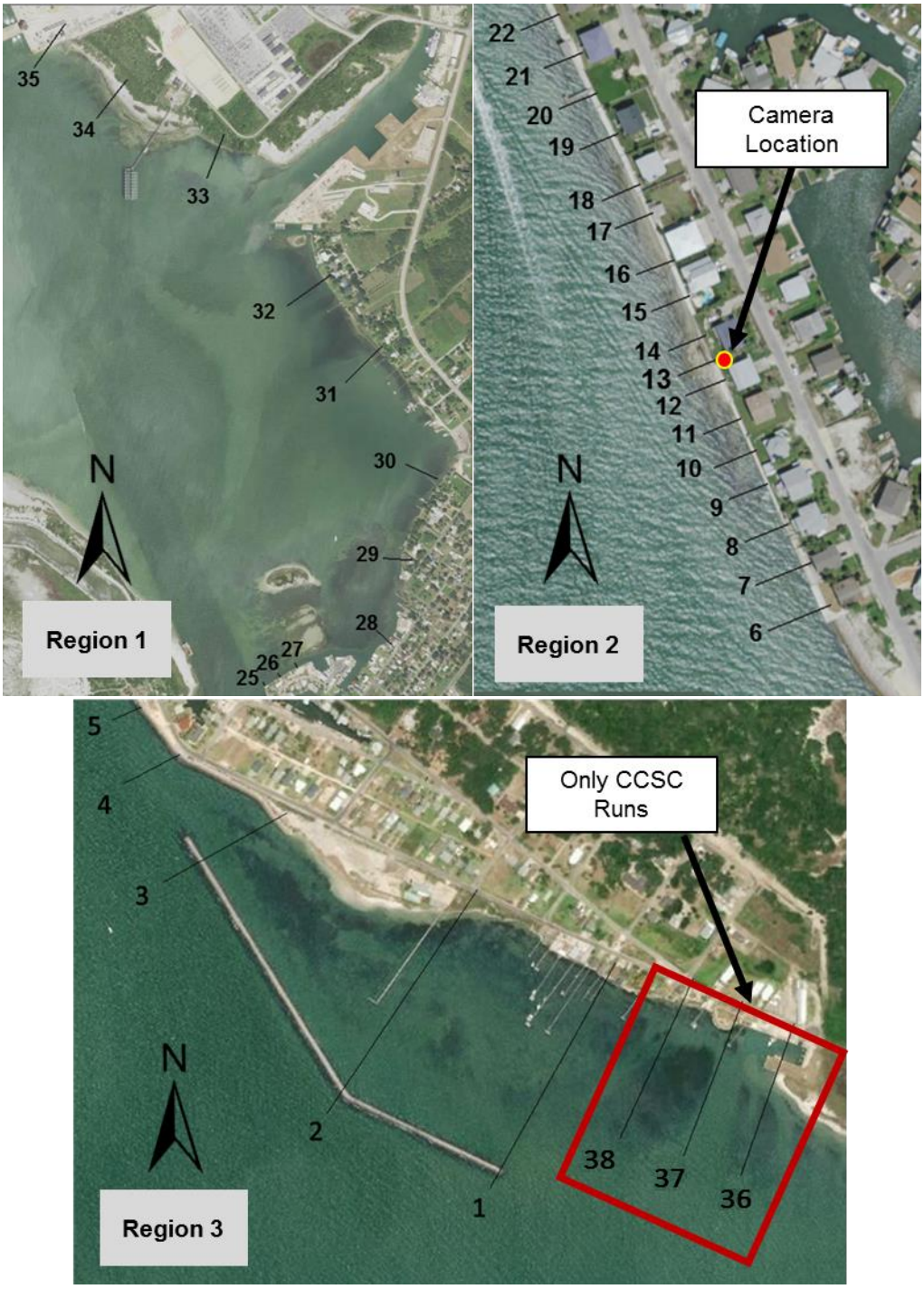

Figure 22. (Top Left) Data extraction transects 25 – 35 are located within Region 1. (Top Right) Transects 6 – 22 are located within Region 2. (Bottom) Transects 1 – 5 are located within Region 3. (Transects 23 and 24 were originally located within Region 1, but were determined to not offer value, and were therefore removed from the analysis.) Note that Transects 36 – 38 were added near the end of the analysis to specifically evaluate effects due to passing vessels in the CCSC.

5.1 Overall Results

The resulting average maximum WSE value for each region for each modeled existing condition simulation is shown in Table 9. These results, which are representative of the existing conditions, are used as a comparison tool to evaluate the results of the proposed conditions and identify any potential impacts. While the results between vessels simulates do vary for each Region, it is important to note that the overall difference in the average max WSE between vessel simulations in the LQC is relatively miniscule; the greatest difference in max WSE between LQC vessel simulations within Region 1, 2, and 3 are 0.26 ft, 0.16 ft, and 0.53 ft, respectively.

Table 9. Resulting average maximum water surface elevation (WSE) values by Region, for each existing conditions model run.

Run No.	Run Direction	Channel/ Grid	Ship Hull Type	Region 1 (Ingleside Cove) [ft MLT]	Region 2 (Bulkheads) [ft MLT]	Region 3 (Revetment & Breakwater) [ft MLT]
Existing Conditions Runs						
1	Inbound	LQC	Bulk Carrier	2.69	5.05	3.46
2	Outbound	LQC	Bulk Carrier	2.73	4.98	3.75
3	Inbound	LQC	LNG Tanker	2.64	4.91	3.30
4	Outbound	LQC	LNG Tanker	2.75	4.89	3.64
5	Inbound	LQC	Suezmax Tanker – 45’	2.80	5.01	3.49
6	Outbound	LQC	Suezmax Tanker – 45’	2.90	5.00	3.83
7	Inbound	CCSC	Suezmax Tanker – 45’	N/A	2.05	2.20
8	Outbound	CCSC	Suezmax Tanker – 45’	N/A	3.82	3.88

The resulting regional average maximum WSE value for each modeled simulation for Proposed Conditions A, B, and C is shown in Table 10. Notice that additional columns were added to this table; these “% Diff. from E.C.” columns show how much the resulting max WSEs from the proposed conditions differ from those of the exiting conditions (E.C.), shown in Table 9. However, since the Suezmax Tanker vessels were only simulated with a 45 ft draft in the existing conditions runs (because existing conditions is not deep enough to allow a 52 ft draft), the “% Diff. from E.C.” values for the proposed conditions with a Suezmax Tanker with 52 ft draft are calculated by comparing those results to the results of the Suezmax Tanker with 45 ft draft under existing conditions.

Within each region and for each proposed condition, the vessel simulations were compared against each other. The “% Diff. from E.C.” value associated with the vessel simulation that causes the greatest difference from its existing conditions run, is bolded and underlined (i.e., the greatest “% Diff. from E.C.” value among vessel runs within each proposed condition and region). For example, in Region 2, for the proposed CCSC deepening/widening condition, Run No. 17, with the Suezmax Tanker with 52 ft draft routed inbound along the CCSC, caused the average max WSE to increase by 3.8% from the Suezmax Tanker with 45 ft draft routed inbound simulation under existing conditions.

However, when evaluating the level of impact of each vessel simulation, the "% Diff. from E.C." value is not the only parameter to consider; it is also critical to evaluate the actual max WSE value. For example, while Run No. 17 did result in the greatest "% Diff. from E.C." value within Region 2 for that particular proposed condition, the average max WSE value associated with this simulation is only 2.12 ft MLT. Whereas, the average max WSE value for Run No. 9 in Region 2 is 5.07 ft MLT, and this is the greatest WSE value among all the simulations under the CCSC Deepening/Widening runs within Region 2. These max WSE values must be evaluated against the shoreline elevations to determine if overtopping is a risk. Therefore, for each Region and proposed condition, the highest average max WSE values are also bolded and underlined. Furthermore, the average max WSE value that is the greatest among all the proposed conditions for each region is indicated with an asterisk (*); this value is indicative of the worst-case scenario of all simulations in this study for each region.

Table 10. Resulting average maximum water surface elevation (WSE) values by Region, for each model run under the proposed conditions.

Run No.	Run Direction	Channel / Grid	Ship Hull Type	Region 1 (Ingleside Cove) [ft MLT]	Region 1 % Diff. from E.C.	Region 2 (Bulkheads) [ft MLT]	Region 2 % Diff. from E.C.	Region 3 (Revetment & Breakwater) [ft MLT]	Region 3 % Diff. from E.C.
Proposed Condition A: CCSC Deepening/Widening Runs									
9	Inbound	LQC	Bulk Carrier	2.69	0.1%	**5.07***	0.3%	3.46	0.1%
10	Outbound	LQC	Bulk Carrier	2.73	**0.2%**	4.98	0.0%	3.76	0.2%
11	Inbound	LQC	LNG Tanker	2.65	0.1%	4.91	0.0%	3.30	0.1%
12	Outbound	LQC	LNG Tanker	2.75	0.1%	4.90	0.1%	3.66	0.7%
13	Inbound	LQC	Suezmax Tanker – 45'	2.77	-1.0%	5.01	0.1%	3.49	0.2%
14	Outbound	LQC	Suezmax Tanker – 45'	**2.90***	0.1%	5.01	0.1%	3.85	0.6%
15	Inbound	CCSC	Suezmax Tanker – 45'	N/A	N/A	2.02	-1.4%	2.15	-2.1%
16	Outbound	CCSC	Suezmax Tanker – 45'	N/A	N/A	3.51	-8.0%	3.64	-6.1%
17	Inbound	CCSC	Suezmax Tanker – 52'	N/A	N/A	2.12	**3.8%**	2.33	3.1%
18	Outbound	CCSC	Suezmax Tanker – 52'	N/A	N/A	3.88	1.6%	**4.04***	**4.6%**
Proposed Condition B: CCSC deepening/widening conditions with BUS C-Q									
19	Inbound	LQC	Bulk Carrier	2.74	1.6%	**5.06**	0.1%	3.51	1.6%
20	Outbound	LQC	Bulk Carrier	2.73	0.1%	4.98	0.0%	**3.96**	5.6%

Table 10 continued.

Run No.	Run Direction	Channel / Grid	Ship Hull Type	Region 1 (Ingleside Cove) [ft MLT]	Region 1 % Diff. from E.C.	Region 2 (Bulkheads) [ft MLT]	Region 2 % Diff. from E.C.	Region 3 (Revetment & Breakwater) [ft MLT]	Region 3 % Diff. from E.C.
21	Inbound	LQC	LNG Tanker	2.69	**1.9%**	4.90	-0.2%	3.38	2.5%
22	Outbound	LQC	LNG Tanker	2.76	0.2%	4.90	0.1%	3.81	4.7%
23	Inbound	LQC	Suezmax Tanker – 45’	2.84	1.7%	5.05	0.9%	3.59	2.9%
24	Outbound	LQC	Suezmax Tanker – 45’	**2.90***	0.1%	5.01	0.1%	3.94	3.0%
25	Inbound	CCSC	Suezmax Tanker – 45’	N/A	N/A	2.06	0.5%	2.21	0.7%
26	Outbound	CCSC	Suezmax Tanker – 45’	N/A	N/A	2.66	-30.5%	2.94	-24.3%
27	Inbound	CCSC	Suezmax Tanker – 52’	N/A	N/A	2.67	**30.3%**	3.63	**60.6%**
28	Outbound	CCSC	Suezmax Tanker – 52’	N/A	N/A	2.86	-25.2%	3.51	-9.2%
Proposed Condition C: CCSC deepening/widening conditions with BUS C-Q and BUS I-C									
29	Inbound	LQC	Bulk Carrier	2.67	-0.6%	5.05	-0.1%	3.51	1.6%
30	Outbound	LQC	Bulk Carrier	2.65	-2.7%	4.98	0.0%	3.92	**4.5%**
31	Inbound	LQC	LNG Tanker	2.64	**-0.3%**	4.90	-0.2%	3.39	2.7%
32	Outbound	LQC	LNG Tanker	2.66	-3.4%	4.89	0.0%	3.79	4.1%
33	Inbound	LQC	Suezmax Tanker – 45’	**2.75**	-1.4%	**5.06**	**1.0%**	3.58	2.8%
34	Outbound	LQC	Suezmax Tanker – 45’	2.74	-5.2%	5.01	0.0%	**3.93**	2.5%
35	Inbound	CCSC	Suezmax Tanker – 45’	N/A	N/A	N/A	N/A	N/A	N/A
36	Outbound	CCSC	Suezmax Tanker – 45’	N/A	N/A	N/A	N/A	N/A	N/A

Of all the simulated runs for existing and proposed conditions, one specific run (vessel and conditions) was identified as a representative scenario. As previously mentioned, the purpose of identifying one representative scenario was so the future water level conditions and mitigation measure tests could be performed with a single vessel and conditions scenario. Overall, there is relatively little difference in results between vessel types. However, with that said, focus was placed on the section of shoreline along Bayshore Drive that is adjacent to the LQC (Region 2). In other words, the representative scenario was chosen based on its ability to allow for the best evaluation of potential impacts within

the whole project site, but specifically at the Bayshore Drive waterfront properties, because this location was identified as the most vulnerable to impacts from passing vessel activities. After this consideration, the representative scenario was chosen as Run No. 29: LQC grid with Proposed Condition C: CCSC deepening/widening with BUS C-Q and BUS I-C, and the Bulk Carrier vessel heading inbound. Thus, results for the future water level condition and mitigation measure tests using the representative scenario are provided in Table 11 and Table 13, respectively.

Table 11. Resulting average max WSE values per region for each of the evaluated Future Water Level Conditions.

Run No.	Water Level Condition	Region 1 (Ingleside Cove) [ft MLT]	Region 1 % Diff. from E.C.	Region 2 (Bulkheads) [ft MLT]	Region 2 % Diff. from E.C.	Region 3 (Revetment & Breakwater) [ft MLT]	Region 3 % Diff. from E.C.
37*	MSL (1.7 ft MLT)	2.57	-	5.18	-	3.40	-
38	Future Water Level Condition A: MSL + RSLR (2.61 ft MLT)	3.36	30.6%	5.30	2.4%	4.04	19.0%
39	Future Water Level Condition B: Elevated Tide (3.9 ft MLT)	4.51	75.6%	5.50	6.4%	4.94	45.5%

*Recall that Run No. 37 represents existing conditions and these results are simply used as a comparison to evaluate the results of the future water level conditions.

In addition to evaluating the resulting percent difference from existing conditions for the evaluated future water level conditions, the measured change in max WSE directly caused by the passing vessel was also evaluated for each scenario. These are provided in Table 12. These results show that the impact caused directly from the passing vessel decreases as the initial water level increases. However, the total impact due to the combination of the passing vessel activity with the elevated initial water level is still greater than that of existing conditions, thereby increasing the risk and vulnerability to overtopping at the shoreline adjacent to the channel – this is what is shown by the "% Diff. from E.C." values in Table 11.

Table 12. Resulting average max change in WSE per region for each of the evaluated Future Water Level Conditions.

Run No.	Water Level Condition	Region 1 Resulting Max Change in WSE [ft]	Region 2 Resulting Max Change in WSE [ft]	Region 3 Resulting Max Change in WSE [ft]
37*	MSL (1.7 ft MLT)	+0.87	+3.48	+1.7
38	Future Water Level Condition A: MSL + RSLR (2.61 ft MLT)	+0.75	+2.69	+1.43
39	Future Water Level Condition B: Elevated Tide (3.9 ft MLT)	+0.61	+1.6	+1.04

Table 13. Resulting average max WSE values per region for each of the evaluated Potential Mitigation Measures.

Run No.	Potential Mitigation Measure	Region 1 (Ingleside Cove) [ft MLT]	Region 1 % Diff. from E.C.	Region 2 (Bulkheads) [ft MLT]	Region 2 % Diff. from E.C.	Region 3 (Revetment & Breakwater) [ft MLT]	Region 3 % Diff. from E.C.
40*	Mitigation Measure A: Elevate Bulkhead Caps in Region 2	2.15	-	5.14	-	3.40	-
41	Mitigation Measure B: Reduce Vessel Speed to 4 knots	1.97	-8.2%	5.23	1.7%	3.23	-4.9%
42	Mitigation Measure C: Install Protection Structure (i.e., lengthen existing breakwater) Seaward of Region 2 Bulkheads	1.82	-15.3%	2.24	-56.4%	2.41	-29.0%

*Recall that Run No. 40 represents existing conditions and that the results of this run are simply used as a basis for determining required bulkhead cap elevations to prevent overtopping (Mitigation Measure A).

Refer to Figure 16 for an image of the modeling grid used to test Mitigation Measure C. Note the positive percent difference from existing conditions for Mitigation Measure B in Region 2; this indicates that the resulting average max WSE during this simulation was higher than that from the existing conditions simulation. This is likely due to the slower vessel speed creating a longer period bore wave that can more easily run up the shoreline within Region 2, thus magnifying the passing vessel effects in this case.

5.2 Proposed Condition A: CCSC Widening/Deepening

The results in Table 10 show that Proposed Condition A: CCSC Widening/Deepening, will cause a slight increase in max WSEs within the project area where the greatest impact occurs in Region 3; however, these increases are all less than 5 inches for the scenarios and locations analyzed:

- Within Region 1, the greatest resulting average max WSE is 2.90 ft MLT; this is only a 0.1% increase from existing conditions, which correlates to an increase in max WSE of 0.04 inches.
- Within Region 2, the greatest resulting average max WSE is 5.07 ft MLT, which is a 0.3% increase from existing conditions; this correlates to an increase in max WSE of 0.16 inches.
- Within Region 3, the greatest resulting average max WSE is 4.04 ft MLW; this is a 4.6% increase from existing conditions, which correlates to an increase of 4.67 inches. However, this observed result is likely due to the deeper draft on the simulated vessel since this max WSE value occurs in Run No. 18, which utilizes a 52 ft draft for the Suezmax Tanker. Whereas, Run No. 16, which used a 45 ft draft for the Suezmax Tanker under the same proposed conditions resulted in an average max WSE of 3.64 ft MLT, which is actually a decrease from existing conditions of 6.1% (correlates to a decrease in max WSE of 2.86 inches). Thus, it's possible that the deeper draft (52 ft) of the vessel is what causes such an increase in WSE, and not the CCSC Widening/Deepening conditions. Furthermore, it may be expected that Region 3 receives the greatest impact from the deeper draft vessels because the proposed deeper draft vessels only navigate through the CCSC and not the LQC.

It's important to note that values in Table 10, which are referenced above, are averages across all transects within each Region. Individual max WSE results at each transect per vessel simulation for Proposed Condition A: CCSC Widening/Deepening in Region 1 and Region 2 is shown in Figure 23 and Figure 24, respectively. Results for Region 3 are shown in Figure 25 and Figure 26. Note that several runs resulted in similar water surface elevations along the transects analyzed, thus the points shown on the figures may be overlapped and not visible.

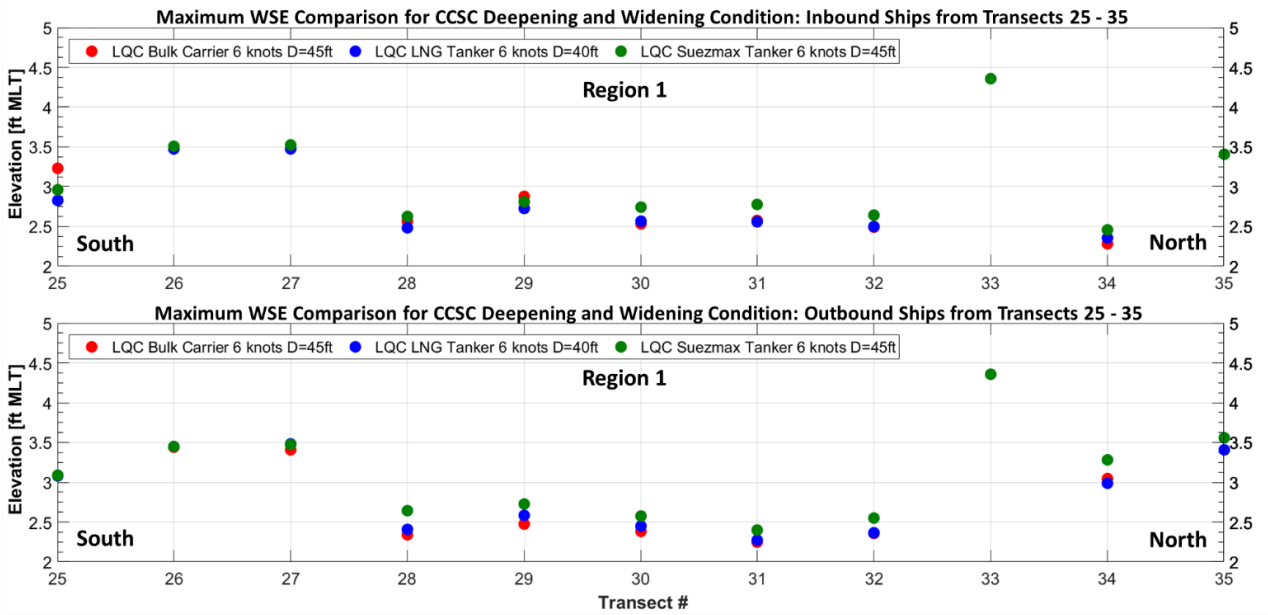

Figure 23. Resulting max WSEs per transect within Region 1 for the Proposed Condition A: CCSC widening/deepening. The WSE data points are color coded to the vessel simulation.

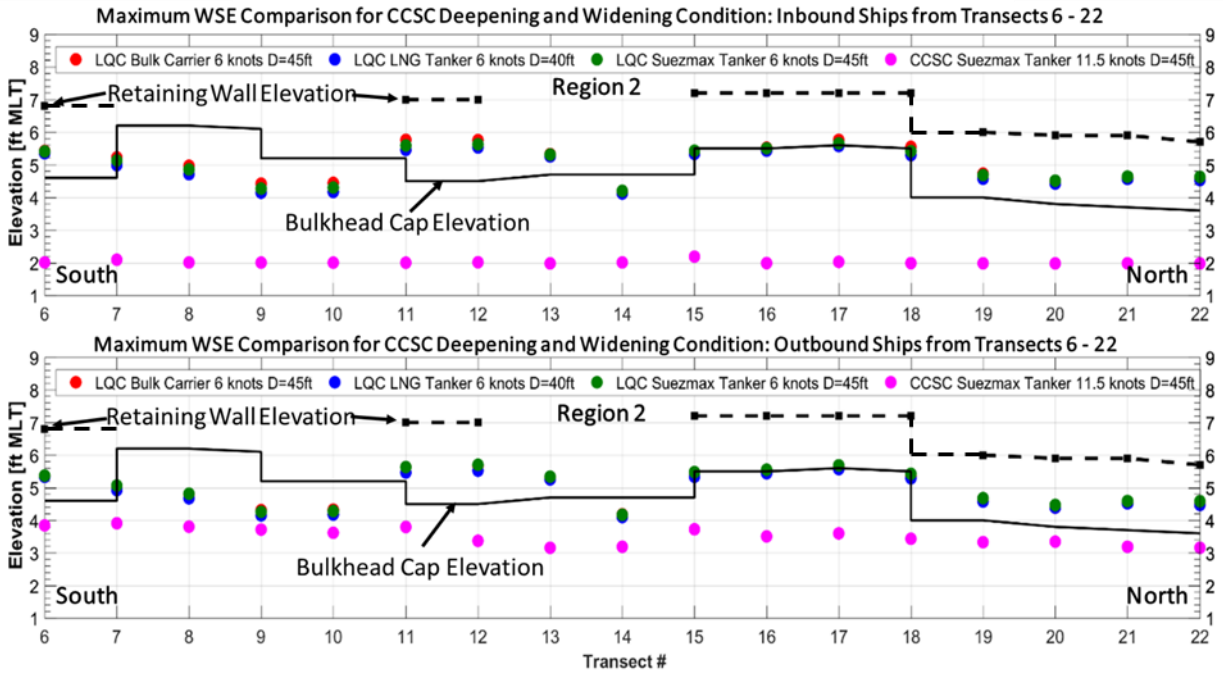

Figure 24. Resulting max WSEs per transect within Region 2 for the Proposed Condition A: CCSC widening/deepening. The WSE data points are color coded to the vessel simulation; the black solid line represents the bulkhead cap elevations; the dashed black line represents the retaining wall top elevations.

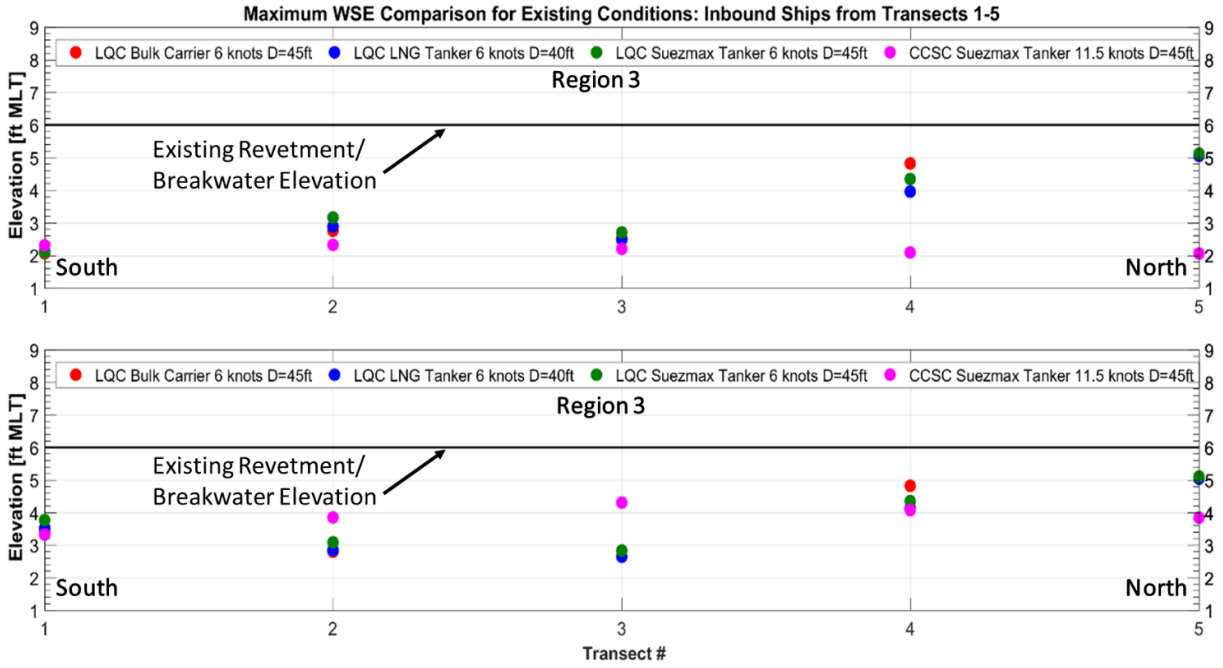

Figure 25. Resulting max WSEs per transect within Region 3 for the Proposed Condition A. The WSE data points are color coded to the vessel simulation; the black solid line represents the crest elevation of the breakwater and revetment.

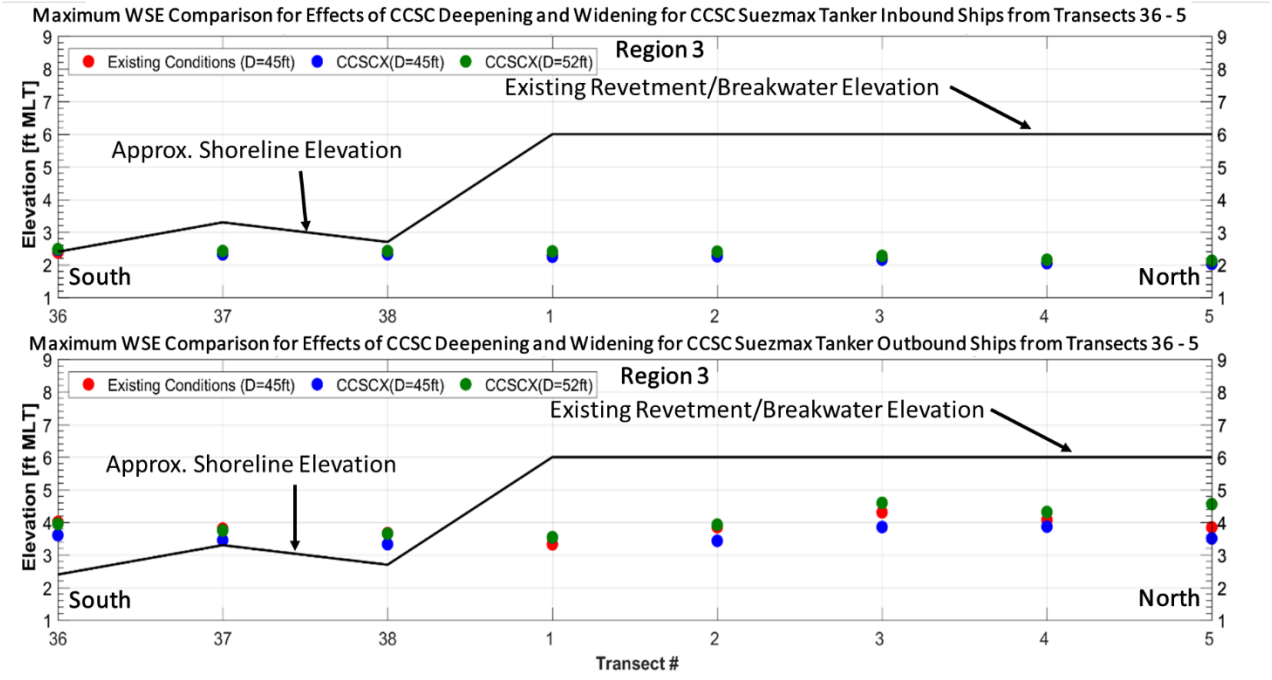

Figure 26. Resulting max WSEs per transect within Region 3 for Proposed Condition A: CCSC widening/deepening. The WSE data points are color coded to

the CCSC vessel simulation; the black solid line represents the crest elevation of the breakwater, revetment, and shoreline.

The impacts of Proposed Condition A: CCSC Widening/Deepening was investigated further for Region 2 using

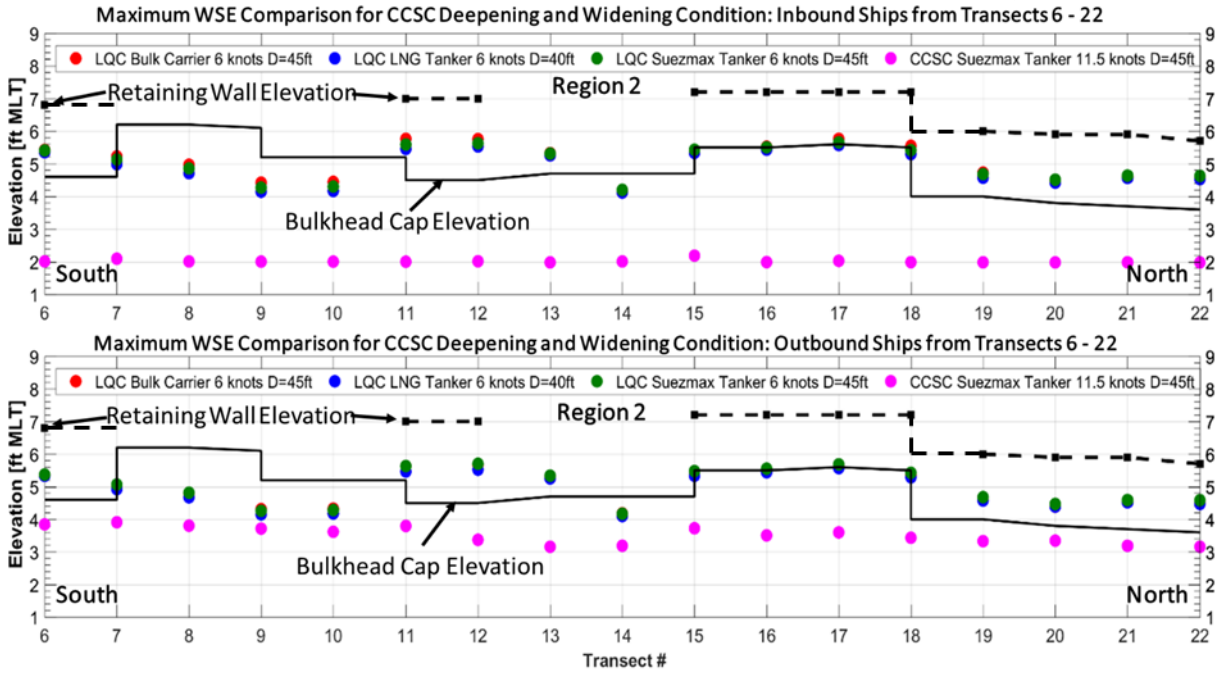

Figure 24. Within this figure, the black solid lines represent the bulkhead cap elevations and the black dashed lines represent the top retaining wall elevations at the waterfront properties. For this region, overtopping is defined as a max WSE above the highest elevation of a bulkhead, which for many transects is the retaining wall. The results in the figure show that overtopping of the bulkhead is only observed at Transect No. 13, and only occurs during the passing vessel activity through the LQC. All of the other transects which show overtopping of the bulkhead cap also have a retaining wall at a higher elevation which prevents overtopping of the bulkhead as a whole. Transect No. 13 is located at the property bulkhead where overtopping is known to occur under existing conditions, as this was the location where overtopping was captured by a security camera on April 5, 2018 (recall that this event was used as the targeted simulation for the model validation run; see Section 3.4). Therefore, overtopping is expected to occur at this location regardless of existing conditions or Proposed Condition A. Furthermore, Proposed Conditions A: CCSC Widening/Deepening, do not worsen the overtopping. This latter statement can be concluded from comparing the proposed conditions results to those of the existing conditions at Transect No. 13.

Figure 27 and Figure 28 show the overall maximum WSE at each point along the transect for Transects No. 13 and 20, respectively due to a range of vessel simulations. In these figures, the brown shaded region represents the bathymetry/topography at each transect. Each colored-coded line represents the resulting max WSE due to a specific vessel simulation. These figures are presented to show how the presence of the retaining wall landward of the bulkhead at Transect No. 20 inhibits complete overtopping, compared to Transect No. 13 where there is only a bulkhead cap and no retaining wall. For example, at

Transect No. 13, the max WSE along the transect for three of the simulated vessels results in overtopping of the bulkhead cap. However, at Transect No. 20, the resulting max WSEs caused by the same vessel simulations do not result in total overtopping due to the presence of the retaining wall landward of the bulkhead cap.

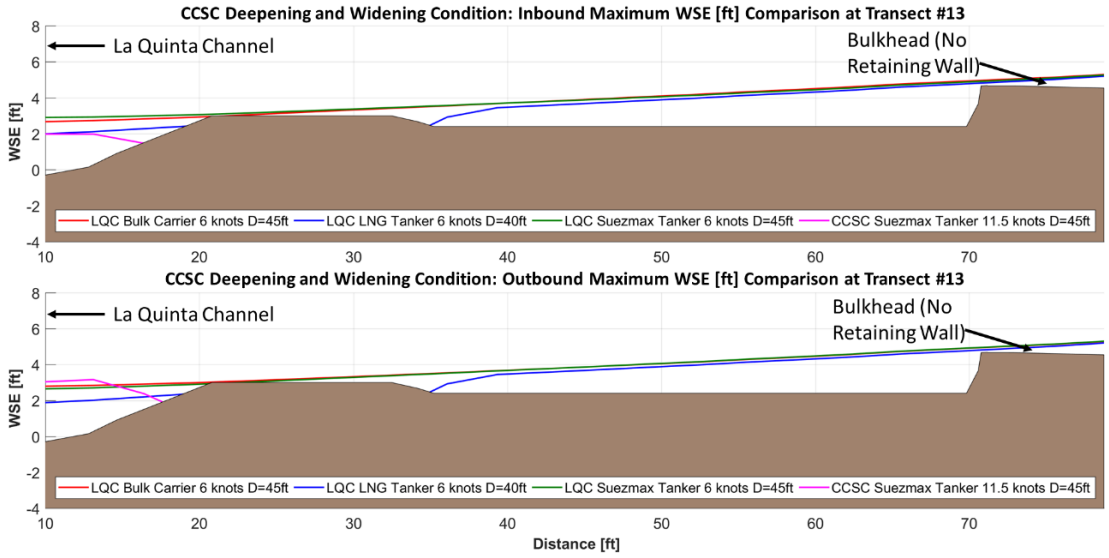

Figure 27. Cross Section of Maximum WSE along Transect No. 13 for CCSC deepening/widening for all modeled vessels; brown shaded area represents the bathymetry/topography at this transect location.

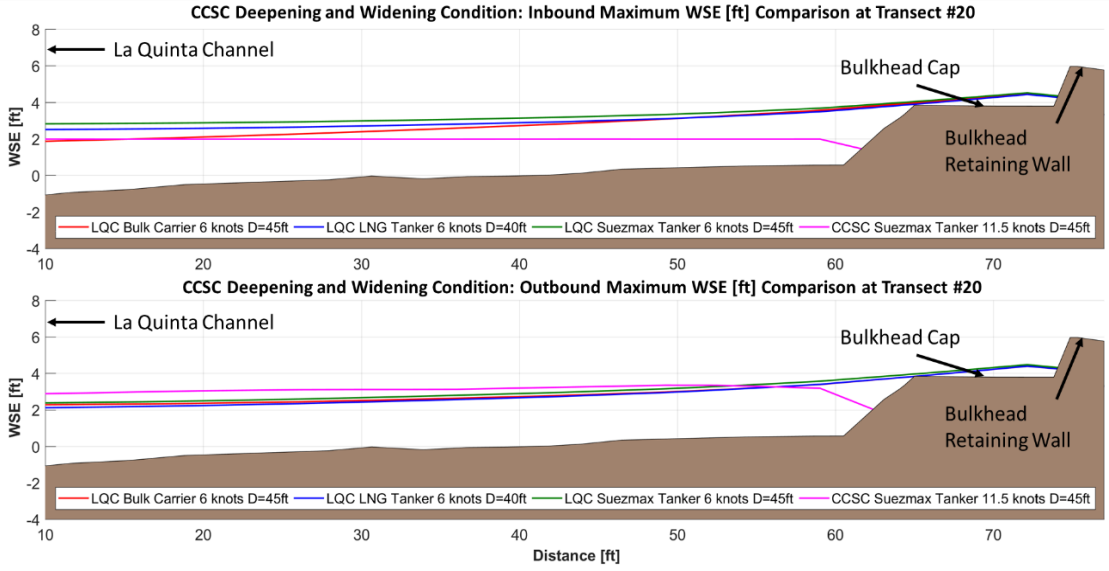

Figure 28. Cross Section of Maximum WSE along Transect No. 20 for CCSC deepening/widening for all modeled vessels; brown shaded area represents the bathymetry/topography at this transect location.

The impacts of Proposed Condition A: CCSC Widening/Deepening can also be understood by assessing the aerial view plots of the model simulations, showing the max WSEs and comparing those to existing conditions. Figure 29 shows the resulting max WSEs in Regions 2 and 3 from Run No. 9, which results in the highest average max WSE of 5.07 ft MLT. While Figure 30 shows the difference between this simulation and the same vessel simulation but under existing conditions (Run No.1). The latter figure shows that the difference in maximum WSEs between the two simulations (Proposed Condition A versus existing conditions) is mostly below +0.2 ft. This indicates that the Proposed Condition A results in an increase in max WSEs of less than 0.2 ft throughout the overall area of Region 2 and Region 3.

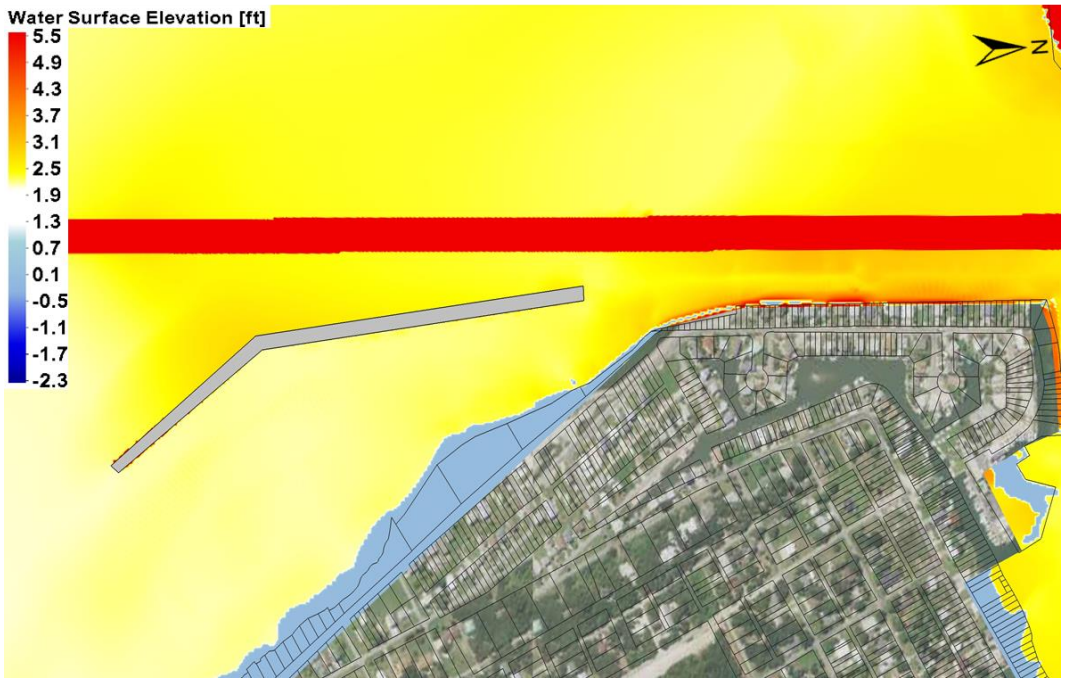

Figure 29. Resulting max WSEs within Regions 2 and 3 for Run No. 9 for Proposed Conditions A. Note that the solid red color indicates the path of the vessel, and the solid light blue areas are grid cells that have a ground elevation lower than 3 meters but remain dry in the computation.

Figure 30. Resulting WSE difference within Regions 2 and 3 between Proposed Conditions A and existing conditions. Warm colors (yellow-reds) indicate where areas experience a higher max WSE due to the proposed conditions, and cool colors (light-dark blue) show areas where max WSEs are lower due to the proposed conditions. Note that little color is visible in these results, indicating that this simulation resulted in very little changes between the two conditions.

The max WSE values across the grid in Region 3 for Run No. 18 (Proposed Condition A with 52 ft draft Suezmax Tanker heading outbound of the CCSC) are shown in Figure 31. Recall that this scenario results in an average max WSE of 4.04 ft MLT; this is a 4.6% increase from the existing conditions result with the Suezmax Tanker with 45 ft draft. Figure 32 shows the difference in resulting max WSE from Run No. 18 compared to those of existing conditions with the 45 ft draft Suezmax. In this figure, the warm colors (yellow-red) show where max WSE values are higher than existing conditions, and cool colors (light-dark blue) show areas where max WSE are lower than existing conditions. The purpose of showing these figures is to understand how the increase in vessel draft causes an impact in max WSEs within the project area.

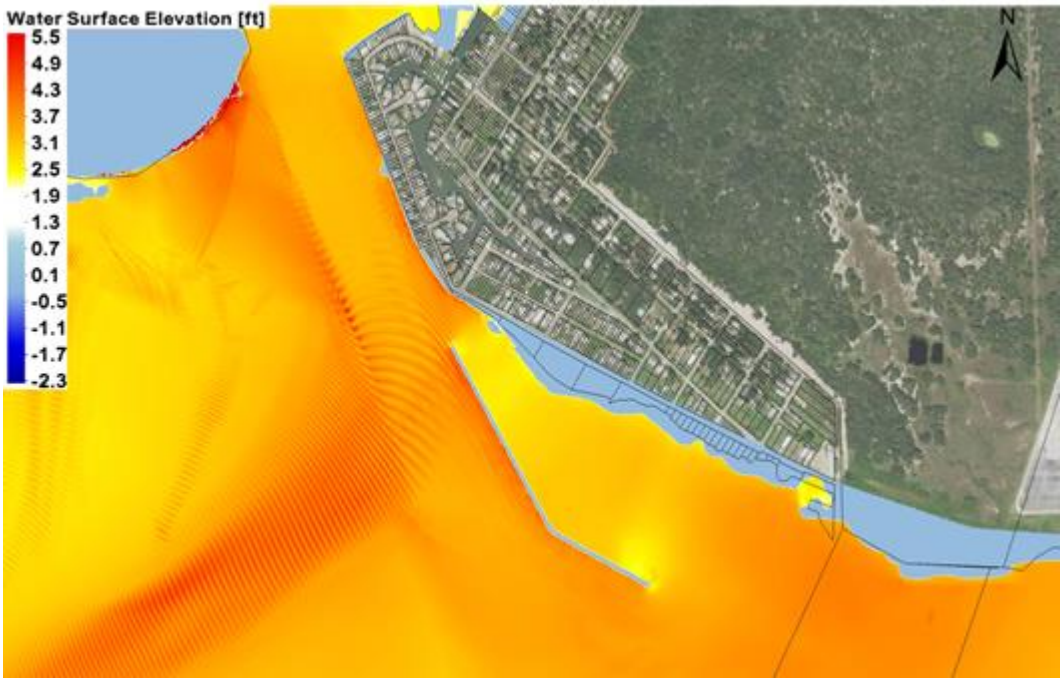

Figure 31. Resulting max WSEs in Region 3 from Run No. 18 (CCSC Suezmax tanker with 52' draft heading outbound with Proposed Condition A: CCSC deepening/widening). Areas in solid light blue are grid cells with ground elevation lower than 3 meters, but remain dry in the computation.

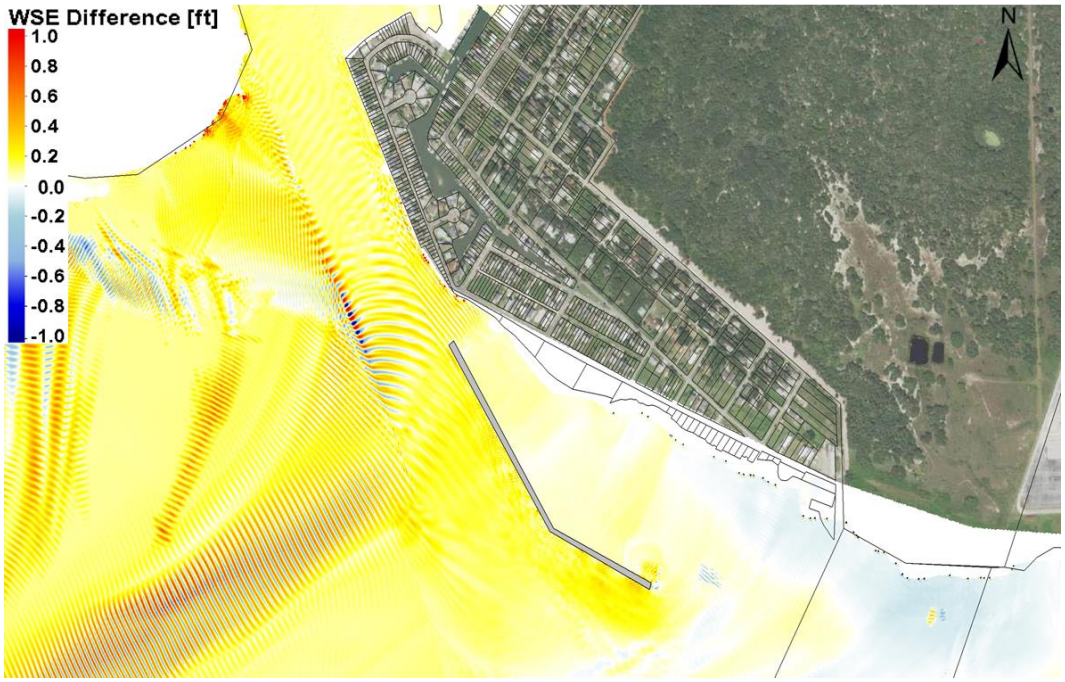

Figure 32. Difference in max WSE due to the 52 ft draft Suezmax Tanker with Proposed Condition A, compared to max WSEs with existing conditions and the 45 ft draft Suezmax. Warm colors (yellow-reds) indicate where areas experience a higher max WSE due to the 52 ft draft vessel with proposed conditions, and cool

colors (light-dark blue) show areas where max WSEs are lower due to the 52 ft draft vessel with proposed conditions.

5.3 Proposed Condition B: CCSC Widening/Deepening with BUS C-Q

Results from the model analysis of Proposed Condition B: CCSC Widening/Deepening with BUS C-Q, indicate that the presence of BUS C-Q will cause little impact to Regions 1 and 2, and will cause the greatest impact within Region 3. This is to be expected since BUS C-Q is located closest to Region 3. However, with that said, the overall increases in max WSEs are all less than 3 inches:

- Within Region 1, the greatest resulting average max WSE is 2.90 ft MLT; this is only a 0.1% increase from existing conditions, which correlates to an increase in max WSE of 0.02 inches.
- Within Region 2, the greatest resulting average max WSE is 5.06 ft MLT, which is a 0.1% increase from existing conditions; this correlates to an increase in max WSE of 0.04 inches.
- Within Region 3, the greatest resulting average max WSE is 3.96 ft MLW; this is a 5.6% increase from existing conditions, which correlates to an increase of 2.52 inches in max WSE.

Individual max WSE values per vessel simulation for Proposed Condition B: CCSC Widening/Deepening with BUS C-Q at each transect in Region 1 and Region 2, are shown in Figure 33 and Figure 34, respectively. Results for Region 3 are shown in Figure 35 and Figure 36. Two plots are provided for Region 3 because the additional Transect Nos. 36 – 38 were tested separately with only the CCSC modeling grid using the 52 ft draft Suezmax.

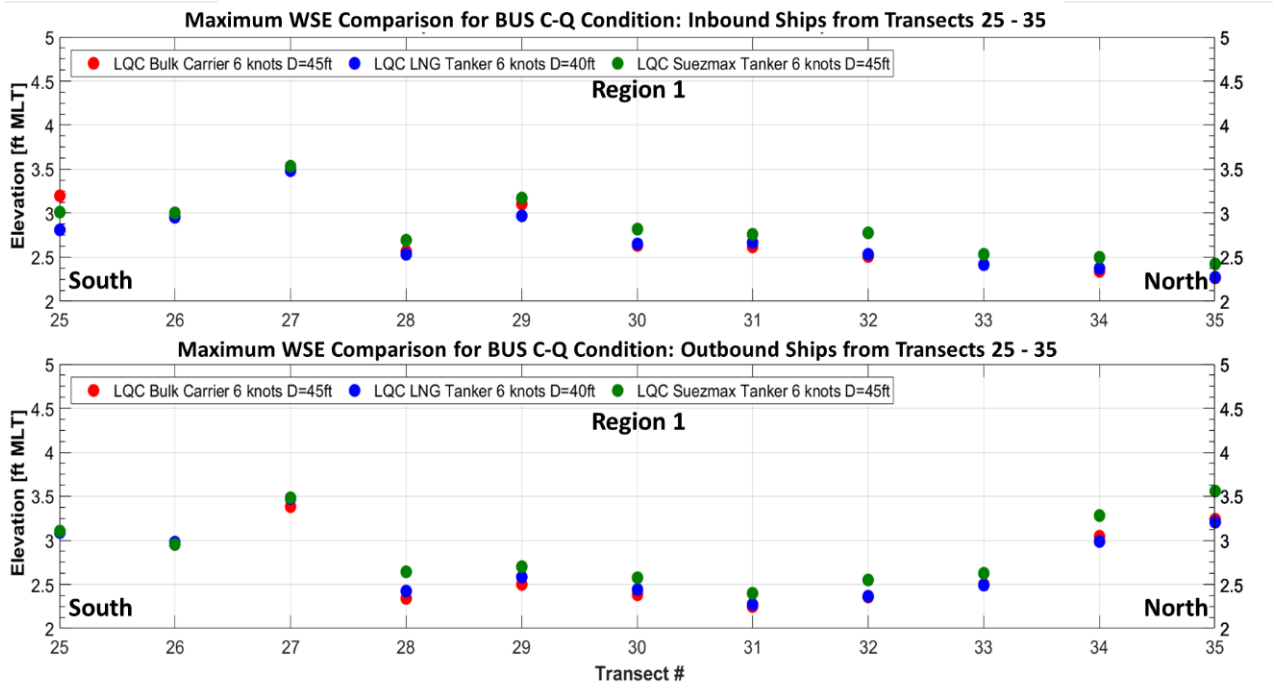

Figure 33. Resulting max WSEs per transect within Region 1 for the Proposed Condition B: CCSC widening/deepening and BUS C-Q. The WSE data points are color coded to the vessel simulation.

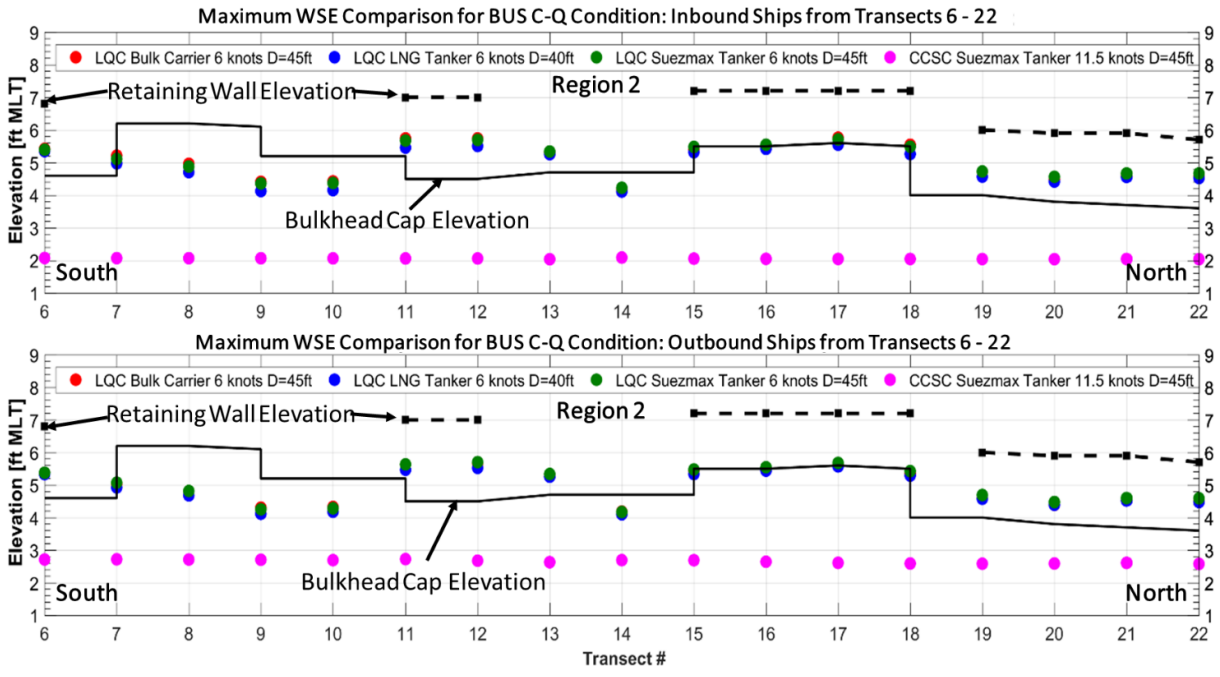

Figure 34. Resulting max WSEs per transect within Region 2 for the Proposed Condition B: CCSC widening/deepening and BUS C-Q. The WSE data points are

color coded to the vessel simulation; the black solid line represents the bulkhead cap elevations; the dashed black line represents the retaining wall top elevations.

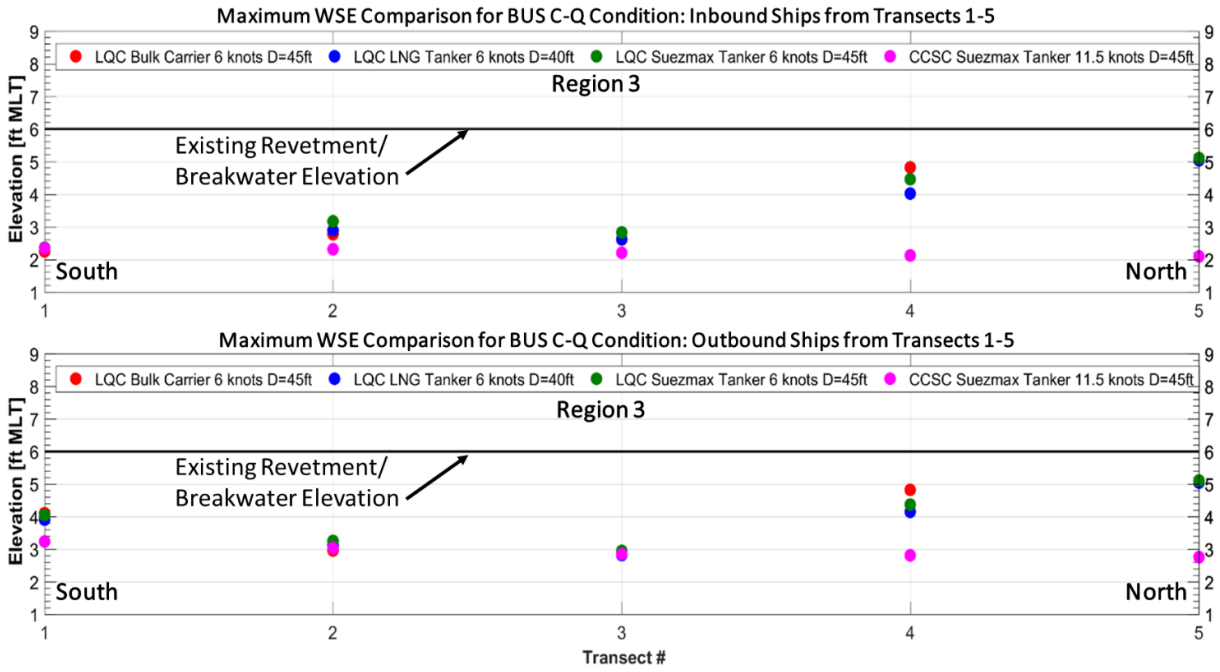

Figure 35. Resulting max WSEs per transect within Region 3 for the Proposed Condition B: CCSC widening/deepening and BUS C-Q. The WSE data points are

color coded to the vessel simulation; the black solid line represents the crest elevation of the breakwater and revetment.

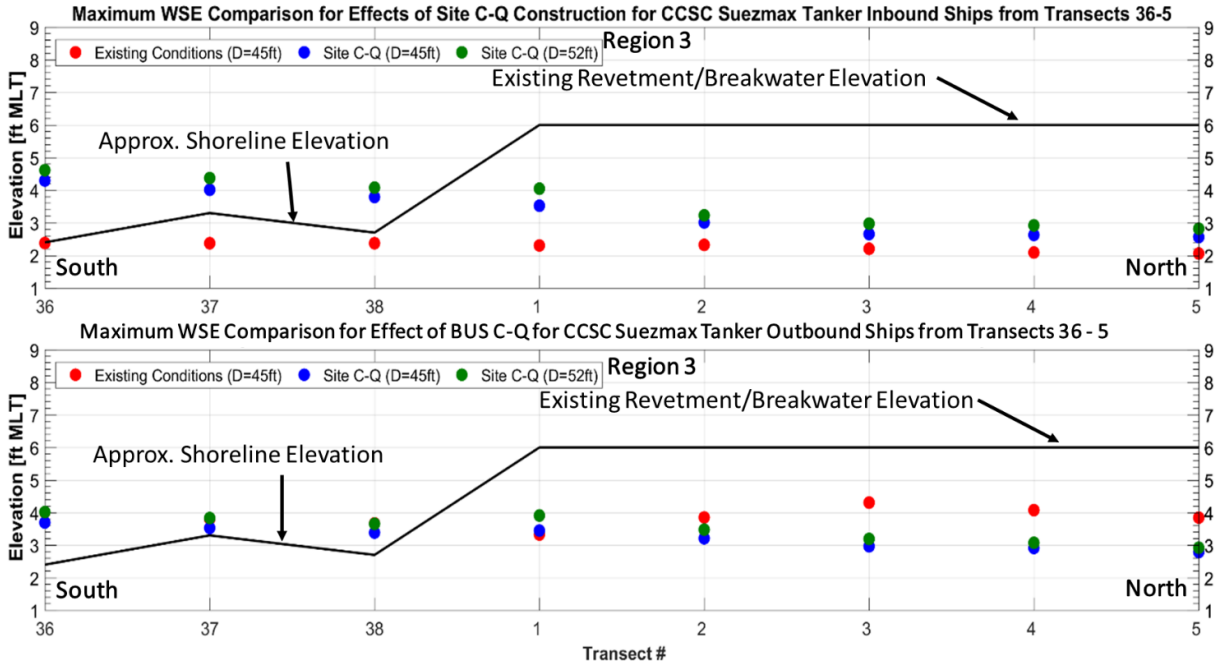

Figure 36. Resulting max WSEs per transect within Region 3 for Proposed Condition B: CCSC widening/deepening and BUS C-Q. The WSE data points are color coded to the CCSC vessel simulation; the black solid line represents the crest elevation of the breakwater, revetment, and shoreline.

The impacts of Proposed Condition B: CCSC Widening/Deepening with BUS C-Q, is also further investigated within Region 2 using the results shown in Figure 34. This figure shows that overtopping does occur at Transect 13, which is where it is known to occur during present-day/existing conditions. However, no overtopping is observed at any of the other transects. Thus, Proposed Condition B is not expected to worsen overtopping within Region 2.

The impacts or Proposed Condition B is further investigated for Region 3 as well. An aerial showing the difference in max WSE between Run No. 28 (CCSC Suezmax Tanker with 52 ft draft heading outbound with Proposed Condition B) and Run No. 8 (CCSC Suezmax Tanker with 45 ft draft heading outbound under existing conditions) is shown in Figure 37. The warm (reds) and cool (blues) colors indicate where max WSEs are higher and lower (respectively) during these proposed conditions when compared to those of the existing conditions. Thus, it is evident that Proposed Condition B (CCSC deepening/widening with BUS-C-Q) does cause an increase in max WSEs landward of the existing breakwater in Region 3.

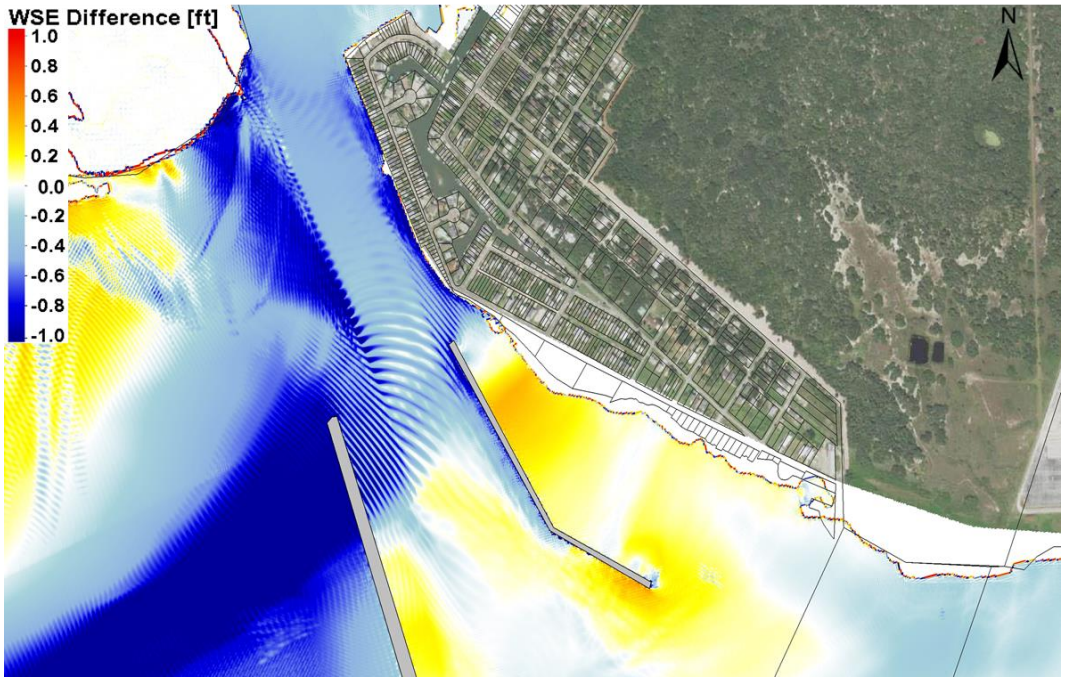

Figure 37. Resulting difference in max WSEs in Region 3 between Run No. 28 (CCSC Suezmax tanker with 52' draft heading outbound with CCSC widening/deepening and BUS C-Q proposed conditions) and Run No. 8 (CCSC Suezmax tanker with 45' draft heading outbound under existing conditions).

It's important to understand the impact of the presence of BUS C-Q during inbound vessel activity in the CCSC as well. Figure 38 is an aerial view showing the difference in max WSEs for the Suezmax Tanker with 52 ft draft heading inbound in the CCSC with the presence of BUS C-Q compared to the same simulation but without the presence of BUS C-Q. Note how the presence of the BUS C-Q results in max WSEs that are higher by up to 1 ft throughout most of the Region 3 area, and even into the Region 2 area. With the presence of BUS C-Q, the waterway between C-Q and the existing breakwater becomes restricted, and likely channels the vessels' bore wave up the LQC, resulting in these observed higher max WSEs. However, the overall difference in increased max WSEs are under 1 ft. Also, considering that the modeled location of the BUS C-Q is only approximate, the site could be moved west to decrease the channeling effect and minimize the impact of elevating the local water levels.

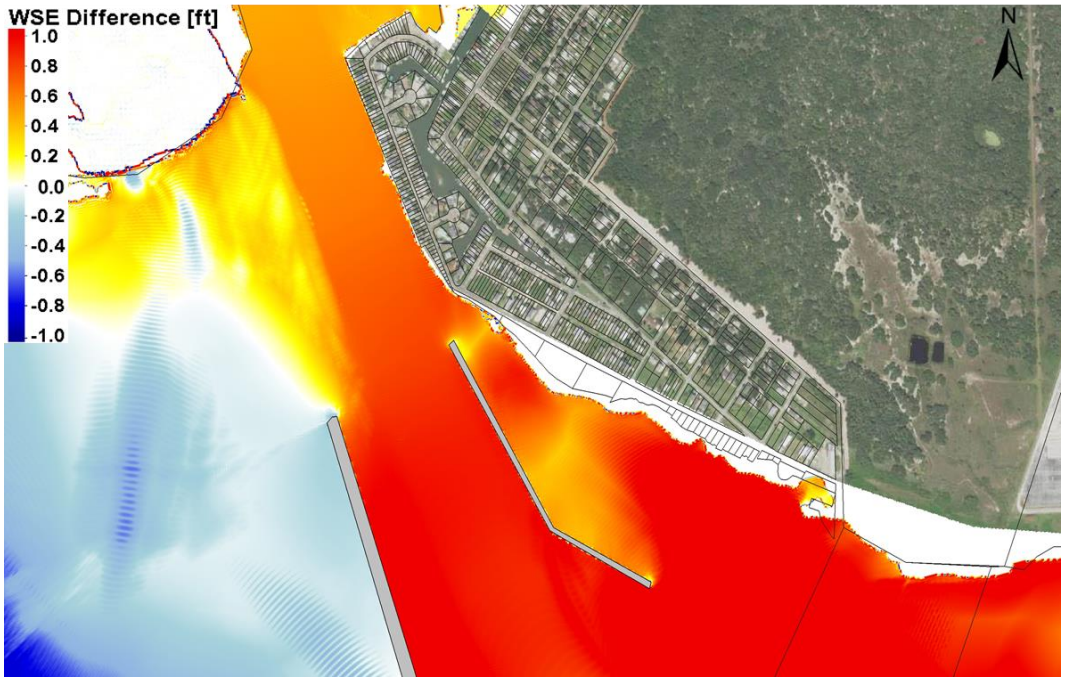

Figure 38. Difference in max WSEs in Region 3 from Run No. 27 (CCSC Suezmax Tanker with 52 ft draft heading inbound with BUS C-Q) compared to Run No. 17 (CCSC Suezmax Tanker with 52 ft draft heading inbound without the presence of BUS C-Q)

Furthermore, Figure 36 show that at Region 3 Transects 36 – 38 (refer to Figure 22), where the shoreline is not protected by the existing offshore breakwater, under exiting conditions outbound vessels result in higher max WSE values than inbound vessels. Also, under the CCSC Deepening/Widening proposed condition, the max WSE values are either extremely similar or less than those of existing conditions, indicating that this proposed scenario will not negatively impact this section of shoreline. However, under the CCSC Deepening/Widening with BUS C-Q, the max WSE values for inbound ships are slightly higher than those of the existing conditions at Transects 36 – 38. This observation indicates that this section of shoreline that is not protected by the breakwater will experience negative impacts (i.e., higher risk of flooding or overtopping) under this proposed scenario for inbound vessels. These effects may also be reduced by shifting C-Q westward to reduce the channeling effects on the inbound vessel wakes.

5.4 Proposed Condition C: CCSC Widening/Deepening with BUS C-Q and BUS I-C

The modeling results in Table 10 show that Proposed Condition C: CCSC Widening/Deepening with BUS C-Q and BUS I-C show that the presence of both BUS C-Q and I-C will cause decreases in max WSEs within Region 1, but increases in max WSEs within Regions 2 and 3. However, these increases in max WSEs are all under 1.5 inches:

- Within Region 1, the greatest resulting average max WSE is 2.75 ft MLT; this is a decrease from existing conditions by 1.4%, which correlates to a decrease in max WSE of 0.5 inches.

- Within Region 2, the greatest resulting average max WSE is 5.06 ft MLT, which is a 1.0% increase from existing conditions; this correlates to an increase in max WSE of 0.61 inches.
- Within Region 3, the greatest resulting average max WSE is 3.93 ft MLW; this is a 2.5% increase from existing conditions, which correlates to an increase in max WSE of 1.15 inches.

Individual max WSE values per vessel simulation for Proposed Condition C: CCSC Widening/Deepening with BUS C-Q and BUS I-C at each transect in Region 1, Region 2, and Region 3 are shown in Figure 39, Figure 40, and Figure 41, respectively.

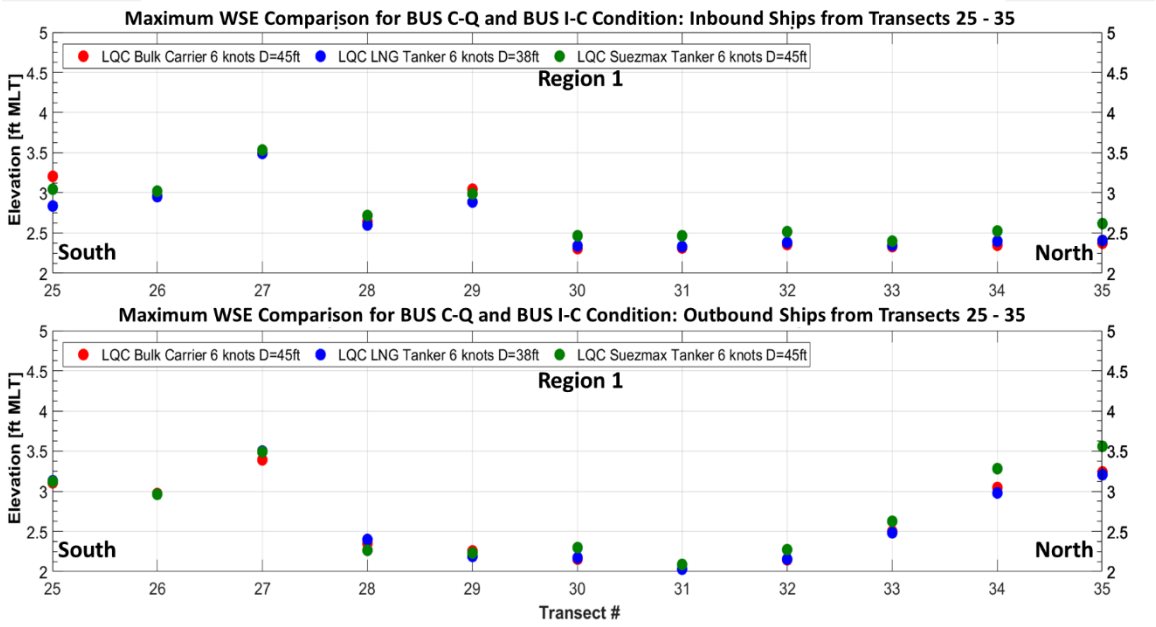

Figure 39. Resulting max WSEs per transect within Region 1 for the Proposed Condition C: CCSC widening/deepening with BUS C-Q and I-C. The WSE data points are color coded to the vessel simulation.

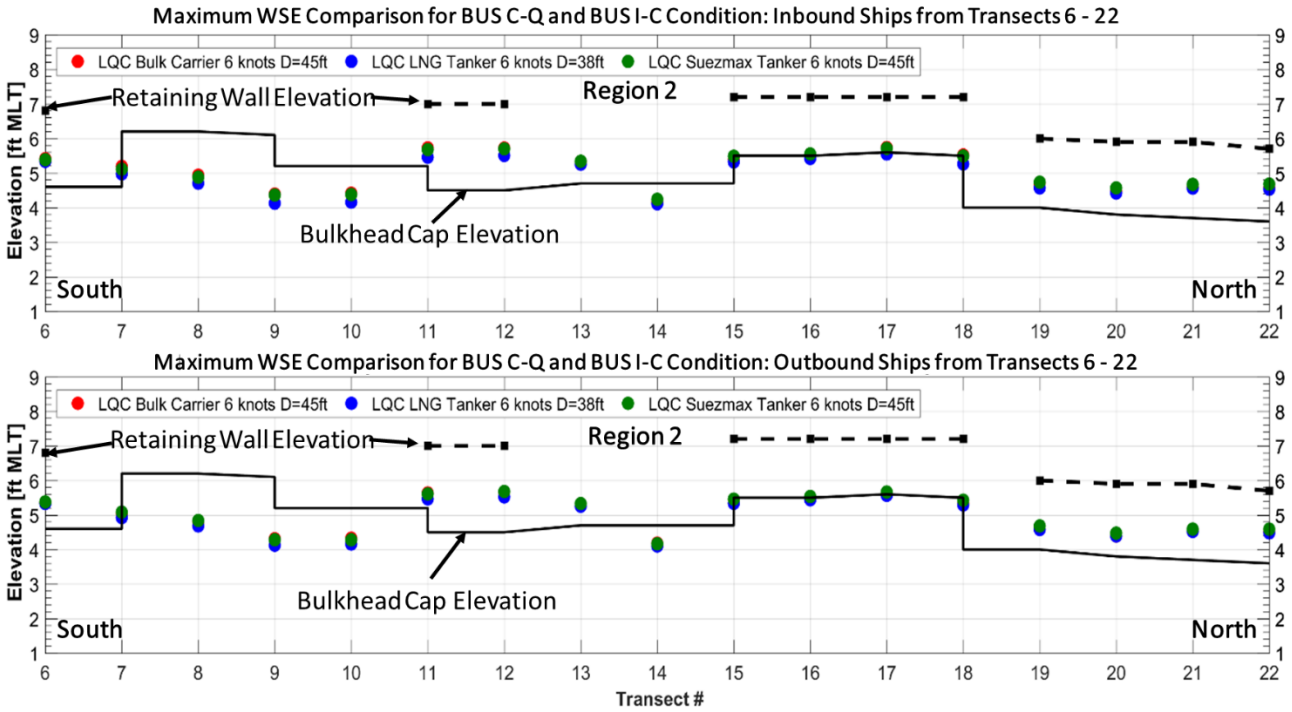

Figure 40. Resulting max WSEs per transect within Region 2 for the Proposed Condition C: CCSC widening/deepening with BUS C-Q and Site I-C. The WSE data points are color coded to the vessel simulation; the black solid line represents the

bulkhead cap elevations; the dashed black line represents the retaining wall top elevations.

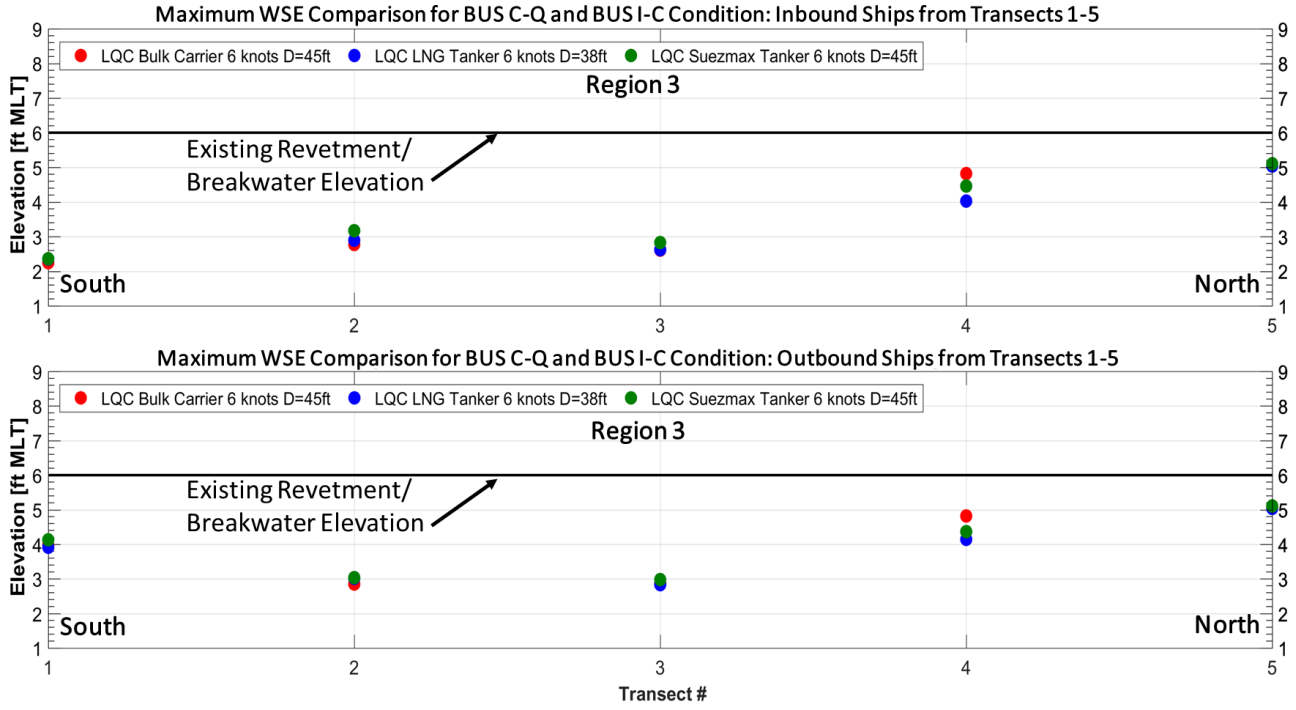

Figure 41. Resulting max WSEs per transect within Region 3 for Proposed Condition C: CCSC widening/deepening with BUS C-Q and BUS I-C. The WSE data points are color coded to the vessel simulation; the black solid line represents the crest elevation of the breakwater and revetment.

The impacts of Proposed Condition C: CCSC Widening/Deepening with BUS C-Q and BUS- I-C, is also further investigated within Region 2 using the results shown in Figure 40. This figure shows that overtopping does occur at Transect 13, which is where it is known to occur during present-day/current conditions. However, no overtopping is observed at any of the other transects. Thus, similar to the other proposed conditions, Proposed Condition C is not expected to worsen overtopping within Region 2.

The impacts within Region 1 are further investigated by assessing the aerial plot showing the difference in max WSE from Proposed Condition C compared to results from existing conditions. This comparison is shown in Figure 42; this figure shows where water surface elevations are lower (cool colors – light to dark blue) and higher (warm colors – yellow to red) under these proposed conditions compared to the results under existing conditions. This figure further shows how the presence of BUS I-C results in a decrease in max WSE across most of the area by the shoreline within Region 1. Increases within the interior of I-C are caused by pressure effects from the vessels diffracting around the levee as the vessel passes and getting trapped in the lee of the structure.

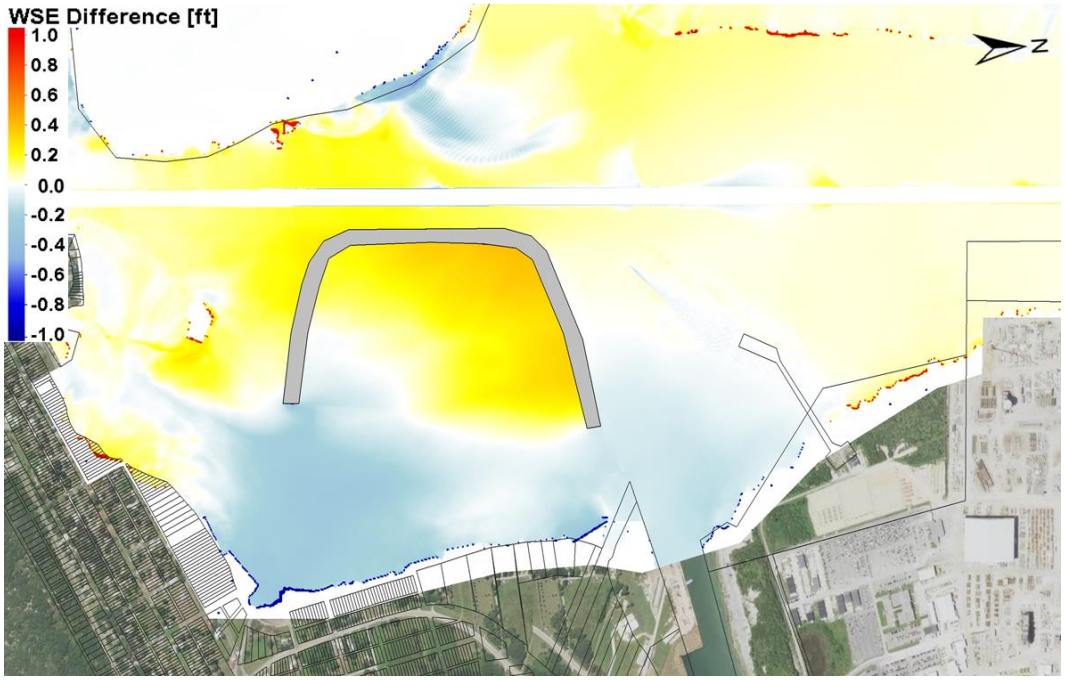

Figure 42. Resulting difference in WSEs in Region 1 between Run No. 29 (LQC Bulk Carrier heading inbound with Proposed Condition C) and Run No. 1 (LQC Bulk Carrier heading inbound under existing conditions).

5.5 Comparisons of Proposed Conditions for Region 2

The results of the three proposed conditions are evaluated against each other at Region 2. Figure 43 compares the results from the existing conditions model simulations against the results of all three proposed conditions at Region 2 using the representative vessel scenario. Notice how at each transect the data points for all the different conditions are barely visible – this is because the existing conditions and all proposed conditions result in extremely similar max WSE values. This comparison further shows that none of the proposed conditions will worsen the overtopping that is currently experienced within Region 2.

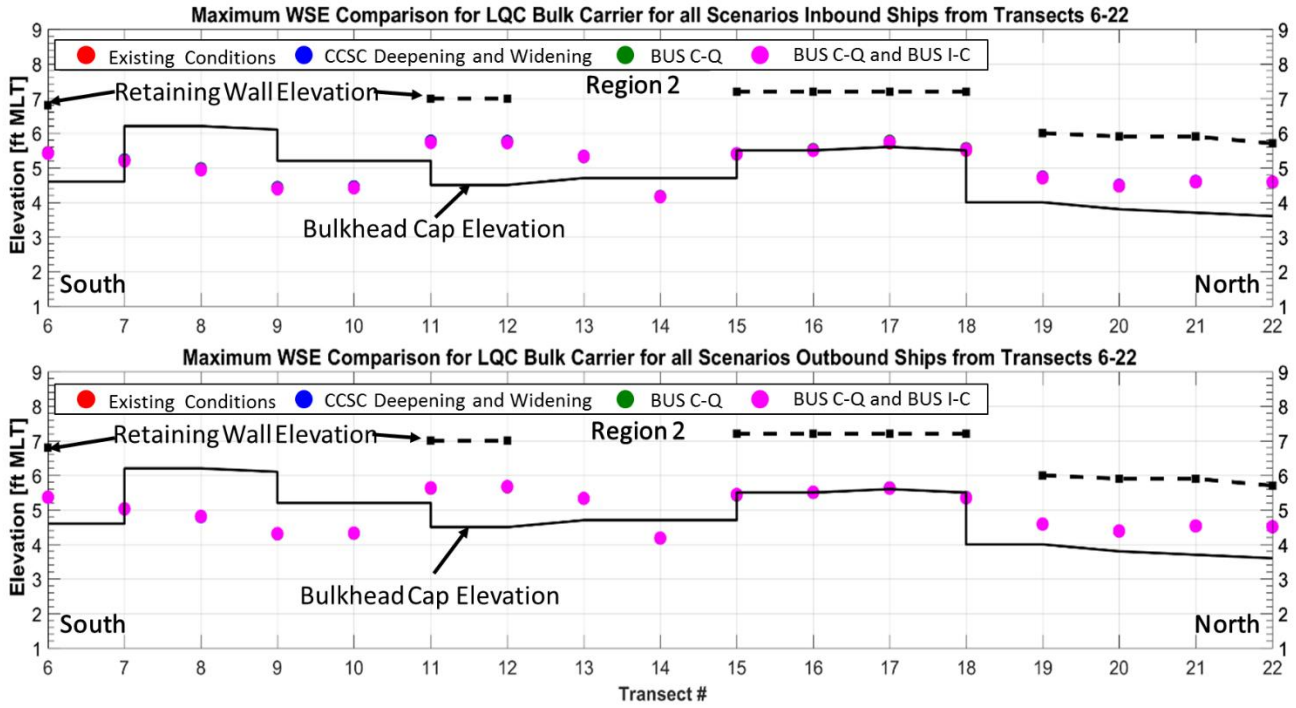

Figure 43. Resulting max WSE values per transect within Region 2 for the existing conditions and all three proposed conditions, using the representative vessel scenario. The data points are color coordinated to each different existing and proposed condition. At each transect, the resulting max WSE values are extremely similar among all the conditions, thus the data points closely overlap each other and are difficult to see on the plot.

5.6 Berry Island

Mott MacDonald was also asked to perform a cursory review of the potential impacts to Berry Island, the island to the west of the LQC. A review of the maximum WSEs at extraction points along the island show the most impact to water levels occurs from Proposed Condition C: CCSC deepening/widening with BUS C-Q and BUS I-C, with outbound vessels. The maximum WSE over the time series was evaluated for extraction points along the eastern shore of Berry Island and are shown in Figure 44 for the existing and proposed conditions for the Bulk Carrier sailing outbound in the LQC. The figure show that the WSE does not differ significantly between the existing conditions and Proposed Conditions A and B. However, with the construction of BUS I-C (Proposed Condition C), the WSE is shown to increase, with extraction points 42 and 49 displaying an approximately 0.5 ft increase. It is not expected that this increase will have significant effects on the shoreline.

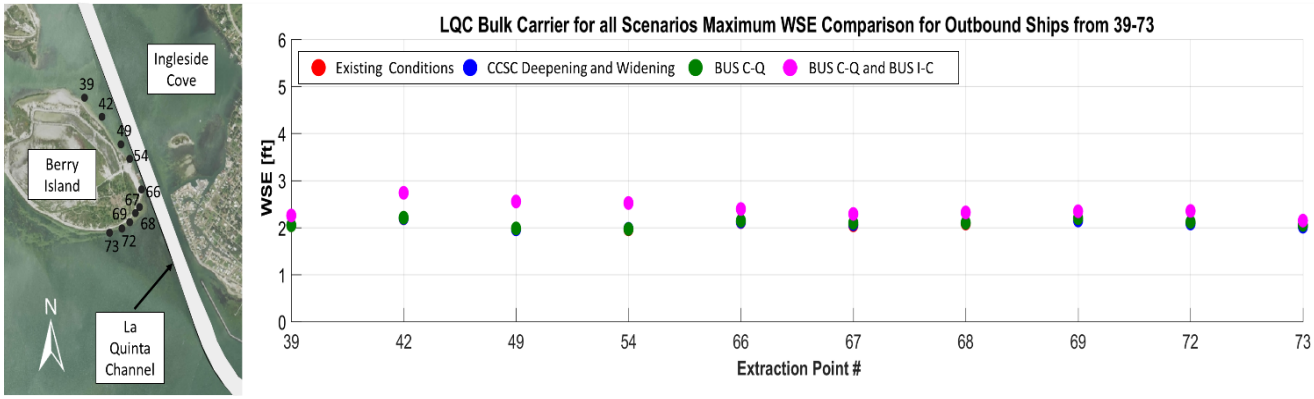

Figure 44. Resulting max WSEs per extraction points along Berry Island within Region 1 for the existing and proposed conditions for the Bulk Carrier sailing outbound in the LQC. The WSE data points are color coded to the vessel

5.7 Future Water Levels

The results from the Future Water Level Condition tests are discussed by region in the following 3 sections. In general, these tests show results that are to be expected, i.e., higher initial water level scenarios do increase resulting max WSEs caused by passing vessel activity.

5.7.1 Region 1

The Future Water Level Condition test results show that an increase in initial water elevation causes an increase in the vessel-induced max WSE. Figure 45 shows the results of Future Water Level Condition A (MSL + RSLR) and B (5-yr Elevated Tidal Event) at each transect within Region 1.

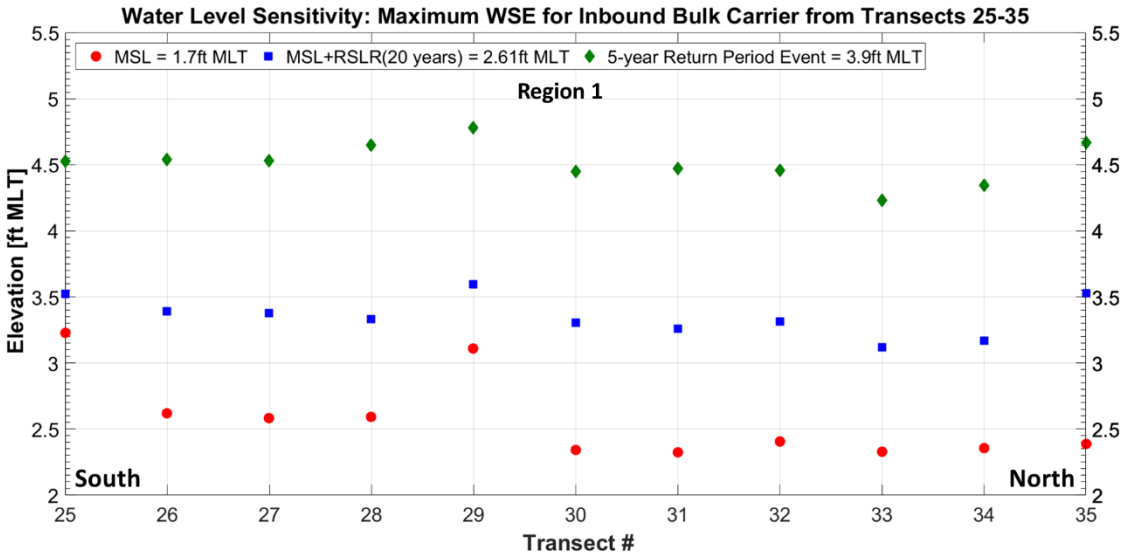

Figure 45. Resulting max WSE per transect within Region 1 for the Future Water Level Condition tests, where each data point is color coordinated to a specific water level scenario.

5.7.2 Region 2

The results of the water level tests per transect within Region 2 are shown in Figure 46. These max WSE values show that the risk of additional overtopping at Transect No. 14 increases with increased initial water levels (see Figure 47). Higher max WSE values also indicate that greater volumes of water will overtop the bulkhead. With increased overtopped volume, damage on the landward side of the bulkhead (such as scouring), will likely be more severe. However, for most of the transects, the WSE may overtop the bulkhead cap, but the presence of a higher retaining wall at the back of the bulkhead is anticipated to inhibit overtopping onto to landward property.

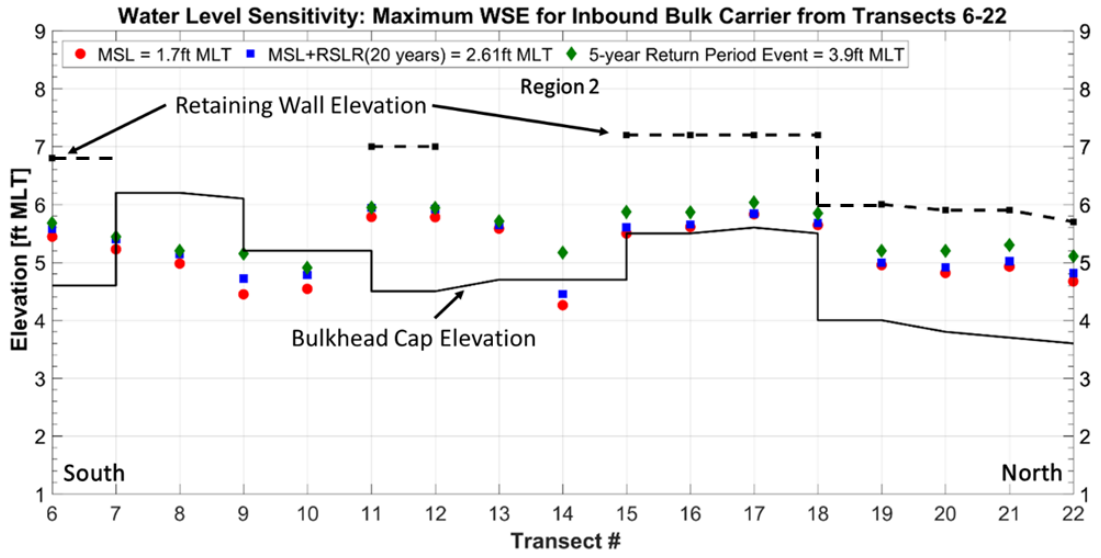

Figure 46. Resulting max WSE per transect within Region 2 for the Future Water Level Condition tests, where each data point is color coordinated to a specific water level scenario.

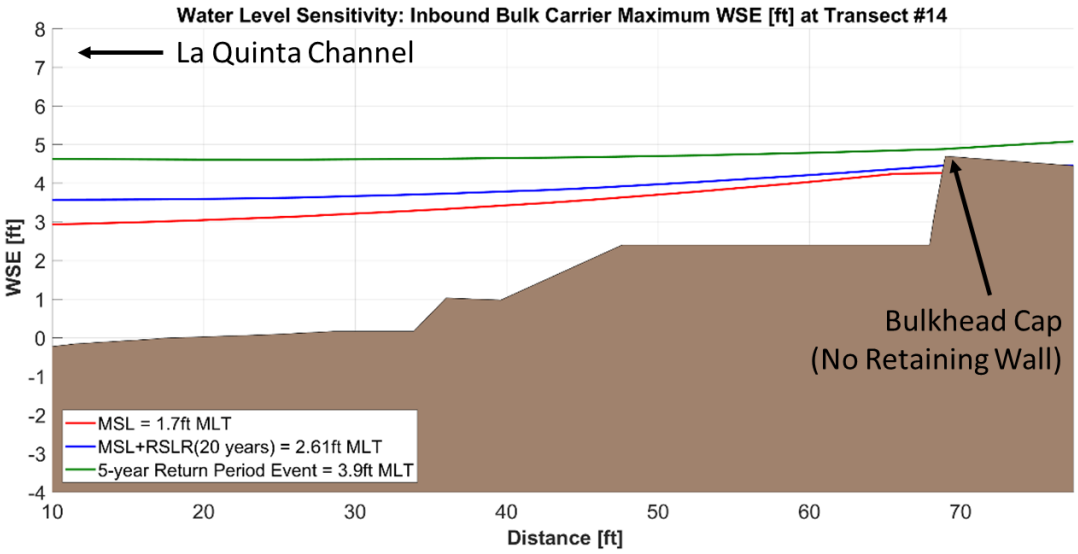

Figure 47. Cross Section of Maximum WSE along Transect No. 14 for different water level scenarios; brown shaded area represents the bathymetry/topography at this transect location.

5.7.3 Region 3

The max WSE values at each transection in Region 3 from the Future Water Level Condition simulations are shown in Figure 48. These results show that even with higher initial water level scenarios, the breakwater and revetment are not overtopped, thus the shoreline remains protected from passing vessel activity under these initial water level scenarios.

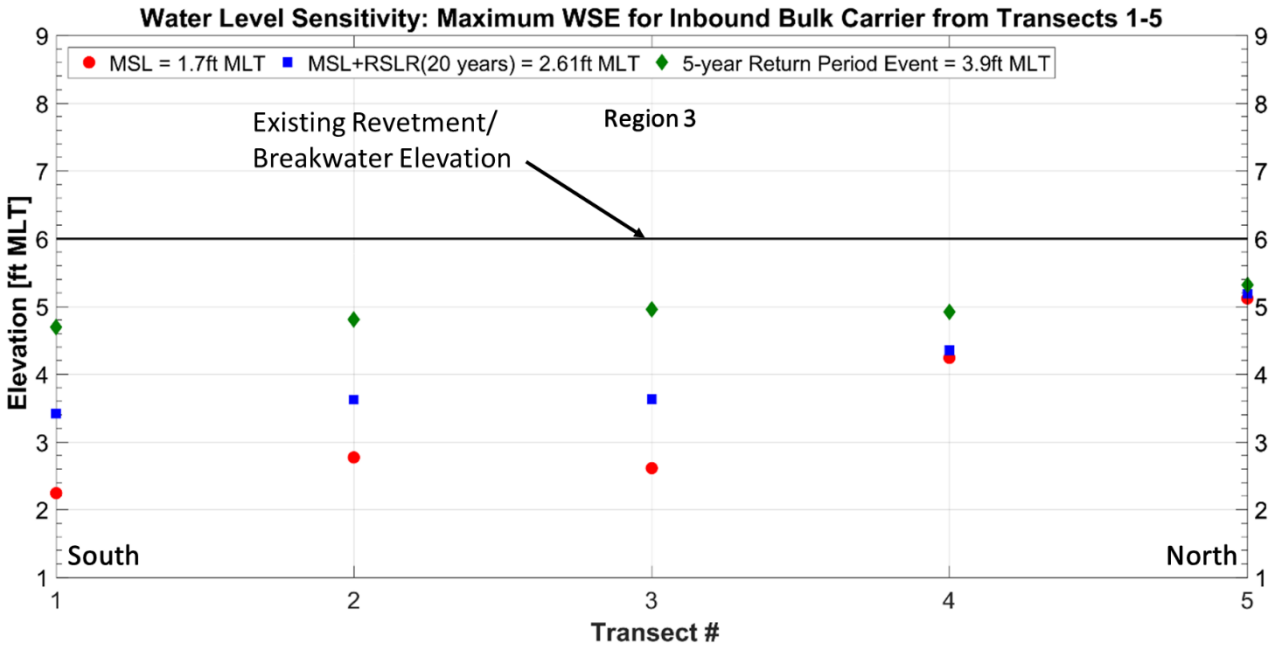

Figure 48. Resulting max WSE per transect within Region 3 for the water level sensitivity tests, where each data point is color coordinated to a specific water level scenario.

5.8 Mitigation Measures

The results of the three potential mitigation measures are discussed by Region in the following sections. It is important to understand that the mitigation measures were developed specifically to reduce impacts to Region 2. Therefore, the sections for Region 1 and 3 discuss any residual effects observed within these Regions, due to the mitigation measure proposed for protecting shorelines within Region 2. It is also important to note that these mitigation measures were developed to a conceptual level only – no assessments were performed to determine feasibility, constructability, funding source, permitting restrictions, or impacts to resources, sedimentation, public access to the waterway, etc.

Recall that the three proposed mitigation measures include the following:

- Potential Mitigation Measure A: Increase bulkhead cap/retaining wall elevations within Region 2 to prevent overtopping at waterfront properties along Bayshore Drive caused by passing vessel scenarios evaluated in this study. The proposed new cap elevation for the bulkhead/retaining walls would be recommended to exceed the highest resulting max WSE that results within Region 2 from the passing vessel simulations with the proposed conditions.
- Potential Mitigation Measure B: Reduce vessel speed to 4 knots to help dampen the intensity of the vessel-induced hydrodynamics, and thus reduce risk of overtopping at the properties along Bayshore Drive. Note that a reduced vessel speed will affect vessel maneuverability and port operations, which may render this mitigation measure as infeasible. However, the purpose of this study is only to evaluate the effect on the vessel hydrodynamics due to the reduced speed and does not attempt to asses it's feasibility.

- Potential Mitigation Measure C: Install a protection structure seaward of the Region 2 bulkheads, which is proposed as an extension of the existing breakwater in this study. Refer to Figure 16 for an image of the modeling grid showing the proposed breakwater extension. The existing breakwater structure would extend northward to the northern-most end of Bayshore Drive. The purpose of the protection structure would be to intercept the passing vessel wakes and reduce the wave and surge energy experienced at the shoreline due to the passing vessels. The proposed structure could be constructed of sheet piling and batter piles. The crest elevation of the structure would be determined a t a later point in time, but it is expected that the crest would be similar to the existing breakwater (+6 ft MLT).

5.8.1 Region 1

The impacts to Region 1 from the proposed mitigation measures are shown in Figure 49. In this figure, the resulting max WSE values are shown per transect for Potential Mitigation Measure B (reduce vessel speed to 4 knots) with blue square data points and Potential Mitigation Measure C (breakwater expansion) with the green triangular data points. The red circular data points, which are the max WSE values from the simulation with no mitigation measure (normal vessel speed of 6 knots), are just provided for comparison purposes. Note that all results were simulated with the representative vessel scenario (LQC bulk carrier heading inbound with CCSC widening/deepening and BUS C-Q and BUS I-C). These results show that Potential Mitigation Measures B and C will help reduce max WSEs within Region 1.

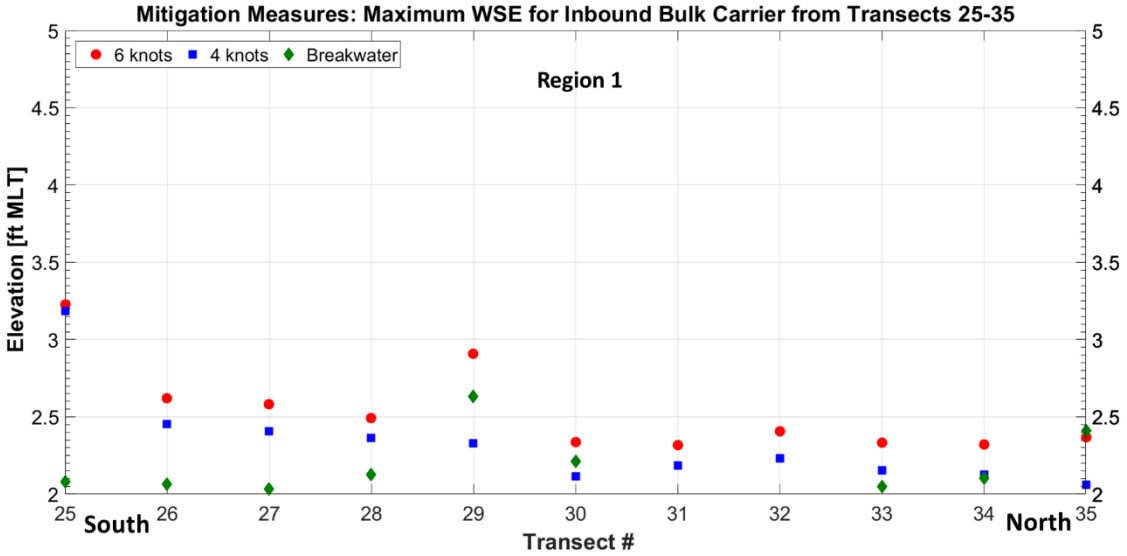

Figure 49. Resulting max WSE values per transect within Region 1 for the modeled mitigation measures. Each data point is color coordinated a different simulation. Note that the data points from the vessel simulation at the 6-knot speed is not considered a mitigation measure, it is only shown for comparison purposes.

While the vessel speed at 4 knots does result in lower max WSEs when compared to the 6-knot simulation, the extension of the breakwater is observed to generally provide greater reductions in max WSE across Region 1. This is further show in Figure 50. This figure shows the change in max WSEs from the presence of the extended breakwater with the representative vessel and proposed scenario, when compared to existing conditions. Warm colors (yellow to red) show where max WSEs are greater under this mitigation and

proposed condition when compared to the existing conditions, and cooler colors (light to dark blue), show areas where max WSEs are lower under this condition when compared to the existing conditions. Note how max WSEs are predominantly lower (cooler colors) across the grid within Region 1.

Note that all mitigation measures shown are for preliminary comparison purposes only and have not been evaluated based on their feasibility. Impacts on resources, human access to the waterway, increase in sedimentation, vessel maneuverability, safety, and port operations due to reduced speeds are not investigated as part of this study, and would therefore need to be fully evaluated in a future analysis, before implementing any such proposed measure. Likewise, navigation, access, and circulation impacts from extending the breakwater would also need to be evaluated in a future analysis to determine feasibility of this option.

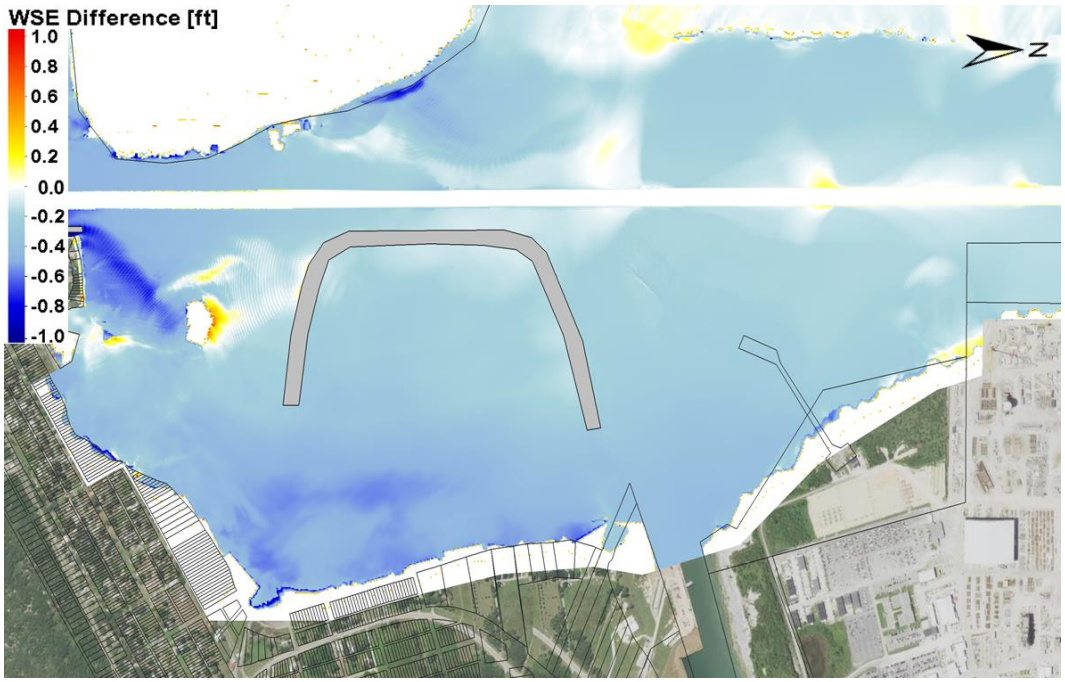

Figure 50. Difference in max WSEs from the representative vessel and condition scenario (LQC bulk carrier heading inbound with CCSC widening/deepening and BUS C-Q and BUS I-C) with the extended breakwater when compared to existing conditions in Region 1.

5.8.2 Region 2

Figure 51 shows the resulting max WSE per transect in Region 2 for the potential mitigation measures. Recall that the blue square data points correlate to Potential Mitigation Measure B (reduced vessel speed) and the green triangular data points correlate to Potential Mitigation Measure C (breakwater extension). These results show that reducing the vessel speed to 4 knots does not decrease the max WSEs, thereby worsening the impacts. This is likely due to the slower speed creating a longer period bore wave that can more easily run up the shoreline at this location, thus magnifying the passing vessel effects in this case. However, the breakwater extension is found to substantially reduce the max WSE values, thereby improving the conditions within Region 2. The red circular data points, showing the results with no mitigation measure, can be used to determine the required elevation for Proposed Mitigation Measure A – elevating

the bulkhead caps and retaining walls at the waterfront properties within Region 2. When determining the minimum bulkhead cap elevations, a freeboard should also be considered to account for a factor of safety and higher water level events. Thus, based on the results of the vessel simulations tested in this study, the recommended cap elevation of all bulkhead/retaining walls within Region 2 should meet, at a minimum, elevation +5.8 ft MLT plus some level of freeboard. As observed in Figure 51, most of the existing bulkhead/retaining wall caps that are captured in the survey data already meet the +5.8 ft MLT elevation. Thus, depending on the determined necessary freeboard (which would need to be evaluated in a more detailed assessment), the physical increase in cap elevation would likely be relatively small (i.e., on the order of 1-2 ft, opposed to 4-5 ft). A sketch showing this concept of increasing the cap elevation of a bulkhead and retaining wall is provided in Figure 52 and Figure 53, respectively. Measure A would have no impacts on vessel hydrodynamics as it does not affect local bathymetry or vessel navigation.

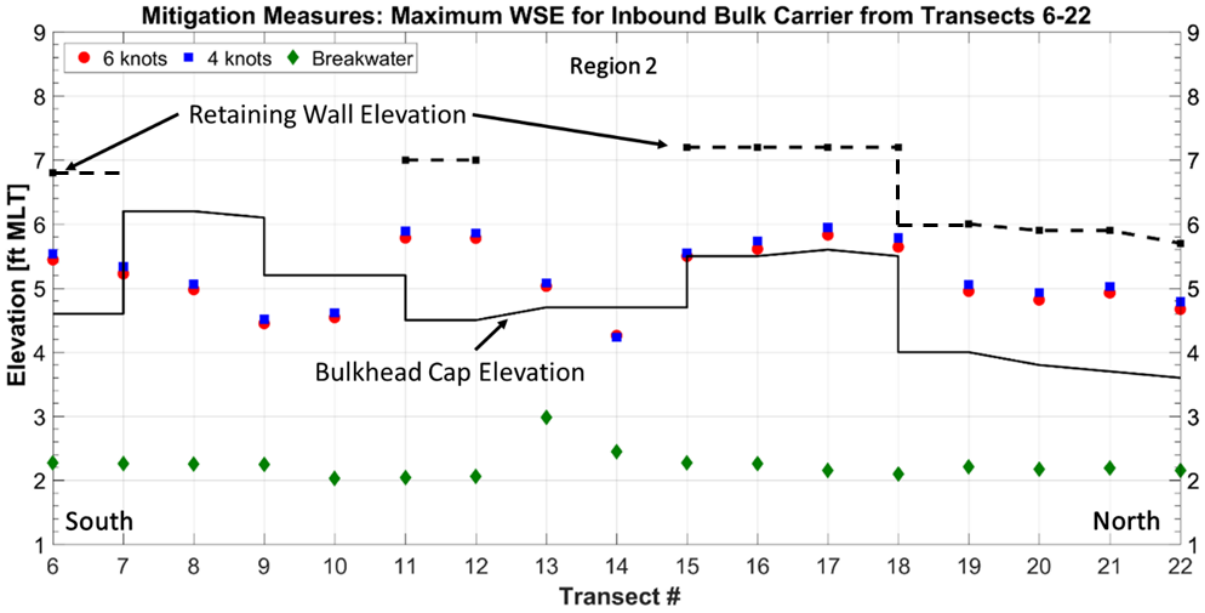

Figure 51. Resulting max WSE values per transect within Region 2 for the modeled mitigation measures. Each data point is color coordinated a different simulation.

Note that the data points from the vessel simulation at the 6-knot speed is shown for determining required bulkhead elevations for Potential Mitigation Measure A.

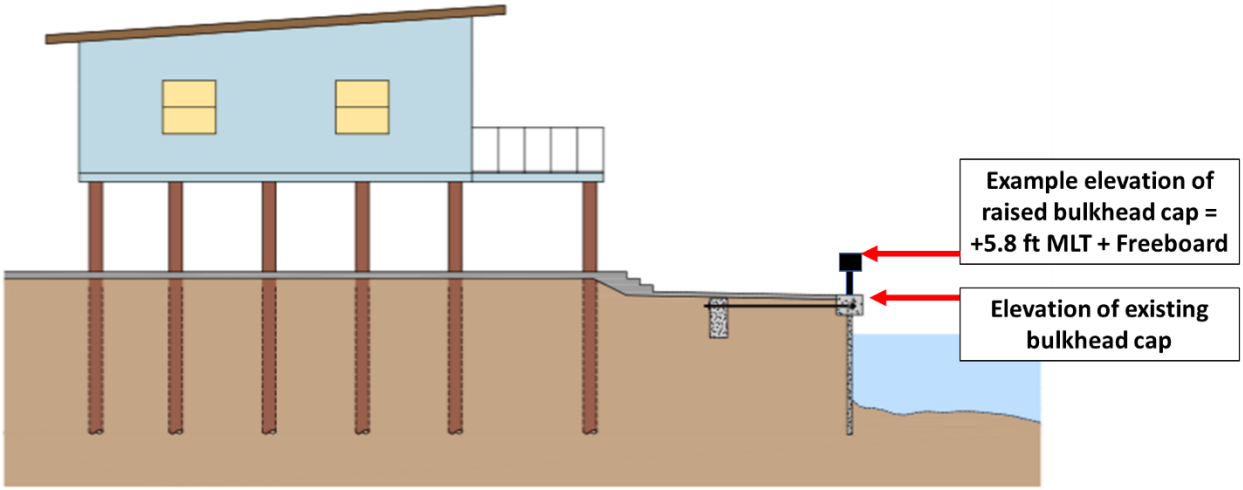

Figure 52. Concept sketch showing an example elevation for a raised bulkhead cap, which based on results of the vessel simulations in this study, would need to be +5.8 ft MLT plus some level of freeboard. Concept sketch is not to scale or accuracy.

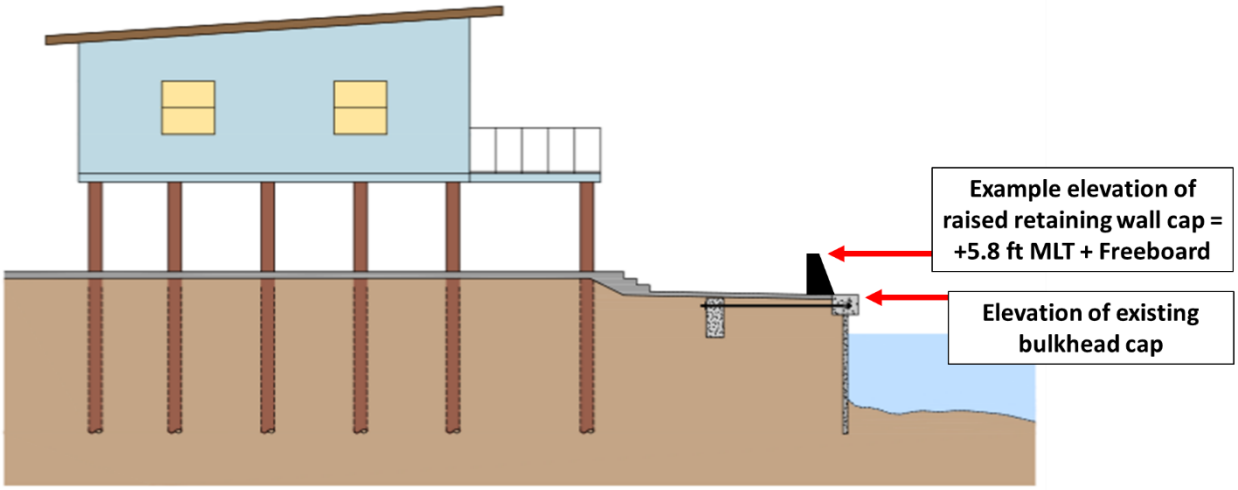

Figure 53. Concept sketch showing an example elevation for a raised retaining wall cap, which based on results of the vessel simulations in this study, would need to be +5.8 ft MLT plus some level of freeboard. Concept sketch is not to scale or accuracy.

The effect of the presence of the extended breakwater is further shown in Figure 54. This figure shows the change in max WSEs from the presence of the extended breakwater with the representative vessel and proposed scenario (LQC bulk carrier heading inbound with CCSC widening/deepening and BUS C-Q and BUS I-C), when compared to existing conditions. Warm colors (yellow to red) show where max WSEs are greater under this mitigation and proposed condition when compared to the existing conditions, and cooler colors (light to dark blue), show areas where max WSEs are lower under this condition when compared to the existing conditions. Notice how the max WSEs are dark blue along the shoreline adjacent to Bayshore Drive due to the presence of the extended breakwater.

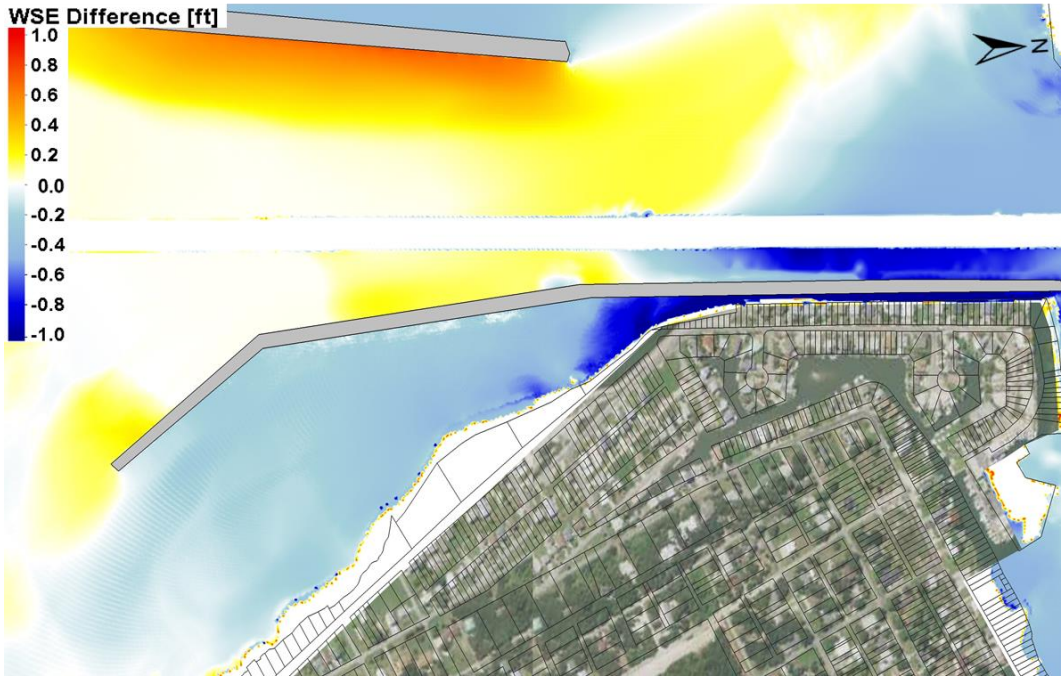

Figure 54. Difference in max WSEs from the representative vessel and condition scenario (LQC bulk carrier heading inbound with CCSC widening/deepening and BUS C-Q and BUS I-C) with the extended breakwater when compared to existing conditions in Regions 2 and 3.

5.8.3 Region 3

The resulting max WSE values within Region 3 for the modeled mitigation measures are shown in Figure 55. This figure shows that the effects of the different mitigation measures range within this region. The breakwater expansion would barely affect max WSEs at areas near the southern end of the existing breakwater (Transects 1 – 3). However, near the northern end of the exiting breakwater (Transects 4 – 5), an expansion would help decrease max WSEs induced by passing vessels; this is further shown in Figure 54 above.

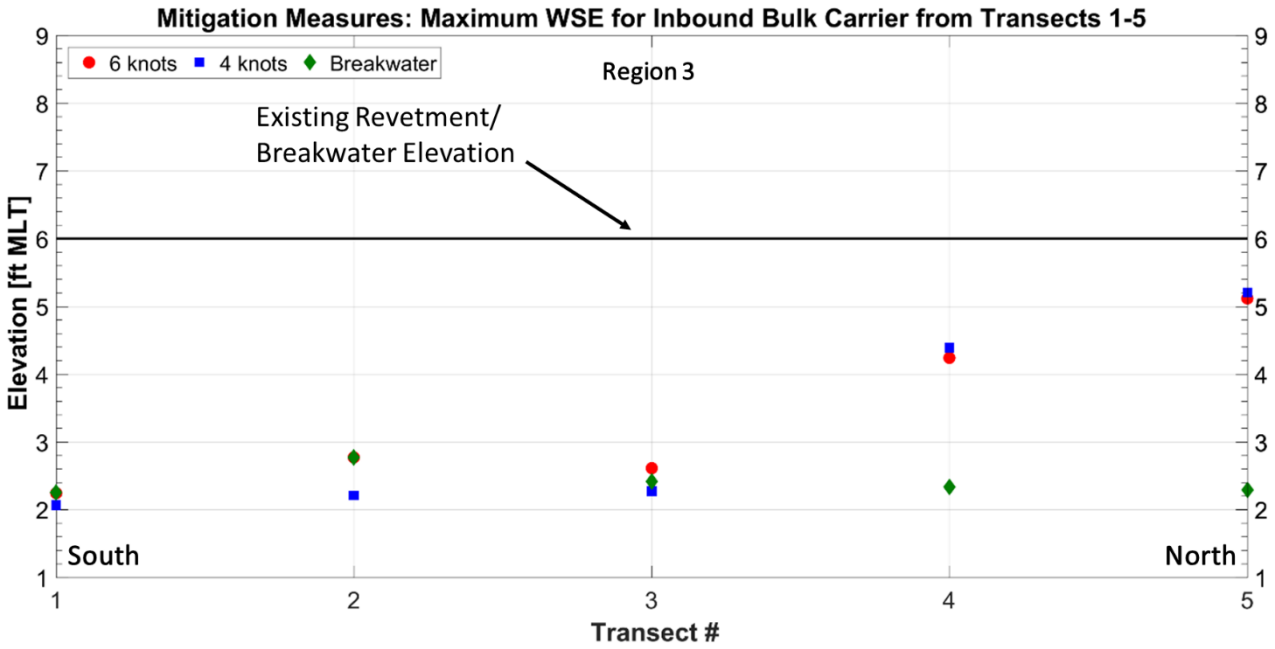

Figure 55. Resulting max WSE values per transect within Region 3 for the modeled mitigation measures. Each data point is color coordinated a different simulation. Note that the data points from the vessel simulation at the 6-knot speed is not considered a mitigation measure, it is only shown for comparison purposes.

6 Conclusions

This technical memorandum summarizes the work and results of a numerical modeling study of vessel hydrodynamics conducted by Mott MacDonald at the request of the Port of Corpus Christi Authority (PCCA) under Service Order No. 2 of PCCA Master Services Agreement NO.18-03. The purpose of this study was to investigate the hydrodynamic effects due to proposed modifications to the Corpus Christi and La Quinta ship channels including the widening of the Corpus Christi Ship Channel, construction of a Beneficial Use/Dredged Material Placement Area (BU/DMPA) near the intersection of the La Quinta and Corpus Christi Ship Channels (BU Site C-Q), and the construction of an additional future BU/DMPA within Ingleside Cove (BU Site I-C). The project goals are listed below, and following each goal, is a summary of the findings and results from this study.

1. Determine changes in passing vessel current velocity and water level fluctuations along the shoreline between existing and proposed conditions.
    a. The existing and proposed conditions were evaluated using a range of vessel types and scenarios. The impacts of the proposed conditions were evaluated by comparing resulting max WSE values along transects through the project area and comparing them to the results of the same vessel simulation but under existing conditions. In general, the proposed conditions were found to cause an increase in max WSEs when compared to the existing condition results. However, all max WSE increases are less than 6 inches at the transects of interest. In addition, each of the different vessel simulations resulted in mostly similar hydrodynamics, with the exception of the 52 ft draft Suezmax vessel, which resulted in higher max WSEs than the comparison simulations with the 45 ft draft Suezmax. Since the location of the proposed BU Sites C-Q and I-C are approximate only, it may be possible to reduce the impacts of the 52 ft draft Suezmax vessel in the CCSC channel by shifting the BUS C-Q towards the west. Additional modeling would be needed to optimize the site's location.
2. Determine physical impacts to the Ingleside On-the-Bay bulkheads and shoreline along the LQC and along the CCSC, including the full length of Bayshore Drive, Ingleside Marina, Ingleside Cove shoreline, and PCCA Island for existing and potential future channel improvement conditions.
    a. The physical impacts at the shoreline were evaluated by comparing the max WSE values at to the bulkhead cap elevations and individual transects within Region 2. The results show that the proposed conditions do not worsen overtopping that is experienced under existing conditions. Max WSE values at each transection location within all regions are documented within this report.
3. Evaluate potential effects of RSLR and various tide/water levels on passing vessel hydrodynamic effects.
    a. Water level tests were performed to evaluate how a range of future water level scenarios would impact resulting max WSE values due to passing vessel activities. The range of water levels tested included: (1) an increment for RSLR; and (2) a 5-yr elevated tidal event. These water level scenarios were tested separately. The results show that in general, an increase in initial water level does result in an increase in max WSE values caused by passing vessels. The magnitude of the resulting increased max

WSE is primarily due to the increased initial water level, as the impact caused directly by the passing vessel is observed to decrease with increasing initial water levels due to the increase in water depth. The tested higher water levels result in increased overtopping impacts to those properties that were overtopped under the existing conditions tested, but the properties that were not overtopped under existing conditions were also not overtopped at the higher water level scenarios tested. However, the freeboards of the non-overtopped bulkheads and retaining walls do decrease, which increases their vulnerability to overtopping under conditions not accounted for in the model simulation, such as wind, surge, and waves.

4. Identify and test potential structural and non-structural mitigation measures for reducing vessel impacts to the shoreline.
    a. This report documents the max WSE values at each transect within Region 2, thus a minimum proposed cap elevation for the bulkheads and retaining walls along the waterfront properties within Region 2 can be determined from the data within this report. A freeboard or safety factor should also be incorporated into the proposed minimum elevation. When compared to the other two mitigation measures (discussed below), this measure is likely to be the most feasible from a cost, constructability, and permitting perspective.
    b. Slowing the vessel speed to 4 knots was found to increase WSEs within Region 2, thus this is no longer considered as a mitigation option. It is possible that slower vessel speeds may reduce max WSEs within this area; however, thorough consideration must be made as to how a significant slowing of the vessel speed will impact shipping and port operations. The modeling has shown, that while slowing the vessel reduces the overall magnitude of the water surface elevation, the slower speed creates a longer period bore wave that can more easily run up the shoreline, thus magnifying the passing vessel effects in this case.
    c. Extension of the existing breakwater was found to substantially reduce max WSE values within Region 2; it also reduced max WSE values within Region 1 and 3. However, this alternative will likely be costlier than increasing the bulkhead cap elevations at the waterfront properties within Region 2. Consideration of the permitting requirements, potential adverse resource impacts, and constructability must also be made.
    d. Note that the purpose of this study was to evaluate the potential impacts to passing vessel hydrodynamic conditions of the mitigation measures tested, the actual feasibility of these measures was not evaluated under this study.

After assessing the results of the analysis performed in this study, the recommended approach for mitigating passing vessel impacts within Region 2 is to either raise the cap elevations of the exiting bulkheads or extend the existing breakwater. Additional recommendations are suggested as follows:

1. Perform a detailed project alternatives analysis to further investigate feasibility, cost, stakeholder input, and constructability of both preferred alternatives (raise the cap elevations of the existing bulkheads and extend the existing breakwater).
2. Deepening the LQC bottom within Region 2 could be an additional test to determine if added vessel keel clearance within Region 2 has an impact on the

vessel-induced hydrodynamics observed at the water surface. However, the level of impact is unknown, thus additional testing would be recommended to determine the potential effects of deepening the LQC bottom within Region 2.

3. Relocating the proposed BUS C-Q could have an impact on vessel-induced hydrodynamics. An additional study is recommended to optimize the location and orientation of these features. Furthermore, coordination with the USACE would be necessary to determine the feasibility of relocating site BUS C-Q.

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