MOTT MACDONALD

Hydrodynamic Analysis of Proposed Edgemoor Terminal

Edgemoor, DE

October 3, 2019

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Executive Summary

Mott MacDonald (MM) performed a hydrodynamic analysis of the proposed Edgemoor Terminal as a subconsultant to Duffield Associates for the Diamond State Port Corporation (DSPC). The proposed Edgemoor Terminal consists of approximately 2,500 linear feet of continuous container wharf to be constructed along the western shoreline of the Delaware River, approximately 2 miles upstream of the Port of Wilmington, DE.

The objective of the analysis was to evaluate potential impacts of the terminal and dredging on hydrodynamics, salinity, sediment transport and erosion/deposition in the surrounding area. Analysis was performed with 3D estuary-wide numerical modeling of hydrodynamics, sediment transport and morphology using the MIKE3 model (DHI 2018). The hydrodynamic modeling simulations included ocean tides, discharges from multiple rivers and the Chesapeake and Delaware Canal, storm surge, local winds, and salinity. Wind-waves, ocean swell and vessel traffic effects were not included.

The modeling domain was constructed using an array of best available data sources including multi-beam and single beam hydrographic survey datasets, LiDAR data, and larger-scale regional survey data sets. The hydrodynamic model was calibrated and validated using measured water levels, velocities, and salinities at multiple locations. The model successfully reproduced measured conditions at multiple locations bounding the project site.

Sediment transport modeling simulations included only suspended sediment concentrations at river boundary conditions, and bottom sediment resuspension directly within the estuary-wide model. Sediment input data were taken from borings collected at the Edgemoor site in October 2017 (Duffield Associates 2017), estuary-wide sediment sampling programs, and qualitative information taken from observed morphological features and anecdotal information.

Anecdotal information from the USACE regarding channel dredging, local morphological features, and experience at the nearby Port of Wilmington indicate that movement of sands is not likely to dominate sediment transport at the site; however, sand transport was simulated and gut-checked using a series of sensitivity analysis simulations. The primary model calibration focus was fluvial silt transport, using the Mud Transport module in MIKE3. The mud transport model was calibrated using measured sedimentation at the Port of Wilmington, with only internal resuspension generating suspended sediment concentrations.

The Port of Wilmington 10-year average sedimentation rate of 1,747 cubic meters per day (2,289 cubic yards per day) as reported in Moffatt & Nichol (2000) was used as the calibration target within the calibration period sediment transport simulations. Model results at the existing Edgemoor site showed modest sedimentation on the existing slope between the shoreline and navigation channel which is logical given the site conditions. In the shallows, wind-waves likely maintain a dynamic equilibrium at the site under present conditions but were not included in the modeling. In addition, a modest sedimentation in shallow water is shown because the transport model was run de-coupled from the hydrodynamic model; the models could be run fully coupled if changes in the very shallow water become of interest. An additional model gut-check was undertaken by reviewing the predicted rates of sedimentation at Anchorage 7, upstream of the Edgemoor site. While not considered a validation, the model's predicted sedimentation rates at Anchorage 7 were similar in magnitude to the reported annual rate of 3 feet per year.

Calculation of peak current speed differences caused by the project (using direct subtraction) show that the project only affects hydrodynamics in the estuary within approximately one berth

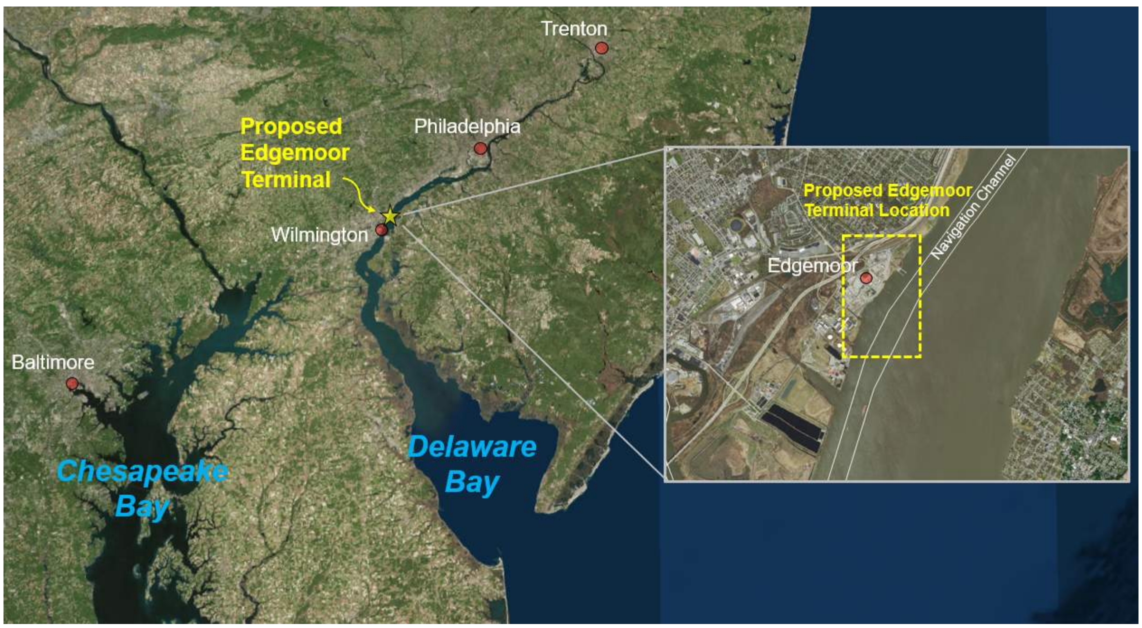
length or less away from the terminal. Since hydrodynamic changes are negligible outside the immediate vicinity of the terminal, sediment transport and morphology are also unaffected outside this area. Sediment transport simulations show no measurable erosion/accretion caused by the project outside the immediate vicinity of the terminal.

1 Introduction

1.1 Overview and Location

Coastal processes analysis was performed by Mott MacDonald (MM) as a subconsultant to Duffield Associates for Diamond State Port Corporation (DSPC) in support of a proposed container terminal at Edgemoor, Delaware. The location of the proposed Edgemoor Terminal is shown in Figure 1, along the west bank of the Delaware River upstream of the Port of Wilmington, DE. The objectives of the analysis were to evaluate potential impacts of the terminal on hydrodynamics, sediment transport and morphology in the surrounding areas.

Figure 1: Proposed Edgemoor Terminal location



1.2 Scope of Analysis

The objective of the analysis is to evaluate river/tidal hydrodynamics and sediment transport near the Edgemoor Terminal, changes that may be induced by the proposed project, and to utilize the analysis in support of permitting efforts underway by DSPC. Conceptual-level terminal and berth design alternatives were provided to MM by Duffield Associates for evaluation of project impacts.

1.3 Proposed Design

Figure 2 shows the conceptual-level design plan for the proposed Edgemoor Terminal (Duffield Associates 2018a). The berth depth of the Proposed Design is 45 feet (MLLW), with a Design Variant also evaluated in the analysis with berth depth 38 feet (MLLW). The Design Variant is the same as the Proposed Design with the exception of berth depth. The terminal design consists of nearshore fill and shoreline advancement, a partial-depth bulkhead, and a pile-supported wharf. The dredged berth has an area of approximately 63 acres (not including side slopes), with the upstream and downstream ends of the berth tapering towards the navigation channel with side slopes of 6H:1V, and a turning basin with diameter 1,700 feet.

Figure 2: Edgemoor Terminal Proposed Design (berth depth 45 feet, MLLW)

2 Site Conditions

2.1 General Background

The Delaware Estuary is one of the larger estuaries in the United States with a watershed area of approximately 14,000 square miles. Edgemoor is located in the upper Delaware Estuary, north of Wilmington, DE. The estuary is heavily influenced by tides with a weaker mean discharge of freshwater from the tributaries, resulting in a well-mixed estuary (Cook et. al 2007). Site conditions of interest in the analysis include hydrodynamics, salinity, and sediment transport. Since the proposed terminal construction will create new areas of deep water, the influence of wind-waves and vessel wakes were not relevant to the impact analysis, and therefore, they were not considered. The following sections provide an overview of the relevant coastal conditions at the site and data sources used in the modeling.

2.2 Tides

Figure 3 shows the locations of various tide measurement stations in the Delaware Estuary. NOAA Station 8540433 Marcus Hook is the nearest station to Edgemoor and is located approximately 6 miles upstream. Table 1 shows the tidal datums for NOAA Station 8540433. The mean tidal range is approximately 6 feet at the site. The North American Vertical Datum of 1988 (NAVD88) was reported to be 2.99 feet relative to Mean Lower Low Water (MLLW) at Edgemoor (USACE Philadelphia District survey drawings at the site).

Figure 3: Locations of measurement stations in Delaware Estuary

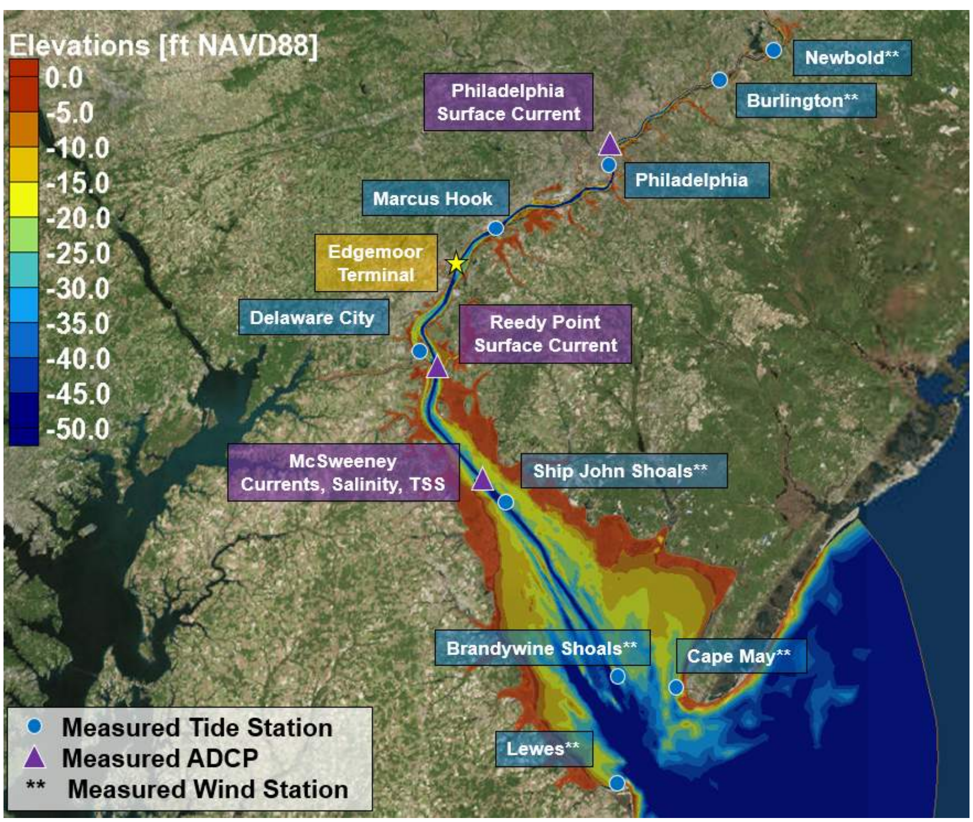


Table 1: Datum Table at Marcus Hook, NOAA Station 8540433

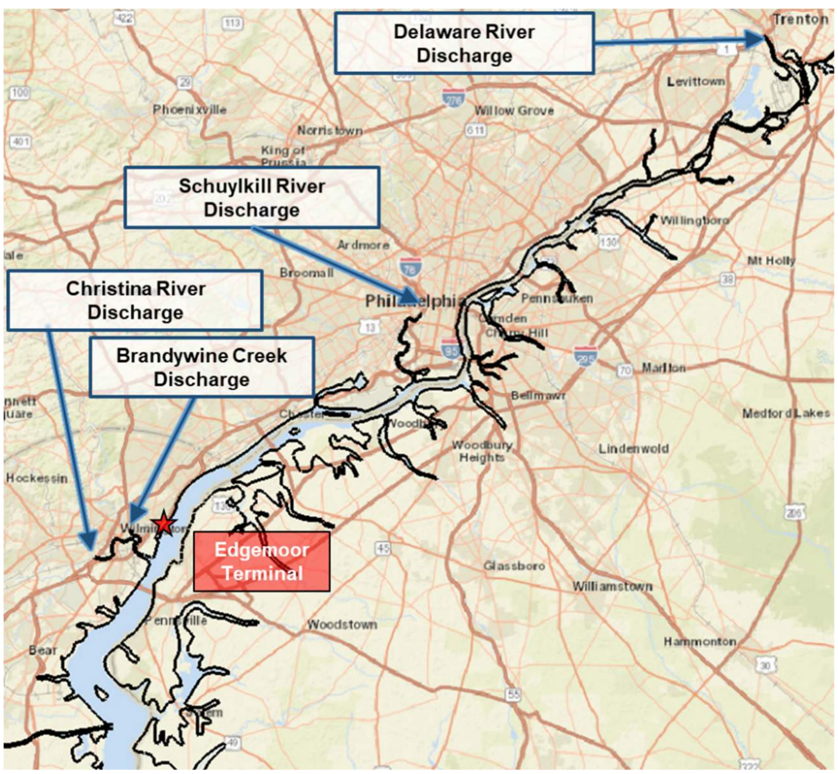
Datum	Elevation [ft, MLLW]
Mean Higher-High Water (MHHW)	6.14
Mean High Water (MHW)	5.78
Mean Tide Level (MTL)	2.98
Mean Sea Level (MSL)	3.13
Mean Diurnal Tide Level (DTL)	3.07
Mean Low Water (MLW)	0.18
Mean Lower Low Water (MLLW)	0.00

Source: https://tidesandcurrents.noaa.gov/datums.html?id=8540433

2.3 River Discharges

The Delaware River contributes over 60% of the total freshwater input to the estuary (Cook et al. 2007). The mean annual inflow of Delaware River at Trenton, NJ is approximately 11,900 cubic feet per second (USGS 2018). Other major rivers contributing discharges to the estuary are the Schuylkill River, Brandywine River, and Christina River, with mean annual inflows of 2,800, 490, and 230 cubic feet per second, respectively (USGS). Figure 4 shows the locations of these rivers.

Figure 4: Locations of major rivers discharging to the Delaware Estuary



2.4 Currents

Tidal/river current measurements were not available at the proposed Edgemoor Terminal site. NOAA PORTS Station 8545240 at Philadelphia (approximately 27 miles northeast of the site) provides surface velocity measurements, with data indicating typical peak ebb and flood current speeds in the range of 3-4 ft/s. NOAA Station 8551910 at Reedy Point (approximately 14 miles south of the site) also provides historical surface velocity measurements (presently discontinued), with data also indicating peak ebb and flood current speeds in the range of 3-4 ft/s.

McSweeney (2017) conducted Acoustic Doppler Current Profiler (ADCP) measurements in 2011 at multiple locations in the lower estuary and reported velocities up to 4-5 ft/s. Cook et. al. (2007) measured velocities in the upper estuary in 2003 at New Castle and Tinicum Island, and reported peak ebb and flood current speeds of approximately 3 ft/s. Moffatt and Nichol (1999) measured current velocities at the Port of Wilmington (located at the mouth of Christina River, 1.7 miles south of Edgemoor), although the measurement locations were not in the main Delaware River. The current speeds measured at the Port of Wilmington were in the range of 0.5 to 1.5 ft/s. Current velocity data used in the model calibration and validation are shown in Section 5.

2.5 Salinity

The Delaware Estuary is considered well-mixed, or weakly stratified, in the upper estuary (Cook et. al. 2007) near Edgemoor. Salinity increases moving downstream, with a maximum of 25 to 30 PSU in the bay. The salt front or salt line, defined as 0.45 PSU by the Delaware River Basin Commission (USACE 2009) is typically located near River Mile (RM) 70 (USACE 2009), a few miles downstream of Edgemoor. However, the location of the salt front changes depending on river flows and can be found between RM 50 and RM 90 (USACE 2009). The Edgemoor Terminal site is located at approximately RM 72.5 according to stationing by the Delaware River Basin Commission (https://www.state.nj.us/drbc/basin/river/).

2.6 Sediments

A site visit was performed on May 11, 2018 11:30 EDT at tidal elevation 4.3 feet (MLLW). The purpose of the site visit was to document shoreline sediment types, nearshore morphological features, and general site conditions. The shoreline consists of a mix of material types including fluvial silt, sand and gravel, depending on location on the beach profile. Shallower and upper-beach areas with more wave activity were observed to be armored by larger materials. Figure 5 shows photos taken during the site visit which indicated a) fluvial silt in the water column, and b) a mixed beach.

Figure 5: Site visit photos on May 11, 2018 11:30 EDT showing a) fluvial silt in the water column, and b) mixed upper beach looking downstream

Site sediments were also characterized using data from soil samples (borings) collected at the site in October 2017 (Duffield Associates 2017). Samples were collected at five (5) different locations with mudline elevations ranging from -4 to -26 feet (MLLW). Figure 6 shows the soil boring locations. The surface layer is composed entirely of MH/dark gray silt, which is very fine with high moisture content. This material is interpreted to be fluvial silt.

The thickness of the fluvial silt increases moving from the shoreline into deeper water, reaches a maximum, then reduces towards the navigation channel with higher current speeds. Table 2 shows the thicknesses and properties of the fluvial silt present on the slope at the project site. Using these data, a cross-section showing the thickness of the fluvial silt was constructed and is shown in Figure 6. The site is likely in a state of constant erosion and deposition (dynamic equilibrium).

Figure 6: Locations of soil borings taken October 2017 (adapted from Duffield Associates 2017)

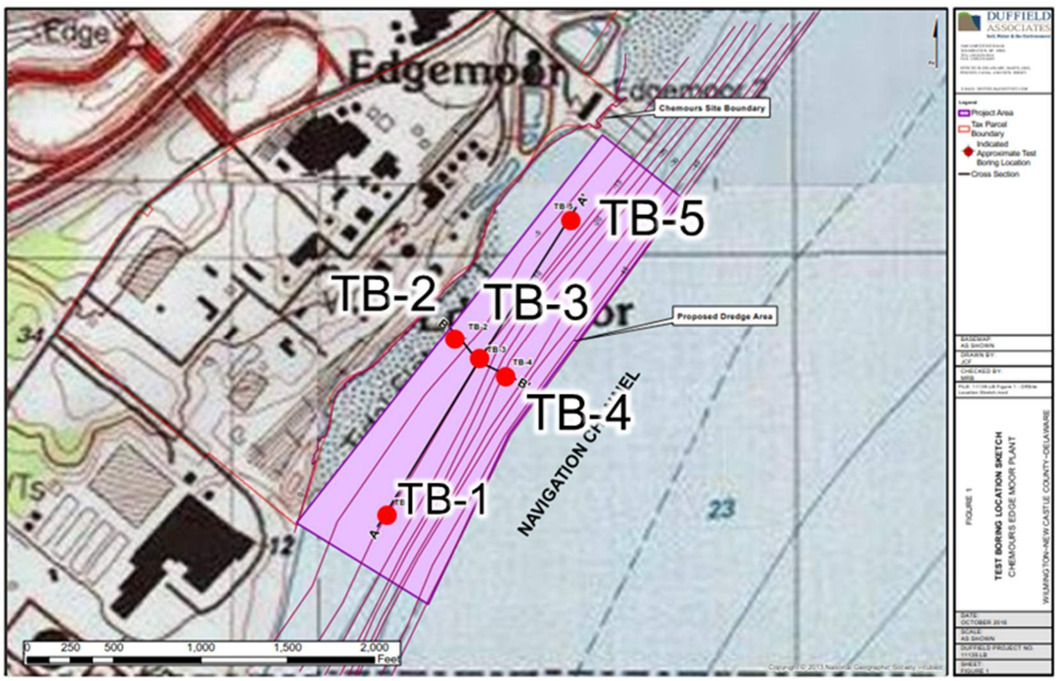


Table 2: Surface Sediment Characteristics at Proposed Edgemoor Terminal

Location	Mudline Elevation [ft, MLLW]	Mud Layer Thickness [ft]	Mud Moisture Content [%]	Mud Percent Passing #200 Sieve
TB-1	-11	8	87.4	96.9
TB-2	-4	4	58.3	98.2
TB-3	-11	11	101.8	98.9
TB-4	-26	5.5	84.7	97.3
TB-5	-9	8	83.1	99.5

Source: Data from Duffield & Associates (October 2017)

Figure 7: Transect location (top) and transect of existing fluvial silt thickness at the site and proposed berth (bottom)

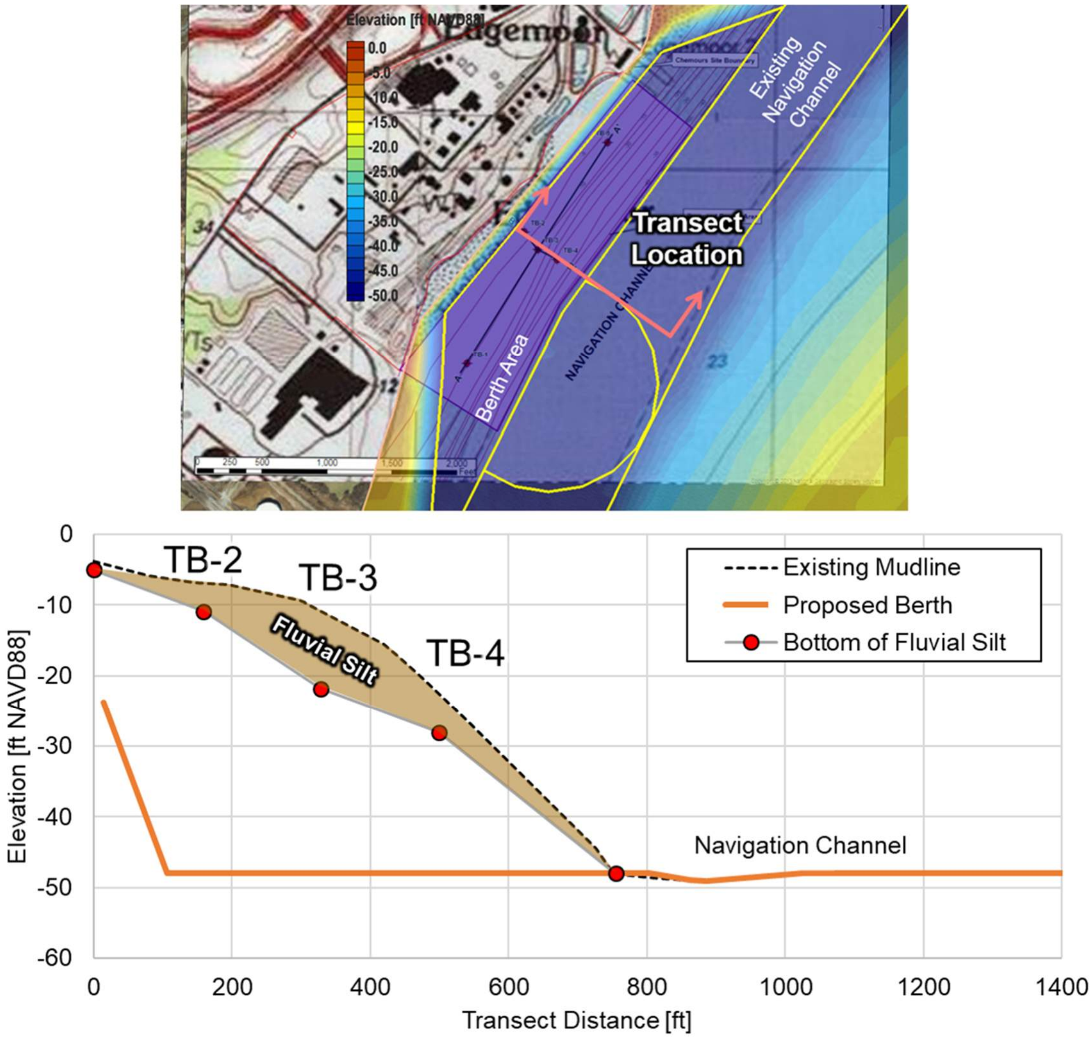
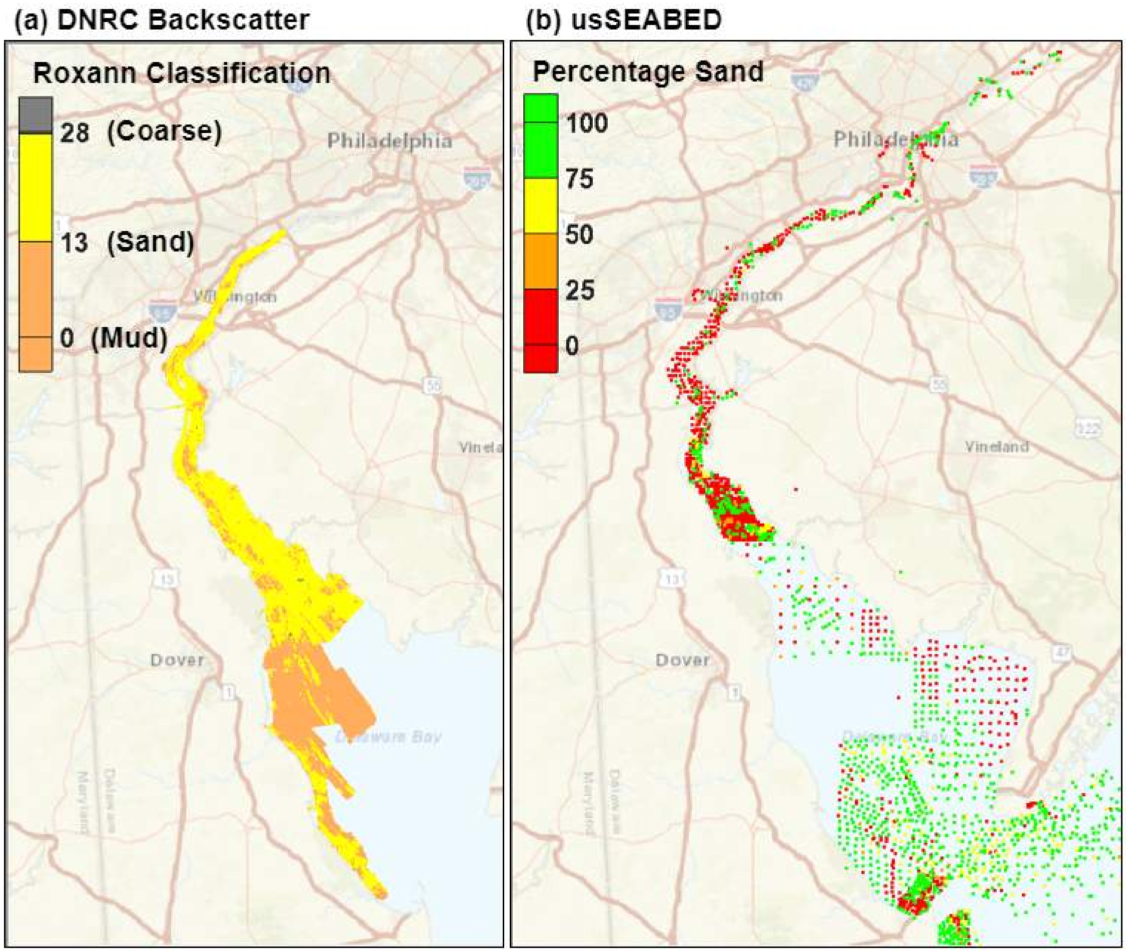


Figure 8 shows bed composition maps for the Delaware Estuary taken from two data sources: DNRC backscatter data (DNRC 2007, shown at left) and usSEABED data showing fraction of sandy material (USGS 2005, shown at right). The Delaware Estuary seabed contains a wide variety of materials which vary spatially based on levels of energy present in current and waves, and proximity to sediment sources. Given the complexity of the seabed in the estuary, and lack of complete sediment grain size information, separate transport simulations were performed using simulations with uniform sediment gradations specified in the domain.

Figure 8: Sediment types in the Delaware Estuary taken from (a) DNRC Backscatter and (b) usSEABED database



2.7 Suspended Sediment Concentrations

Suspended sediment concentration (SSC) data were not available at the Edgemoor site. Cook et. al (2007) measured SSC near New Castle (downstream of Edgemoor) and Tinicum Island (upstream of Edgemoor). Depending on the tidal cycle, SSC in the data collection period in 2003 reached 1.0 kg/m^3 at New Castle and reached 0.2 kg/m^3 at Tinicum Island. McSweeney (2017) conducted ADCP surveys further downstream in 2011 and reported SSC values up to 0.4 kg/m^3 depending on location. Moffatt & Nichol (2000) measured SSC values up to 0.5 kg/m^3 near the Port of Wilmington in 1999. Measurements typically show increases in concentrations during stronger ebb or flood currents and decreases during slack currents.

3 Observed Littoral Processes

3.1 Overview

Bed changes were evaluated to understand sediment transport mechanisms and provide data for model calibration. Sources of information used to calibrate the numerical model included anecdotal dredging information from the USACE Philadelphia District, previous studies at the Port of Wilmington, and hydrographic surveys at the Edgemoor site.

3.2 Navigation Channel Bed Changes

The USACE Philadelphia District provided dredging volumes for various navigation channel ranges in the Delaware River, and anecdotal commentary about the types of sediment removed during maintenance episodes. USACE Philadelphia District provided anecdotal information about sedimentation and maintenance dredging activities in the following statements (Duffield Associates 2018a):

- *Average annual shoaling rates prior to the 45ft deepening project are as follows: Cherry Island Range: 236,000cy, Bellevue Range: 34,000cy*
- *Bellevue Range looks like sand waves coming in on the inside edge*
- *Cherry Island Range is mostly silts*
- *Bellevue Range is averaged out at approximately one dredging event every five years*
- *Cherry Island is averaged out to annual or semi-annual dredging events.*

During subsequent interaction with Duffield Associates, USACE indicated that no dredging records were available for Bellevue and Cherry Island Ranges, and that they have not dredged the area in six years (Duffield Associates 2018d). Average annual sedimentation at Anchorage 7, located upstream of Edgemoor at the Marcus Hook Range, is reportedly in the range of 3 feet per year (Duffield Associates 2018c).

3.3 Port of Wilmington Channel Bed Changes

The Port of Wilmington, located at the confluence between the Christina and Delaware Rivers, experiences high rates of sedimentation. The Port of Wilmington is located at the mouth of the Christina River, with a berth/channel width of 340 feet that is maintained at a depth of 38 feet (MLLW). Figure 9 shows the location of the Port of Wilmington, downstream of the Edgemoor site. Sedimentation at the Port was evaluated and reported in Moffatt & Nichol (2000), which indicated that the channel experiences shoaling of 10 feet in as little as 2 months.

Annual sedimentation rates at the Port fluctuate, depending on river hydrodynamic conditions, with the majority of the sediment originating from the lower estuary. Moffatt & Nichol (2000) reported that the channel experiences a 10-year average daily rate of sedimentation of 1,747 cubic meters per day (equivalent to 835,000 CY per year). Figure 10 shows the 10-year annual average sedimentation reported in Moffatt & Nichol (2000). Note that the modeled sedimentation values in the table shown in Figure 10 were those calculated in the Moffatt & Nichol (2000) study, not the present study. The average annual sedimentation of 835,000 CY was used as the calibration target in the sediment transport modeling.

Figure 9: Port of Wilmington location

Figure 10: Ten-year average shoaling rates (adapted from Figure 6-5, Moffatt & Nichol 2000). Note: "modeled shoaling" values pertain to the Moffatt & Nichol (2000) study.

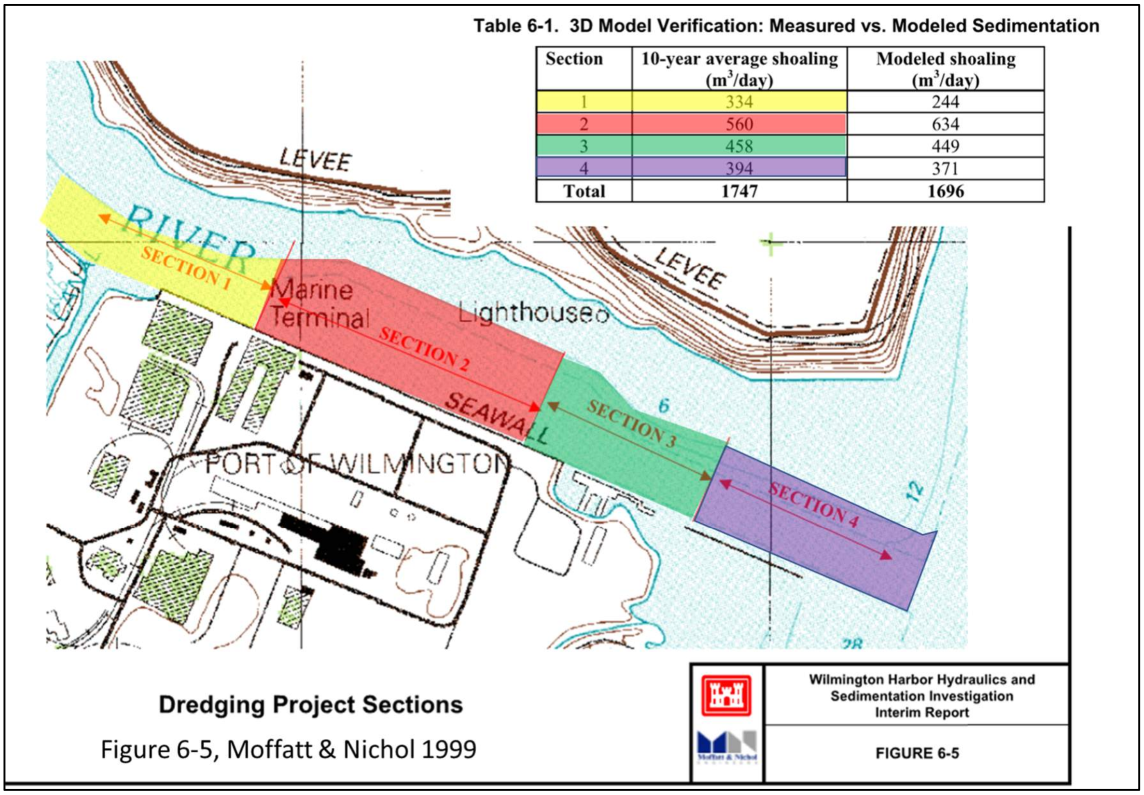


Table 6-1. 3D Model Verification: Measured vs. Modeled Sedimentation

Section	10-year average shoaling (m^3/day)	Modeled shoaling (m^3/day)
1	334	244
2	560	634
3	458	449
4	394	371
Total	1747	1696

3.4 Edgemoor Site Bed Changes (Existing Conditions)

Sedimentation at the existing Edgemoor site was evaluated by comparison of hydrographic survey datasets. A new site hydrographic survey was conducted on July 6, 2018. Figure 11 shows data from the July 2018 survey and two of the most recent USACE navigation channel surveys conducted on April 11 (middle) and May 17 (right), 2018. Figure 12 shows the changes in elevation in the limited areas where the surveys overlap. Changes are relatively small, and typically within 1-2 feet, with a general trend of erosion or minimal change, depending on which 2018 navigation channel survey is analyzed. Erosion occurring immediately adjacent to the navigation channel boundary may indicate side slope failure. Hydrographic surveys from 2013 and 2016 were also evaluated and provide better overlap with the July 2018 survey data.

Figure 11: July 6, 2018 hydrographic survey (left) and USACE April 11, 2018 (middle) and May 17, 2018 (right) navigation channel surveys

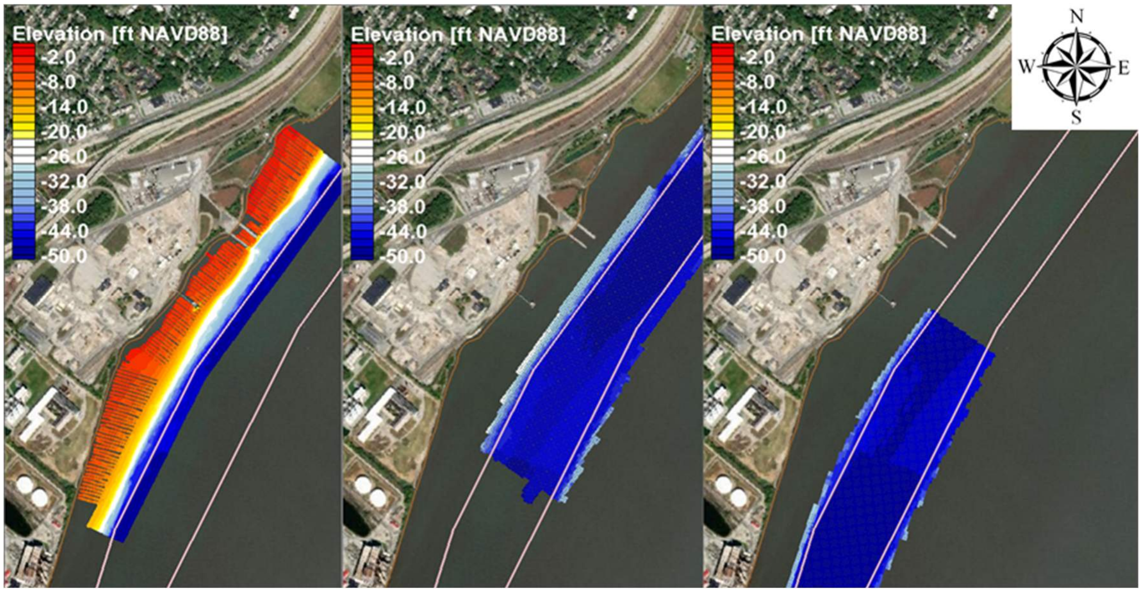


Figure 12: Observed sedimentation and erosion between the July 6, 2018 site survey and 2018 USACE surveys

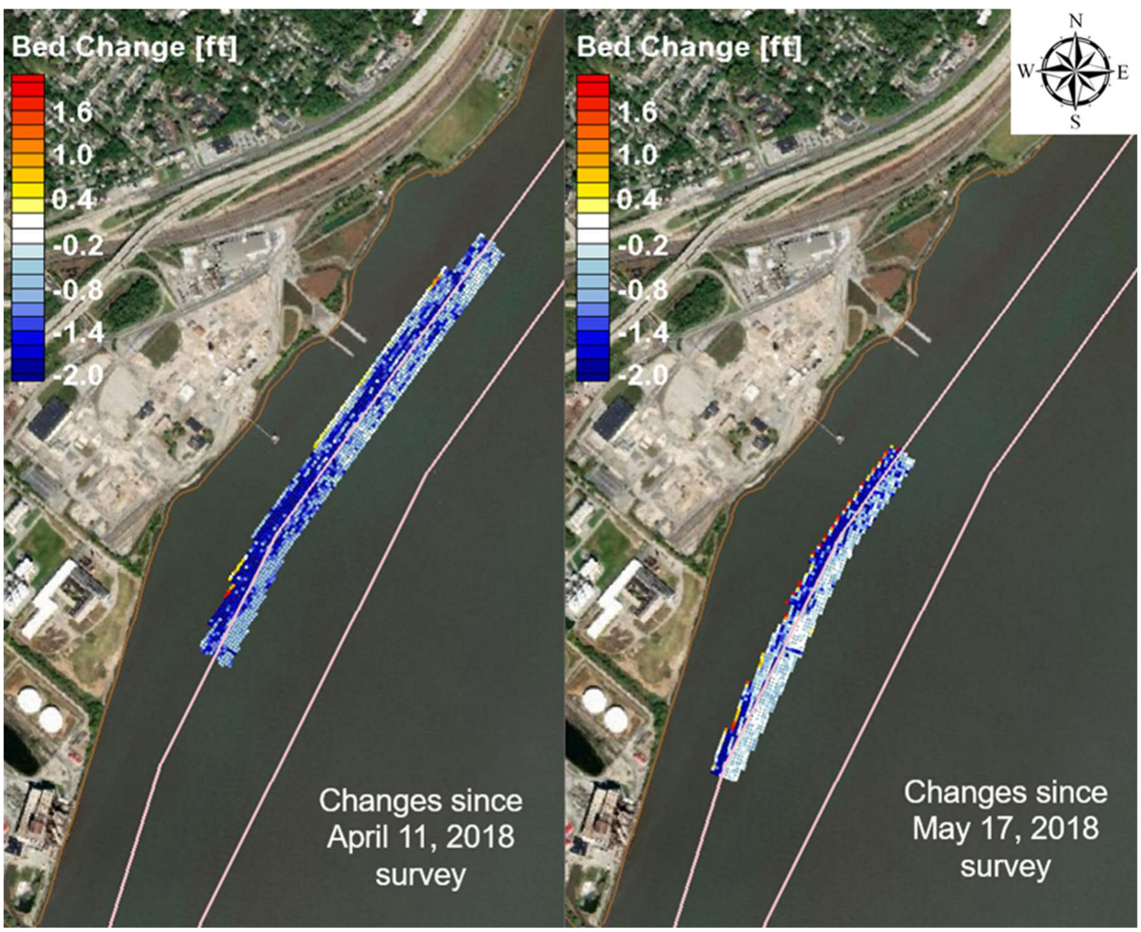


Figure 13 shows the July 2018 survey data, overlaid with the extents of the 2013 (top) and 2016 (bottom) hydrographic survey data from USACE which are shown in white. Figure 14 shows elevation changes between 2013 and 2018 (top), and between 2016 and 2018 (bottom). Changes since 2016 are minimal in all areas except for the deepening that occurred in the NW end of the Cherry Island Range, presumably due to dredging. Per discussion with Duffield Associates on (2018b), the USACE reportedly box-cut rather than dredging side slopes. Greater changes are evident in the comparison between 2013 and 2018 conditions, indicating that between 2013 and 2016, erosion occurred over a limited area of the slope adjacent to the navigation channel. This erosion may have been caused by slope failure, as other areas of the slope showed minimal changes.

Figure 13: Coverage of July 2018 hydrographic survey relative to 2013 (top) and 2016 (bottom) surveys

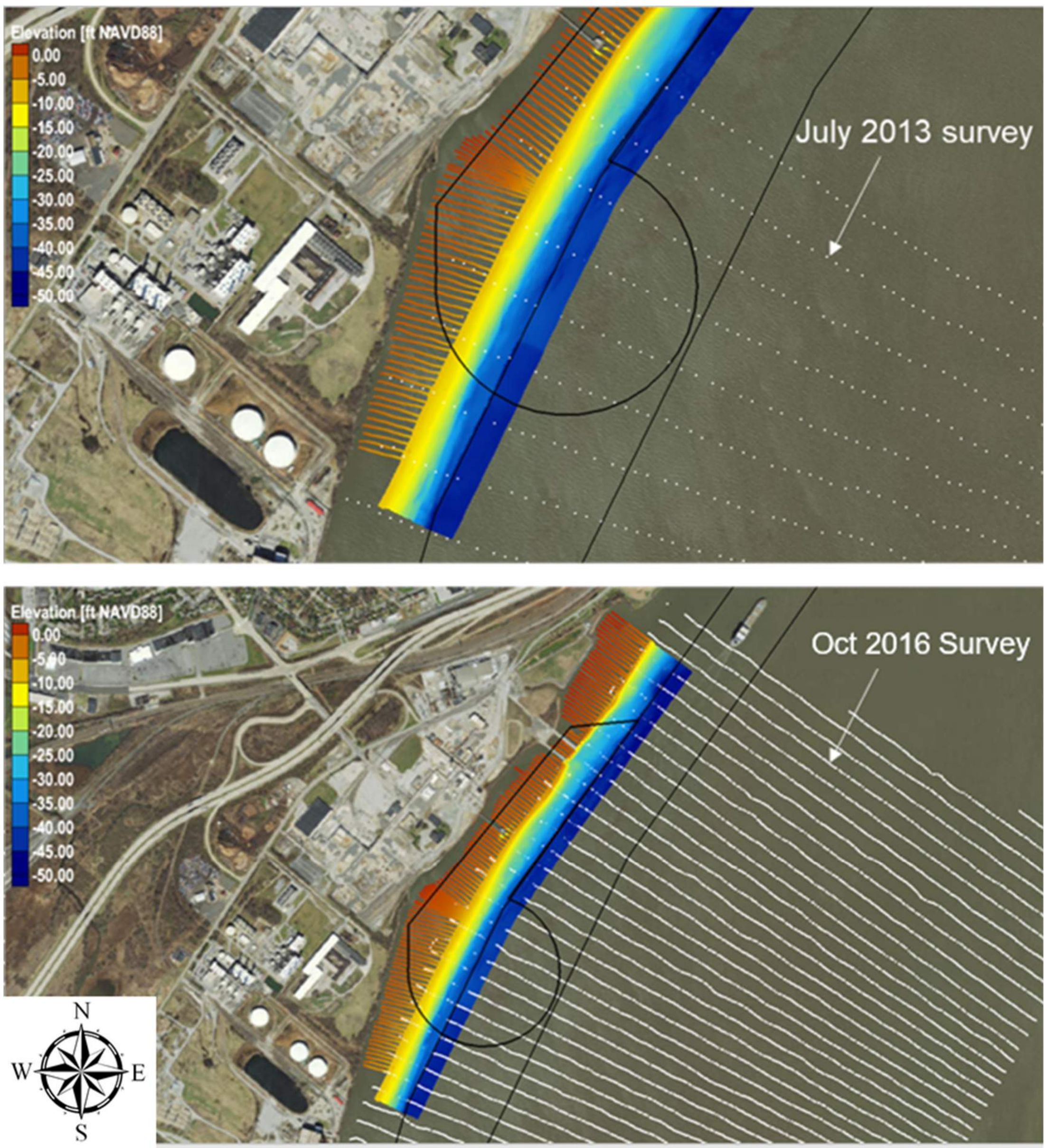
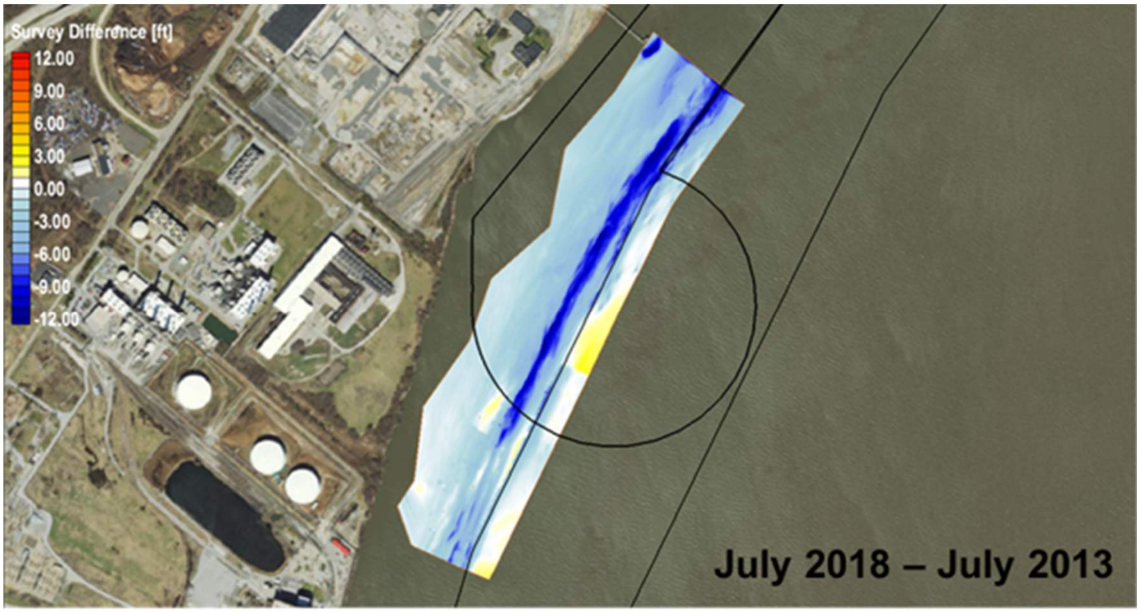
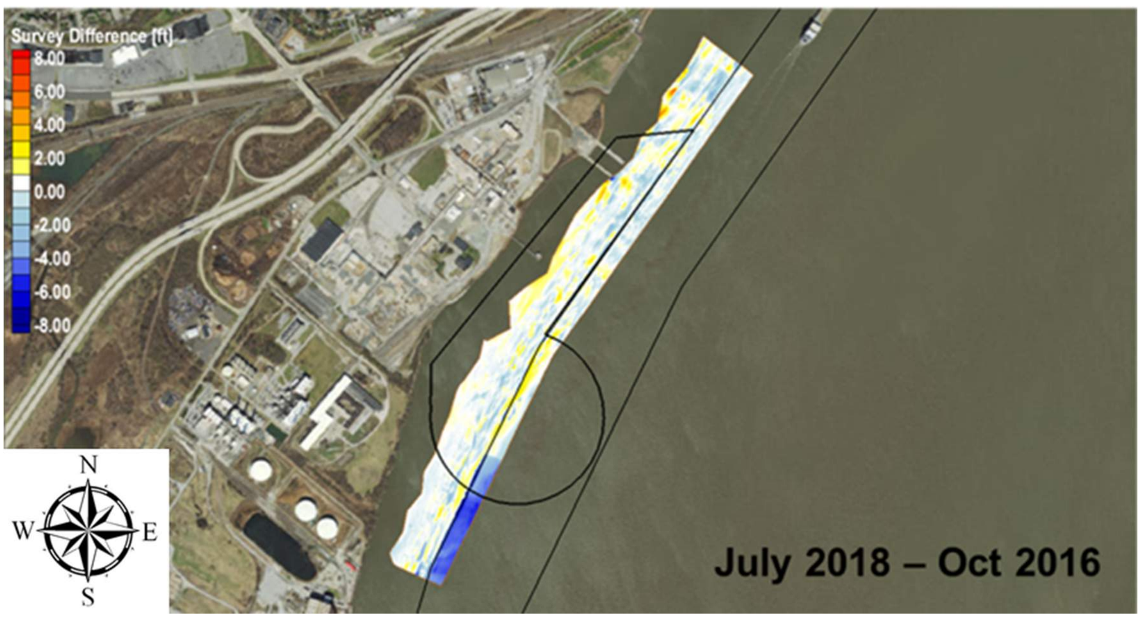


Figure 14: Observed elevation changes between July 6, 2018 survey and 2013 survey (top) and between July 6, 2018 survey and 2016 survey (bottom)





It appears that at its present elevation, the slope between the shoreline and navigation channel has not been experiencing a significant trend of erosion or deposition. This is likely due to a dynamic equilibrium of fluvial silt on the slope which depends on fluctuating current, wind-wave and vessel wake conditions.

4 Numerical Model Setup

4.1 General

A 3D numerical model of the Delaware Estuary was constructed to evaluate hydrodynamics, sediment transport, and potential environmental impacts of the proposed Edgemoor Terminal. The MIKE3 software was utilized. The model simulates three-dimensional (3D) flows, salinity, as well as non-cohesive and cohesive sediment transport. Ocean swell, wind-waves and vessel wakes were not included in the simulations. MIKE3 was chosen for use on the project due to its capability to simulate the relevant, multi-dimensional physical processes in driving transport and sedimentation in the estuary.

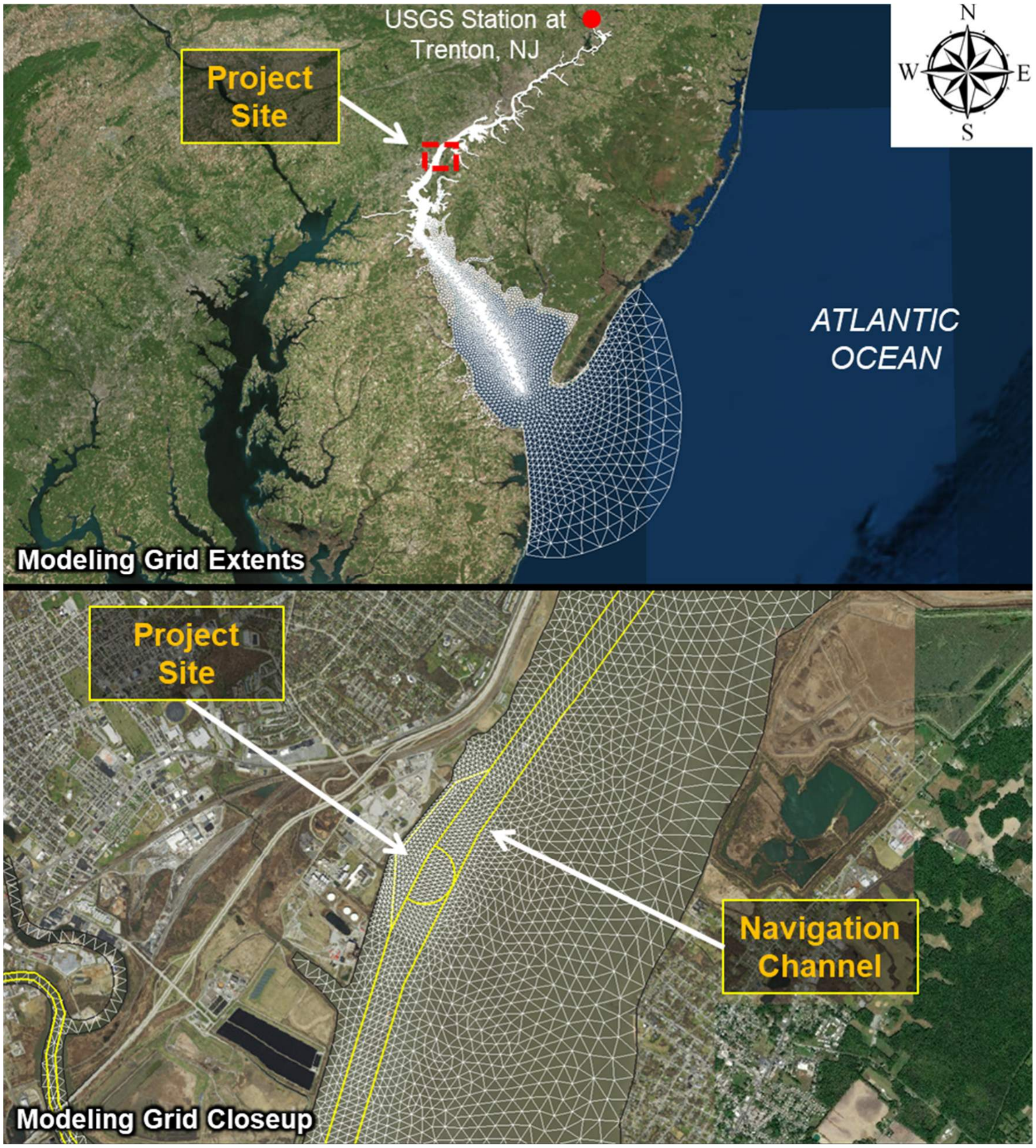
4.2 Model Geometry

To accurately simulate all relevant physical processes at Edgemoor, it was necessary to model the entire Delaware Estuary. The model grid boundaries were constructed such that the extents of the grid were placed at locations with measured boundary conditions. The Delaware River boundary was extended to the USGS station at Trenton, NJ. Likewise, the other river boundaries (e.g. Schuylkill River, Christina River etc) were positioned at USGS station locations. The Chesapeake Canal boundary was located at the NOAA station location which provided historical water level and current velocity data. The ocean boundary was constructed roughly 35 miles offshore to the Atlantic Ocean, sufficient distance to capture accurate tidal constituents from global databases.

Figure 15 shows the MIKE3 modeling domain (top) and resolution at the project site (bottom). The model domain consisted of an unstructured mesh composed solely of triangles with variable resolution, necessary to resolve key processes while allowing reasonable computation times. The final existing conditions model consisted of 16,158 nodes and 28,166 elements with element sizes ranging from approximately 4.5 mi. at the ocean boundary to approximately 65 feet at the project site. A resolution sensitivity test was performed by doubling the model’s resolution globally (cells sizes halved), and results were not measurably affected.

The vertical grid was a sigma-layer grid, with each layer consisting of a percentage of the total depth. The layer thicknesses changed with time as total depths changed. The top and bottom layers were each 10% of the total depth to better resolve wind effects on the surface and bottom shear stress/transport at the bottom. The middle layers were each 20% of the total depth.

Figure 15: MIKE3 modeling grid extents (top) and resolution at project site (bottom)



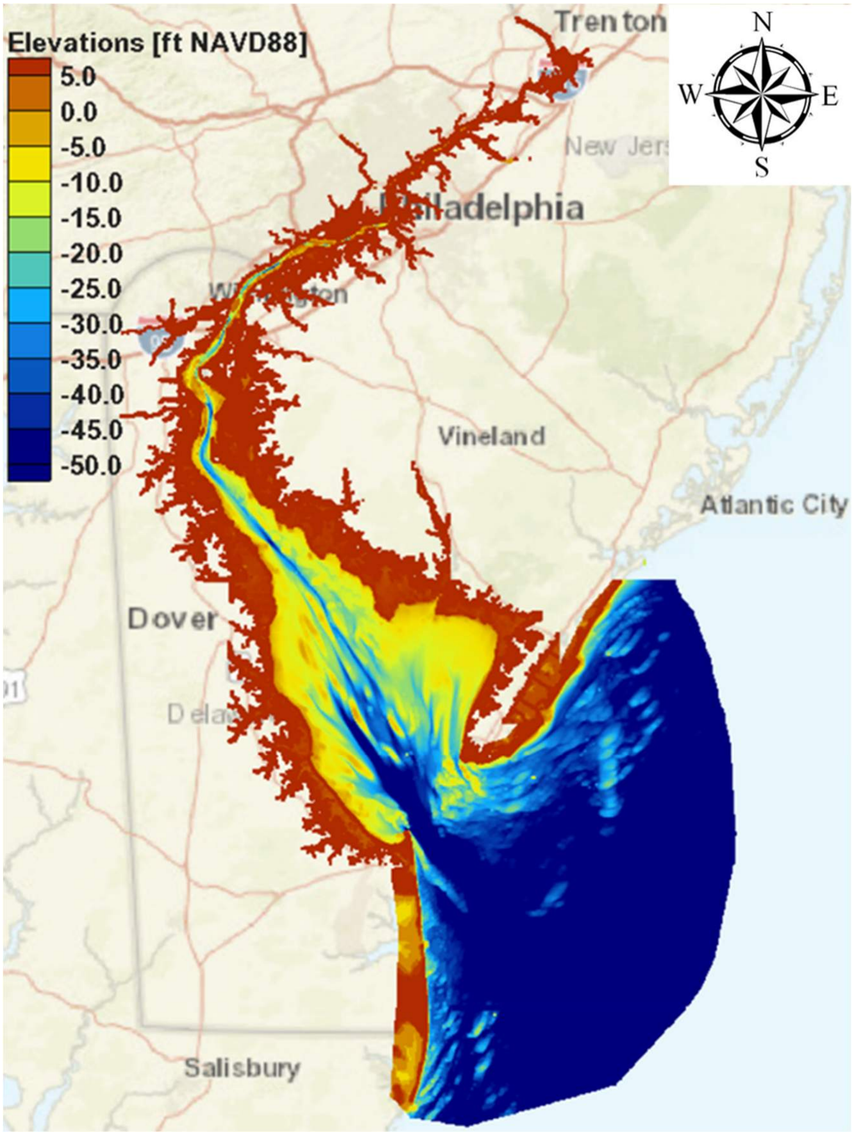
4.2.1 Bathymetry

A mix of bathymetry data sources was used to generate a unified elevation dataset for grid development. The composite dataset is shown in Figure 16. The following data sources were used, in order of priority:

1. July 16, 2018 site hydrographic survey (GBA 2018). The survey is shown in Figure 11.
2. Previous surveys covering Edgemoor and adjacent areas (USACE 2013, 2016, 2018).
3. National Centers for Environmental Information (NCEI) Post Sandy Digital Elevation Model (NCEI 2014).
4. NOAA Digital Navigation Charts.

The composite elevation model was constructed using the NAVD88 vertical datum, and with conversions between NAVD88 and tidal datums taken from NOAA stations and USACE drawings. All modeling was performed using bottom elevations in the modeling domain, and water level boundary conditions, at NAVD88 vertical datum.

Figure 16: Composite elevation dataset used for MIKE3 modeling



4.2.2 Design Alternatives

Figure 17 to Figure 20 show color contour plots of elevations in the modeling domain following interpolation to the modeling grid for Existing Conditions, Proposed Design with berth depth 45 feet (MLLW), and Design Variant with berth depth 38 feet (MLLW), respectively.

Figure 17: MIKE3 model grid bathymetry for Existing Conditions

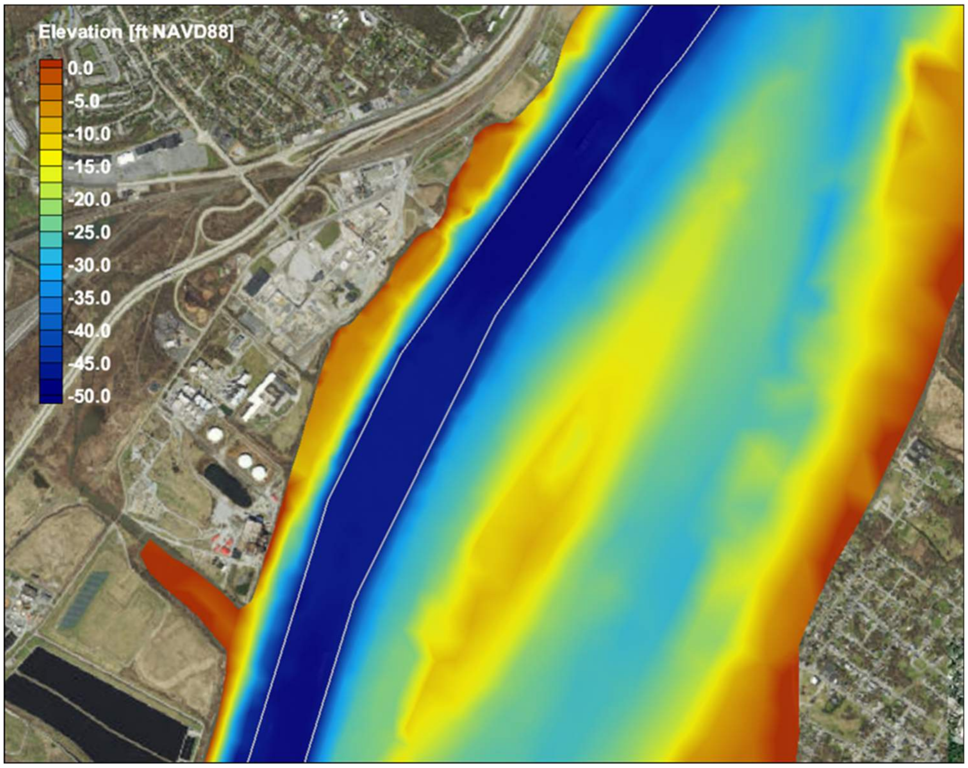


Figure 18: MIKE3 model grid bathymetry for Proposed Design with berth depth 45 feet (MLLW)

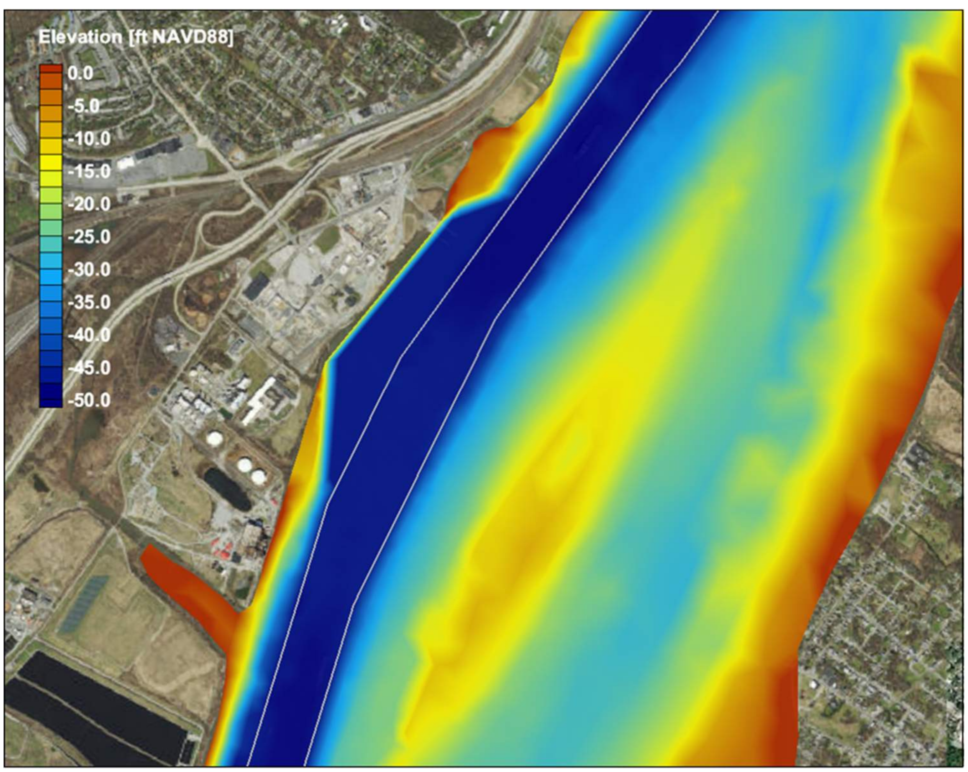


Figure 19: MIKE3 model grid bathymetry for Proposed Design with berth depth 45 feet (MLLW), with grid overlay

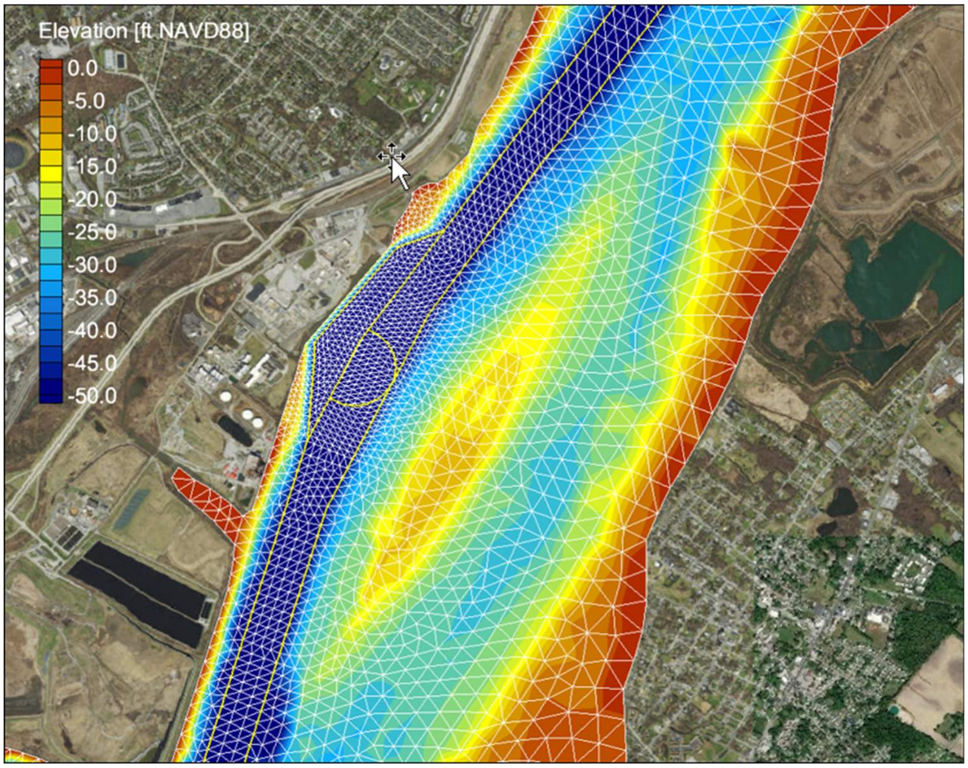
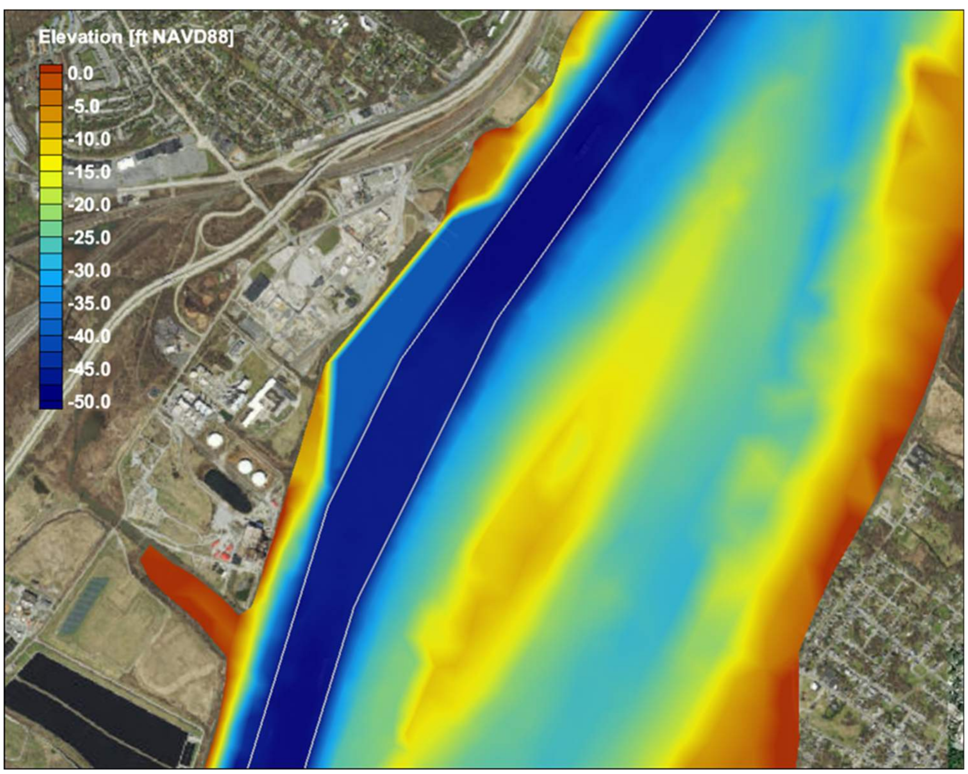


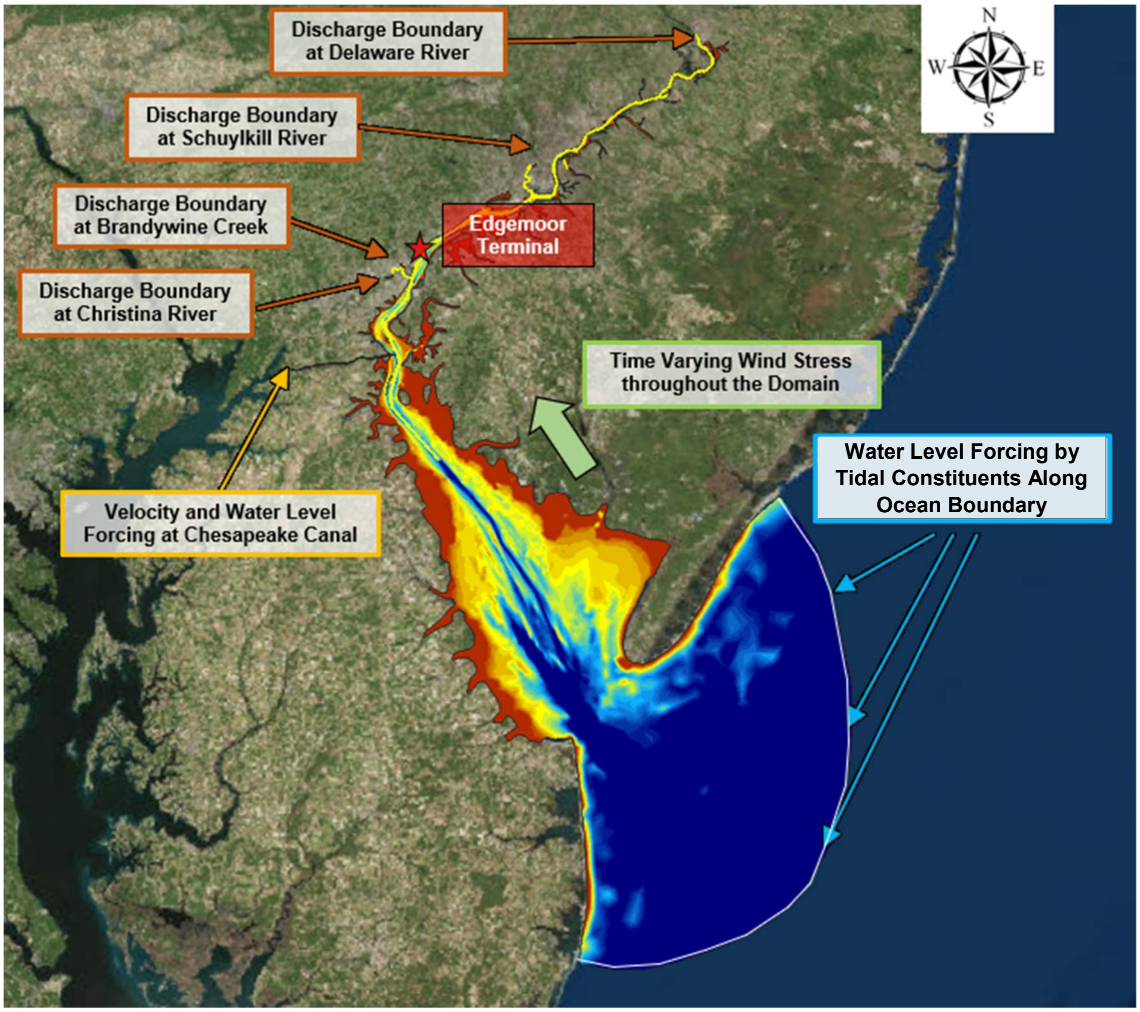
Figure 20: MIKE3 model grid bathymetry for Design Variant with berth depth 38 feet (MLLW)



4.3 Boundary Conditions

Figure 21 shows the locations of model boundary condition inputs. Calibration and validation time periods were chosen based on the availability of measured data to be used as boundary conditions and for model calibration and validation. The period chosen for model calibration was May 1 to June 10, 2011 (calibration period). The model was forced using only measured boundary conditions, i.e. no predictions were used as boundary forcing, except tidal constituents across the ocean boundary.

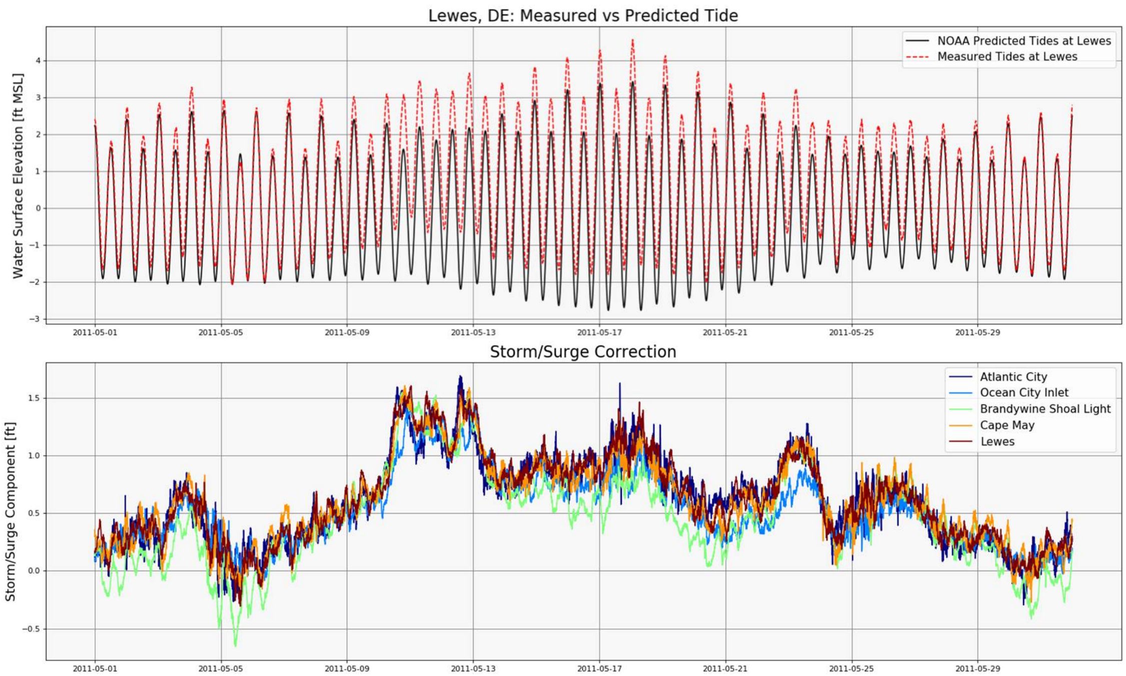
Figure 21: Boundary conditions used to force the MIKE3 model



4.3.1 Ocean Tides

Ocean tides were predicted using ten (10) tidal harmonic constituents extracted from the Global Ocean Tide Model DTU10 at 1/8-degree resolution, provided by DTU Space of National Space Institute (Cheng et al 2010). Other tidal constituent databases were also tested, such as the ADCIRC Atlantic Database (Mukai et al 2002), and Le Provost database (Le Provost et al 1998). Comparisons with measurements at NOAA station 8557380 Lewes indicated that the DTU10 database provided the most accurate boundary conditions. Storm surge (i.e. meteorological component of the tide) was calculated as the difference between measured and predicted tides at multiple stations near the ocean. Figure 22 shows the comparison of measured and predicted tide at Lewes, DE (top), and time histories of computed storm surge at five different locations near the ocean (bottom). All dates and times in figures are UTC. Storm surge as large as 1.5 feet was observed in the calibration period (May 2011). However, storm surge did not vary significantly between the offshore locations. Once calculated, storm surge was added to the time histories of predicted ocean tides used to force the model at each ocean boundary element.

Figure 22: Measured storm surge (meteorological component of the tide)



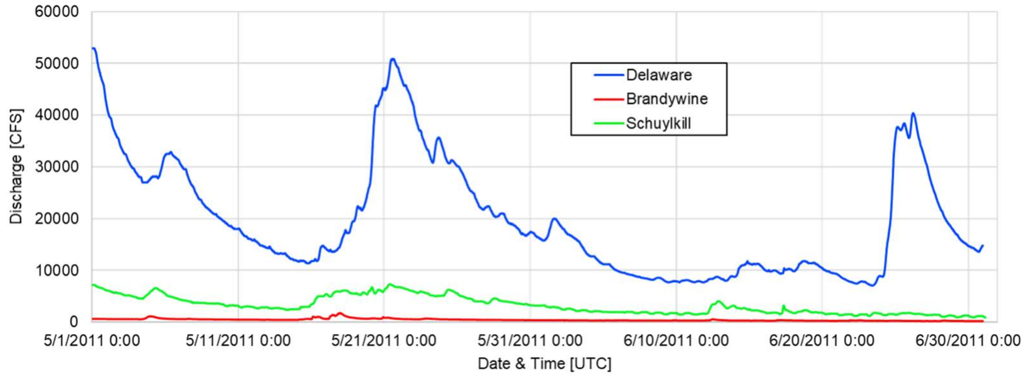
4.3.2 River Discharges

Discharges were input at four locations:

- Delaware River at Trenton, NJ USGS Station 01463500
- Schuylkill River at Philadelphia, PA USGS Station 01474500
- Brandywine River at Wilmington, DE USGS Station 01481500
- Christina River at Wilmington, DE USGS Station 01480120. Note that Christina River discharges were scaled based on mean annual flow since measured time histories were not available.

Chesapeake Canal input flows were also included, consisting of water exchange between Chesapeake and Delaware estuaries. Discharges were estimated using water levels at Chesapeake City NOAA Station 8573927, and current velocities at NOAA Station cb1301. Figure 23 shows time histories of river discharge for these sources. The peak flows in the Delaware River are significantly larger than the flows in the other rivers. It should be noted that additional river discharges reach the Delaware River estuary but were not included here because they contribute little to the hydrodynamic conditions, and no data were available.

Figure 23: River discharges used as boundary conditions



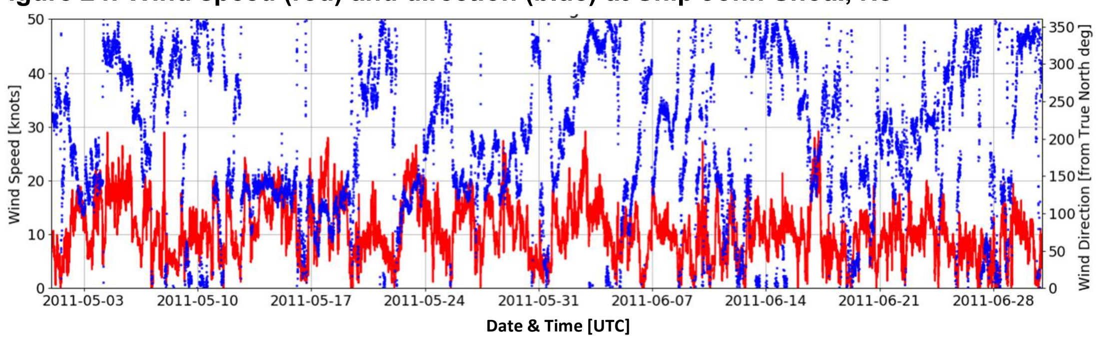
4.3.3 Salinity

Zero salinity (0 PSU) was applied at the river boundaries, and a constant salinity of 32 PSU was applied at the ocean boundary.

4.3.4 Winds

Wind forcing was included in the model in the form of a single wind speed and direction time history. Wind records at local stations were relatively similar in direction and speed. Winds used for forcing were taken from NOAA Station 8537121 at Ship John Shoal which is located near the center of the estuary and corrected to speeds at 32 ft elevation. Figure 24 shows the wind speed and direction included in the MIKE3 model. Winds did not significantly affect hydrodynamics at the project site due to strong tidal currents and relatively large depths.

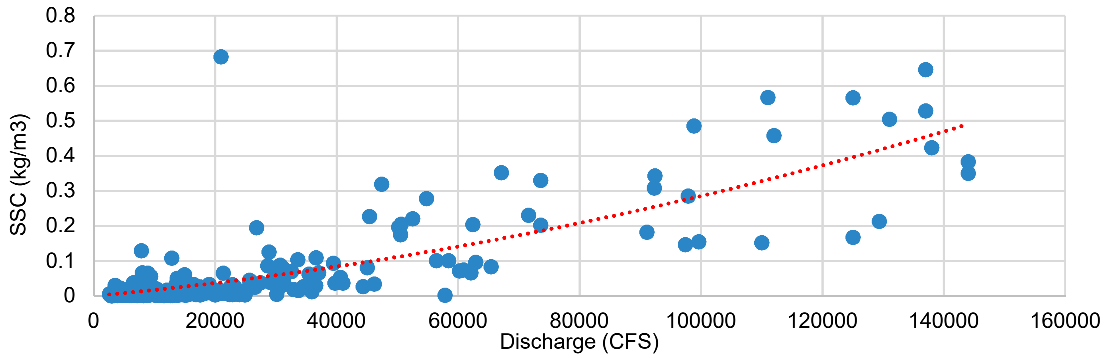
Figure 24: Wind speed (red) and direction (blue) at Ship John Shoal, NJ



4.3.5 Suspended Sediment Concentrations

Measured suspended sediment concentration (SSC) data in the rivers were not available for the entire modeling period. Therefore, sediment concentration boundary conditions were estimated using relationships between SSC and river discharge based on USGS data developed separately for Delaware River, Schuylkill River, and Brandywine Creek. Figure 25 shows the approximate relationship between SSC and Delaware River discharge at Trenton, NJ, as an example. The same process was applied for the Schuylkill River and Brandywine Creek, with Christina River SSC-to-discharge relationship assumed to be the same as Brandywine Creek. At the ocean and Chesapeake estuary boundaries, zero values of SSC were applied. A rigorous analysis of SSC values was not performed. It was determined through sensitivity analysis that SSC values applied at the river boundaries were a small source of suspended sediments at the site compared to those generated within the estuary, therefore no further analysis was performed.

Figure 25: Relationship between suspended sediment concentrations and river discharge, Delaware River at Trenton, NJ



4.4 Initial Conditions

4.4.1 Hydrodynamics

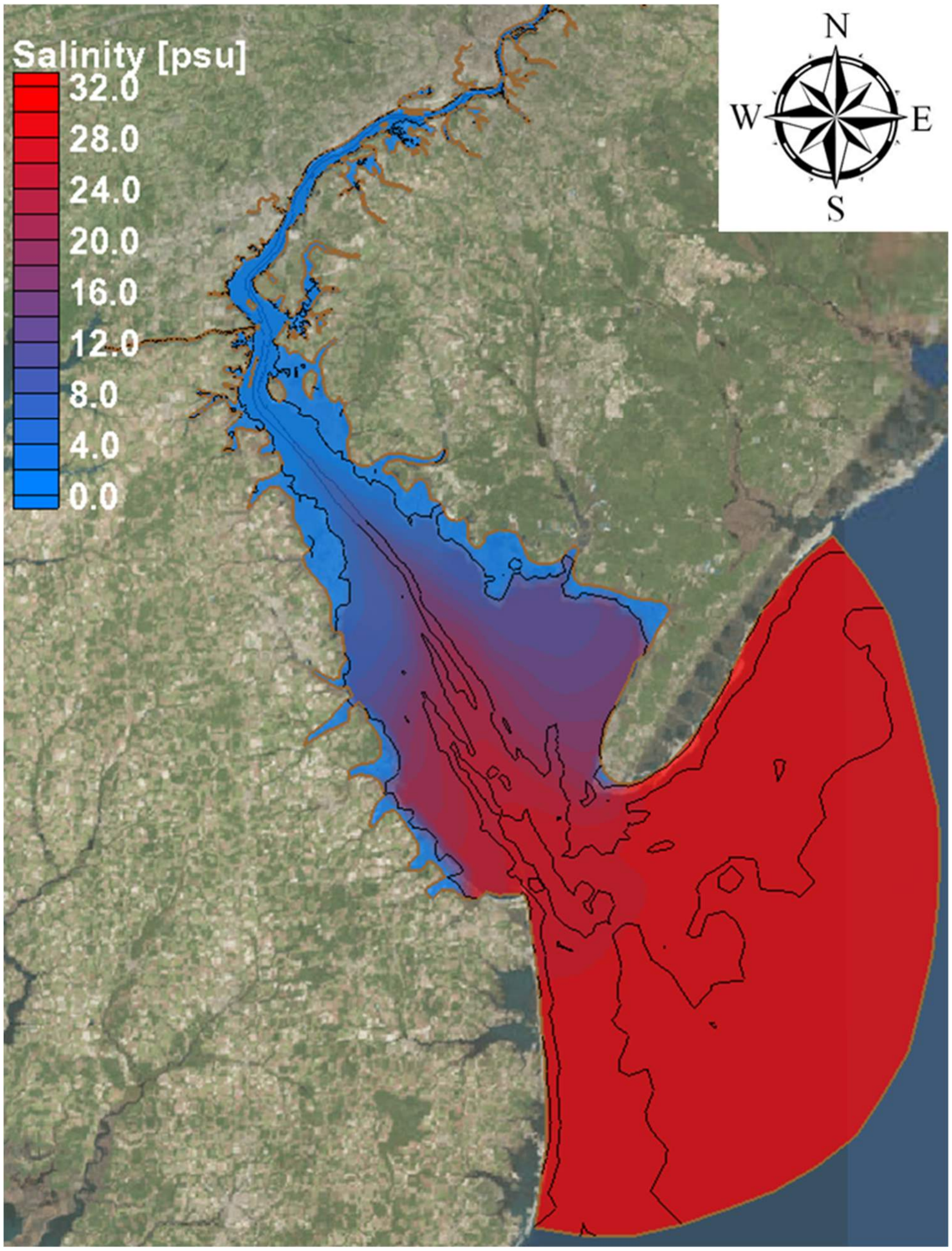
A cold start was utilized in the hydrodynamic simulations with zero velocities and water surface elevation 0.0 ft (MSL) throughout the domain. Evaluation of project impacts on hydrodynamics and salinity were not made within the first week of the simulations.

4.4.2 Salinity

Salinity initial conditions were generated using a 2-month spin-up prior to the start of the calibration simulation. The spin-up simulation started with a basic salinity distribution taken from USACE Delaware River Main Channel Deepening Project (1997), shown in Figure 26. Figure 27 shows the salinity initial condition used in the calibration period simulations.

Figure 26: Salinity distribution in Delaware Estuary (USACE 1997)

Figure 27: Initial salinity distribution for MIKE3 model after 2-month spin-up



4.4.3 Sediment Bed

4.4.3.1 Non-cohesive sediment (sand) transport model

No comprehensive set of specific grain size data were available that could be used to simulate sand transport in the estuary. Only descriptive sediment type information was available. Therefore, in the sand transport module, uniform grain sizes were assigned to the entire modeling domain. Median grain sizes were assigned to all bottom areas, with multiple scenarios tested in different sensitivity testing simulations. Median grain sizes tested include 0.3mm. 0.5mm, 0.8mm, 1.0mm, 1.2mm, 1.4mm, and 1.6mm. The simulations were used as part of a sensitivity analysis to approximately reproduce anecdotal sedimentation information and evaluate sedimentation of sandy material at the Edgemoor site.

4.4.3.2 Cohesive sediment (mud) transport model

In the mud transport module, a two-layer initial bed condition was applied throughout the grid. The top layer was given a 5.5-cm thickness and initial critical shear stress for erosion of 0.28 Pa, and the lower layer was given a 10m thickness and higher initial critical shear stress for erosion of 1.28 Pa. These initial values were obtained using SedFlume data collected for San Francisco Bay mud (Integral Consulting 2017), with the top layer representing more recent deposits and lower layer showing signs of consolidation. Since no SedFlume or similar data were available for the Delaware River estuary, an attempt was made in the model calibration to keep these parameters close to original values, and other parameters were used more extensively for tuning the model to match measured sedimentation at Port of Wilmington.

Many areas of the Delaware Estuary have sandy or coarser bottom material. To minimize the presence of unrealistic sources of mud in the simulations, non-erodible (hard bottom) cells were assigned in certain areas. These areas were identified during initial tests based on unrealistic erosion (tens of meters). It is understood that some areas were simulated using mud bottom where in fact sand exists in real life, however insufficient data exist to generate an accurate bottom material map for use in the modeling effort.

5 Model Calibration and Validation

5.1 General

Calibration and validation time periods were chosen based on availability of measured data for boundary conditions and comparison with model results. The hydrodynamic model was calibrated and validated using measured tides, currents and salinity. Calibration parameters included only bottom roughness, and turbulence parameters to better match observed vertical stratification. The MIKE3 hydrodynamic model was calibrated based on available hydrodynamic data from May 2011, and then validated with field measurements from April 2003.

The sediment transport models were calibrated using long-term average sedimentation rates in the Bellevue Range of the navigation channel (sand transport model) and at the Port of Wilmington (mud transport model). An additional comparison of measured and predicted sedimentation was made at Anchorage 7, upstream of the site. The non-cohesive sediment (sand) transport model could not be truly calibrated due to insufficient data. No sand grain size information or information about where sedimentation occurs were available. Therefore, sensitivity tests were performed to roughly match the USACE-reported average annual dredging volumes in the Bellevue Reach, using variation of median grain size. The mud transport model was calibrated in high-resolution simulations focused on the Port of Wilmington, using the 10-year average daily sedimentation volumes at the Port as a calibration target.

5.2 Hydrodynamic Model Calibration

Multiple hydrodynamic simulations were conducted during the process of model calibration. Results were examined by comparing simulation results with measurements at multiple locations. Figure 28 shows the locations of the measurement stations. The blue stations represent locations with measured water levels, while the purple stations represent locations with measured velocities and/or salinities.

Figure 29 to Figure 31 show comparisons between measured and MIKE3-predicted tides at Cape May, Delaware City, and Marcus Hook, respectively. Cape May is near the ocean, Delaware City is south of Edgemoor, and Marcus Hook is north of Edgemoor. Comparison of measured water levels and MIKE3 model predictions show good agreement, including the lower-frequency variability introduced by storm surge in the ocean. If anything, the simulated water level ranges are slightly larger than measured. The over-prediction of water level ranges does not measurably affect predictions of sediment transport.

Figure 28: Location of measurements used for model calibration (May 2011)

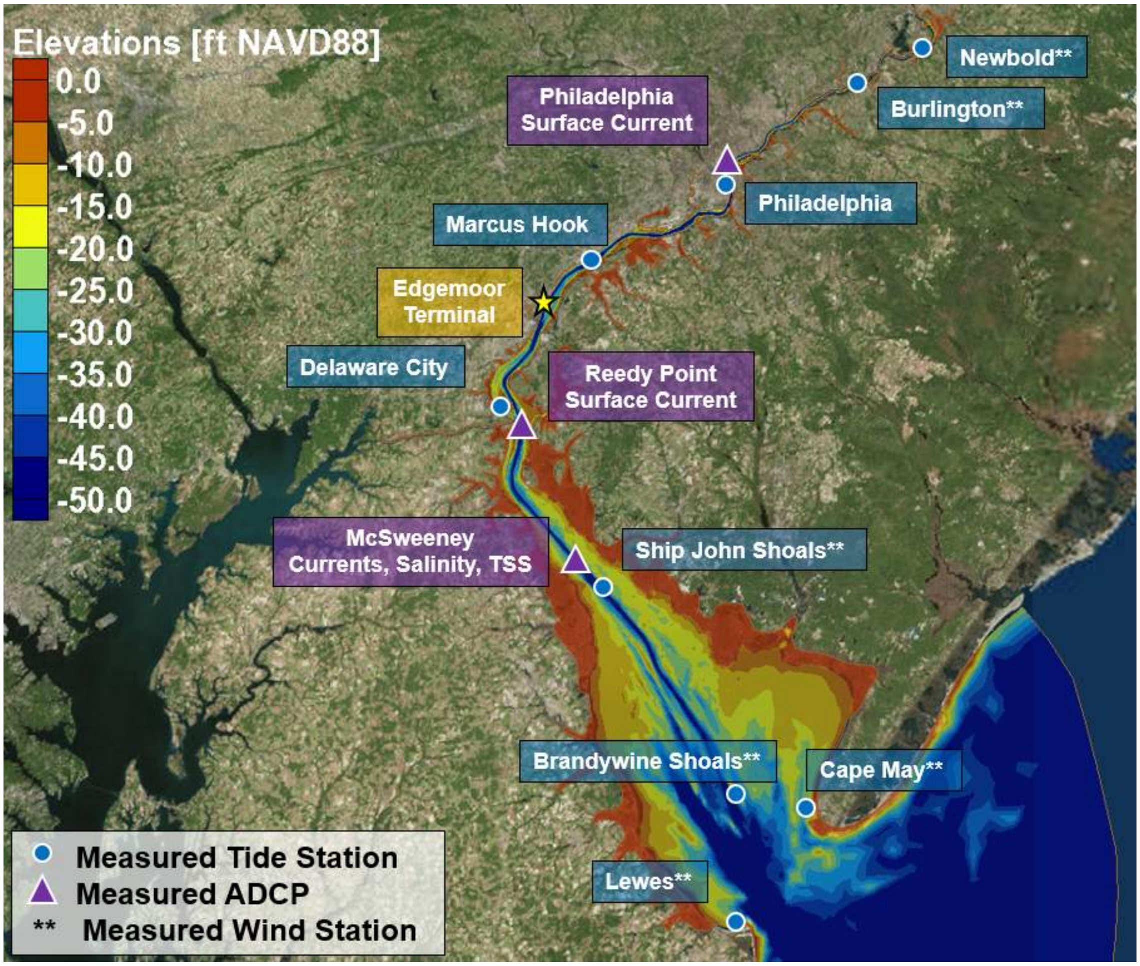


Figure 29: Comparison between measured and MIKE3-predicted water levels at Cape May during May 2011 calibration period

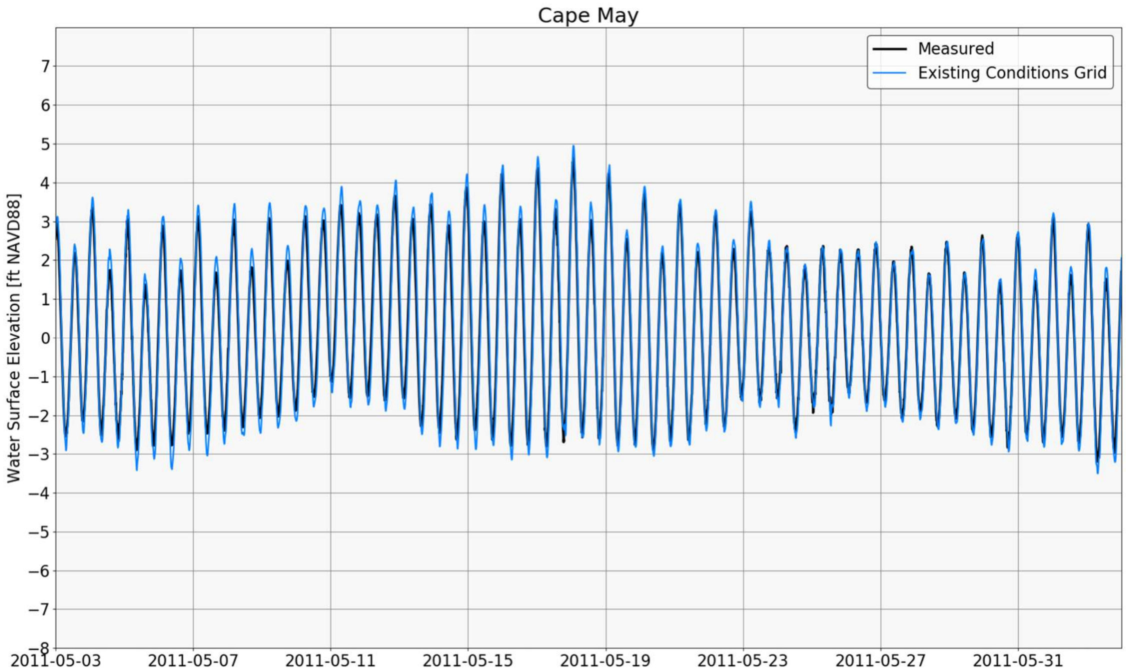


Figure 30: Comparison between measured and MIKE3-predicted water levels at Delaware City during May 2011 calibration period

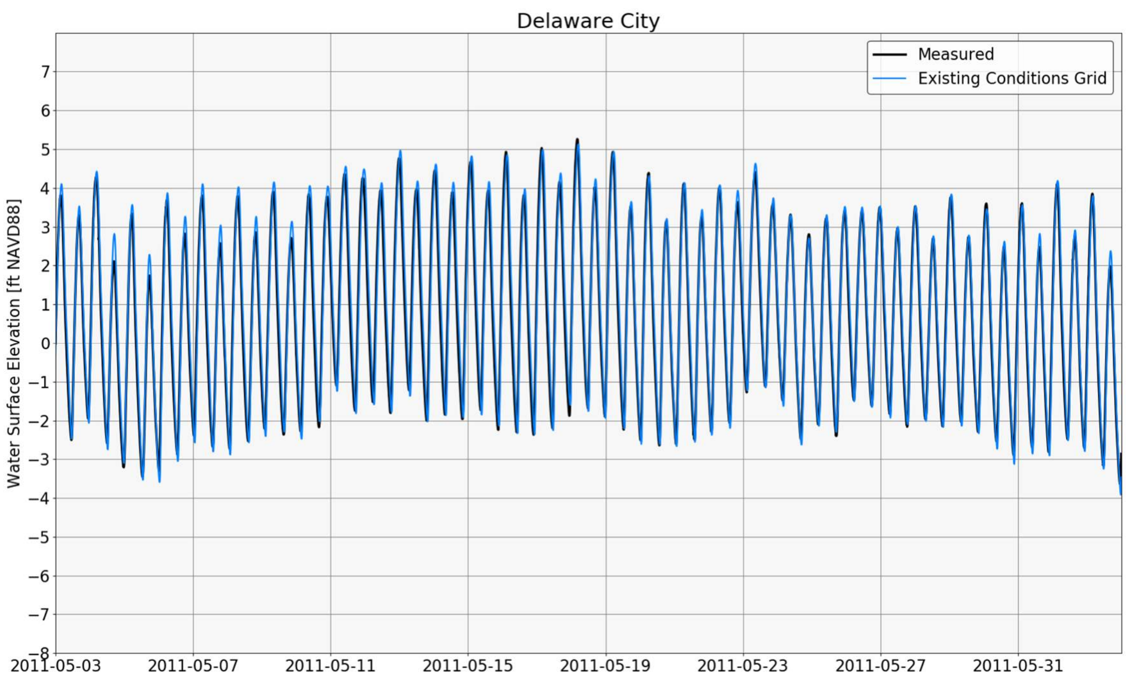
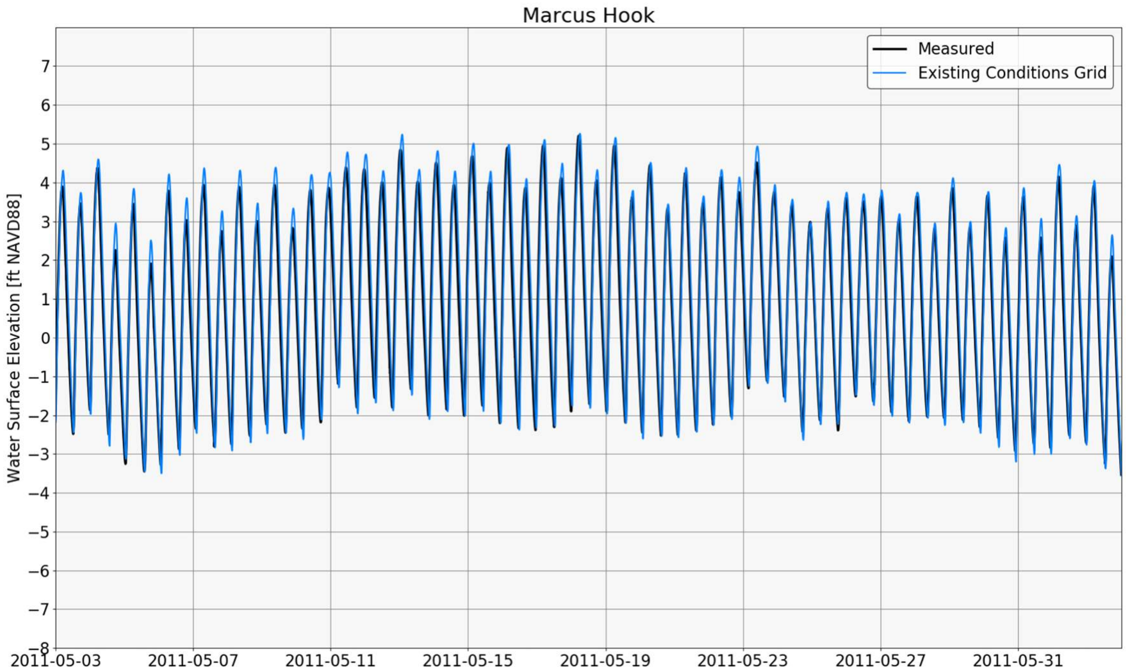


Figure 31: Comparison between measured and MIKE3-predicted water levels at Marcus Hook during May 2011 calibration period



Current velocities reported in McSweeney (2017) were also measured during the May 2011 calibration period, at a location farther south in the estuary near Ship John Shoal, which is shown in Figure 28. Figure 32 shows a comparison between near-bottom, mid-depth and near-surface measured velocities and those predicted by MIKE3. Throughout this report, positive current speeds indicate flood currents, and negative current speeds indicate ebb currents. The correlations in both phase and magnitude are good throughout the water column, despite lack of detailed resolution in model grid and date-specific bathymetry at the measurement location.

Velocities were also measured at Reedy Point and Philadelphia (both surface currents). Figure 33 shows a comparison between measured and predicted surface currents at Reedy Point. The model predicts the surface velocities extremely well on flood tide, and phase and speed are matched very well a vast majority of the time. However, in most instances at peak ebb current, the measurements show a spike in speed that begins partway through the peak ebb time frame. This is likely due to local channelization from nearby areas drying at lower water levels, which was not resolved in the model in this area. The Reedy Point location is complex due to these nearby shallow banks and islands, but also its proximity to the Chesapeake Canal. Clearly the flood and ebb discharges through the estuary are well represented by the model.

Figure 34 shows that the model results compare extremely well with measured surface currents at Philadelphia. The model matches the measurements on both ebb and flood tide, despite the Philadelphia location being well into the estuary after considerable tide wave propagation and transformation, past the Edgemoor site. This excellent match indicates that the discharges through the estuary are well represented by the model at Philadelphia, but also at Reedy Point which is located between Philadelphia and the ocean.

Figure 32: Comparison of measured and MIKE3-predicted current speeds during 2011 calibration period (field data reported in McSweeney 2017)

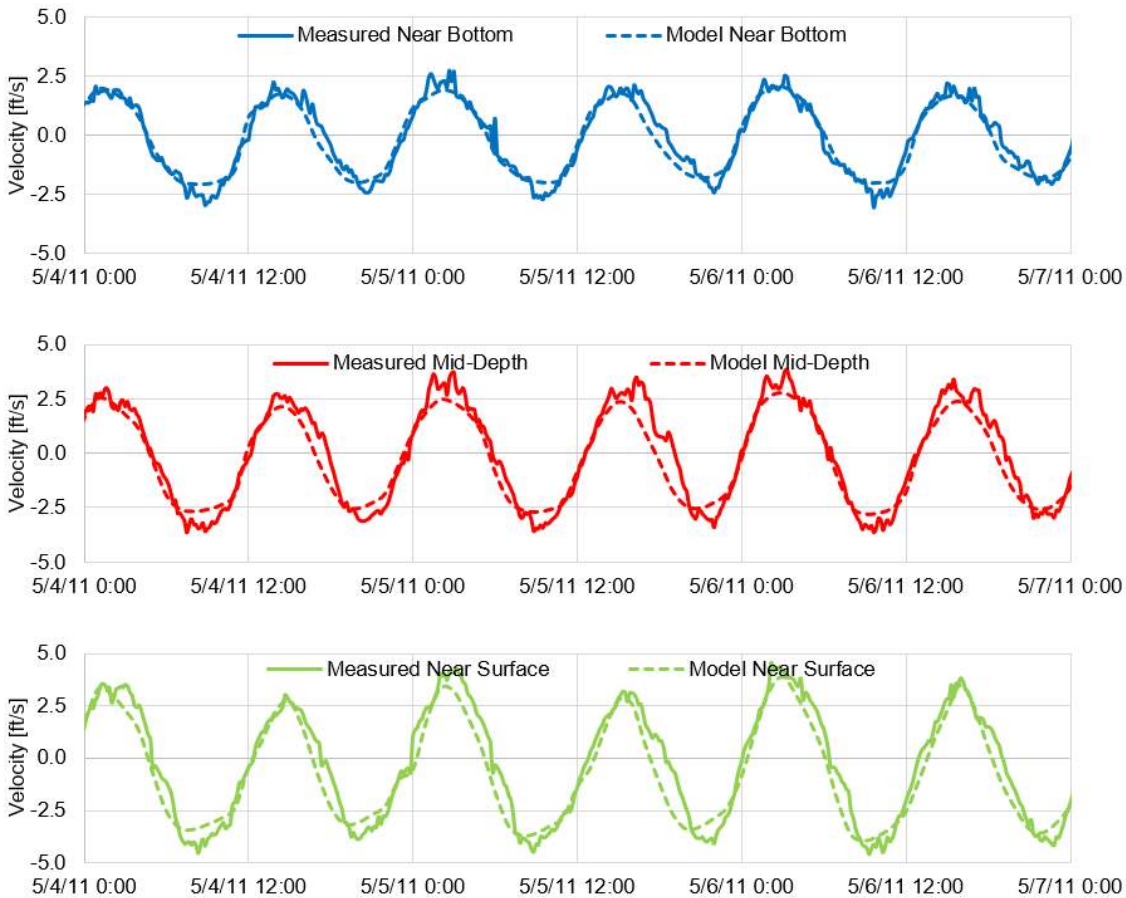


Figure 33: Comparison between measured and MIKE3-predicted surface current speeds during 2011 calibration period at Reedy Point

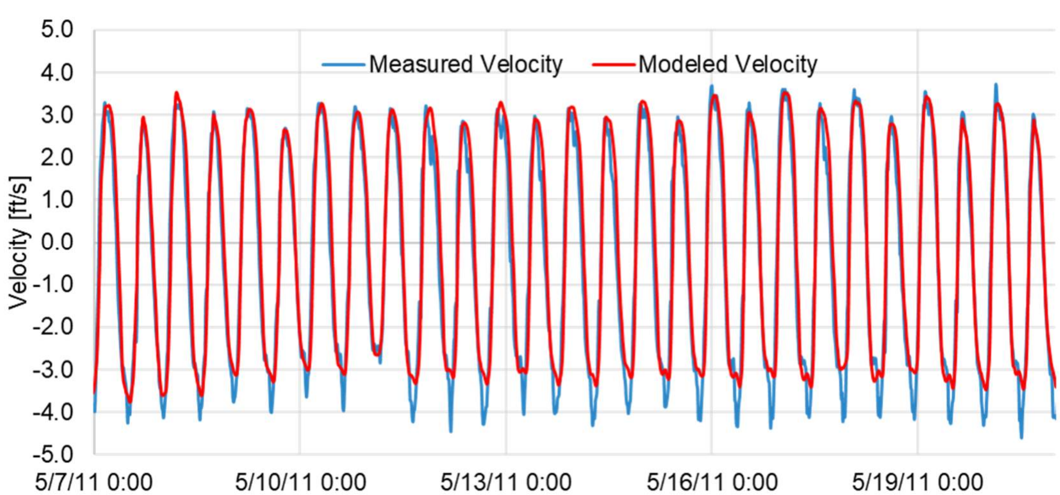


Figure 34: Comparison between measured and MIKE3-predicted surface current speeds during 2011 calibration period at Philadelphia

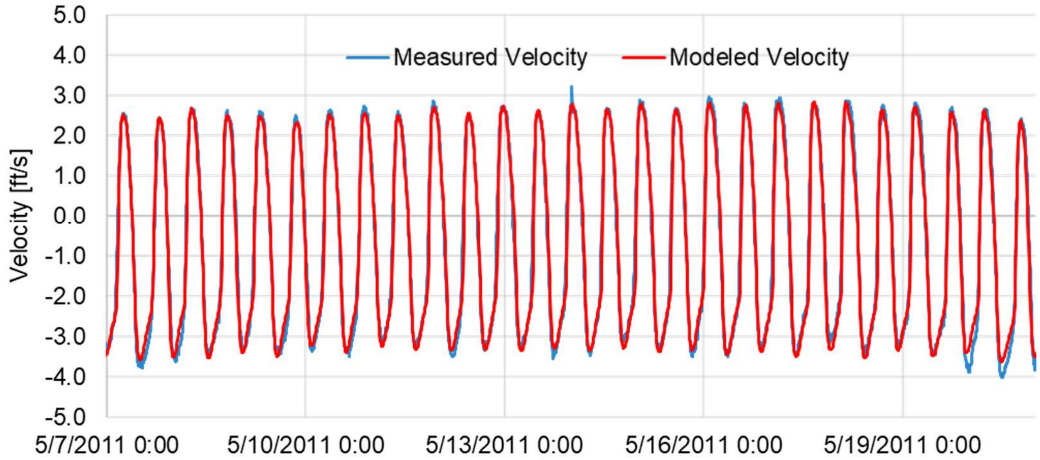
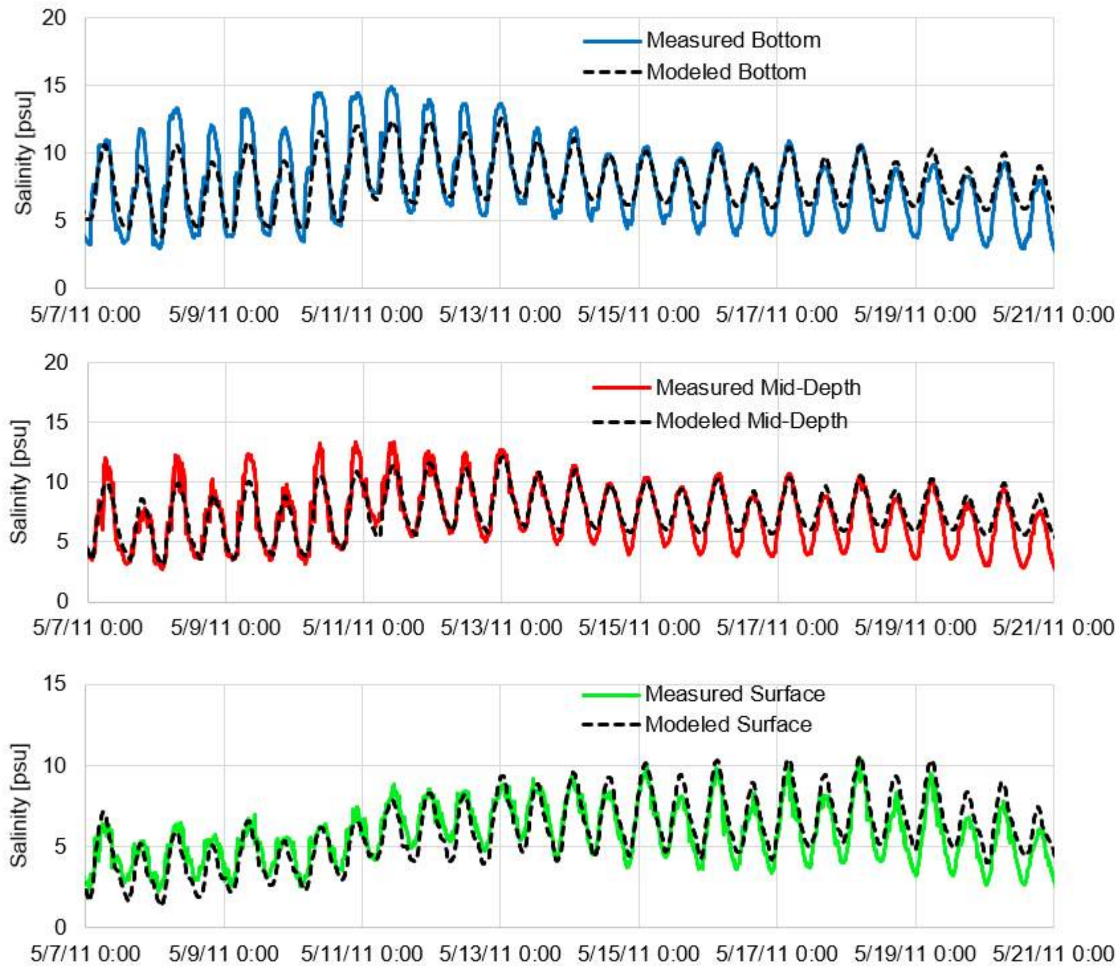


Figure 35 shows a comparison between measured and predicted salinity data reported in McSweeney et. al. (2017). The results indicate a reasonable representation of salinity, its variability over the water column, and approximate magnitudes. The calibration parameters were typical values used in the MIKE3 hydrodynamic model. Manning's roughness 0.02 was used, with the Smagorinsky formulation with default settings for horizontal turbulence, and k-e formulation for vertical turbulence with slight changes to default settings to improve salinity stratification.

Figure 35: Comparison between measured and MIKE3-predicted salinities during 2011 calibration period (field data reported in McSweeney 2017)



5.3 Hydrodynamic Model Validation

The same hydrodynamic model parameters, boundary condition sources and initial conditions were used during the validation simulation. The validation period was April 2003, which was also chosen due to availability of measured data for boundary conditions and comparison with model results. Figure 36 and Figure 37 show water level validations for Delaware City and Marcus Hook, which show a reasonable level of model performance in matching measured tides. In the 2003 validation period, the predicted tidal ranges are slightly larger than observed. It should be noted that no attempt was made to fully reproduce all conditions in 2003 such as different bathymetry, since these data were not available.

Figure 38 shows the model validation with measured surface current speed at Reedy Point, which also demonstrates a reasonable level of model performance, similar to the calibration period. During this time period, no data were available at Philadelphia.

Figure 36: Comparison between measured and MIKE3-predicted water levels at Delaware City during 2003 validation period

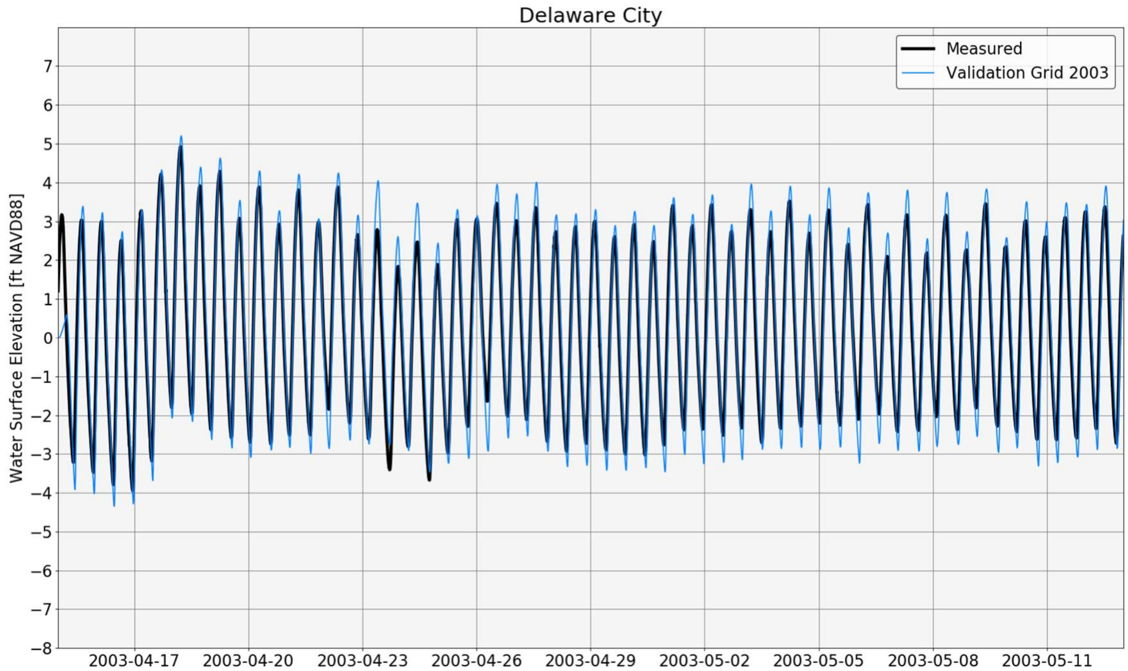


Figure 37: Comparison between measured and MIKE3-predicted water levels at Marcus Hook during 2003 validation period

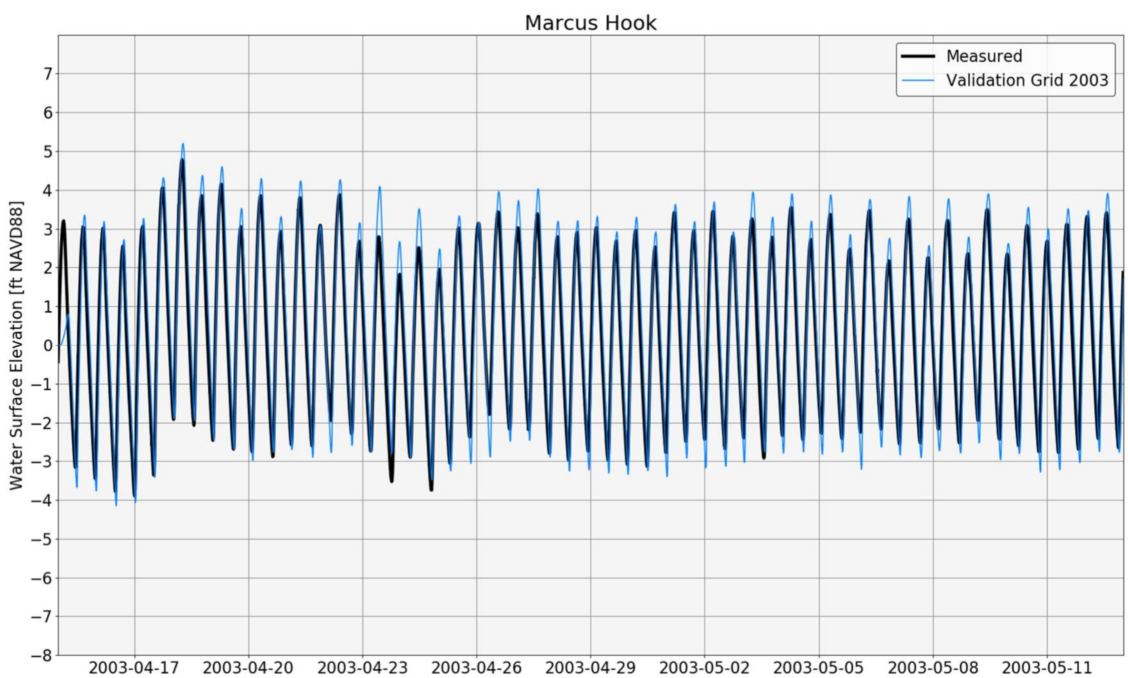
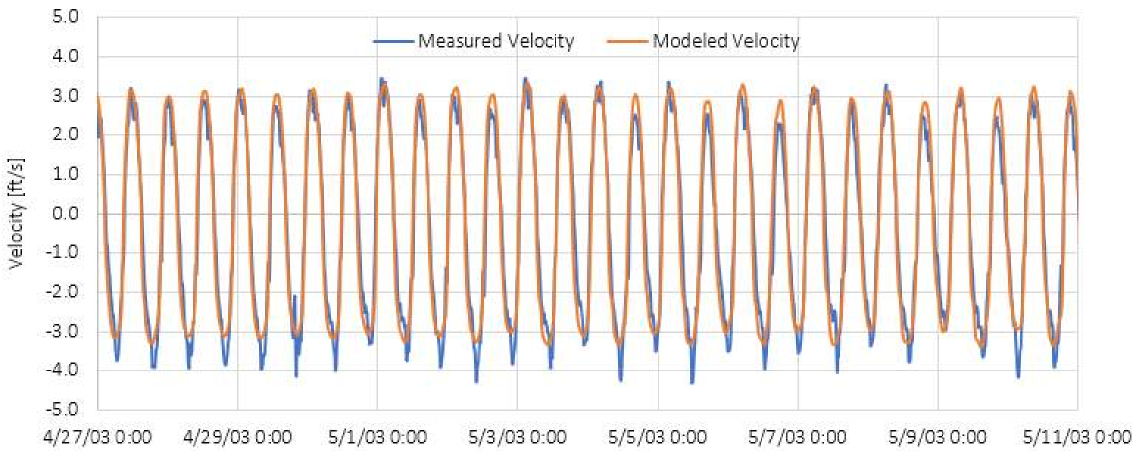


Figure 38: Comparison between measured and MIKE3-predicted surface current speeds at Reedy Point during 2003 validation period



5.4 Sediment Transport Model Calibration

Sediment transport in the Delaware Estuary is complex, with a wide range of sediments types moving throughout the area. Development of an accurate and complete bed sediment map for simulations was not feasible. Therefore, the MIKE3 model was used to separately simulate transport and erosion/deposition of non-cohesive sediments (sand), and cohesive sediments (fluvial silt). The 2011 calibration period hydrodynamics were used to simulate sediment transport.

5.4.1 Non-cohesive Sediment (Sand) Transport Model Calibration

The non-cohesive sediment (sand) transport model was not calibrated in a traditional sense because no sedimentation data for sandy areas were available. In addition, no local grain size data were available for modeling of sandy sediments that were likely to be indicative of those moving near the site. Therefore, a sensitivity analysis was performed by varying the median grain diameter towards a match with the reported average annual sedimentation in the Bellevue Reach (34,000 CY), which is reportedly sandy material (Duffield Associates 2018a). Sand waves observed in the channel with heights in the range of 1 foot and wave lengths in the range of 90-100 feet also indicate sand transport.

Typical sand transport formulations (van Rijn 1984) were used in the model with default parameters. Table 3 shows the volumes of sedimentation observed in the Bellevue Range (navigation channel boundary) as a function of median grain diameter during the calibration period simulations, following extrapolation to annual values. The grain diameter which most closely matched the observed sedimentation rate of 34,000 CY per year was 1.4mm. Finer sand transport simulations resulted in large sedimentation volumes which are not realistic. Based on the good comparison between channel sedimentation volume and long-term average dredging volume, median grain diameter 1.4mm was considered reasonable for simulation of non-cohesive sediment transport and evaluation of project impacts.

Table 3: Navigation Channel Sedimentation in Non-Cohesive Sediment (Sand) Transport Sensitivity Testing Simulations

Median Grain Diameter [mm]	Extrapolated Annual Sedimentation Volume in Bellevue Reach [CY/year]
0.3	950,000
0.5	1,500,000
0.8	1,200,000
1.0	200,000
1.2	80,000
1.4	37,600
1.6	17,300

Notes:
1. Reported average annual sedimentation in Bellevue Reach is approximately 34,000 CY (Duffield Associates 2018a).
2. Only positive bed changes were used in the sedimentation volume calculations. Specifically, erosion in the channel does occur in some areas, but this erosion does not reduce the computed sedimentation.

5.4.2 Mud (Fluvial Silt) Transport Model Calibration

The MIKE3 mud transport (MT) module was calibrated to approximately represent the 10-year observed daily average sedimentation at the Port of Wilmington. Model resolution was increased at the Port of Wilmington to successfully reproduce the observed gyre in the entrance to the Port, include smaller-scale features such as the vertical sheetpile bulkhead running parallel to the navigation channel, and reasonably reproduce sedimentation patterns and the approximate average daily sedimentation volume. The calibration target was therefore approximately 94,000 CY (calibration period portion of 835,000 CY per year). Figure 39 shows the mesh used for mud transport calibration simulations in the Port of Wilmington area.

Multiple parameters were used for model calibration, most importantly the erosion rate parameters and fall velocities. Critical stresses for erosion and deposition were only slightly altered, so that they remained similar to appropriate values measured in other locations for similar sediments. Many mud transport simulations were conducted to refine the transport parameters and reproduce the sedimentation volume matching the long-term average observed calibration period sedimentation of 94,000 CY. The MIKE3 mud transport module was run in de-coupled mode (sediment transport does not affect the hydrodynamics) since bottom elevation changes in the area of interest are relatively small during the calibration period.

Figure 39: Refined grid used for mud transport model calibration at Port of Wilmington area (estuary-wide simulations)

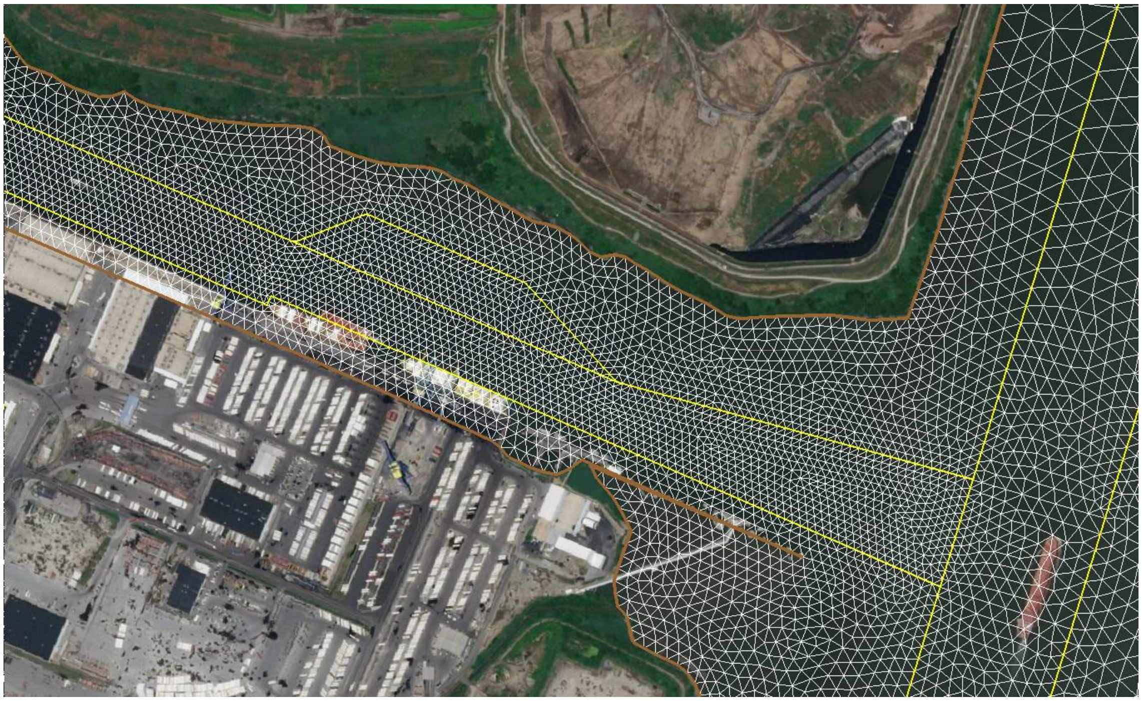


Figure 40 shows bed change maps produced by the USACE and reported in Moffatt & Nichol (2000), which indicate the general pattern of sedimentation to be reproduced. The hydrodynamic and sediment transport models were run for the calibration period and sedimentation volumes were computed. Figure 41 shows the sedimentation modeling results at the Port of Wilmington using the final model calibration parameters, extrapolated linearly to 284 days for qualitative comparison with observed sedimentation shown in Figure 40 (top). The patterns of sedimentation reasonably match those observed in the USACE bed changes figures. The purpose of the validation was primarily to ensure that reasonable suspended sediment concentrations are being generated in the model, and general deposition rates were reasonable.

Figure 40: USACE Philadelphia District bed change maps, in feet (taken from Moffatt & Nichol 2000)

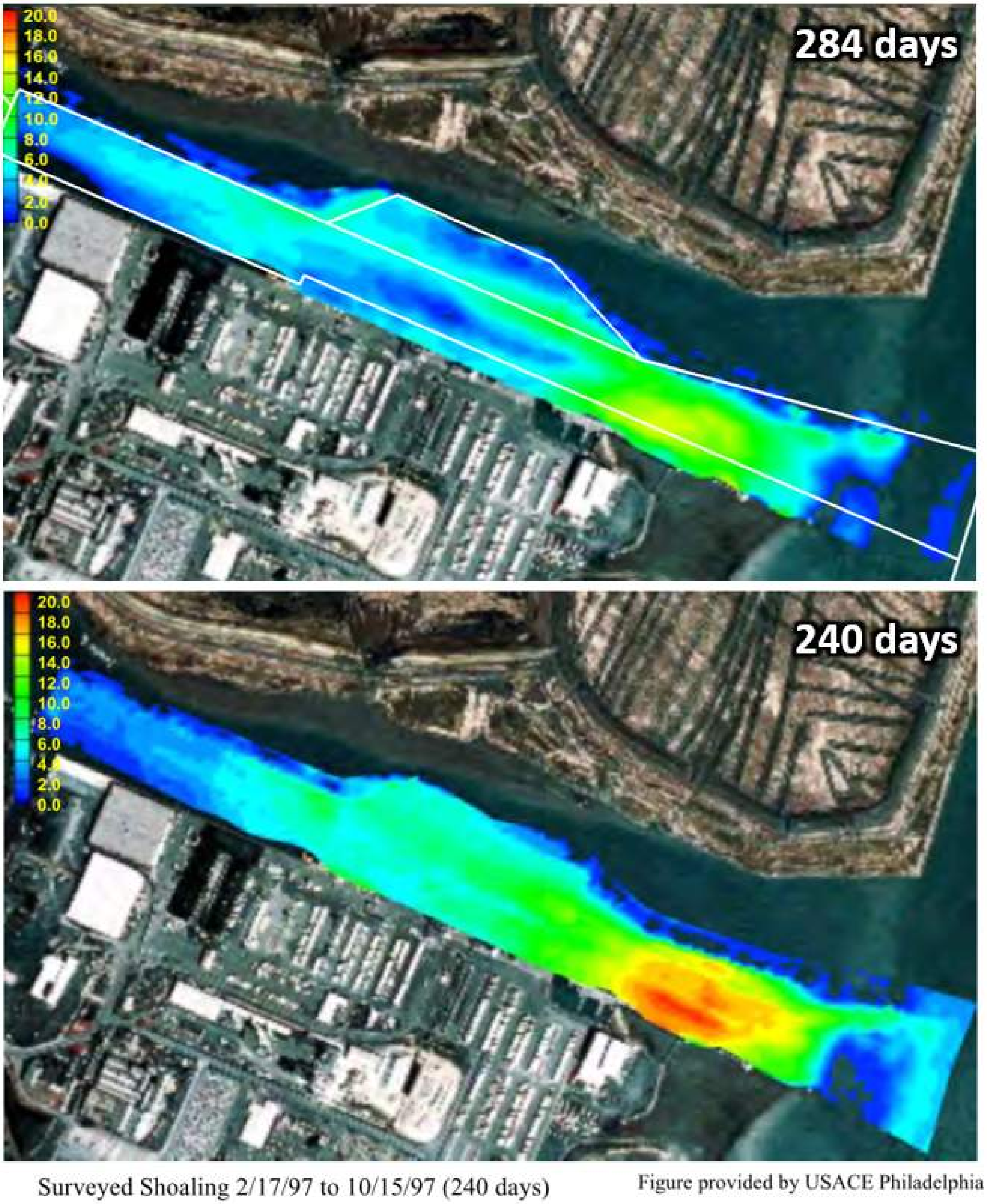


Figure 41: Sedimentation computed at Port of Wilmington by the MIKE3 mud transport model, extrapolated from 41 to 284 days for comparison with Figure 40 (top)

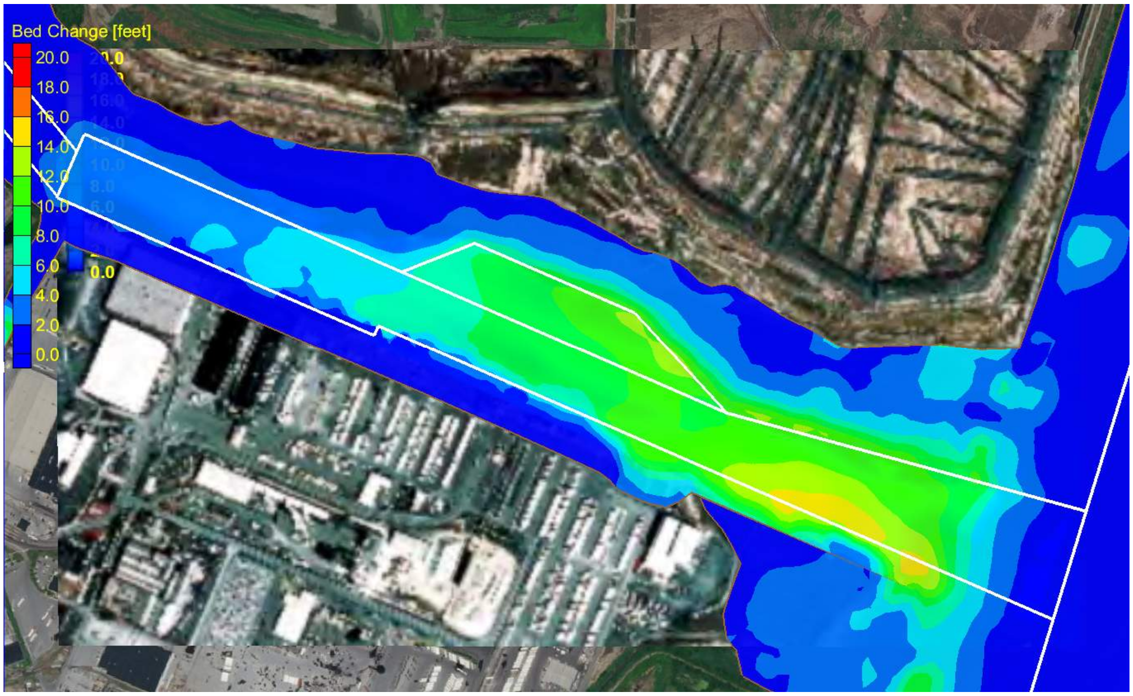


Table 4 shows the final parameters used for MIKE3 mud transport model, including the range tested and final values. The most important calibration parameter was erosion rate coefficient, as the critical shear stresses for erosion and deposition were purposely retained at values similar to those measured for San Francisco Bay Mud. MIKE3 mud transport model parameters were modified until the sedimentation volume reasonably matched the reported sedimentation volume of approximately 94,000 CY (calibration period portion of the annual 835,000 CY). The calibrated model predicted a sedimentation volume of 109,000 CY, roughly 16% above the target volume of 94,000 CY. No further attempts were made to exactly match the calibration period portion of the reported long-term average values.

Table 4: Final Mud Transport Model Calibration Parameters

Parameter	Range of Values Tested	Final Value
Erosion Rate Coefficient	3x10-5 to 3x10-10	3x10-7
Critical shear stress for erosion (top layer)	0.20 to 0.50 Pa	0.40 Pa
Critical shear stress for erosion (bottom layer)	1.20 to 1.50 Pa	1.40 Pa
Fall velocity coefficient	3.8 to 60	30
Critical shear stress for deposition	0.05 to 0.20 Pa	0.10 Pa

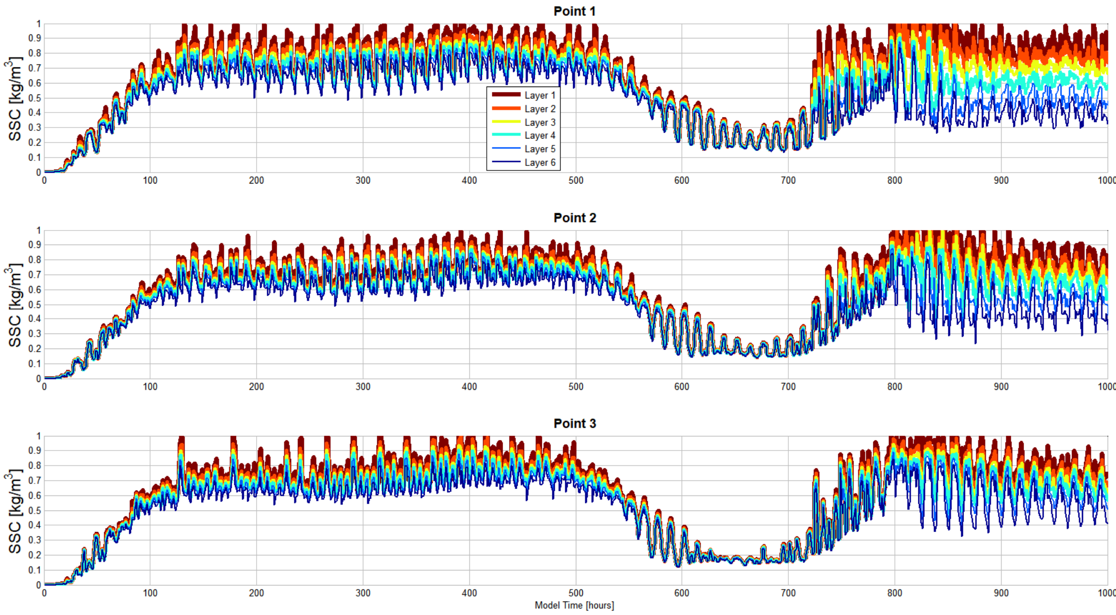
SSC values were analyzed using the final calibrated model results. Figure 42 shows the location where values were extracted.

Figure 43 shows extracted time histories series of SSC values. The model results show that concentrations vary significantly based on river flow conditions, with high flows pushing the higher concentrations downstream of the area, and during low flows, large differences are observed between bottom and surface concentrations. These trends are in general agreement with field measurements. However, concentrations predicted by the model are somewhat higher than observed in historical measurements likely due to heavy local resuspension, which likely contributed to sedimentation predictions slightly higher than the observed long-term average rate. The results of the calibration period transport simulations were considered a reasonable proxy for sedimentation that occurs over the long-term at the Port of Wilmington.

The purpose of model validation is to ensure that a model's results are also reasonable during different time periods, or representative of long-term conditions. Since long-term daily average sedimentation rates are the actual calibration target, validation simulations were not performed. In the future, long-term simulations are recommended to ensure applicability of the model to all potential future conditions.

Figure 42: Extraction points for suspended sediment concentrations

Figure 43: Suspended sediment concentrations extracted from the modeling results at observation points downstream (Point 1), at the Edgemoor Terminal (Point 2), and upstream (Point 3). Layer 1 represents the bottom layer, while Layer 6 represents the surface layer.



5.4.3 Additional Mud Transport Model "Gut-Checks"

The calibrated mud transport model results were further evaluated to ensure that reasonable predictions were being made at other locations in addition to the Port of Wilmington, in particular north of the project site. Two other sites were evaluated in the model: the existing conditions at the Edgemoor Terminal project site, and Anchorage 7, upstream in the Marcus Hook Range.

First, sedimentation at the existing Edgemoor site (without project conditions) was evaluated to ensure that the model shows behavior in conceptual agreement with the observed site changes which are minimal in the shallower water approaching the shoreline. Figure 44 shows the Edgemoor site and location of a cross-shore transect (top), and sketch showing the fluvial silt built up on the profile (bottom). As discussed previously, this slope appears to be in a state of dynamic equilibrium, with a relatively thick layer of silt at medium depths, and silt disappearing on the upper and lower portions of the profile due to increasing wave energy (in the shallows) and stronger currents (towards the navigation channel). Figure 45 shows predicted sedimentation over the calibration period. Results show negligible deposition in the navigation channel as expected. Sedimentation is predicted in the shallows; however, no waves or vessel wakes are included in the simulations which would serve to prevent deposition or cause periods of net erosion of recently deposited fluvial silt in shallow water; also, the sediment transport model was run de-coupled so that when sedimentation occurred in very shallow water, velocities did not increase to prevent the sedimentation.

Figure 44: Transect location (top) and cross-shore profile showing location and thickness of fluvial silt (bottom)

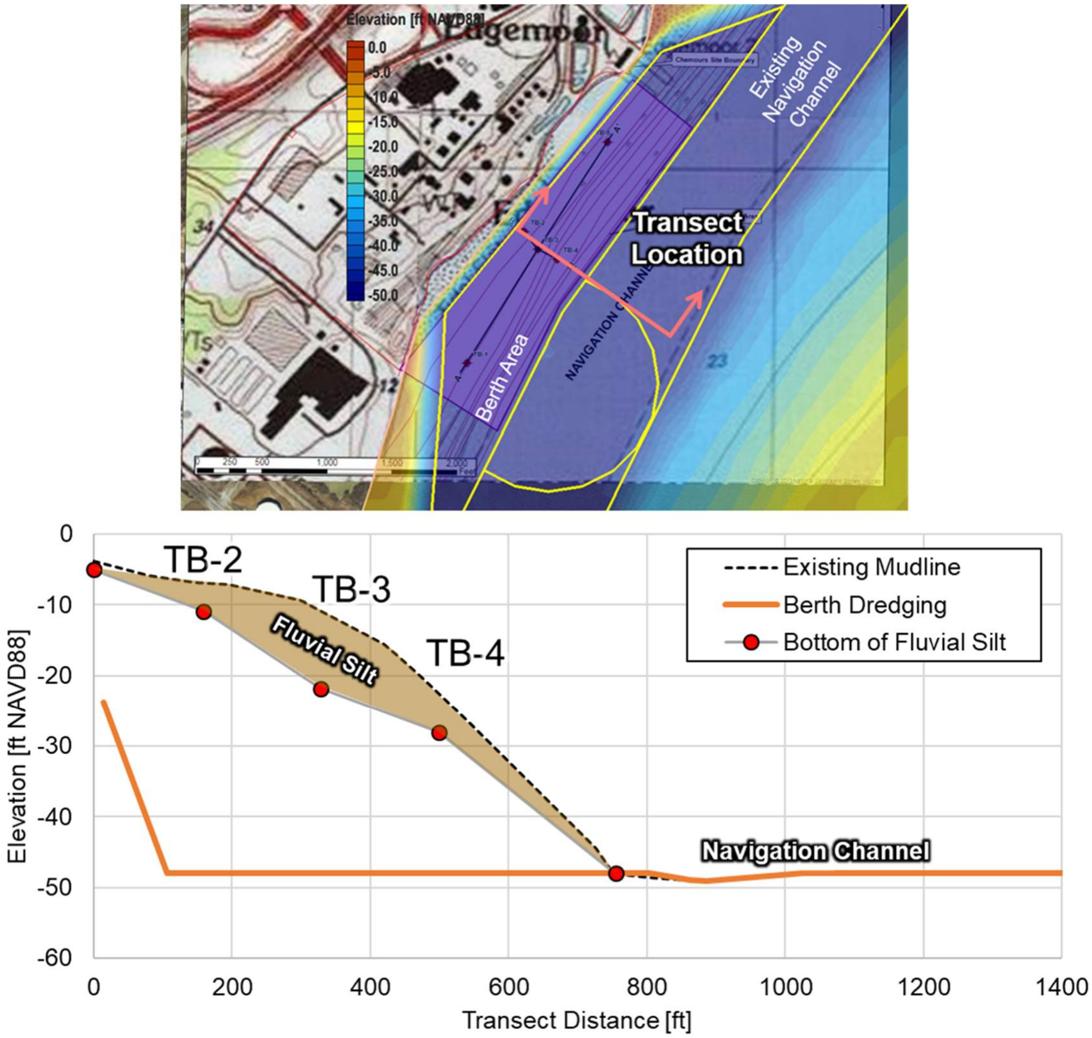
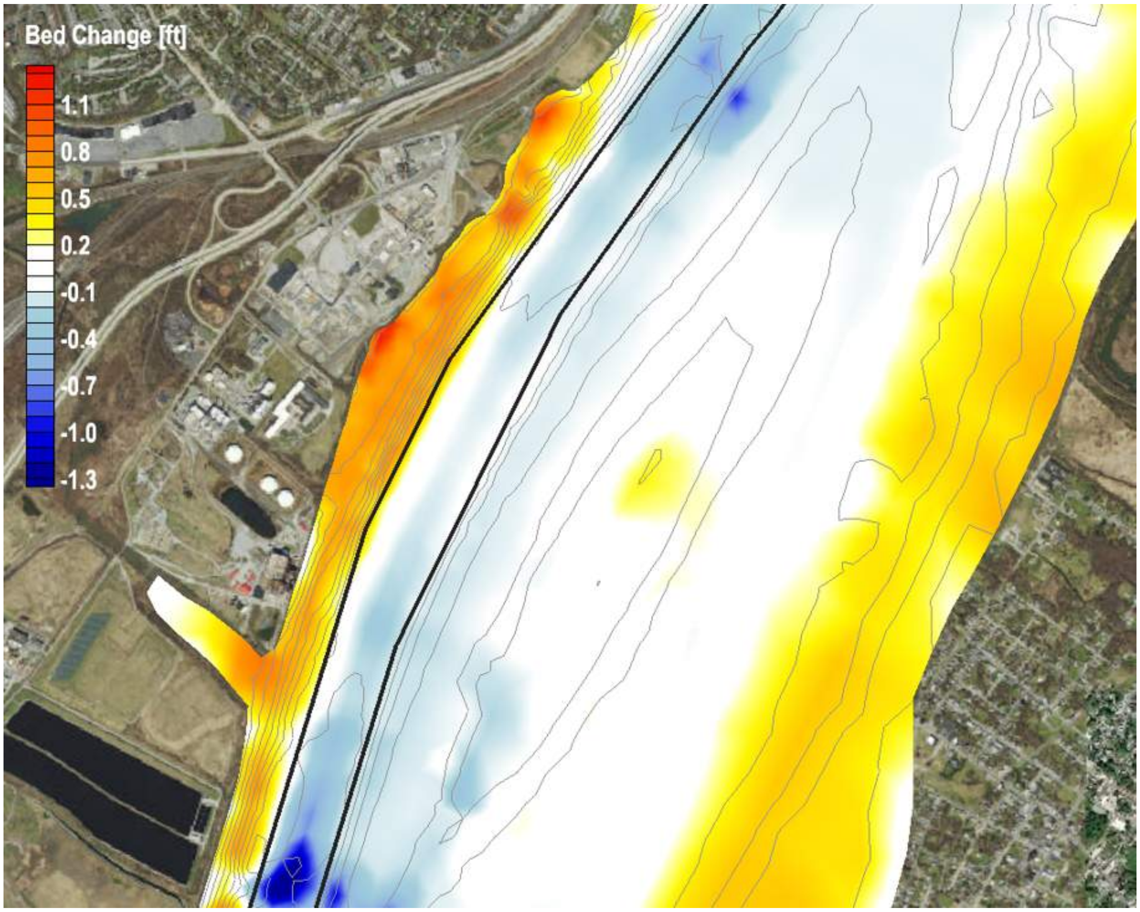


Figure 45: MIKE3 calibration period bed change results near Edgemoor for Existing Conditions

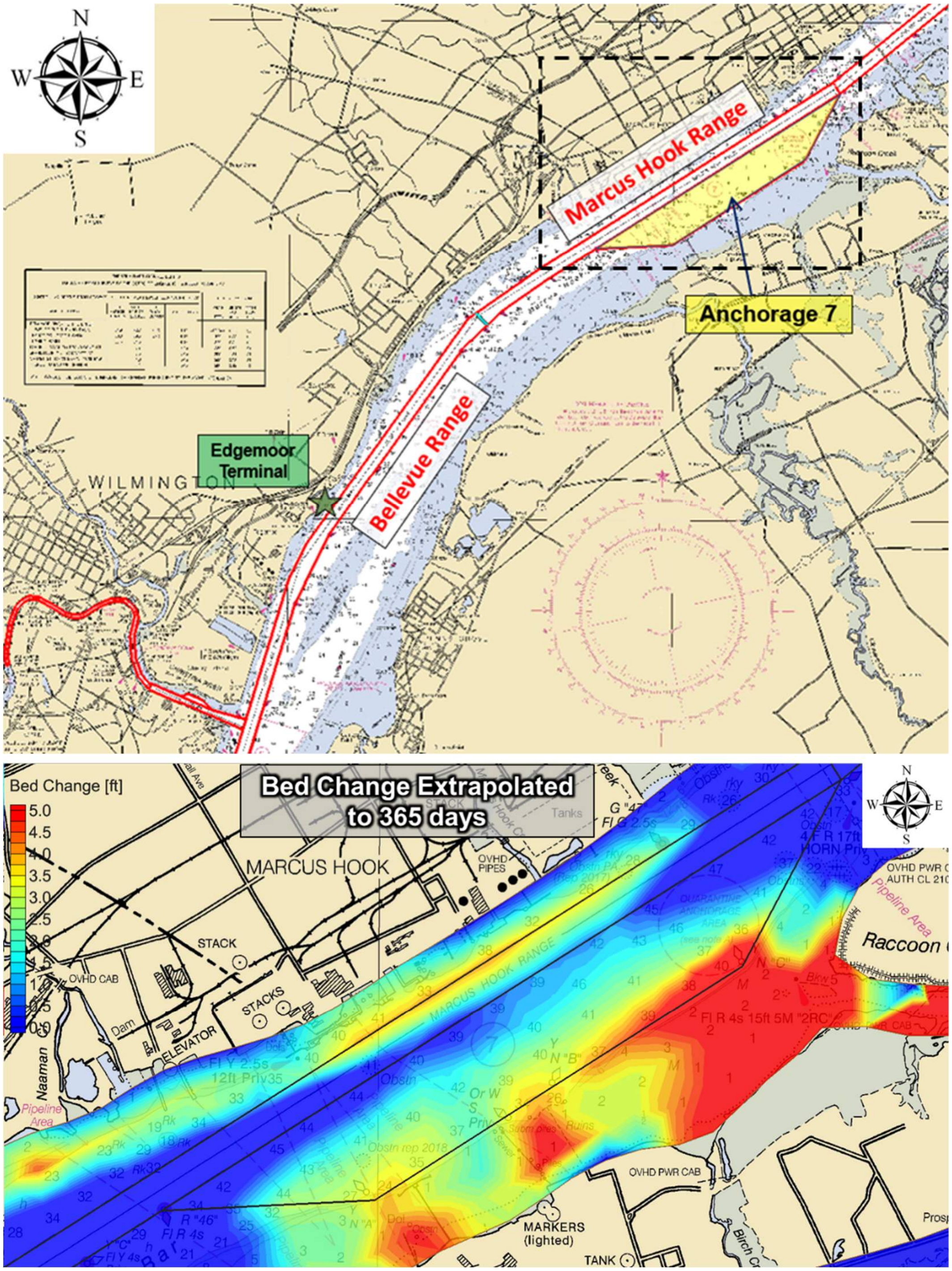


Anchorage 7 is a deep-water anchorage in the Marcus Hook Range, on the south side of the navigation channel. Anchorage 7 is located upstream from the Edgemoor Terminal and experiences a reported rate of sedimentation of approximately 3 feet per year (Duffield Associates 2018c), which is significantly lower sedimentation than the Port of Wilmington. Bed change results in this area were computed, extrapolated linearly to one year, and plotted in Figure 46. Model results indicate that sedimentation rates vary in the area, but are on the correct order of magnitude.

No calibration or validation effort was made at Anchorage 7, and the modeling grid in this location is coarse and unsuitable for accurate predictions. Sedimentation is over-predicted in the shallows due partly to lack of wind-waves and vessel wakes, and hydrodynamic-transport model coupling, in the simulations.

However, the gut-check at Anchorage 7 indicates that the model reproduces the correct order of magnitude of sedimentation rates not only at the Port of Wilmington, but also in the deep water at Anchorage 7, which differ by a factor of 10, and are located on either side of the project site. A more rigorous model validation at Anchorage 7 including comparison with measured deposition patterns would provide additional confidence in the model results.

Figure 46: Location of Anchorage 7 (top) and MIKE3-predicted bed changes at Anchorage 7 extrapolated to one year (bottom). Note: the model was not resolved at Anchorage 7 and no calibration was performed in this area.



6 Impact Analysis

6.1 General

The calibrated and validated numerical model was used to evaluate potential impacts of the proposed Edgemoor Terminal, for two project design variants. Potential impacts evaluated include changes in currents, salinities, and morphology. Scenarios evaluated in the impact analysis include Existing Conditions, Proposed Design with berth depth 45 feet (MLLW), and Design Variant with berth depth 38 feet (MLLW). Note that for all scenarios, the navigation channel was dredged to 45 feet (MLLW) where not already deeper. Potential impacts of the proposed project were evaluated using calibration period modeling simulations. This period included typical tidal conditions, as well as river discharge as high as approximately 50,000 cubic feet per second which is an approximately 98th percentile discharge (USGS, Delaware River at Trenton, NJ).

6.2 Hydrodynamics for Existing and Proposed Design Conditions

Figure 47 and Figure 48 show current velocities for Existing Conditions during peak flood currents and peak ebb currents, respectively. Each figure shows surface (top), mid-depth (middle) and bottom (bottom) velocities. The analysis indicates the following:

- Currents are energetic in this area of the river within the navigation channel and farther east, and slower along the existing slope at Edgemoor.
- Currents in the navigation channel are predicted to be greater than 3 ft/s during both peak ebb and peak flood currents which aligns well with the reported lack of sedimentation of fluvial silts in the Bellevue Range (Duffield Associates 2018a).
- Surface current speeds are similar to those predicted at mid-depth, both of which are significantly stronger than bottom currents.
- Bottom velocities along the shoreline at Edgemoor are less than 0.5 ft/s during peak ebb and flood currents, likely allowing deposition of fluvial silt and modest resuspension during peak currents.

Figure 47: MIKE3-predicted current velocities during peak <u>flood</u> tide for Existing Conditions, at surface (top), mid-depth (middle), and bottom (bottom)

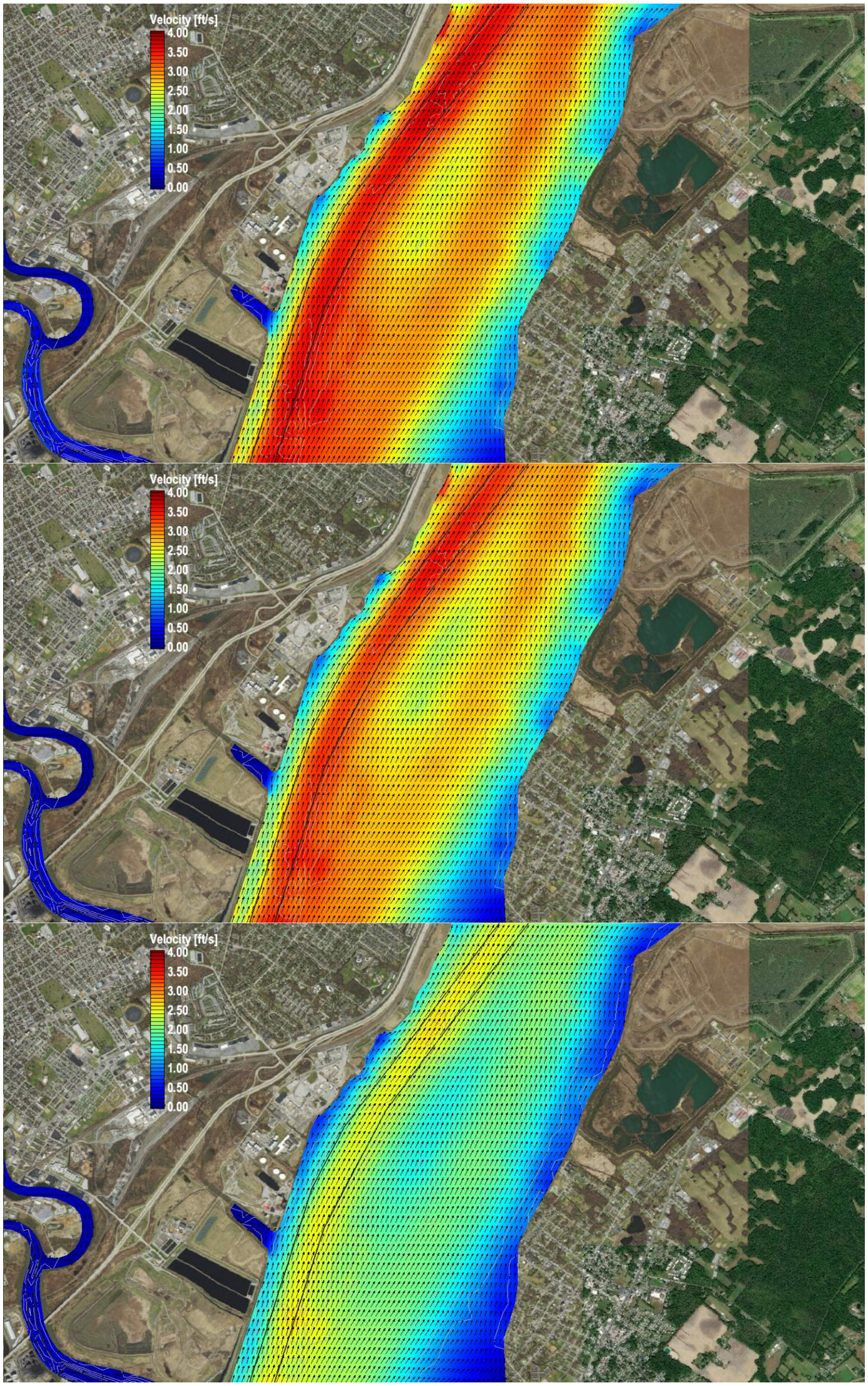
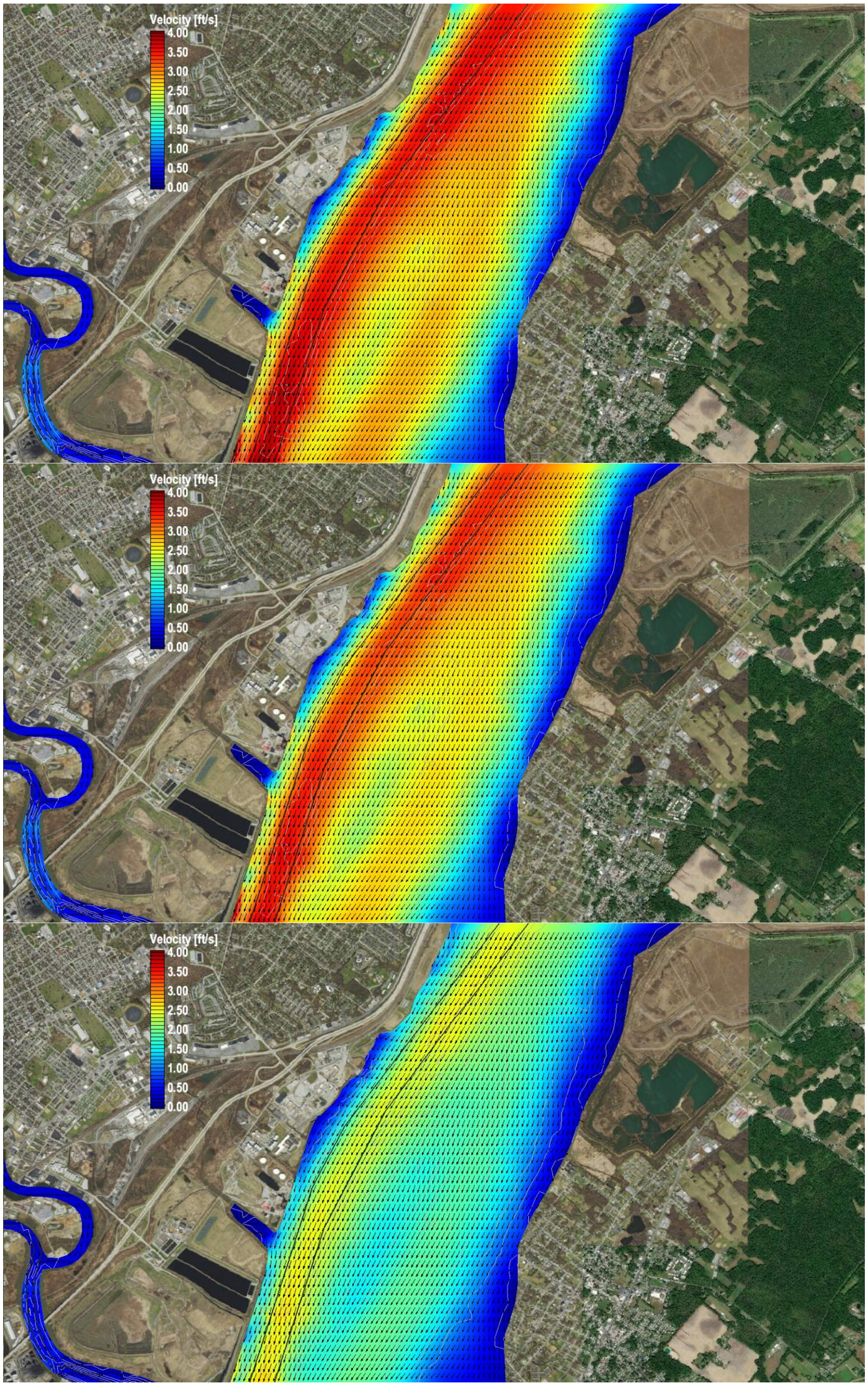


Figure 48: MIKE3-predicted current velocities during peak ebb tide for Existing Conditions, at surface (top), mid-depth (middle), and bottom (bottom)



6.3 Changes in Hydrodynamics for Post-Project Conditions

Side-by-side comparisons of bottom current velocities between Existing Conditions and the Proposed Design/Design Variant were made during peak flood (Figure 49) and peak ebb (Figure 50). Each figure shows Existing Conditions (top), Proposed Design at berth depth 45 feet (MLLW, middle) and Design Variant at berth depth 38 feet (MLLW, bottom). Current velocities after project construction are similar to Existing Conditions, except for areas inside the berth. After dredging the berth, currents are drawn into the open berth area to some degree; this, combined with filling shoreward and partial-depth bulkhead installation, results in similar current velocities for post-project conditions. Differences in hydrodynamics between the Proposed Design and Design Variant are small since the terminal layout is identical except for berth depth.

Changes in currents caused by the project were calculated by direct subtraction of current speeds during peak ebb and flood currents for Existing Conditions and Project Conditions. Figure 51 to Figure 54 show the changes in bottom velocities for Proposed Design and Design Variant relative to Existing Conditions, during peak ebb and peak flood currents. Warm colors (e.g. yellow, orange, red) represent increases in current speeds relative to Existing Conditions, whereas cool colors (light blue, dark blue) represent decreases in current speeds relative to Existing Conditions.

The results show that construction of the project causes a slight decrease in peak current speeds (~0.5 ft/s) relative to Existing Conditions offshore of the berth, due to the deepened berth attracting some tidal flow. At the downstream and upstream ends of the berth (near the 6H:1V slopes), the berth shape results in slightly increased current speeds (up to ~1 ft/s) as flows accelerate up and over the shallow banks. Overall, the effects of the project (for either berth depth) on current speeds are limited to the immediate vicinity of the terminal.

Figure 49: MIKE3-predicted bottom velocities at peak <u>flood</u> tide for Existing Conditions (top), Proposed Design with berth depth 45 feet (MLLW, middle) and Design Variant with berth depth 38 feet (MLLW, bottom)

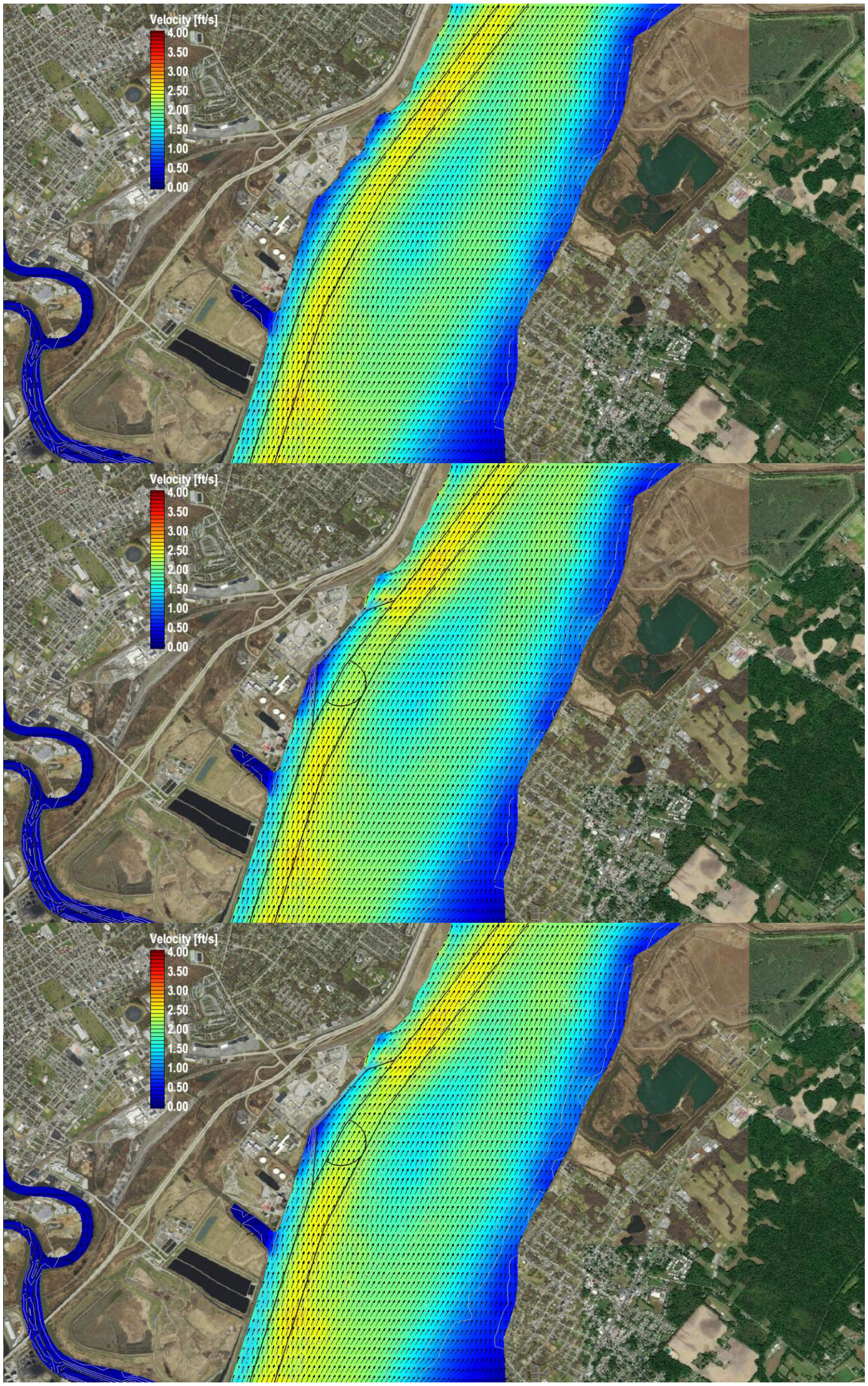


Figure 50: MIKE3-predicted bottom velocities at peak ebb tide for Existing Conditions (top), Proposed Design with berth depth 45 feet (MLLW, middle) and Design Variant with berth depth 38 feet (MLLW, bottom)

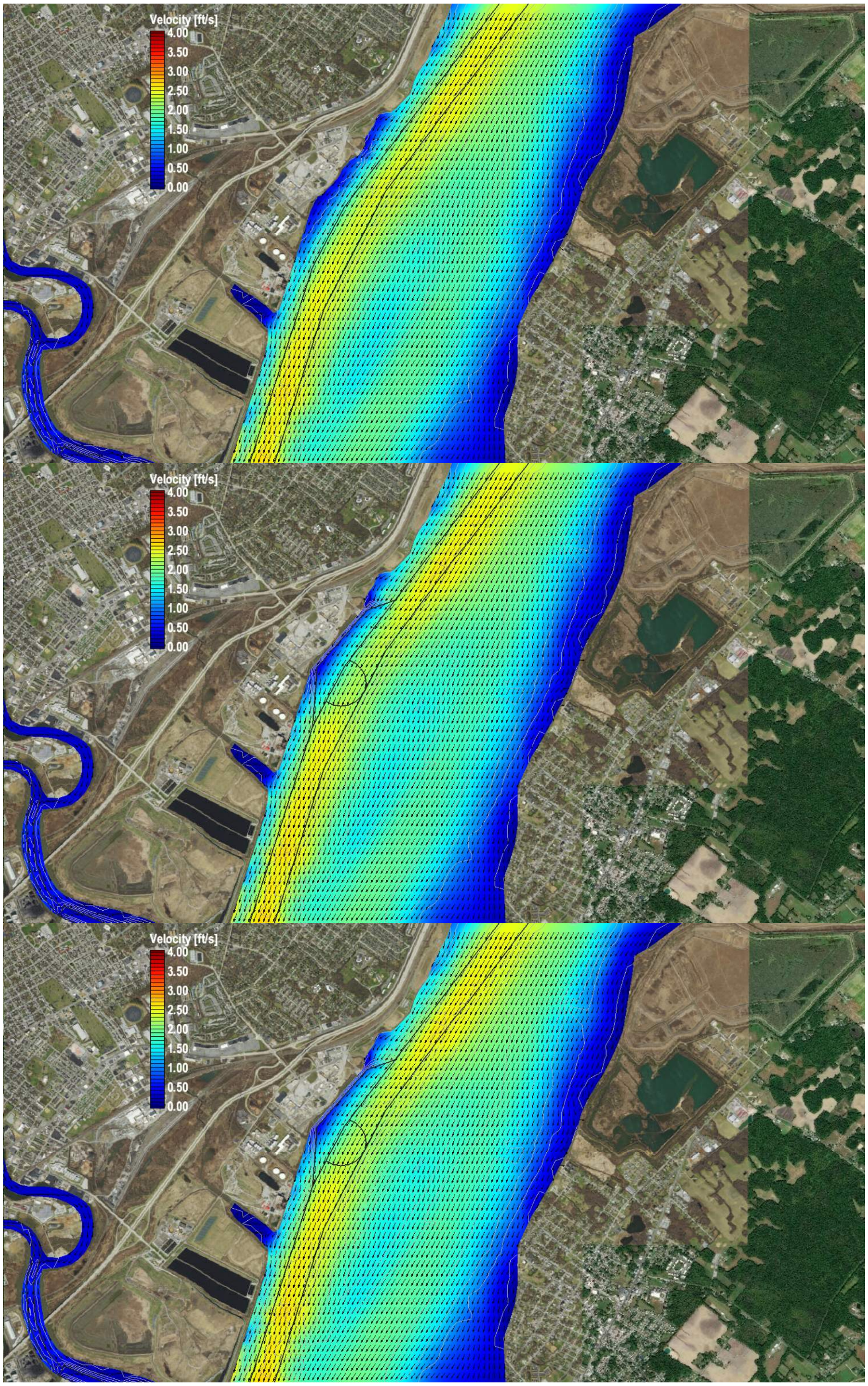


Figure 51: MIKE3-predicted changes in bottom velocities at peak flood tide for Proposed Design with berth depth 45 feet (MLLW) at surface (top), mid-depth (middle) and bottom (bottom)

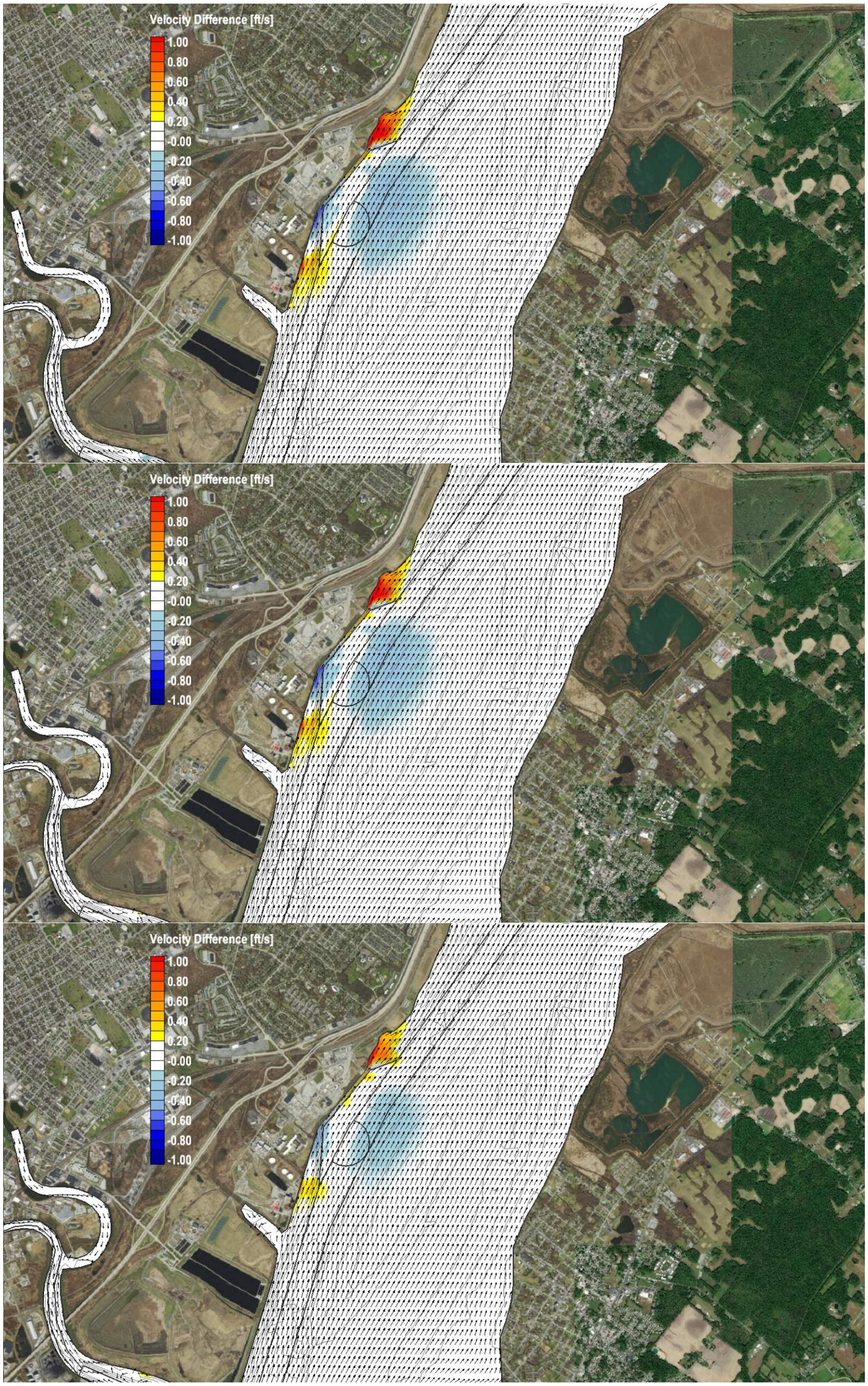


Figure 52: MIKE3-predicted changes in bottom velocities at peak <u>ebb</u> tide for Proposed Design with berth depth 45 feet (MLLW) at surface (top), mid-depth (middle) and bottom (bottom)

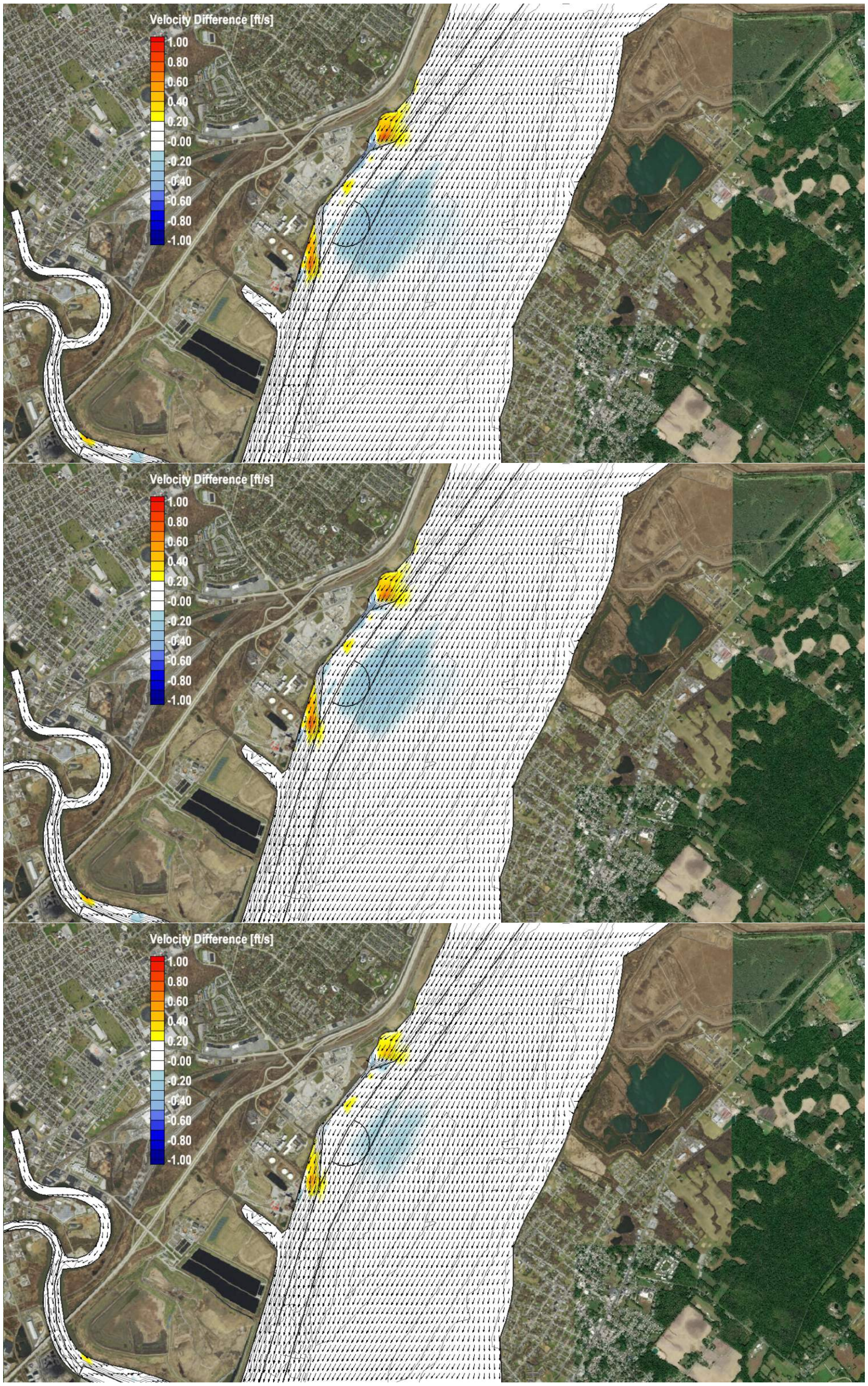


Figure 53: MIKE3-predicted changes in bottom velocities at peak <u>flood</u> tide for Design Variant with berth depth 38 feet (MLLW) at surface (top), mid-depth (middle) and bottom (bottom)

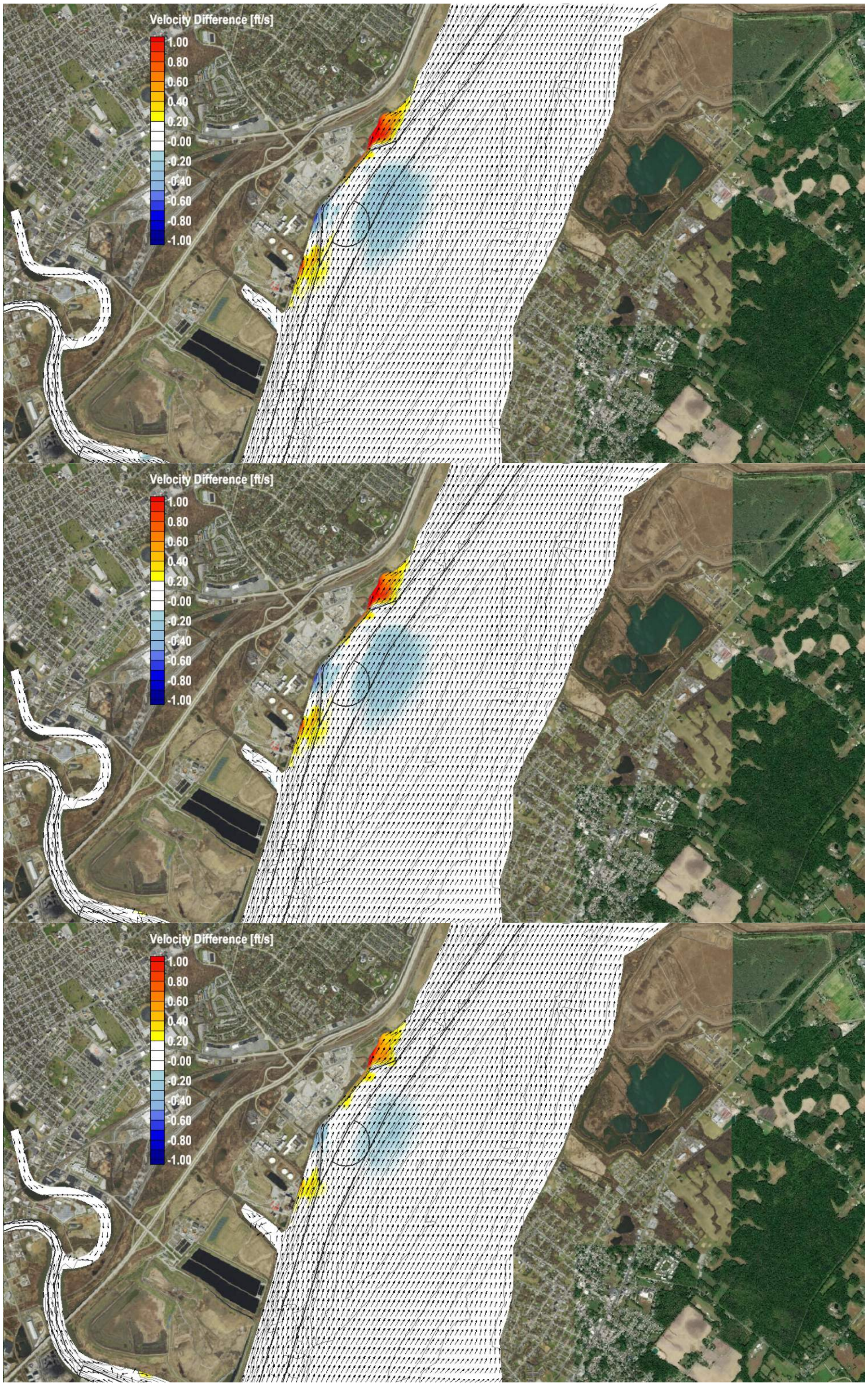
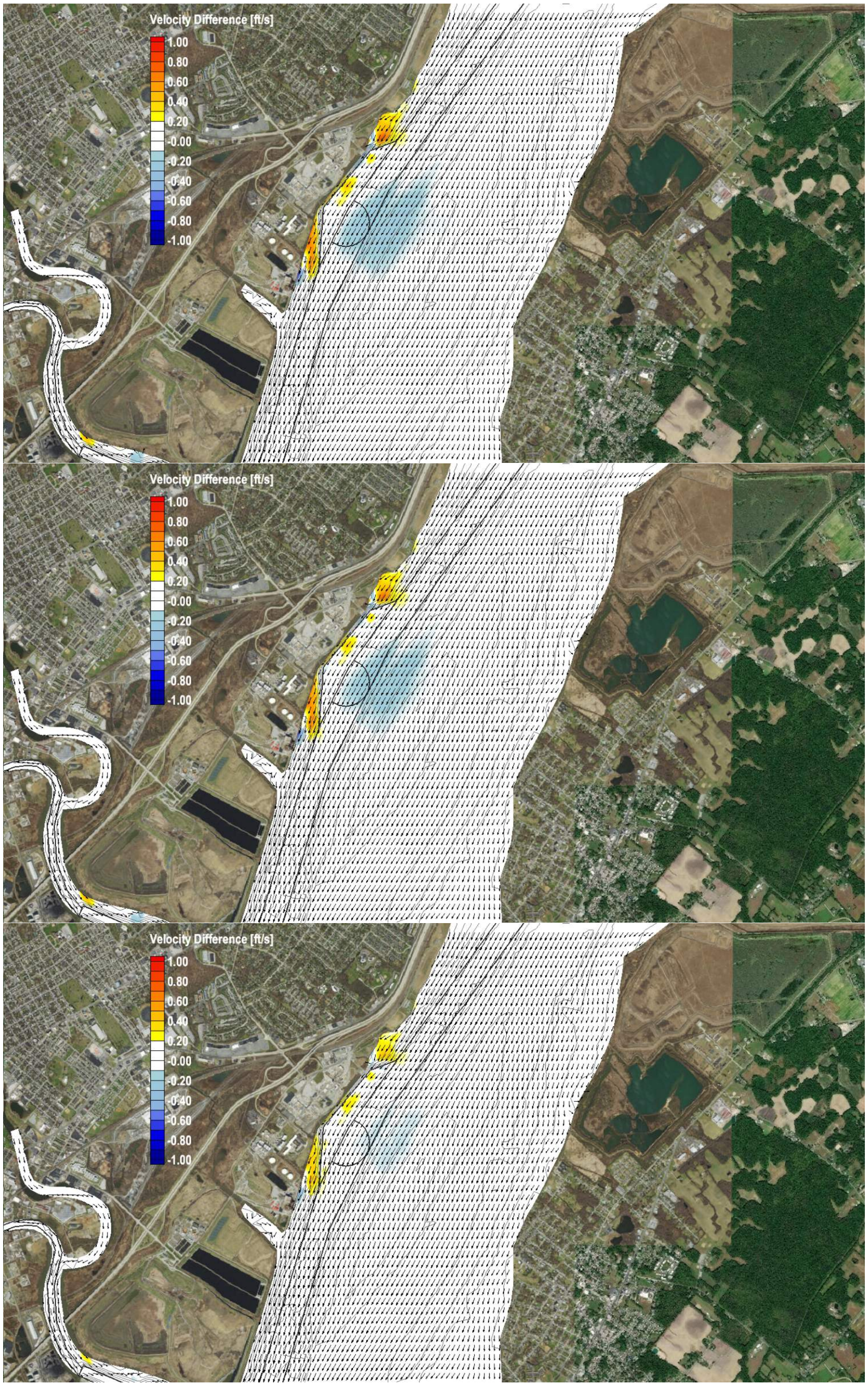


Figure 54: MIKE3-predicted changes in bottom velocities at peak <u>ebb</u> tide for Design Variant with berth depth 38 feet (MLLW) at surface (top), mid-depth (middle) and bottom (bottom)



Changes in current speeds due to the project were also evaluated using time histories of velocities in the navigation channel, both downstream and upstream of the project site. Figure 55 shows the locations of extraction points used to evaluate time histories of bottom, mid-depth and surface current velocities and changes induced by the project. The current velocities at these locations are plotted in Figure 56 to Figure 60, with negative values representing ebb-directed currents. Changes in current speeds at Points 1, 2, 4, and 5 are not measurable. At Point 3 which is immediately adjacent to the project site, the current speeds are slightly decreased as already shown in the plan view difference plots.

Figure 55: Extraction points for comparison between time histories of velocity and salinity for Existing Conditions and Project Conditions

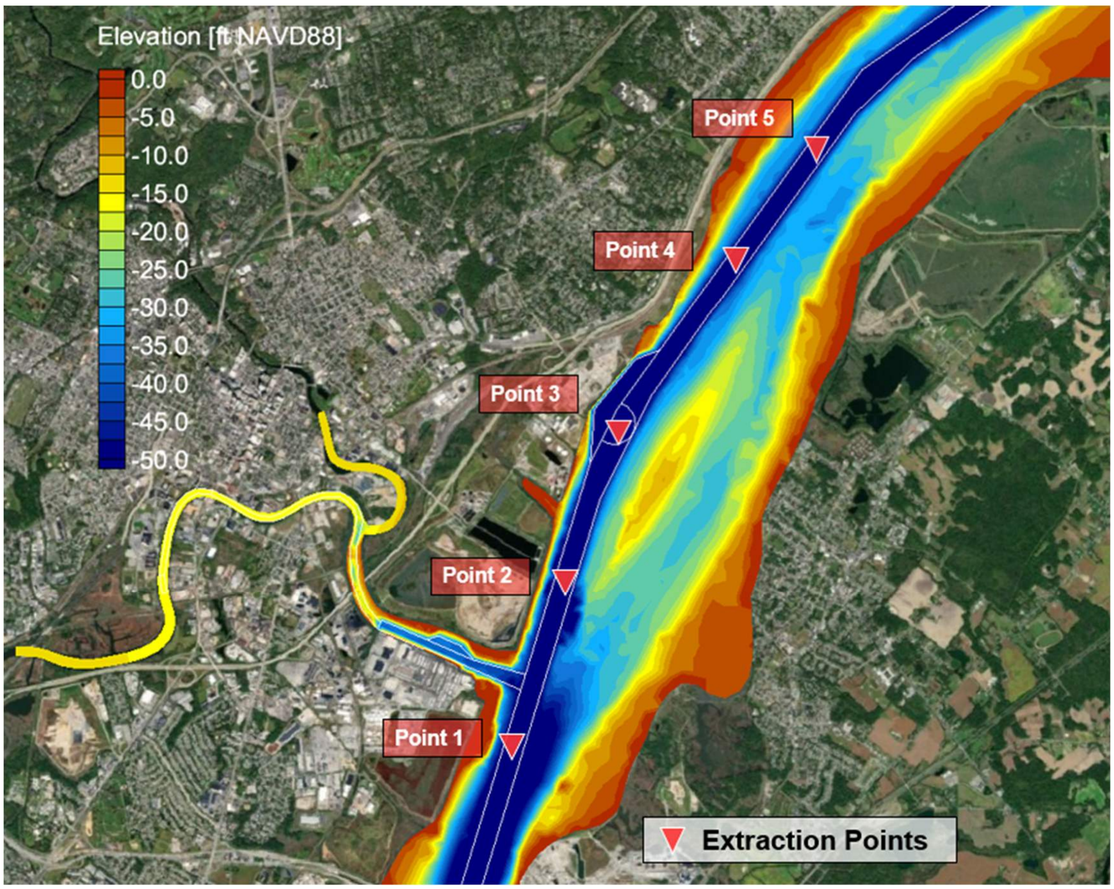


Figure 56: Comparison between current velocities for Existing Conditions and Project Conditions at Point 1

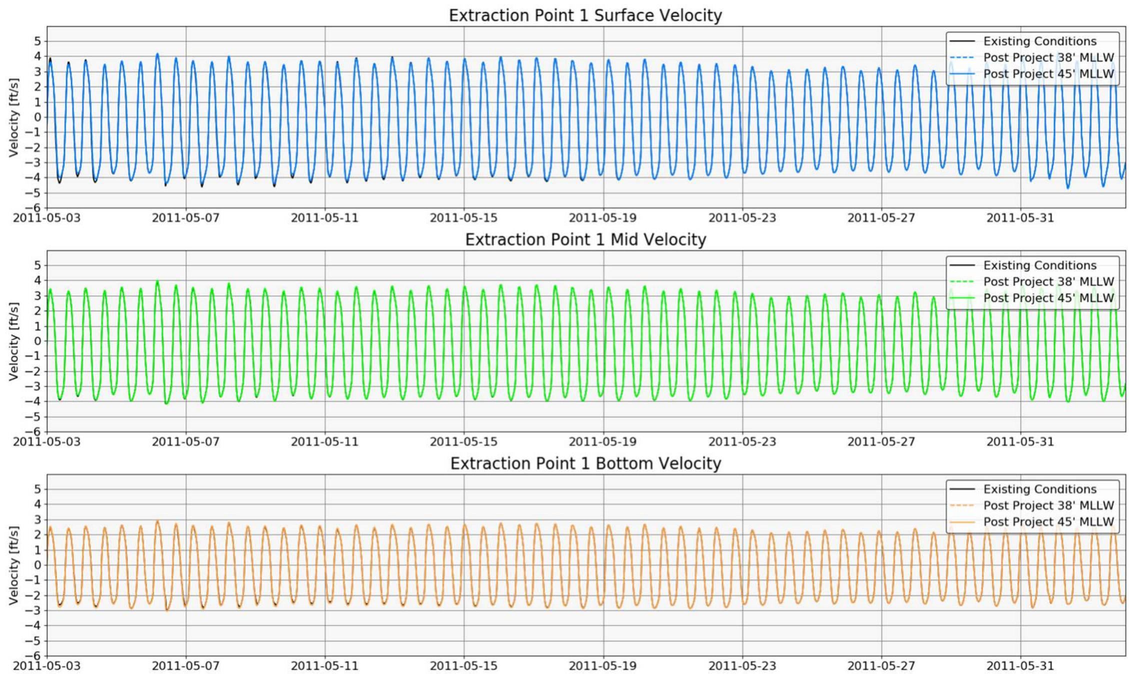


Figure 57: Comparison between current velocities for Existing Conditions and Project Conditions at Point 2

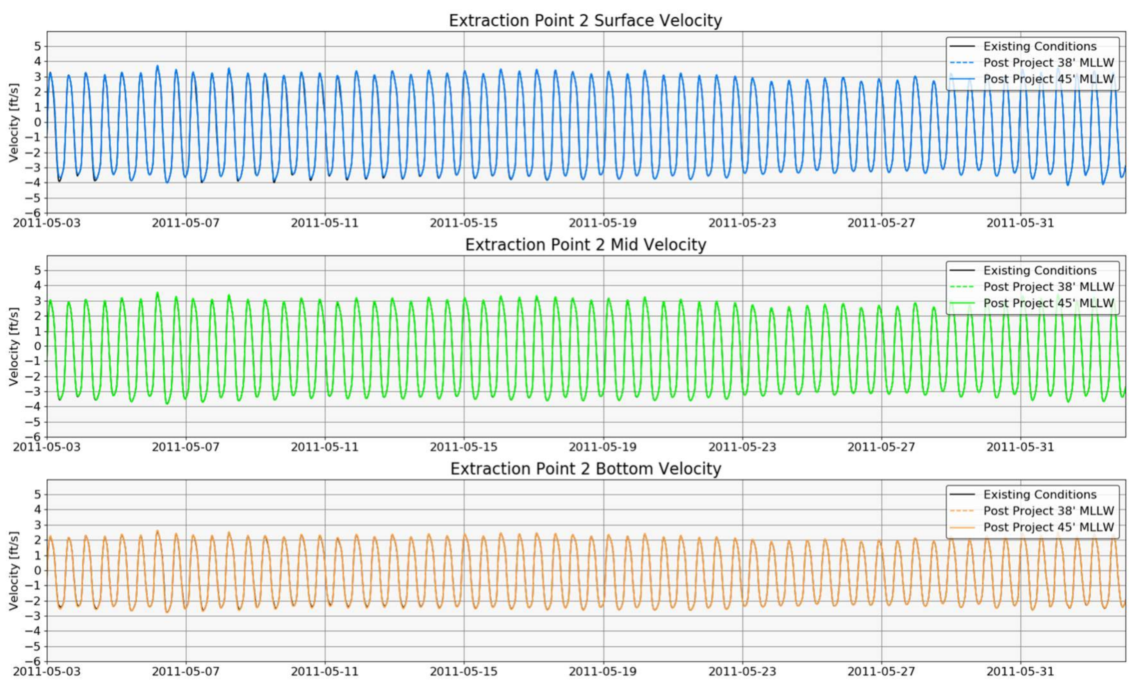


Figure 58: Comparison between current velocities for Existing Conditions and Project Conditions at Point 3

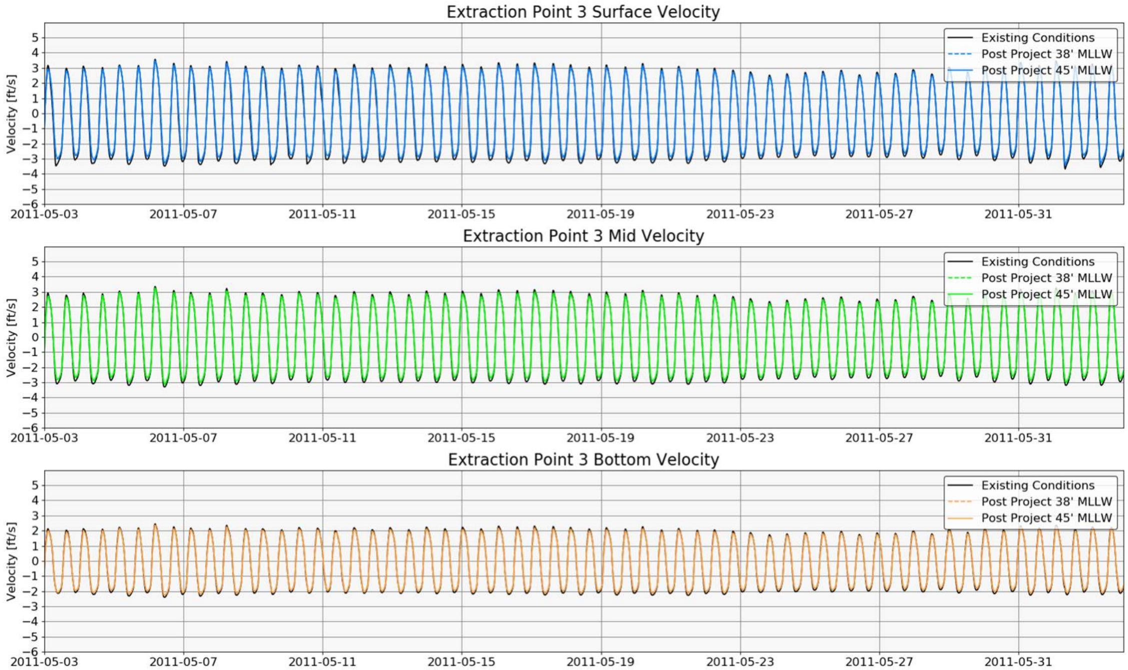


Figure 59: Comparison between current velocities for Existing Conditions and Project Conditions at Point 4

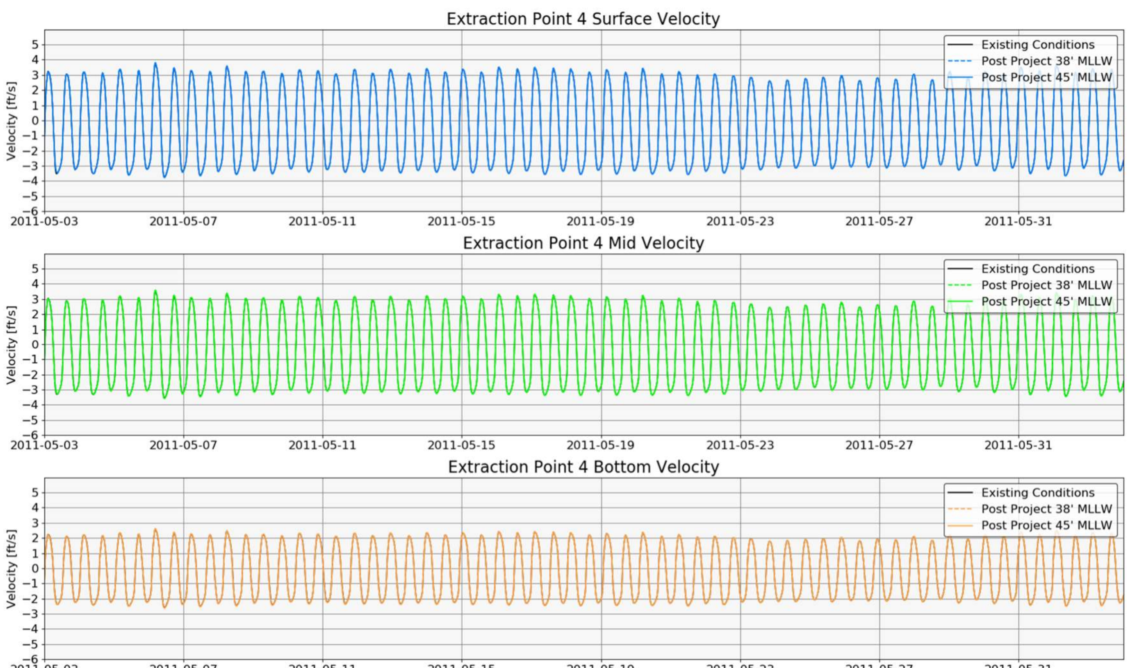
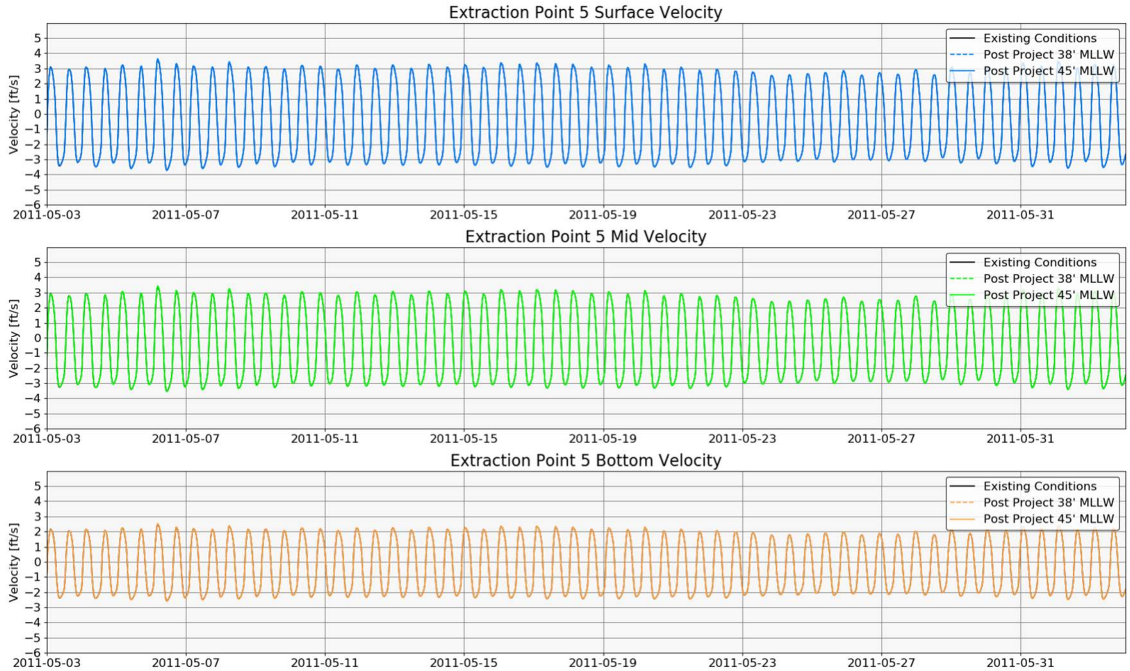


Figure 60: Comparison between current velocities for Existing Conditions and Project Conditions at Point 5



6.4 Changes in Salinity for Post-Project Conditions

Time histories of salinity were also extracted at Points 1-5 to evaluate whether the project induces any significant salinity changes upstream and downstream of the site. Figure 61 to Figure 65 show that salinity changes due to project construction are likely to be negligible.

Figure 61: Comparison between salinities for Existing Conditions and Project Conditions at Point 1

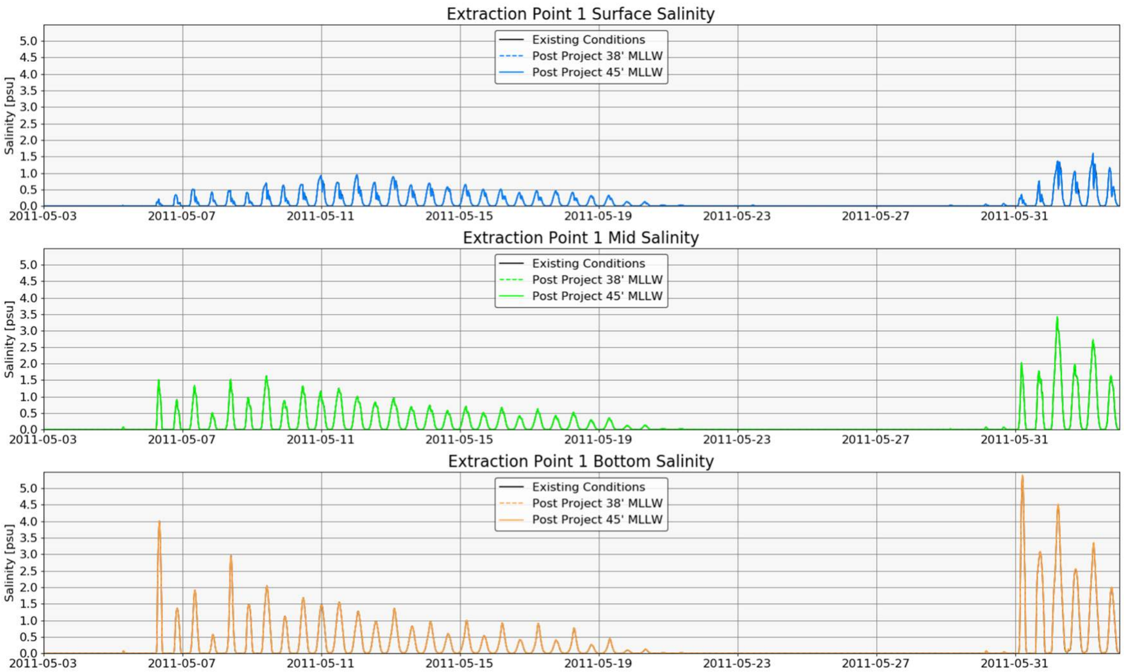


Figure 62: Comparison between salinities for Existing Conditions and Project Conditions at Point 2

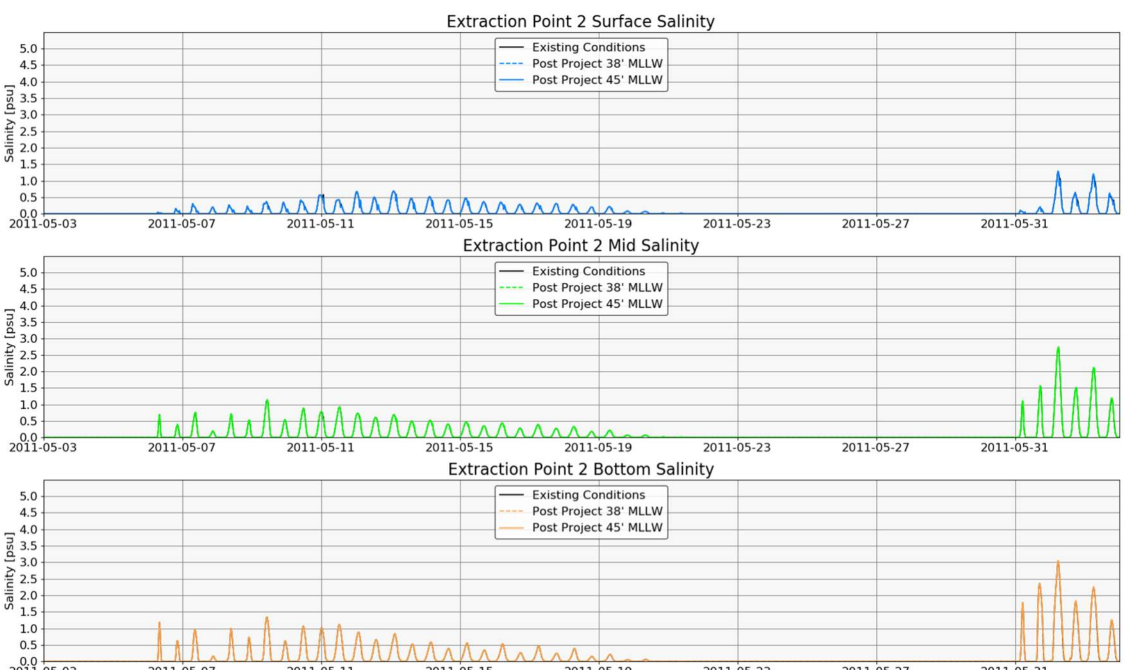


Figure 63: Comparison between salinities for Existing Conditions and Project Conditions at Point 3

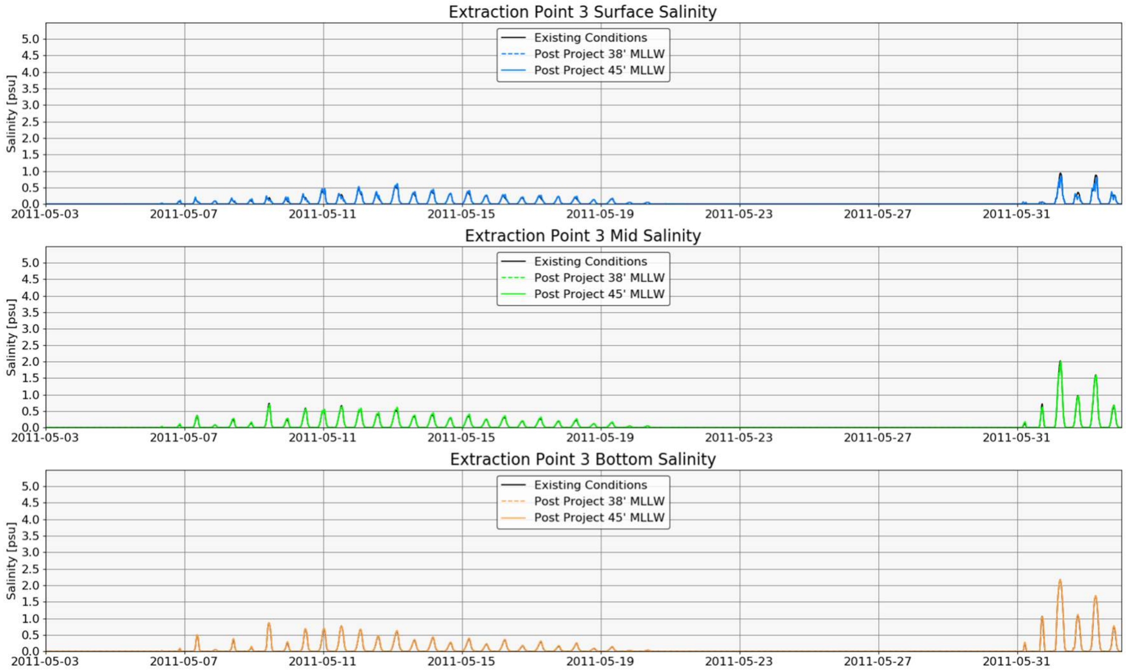


Figure 64: Comparison between salinities for Existing Conditions and Project Conditions at Point 4

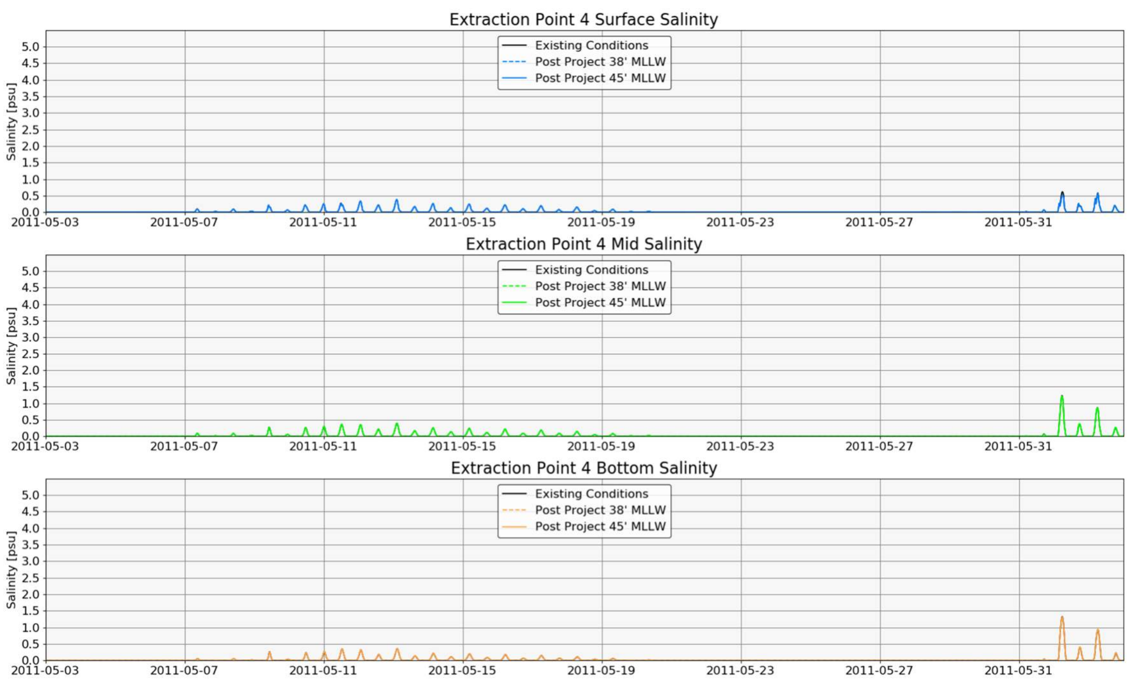
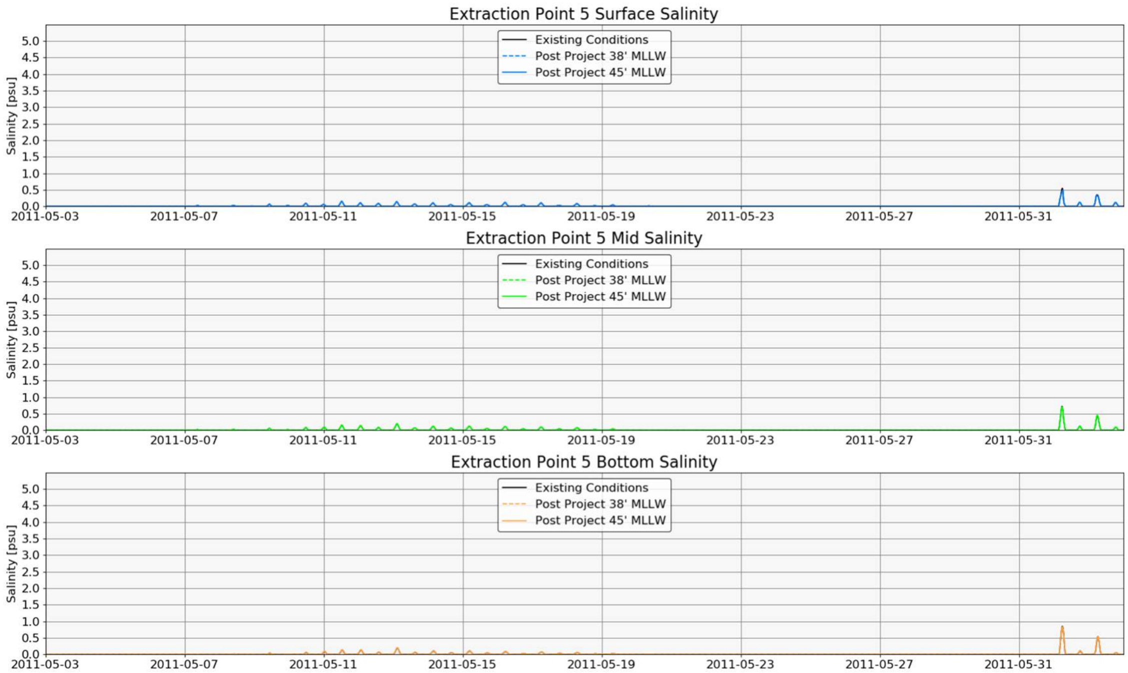


Figure 65: Comparison between salinities for Existing Conditions and Project Conditions at Point 5



6.5 Changes in Erosion/Deposition for Post-Project Conditions

The Proposed Design and Design Variant were evaluated to determine how the changes in currents may affect sedimentation (or erosion) in the surrounding areas. Potential impacts to bed changes in the area were evaluated separately for sand transport and for mud transport.

6.5.1 Sand Transport

Sand transport simulations with median grain size 1.4mm were performed to determine effects of the project on surrounding bed changes. Figure 66 and Figure 67 show the calibration period bed change for the Proposed Design (berth depth 45 feet, MLLW), and Design Variant (berth depth 38 feet, MLLW), relative to bed changes predicted for Existing Conditions. In these figures, the Existing Conditions bed change results from the calibration period simulations were directly subtracted from bed changes for each project condition, resulting in a representation of relative changes caused by the project. The project induces only very small changes in sand transport and erosion/deposition outside the berth area, and negligible changes in the navigation channel. The annualized increase in sedimentation within the entire navigation channel due to sand transport changes is small. Existing sand-based sedimentation within the combination of Bellevue Range and Cherry Island Range for Existing Conditions was predicted to be 90,382 CY per year; sedimentation was predicted to increase to 91,232 CY per year for Proposed Design (berth depth 45 feet, MLLW), and increase to 90,533 CY per year for Design Variant (berth depth 38 feet, MLLW). The maximum increase in sedimentation is less than 1,000 CY per year, in the entire navigation channel.

Figure 66: Relative sand bed changes caused by the Proposed Design at berth depth 45 feet (MLLW), computed as difference from Existing Conditions

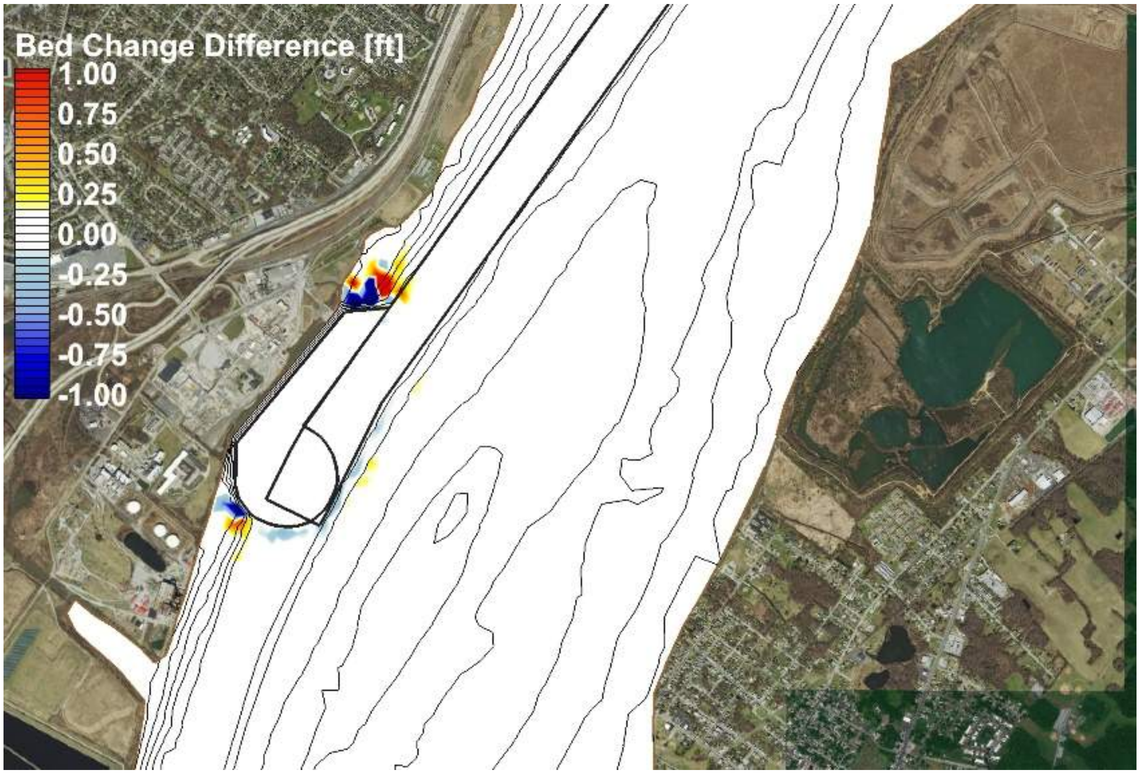
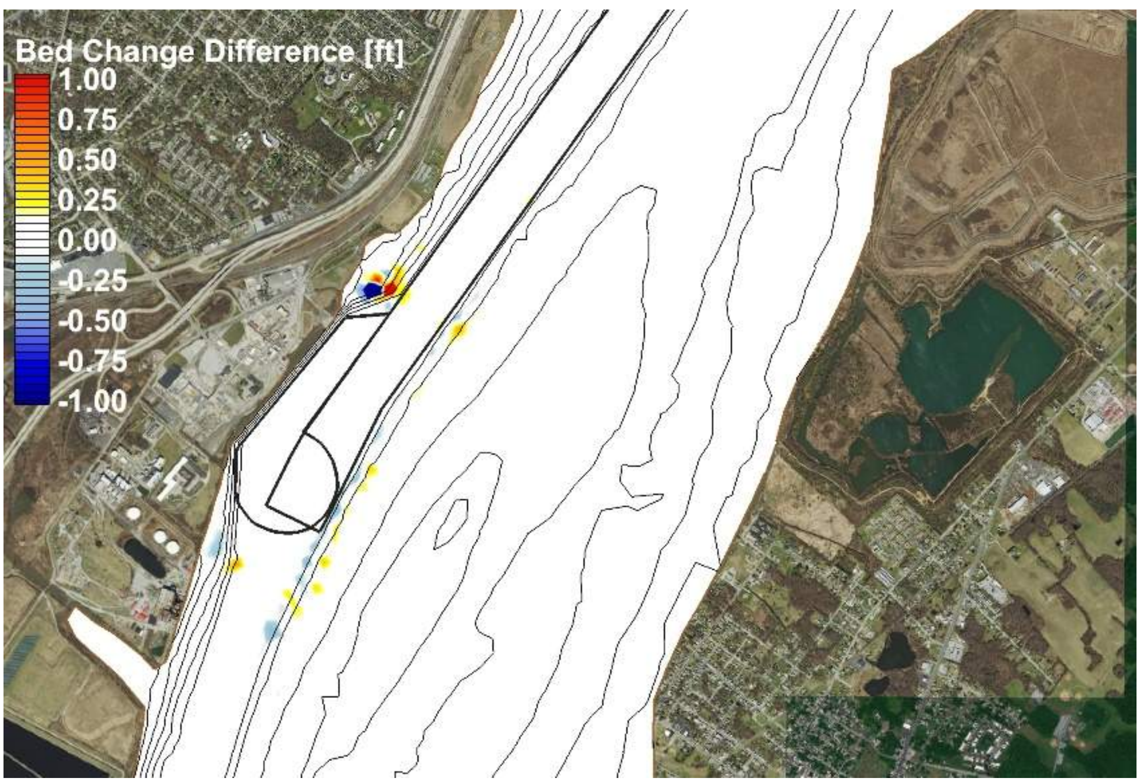


Figure 67: Relative sand bed changes caused by the Design Variant at berth depth 38 feet (MLLW), computed as difference from Existing Conditions



6.5.2 Mud Transport

Mud transport simulations representing transport of fluvial silt were also performed to determine effects of the project on surrounding bed changes. Figure 68 and Figure 69 show the calibration period bed changes for the Proposed Design (berth depth 45 feet, MLLW), and Design Variant (berth depth 38 feet, MLLW), respectively, relative to bed changes predicted for Existing Conditions. In these figures, the Existing Conditions bed change results from the calibration period simulations were directly subtracted from bed changes for each project condition, resulting in a representation of relative changes caused by the project. The project causes relative erosion/accretion changes in the vicinity of the berth, most notably erosion on the shallow slopes upstream and downstream, and slight sedimentation on the west side of the navigation channel.

Potential changes were evaluated in the area including both the Bellevue Range and Cherry Island Range. During the calibration period simulations, the differences between erosion and accretion volumes in the navigation channel for Existing Conditions, the Proposed Deign, and Design Variant, represent negligible portions (less than 1%) of overall volumetric changes occurring under Existing Conditions. These volumes represent negligible potential for sedimentation in the navigation channel when spread over the large channel areas under consideration and are not expected to contribute significantly to channel maintenance dredging requirements.

Figure 68: Relative mud bed changes caused by the Proposed Design at berth depth 45 feet (MLLW) relative to Existing Conditions

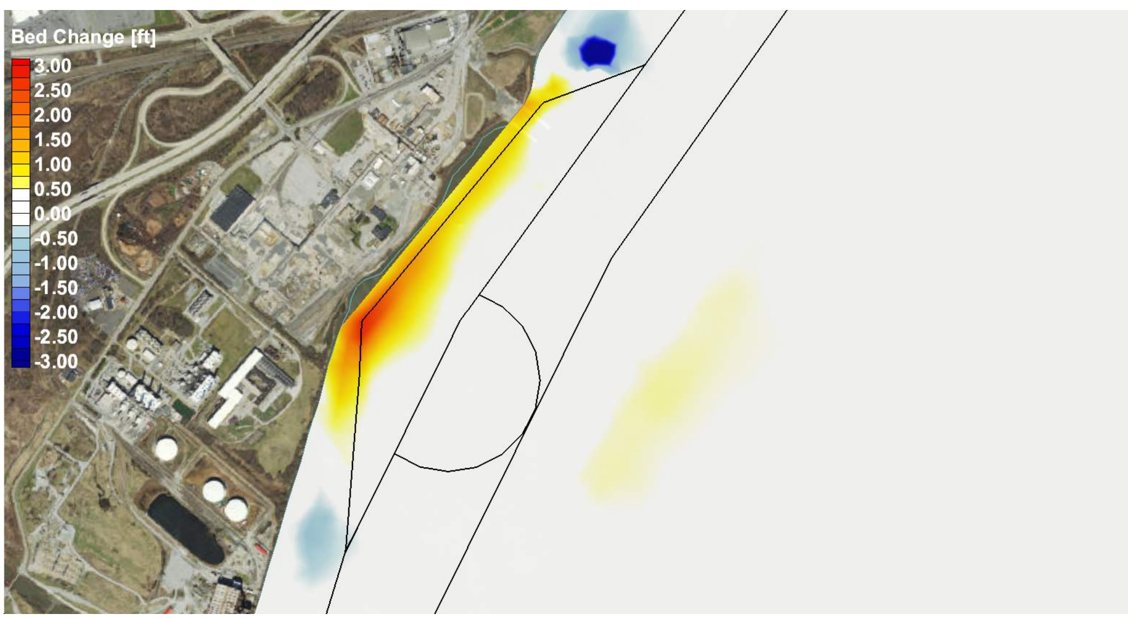
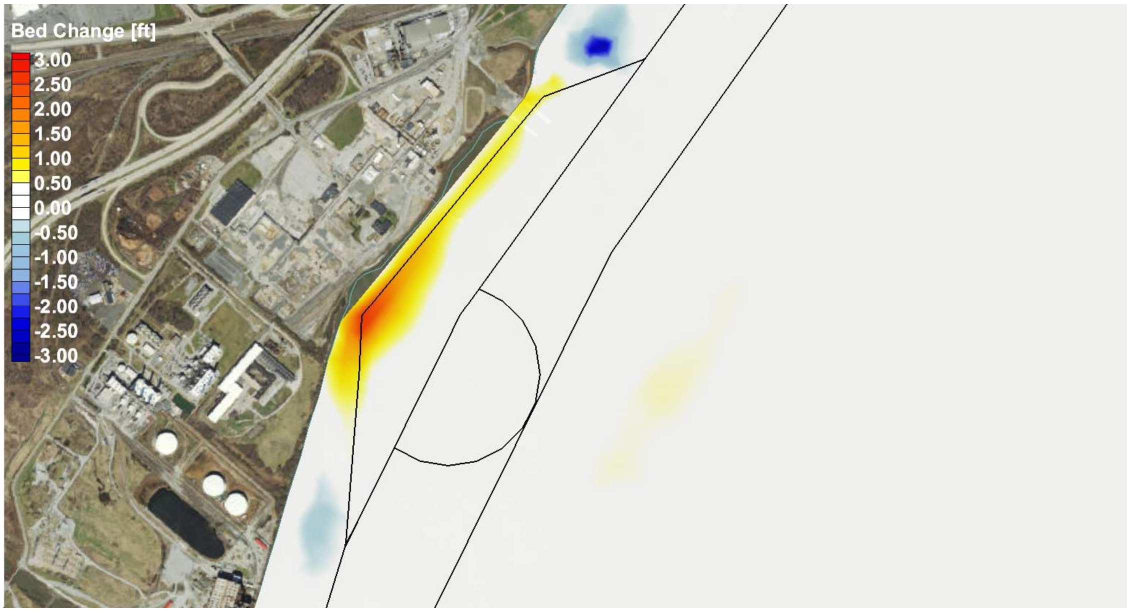


Figure 69: Relative mud bed changes caused by the Design Variant at berth depth 38 feet (MLLW) relative to Existing Conditions



6.6 Impact Analysis Conclusions

Results show that effects of project construction at either depth 45 feet (MLLW) or 38 feet (MLLW) on current velocities, salinity and bed changes in surrounding areas are limited to the immediate vicinity of the terminal. The immediate vicinity of the terminal, in this case, includes less than half of the berth length upstream or downstream of the terminal extents. Changes in current speeds or directions are not expected to affect navigation. Salinity changes are likely to be negligible even in the immediate vicinity of the terminal.

Simulations of both sand transport and mud transport were performed and effects of the proposed project on navigation channel sedimentation were evaluated. Potential changes were evaluated in the area including both the Bellevue Range and Cherry Island Range. The project is expected to result in less than 1,000 CY per year of additional sedimentation for sand, for either the Proposed Design and Design Variant. The Proposed Design and Design Variant generated negligible changes in erosion and deposition of fluvial silt in the navigation channel relative to changes occurring under Existing Conditions. The volumetric changes represent negligible changes in elevation and are not expected to contribute significantly to the existing navigation channel maintenance dredging requirements.

7 Conclusions

Hydrodynamic and sediment transport analysis was performed by Mott MacDonald (MM) as a subconsultant to Duffield Associates for the Diamond State Port Corporation (DSPC), in support of proposed container terminal development at Edgemoor, Delaware. The objective of the analysis was to evaluate potential impacts of the terminal on hydrodynamics, sediment transport and erosion/deposition in the surrounding areas.

Analysis indicates that the project only affects hydrodynamics in the estuary within approximately one berth length or less away from the terminal. Since hydrodynamic changes are negligible outside the immediate vicinity of the terminal, sediment transport and morphology are also unaffected outside this area. Sediment transport simulations show no measurable erosion/accretion caused by the project outside the immediate vicinity of the terminal.

Sedimentation modeling performed as part of this study indicates that the Edgemoor Terminal berth deepening is likely to create a depositional zone which is primarily susceptible to sedimentation from fluvial silts, and to a lesser extent sand. Based on lack of sediment data already discussed in Section 5, project team discussions, and analysis of the present sedimentation modeling results, additional on-site data collection and sampling are deemed appropriate to refine the model input parameters to more accurately represent on-site conditions. Site-specific sediment transport parameters such as critical shear stress values for erosion and deposition may have a significant impact on predicted sedimentation rates in the basin. Mott MacDonald recommends that the design team perform SedFlume testing on undisturbed sediment samples to be collected at the site in order to obtain more accurate, site-specific sediment property information.

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