US Army Corps of Engineers®
New York District

NEW YORK AND NEW JERSEY HARBOR DEEPENING CHANNEL IMPROVEMENTS

NAVIGATION STUDY

FINAL INTEGRATED FEASIBILITY REPORT & ENVIRONMENTAL ASSESSMENT

APPENDIX B1:

Channel Design

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1. Introduction

The U.S. Army Corps of Engineers (USACE) New York District (CENAN), in partnership with the Port Authority of NY &NJ (PANYNJ) is evaluating measures to improve the operational efficiency of commercial vessels currently using the federal navigation channels at the New York and New Jersey Harbor as well as commercial vessels projected to use it in the future. This Engineering Appendix details the methodology, assumptions and analyses completed to determine sufficient details to prepare costs of alternatives for plan formulation leading to a NED plan. The focus of this feasibility study is limited only to those locations and channels that were deepened in the Harbor Deepening Project (HDP) that was completed in 2016.

2. Existing Federal Channels

2.1. General

The New York and New Jersey Harbor is located along the northern portion of Atlantic Seaboard of the United States, approximately 270 miles north of Norfolk, Virginia and 200 miles south of Boston, Massachusetts. The harbor is located at the confluence of the Hudson River and the East River at the southern tip of Manhattan. It extends south through the Verrazano Narrows to the New York Bight and empties into the Atlantic Ocean; it is one of the largest natural harbors in the world. The Upper Bay is north of the Verrazano Narrows and the Lower Bay is south of the Verrazano Narrows.

The Port of New York and New Jersey is the largest port on the east cost of the United States and the third largest in the nation. The NY District presently maintains approximately 240 miles of navigation channels within the harbor, which are used intensively for both commercial and recreational vessels. Other channels within the harbor are maintained by PANYNJ, the City of New York, and various commercial interests. All channels within the harbor are maintained as two-way channels; however, there are occasions when certain channels are limited to one-way traffic. The Kill Van Kull Channel, for example, must be closed to two-way traffic, except for very small vessels, when it is traversed by an Ultra Large Container Vessel (UCLV). Figure 1 shows the study area and the existing navigation channels within the port. Those channels of interest to this study are described in detail below.

The lead federal agency for this study is USACE. The non-federal sponsor for this study is the Port Authority of New York and New Jersey (PANYNJ).

The goal of this study is to reasonably maximize the contribution that the channels provide to national economic development (NED), consistent with protecting the Nation's environment, by addressing the physical constraints and inefficiencies in the existing navigation system's ability to safely and efficiently serve the current and forecasted vessel fleet and process the forecasted cargo volumes.

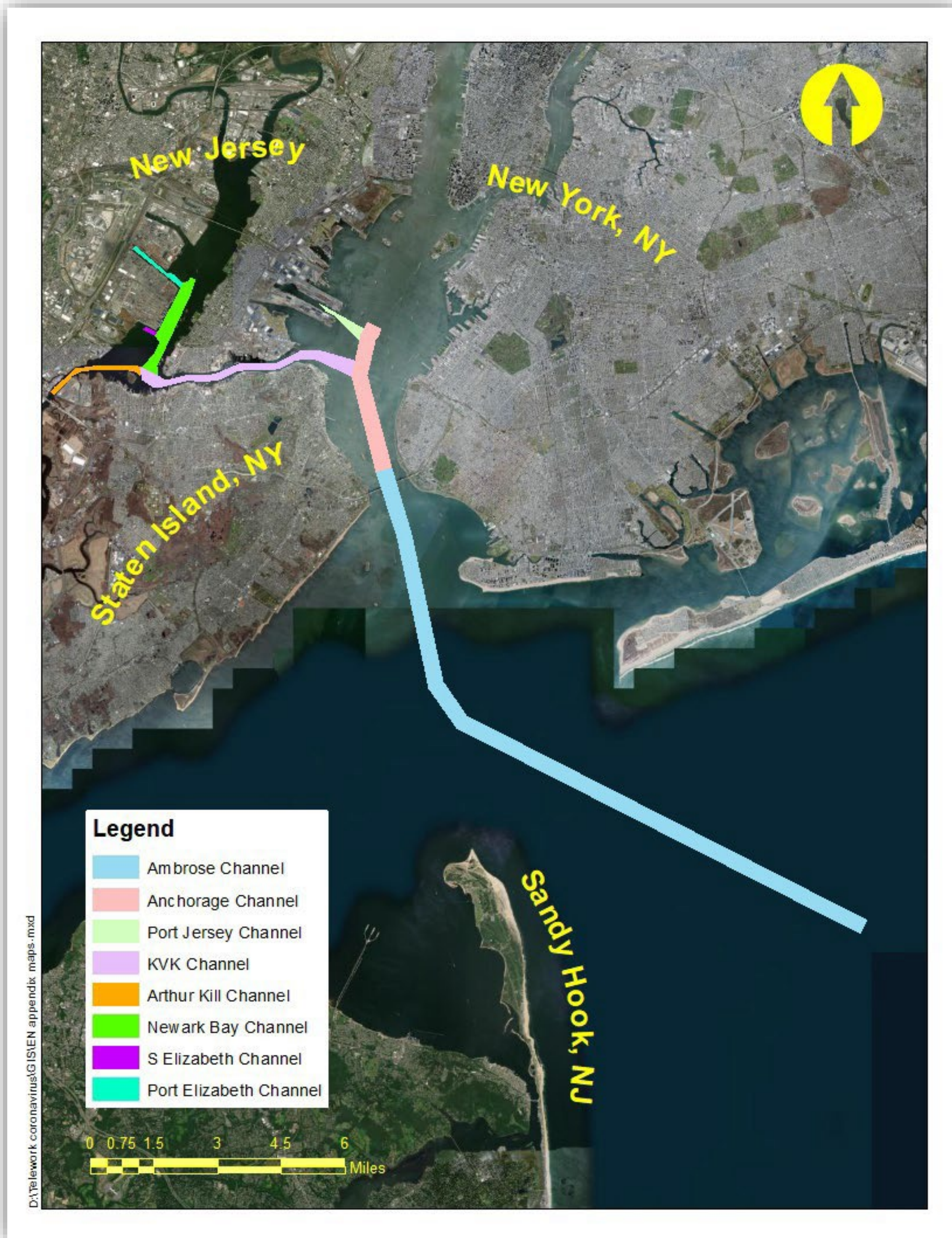

Figure 1. Location Map of NY & NJ Harbor

2.1.1. Ambrose Channel

Ambrose Channel is the entrance channel into NY & NJ Harbor. The channel extends for approximately 16.9 miles at a width of 2000 feet, ending approximately 2000 feet north of the Verrazano Narrows Bridge. Traffic in the Ambrose Channel is two-way for deep-draft vessels, with an occasional overtaking one vessel by another in the same direction. At its mouth, the Ambrose Channel is greater than 90 feet below Mean Lower Low Water (MLLW); its maintained depth is 53 feet below MLLW. The channel is commercially mined for sand and is therefore deeper than the maintained depth in many locations. Inbound vessels reduce their speed to approximately 12 to 14 knots from sea when entering Ambrose Channel.

2.1.2. Anchorage Channel

Anchorage Channel is the primary channel in the Upper Bay. It connects the Ambrose Channel, through the Narrows, with the Kill Van Kull channel and also the Port Jersey Channel. The Anchorage Channel is 2000 feet wide and is maintained to a depth of 50 feet below MLLW. The 50-foot depth does not continue for the entire length of the Anchorage Channel but stops approximately 4,300 feet north of its confluence with the Port Jersey Channel. Above of this point, the channel is maintained to a depth of 45 feet below MLLW.

2.1.3. Port Jersey Channel

The existing Port Jersey Channel is a non-federal channel that provides access to both GCT-Bayonne (formerly the Global Marine Terminal) and the Port Authority Auto Marine Terminal (formerly the NorthEast Auto Terminal (NEAT) on the north side of the channel, and the former Marine Ocean Terminal at Bayonne (MOTBY) on the south side of the channel, which is currently being redeveloped. The straight-line distance width at the mouth of the channel is approximately 1635 feet, while the channel width between the two berthing docks is approximately 450 feet. There is a 1200-foot diameter turning basin at the western end of the Port Jersey Channel. Deep draft traffic in Port Jersey Channel is one way. Smaller containerships turn in the turning basin; however, larger ships turn in Anchorage Channel and back into Port Jersey, or back out of Port Jersey and turn in Anchorage Channel, depending on which side of the ship must face the berth. Port Jersey Channel is currently maintained to a depth of 50 feet below MLLW. A large diameter sewerage pipe, owned by the Passaic Valley Sewerage Commission (PVSC) and constructed approximately 1925, crosses below the invert of the channel. Steel plates are placed over the sewer line for protection. Any further deepening to the Port Jersey Channel will have to consider the impact it might have on the sewer line.

2.1.4. Kill Van Kull Channel

The Kill Van Kull (KVK) is a tidal straight between Staten Island, NY to the south and Bayonne, NJ to the north. It is approximately 5.3 miles long and links shipping operations between the Anchorage Channel to the east and Newark Bay to the west. The Bayonne Bridge crosses the channel at the western end, which was raised in 2017 to 215 feet above mean high water at midspan to accommodate the vertical clearance of the New Panamax class of ship. Ultra-Large Container

Vessels (ULCVs) typically sail at a speed of approximately 4 to 5 knots through the Kill Van Kull. The channel varies in width from approximately 800 feet at its most narrow to approximately 2000 feet at its widest, at its confluence with the Anchorage Channel. The channel centerline has a total of 18 bends ranging in deflection from less than 1º to approximately 34º. This greatest deflection comes just after passing under the Bayonne Bridge, from east to west, beyond which a ship must begin a 120º turn around Bergen Point at the confluence of the Kill Van Kull and Newark Bay Channels. The Kill Van Kull is currently maintained to a depth of 50 feet below MLLW.

2.1.5. Newark Bay Channels (Main Channel, South Elizabeth Channel & Port Elizabeth Channel

The Newark Bay Channels are comprised of the Main Channel and several port access channels. The Main Channel is divided into three reaches – the South, Middle and North reaches. The port access channels include the South Elizabeth Channel, the Port Newark Pierhead Channel, the Port Elizabeth Channel and the Port Newark Channel. The Port Newark Channel is not included as part of this channel improvements study.

Together, these channels service more than 60 berths at the Port Newark/ Port Elizabeth on the west shore of Newark Bay. The Main Channel varies in width from approximately 2360 feet at the Bergen Point bend down to approximately 800 feet just north of the Port Elizabeth Channel. The Bergen Point bend is also used as a turning basin for containerships backing out of the Arthur Kill. The access channels vary in width from approximately 500 feet at the South Elizabeth Channel and at the western end of the Port Elizabeth Channel, to approximately 750 feet at the eastern end of the Port Elizabeth Channel. Traffic in the main channel is two-way except for the Bergen Point bend; access channels are limited to one-way traffic. The Newark Bay Main Channel, South Elizabeth Channel and Port Elizabeth Channel are maintained to a depth of 50 feet below MLLW.

2.1.6. Arthur Kill Channel

The Arthur Kill is a 13.2 mile channel that separates Staten Island, NY from Union and Middlesex Counties, NJ. The reach under consideration for this study extends from its confluence with the Kill Van Kull and Newark Bay Channels to a distance 2.4 miles west to the GCT-New York Marine Terminal, formerly called the Howland Hook Marine Terminal. The existing channel, with a depth of 50 feet, varies in width from 500 to 600 feet. Containerships bound for GCT-New York will either turn at Bergen Point and back down the Arthur Kill to the GCT-New York terminal, or back out of port, turn at Bergen Point and proceed outbound through Kill Van Kull.

2.2. Physical Conditions of NY & NJ Harbor

2.2.1. Climate

The Upper Bay of the New York/New Jersey Harbor (NYNJH) system is approximately 18.6 square miles and is considered humid subtropical, with cold winters and hot, moist summers. The daytime temperatures generally stay above freezing but average lows drop to 27°F. Snow is common in winter with varied amounts and winter rain is also common. Spring is pleasantly warm and the temperature rises to around 77°F by mid-May. Summers are generally hot and humid, with average highs around 84°F. Autumn in the area has mild temperatures and low humidity and are generally sunny. The average maximum temperature during the summer months (June to August) since the year 2000 is 79.8°F. The average minimum temperature during the summer months is 72°F. The average maximum temperature during the winter months (December to March) is 45.6°F. The average minimum temperature during these winter months is 28.8°F.

2.2.2. Tides

The tides in New York Harbor are semi-diurnal with a period of approximately 12.4 hours. In each tidal day of 24.8 hours, two high tides and two low tides occur, with one of the high tides higher than the other. Tidal datums at NOAA Stations The Battery, NY (Station ID 8518750) and Sandy Hook, NJ (Station ID 8531680) are provided in Table 1. Each of these NOAA tide stations are referenced in this appendix. The mean tide range at The Battery is 4.53 feet; the great diurnal tide range is 5.06 feet. The highest observed tide at The Battery was 11.27 feet NAVD88 during Hurricane Sandy on 30 October 2012. The lowest observed tide level was -7.06 feet NAVD88, occurring on 02 February 1976. The mean tide range at Sandy Hook, NJ is 4.70 feet; the great diurnal tide range is 5.23 feet. The highest observed tide at Sandy Hook, NJ was 7.27 feet NAVD88 during Hurricane Donna on 12 September 2012. The lowest observed tide level was -7.53 feet NAVD88, occurring on 02 February 1976.

Table 1. Tidal Datums, 1982-2001 Epoch

Datum	The Battery, NY (ft, NAVD88)(Station ID 851870)	Sandy Hook, NJ (ft, NAVD88) (Station ID 851870)
MHHW	2.28	2.41
MHW	1.96	2.08
MTL	-0.30	-0.27
MLW	-2.57	-2.62
MLLW	-2.77	-2.84
Mean Tide Range	4.53	4.70
Great Diurnal Range	5.05	5.25

2.2.3. Currents

Tidal currents in NY & NJ Harbor are moderate, with flood currents ranging from 0.6 to 2.2 knots, and ebb currents ranging from -1.1 to -2.1 knots. At the Narrows, ebb currents are typically stronger than flood currents, with a maximum ebb of 2.0 knots. At Bergen Point, flood currents are typically stronger than ebb, with maximum flood currents coinciding with spring tide. High water slack tide at the Narrows occurs approximately 1.5 hours after high water at the Battery; high water slack tide at Bergen Point occurs approximately 1 hour before high tide at the Battery. Publicly available data, collected from June and July 2019, was downloaded from the NOAA website and are provided in Table 2. Locations for where this data was collected is provided in Figure 2.

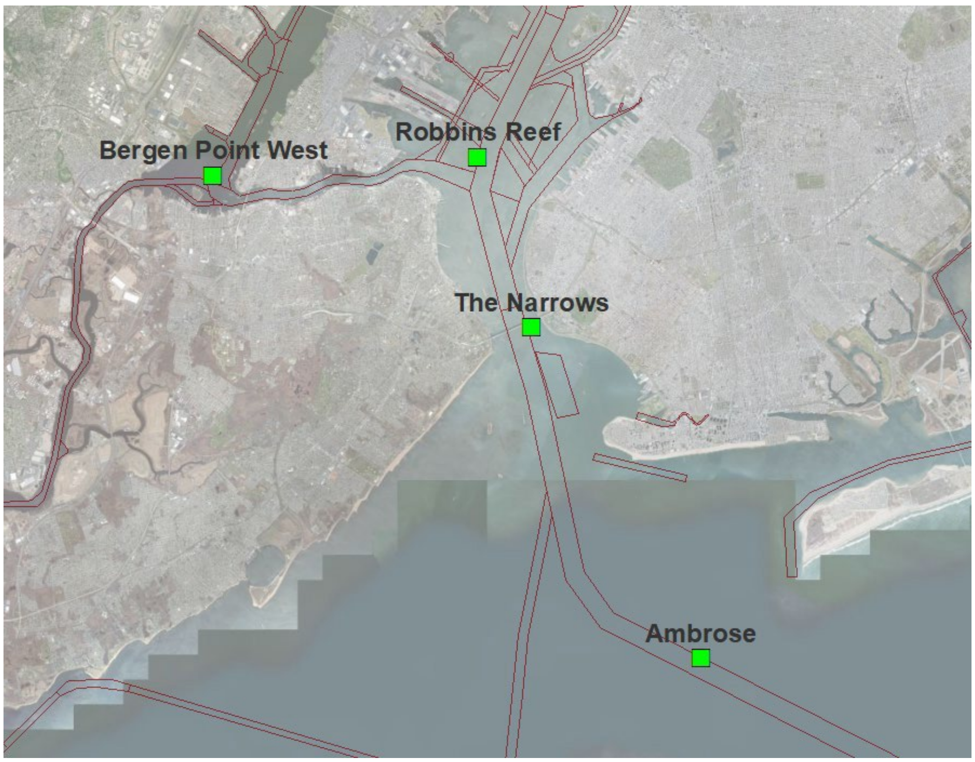

Figure 2. NOAA Current Data Locations

Table 2. Ebb and Flood currents throughout NY & NJ Harbor

Location	Average Ebb (knots)	Average Flood (Knots)
Ambrose Channel	-1.68	1.54
Robbins Reef	-1.58	1.28
Bergen Point West Reach	-1.49	1.84
The Narrows	-2.00	1.31

2.2.4. Wind & Wave Climate

The wave climate in NY & NJ Harbor is comprised of a mixture of swell waves that propagate from the New York Bight and locally generated sea waves generated by local wind conditions. The closest USACE Wave Information Studies (WIS) to the NY & NJ Harbor is station (ID: 63126) (Figure 3). The wave rose for this location is described in Figure 4 and the wind rose in Figure 5. This station experiences wind from every direction with greater speed from the west and is impacted by waves coming from primarily the Southeast direction in the Atlantic Ocean.

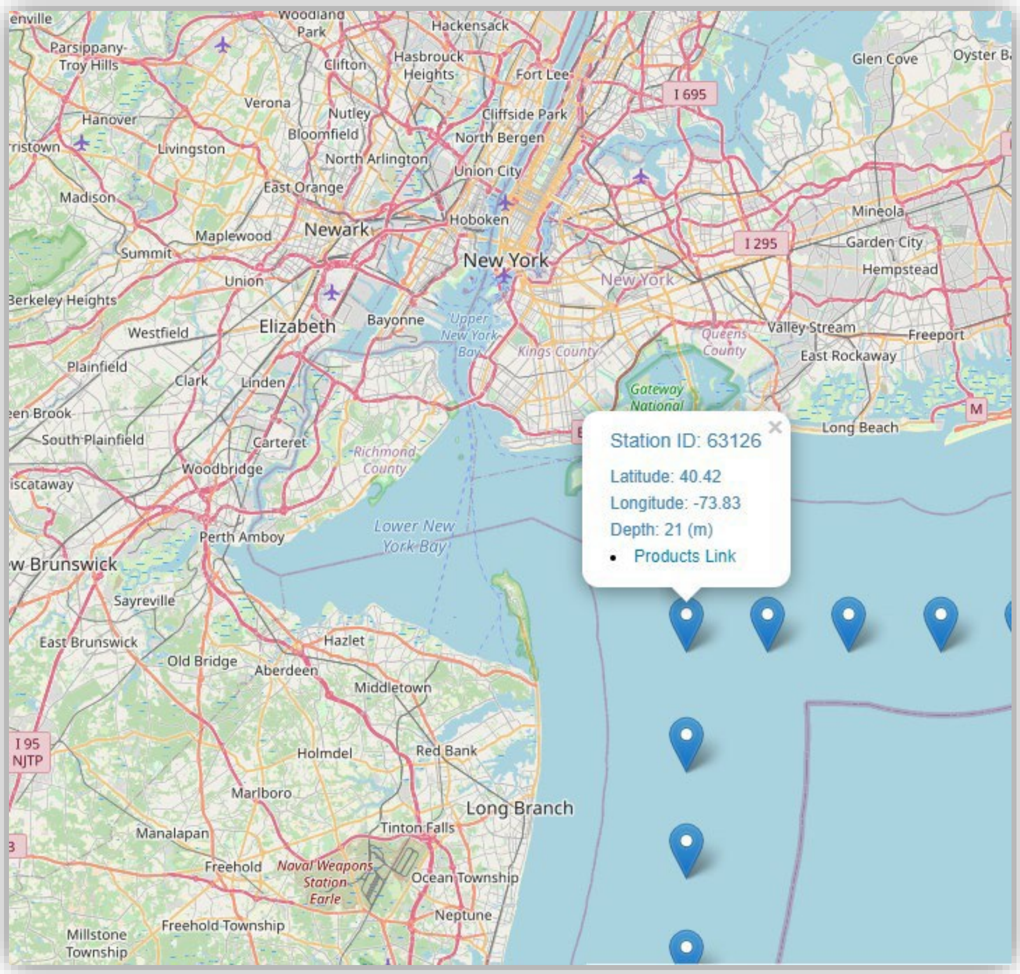

Figure 3. *Location of WIS Station ID 63126*

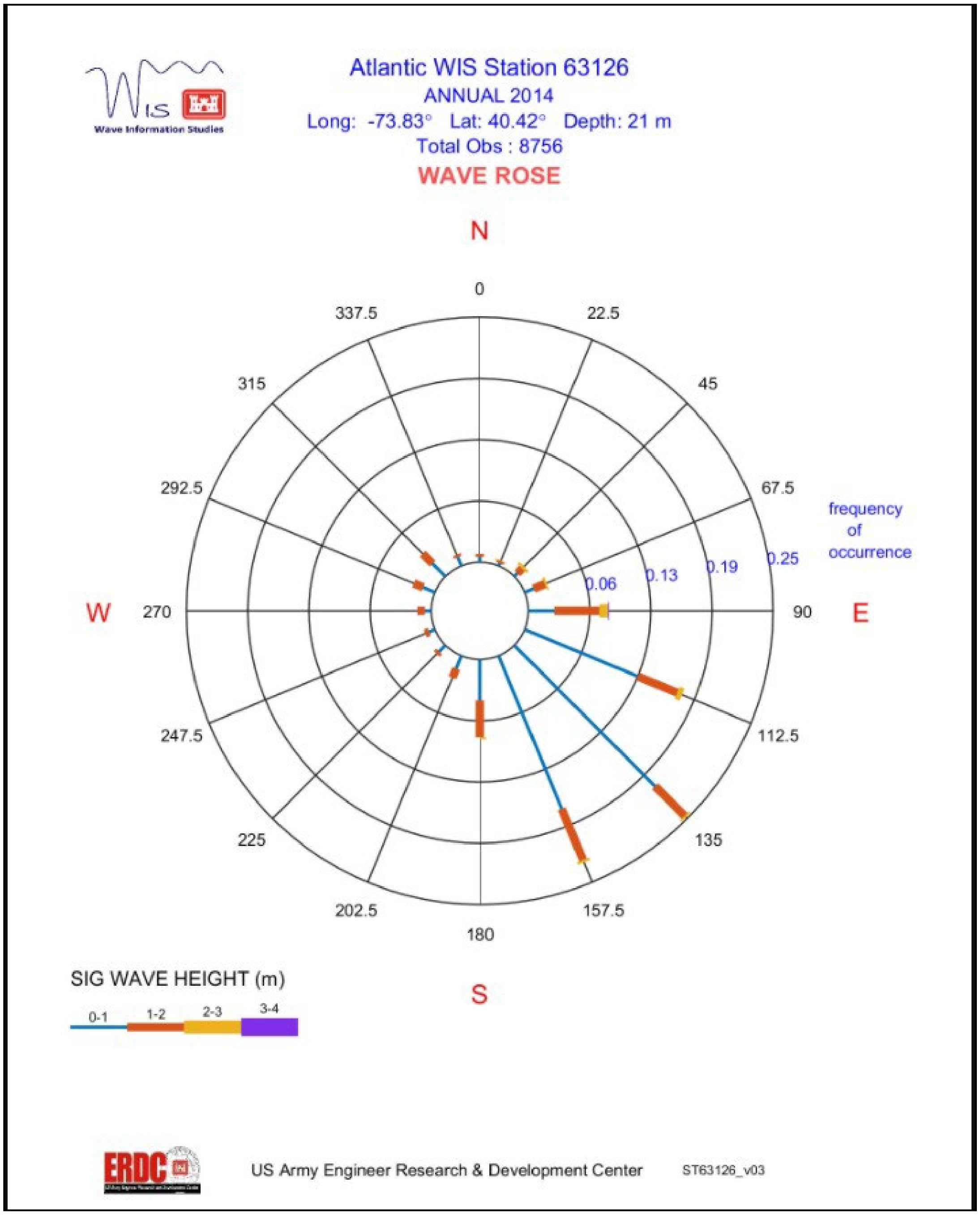

Figure 4. Wave Rose Created by the USACE Wave Information Studies (WIS), Station ID 63126

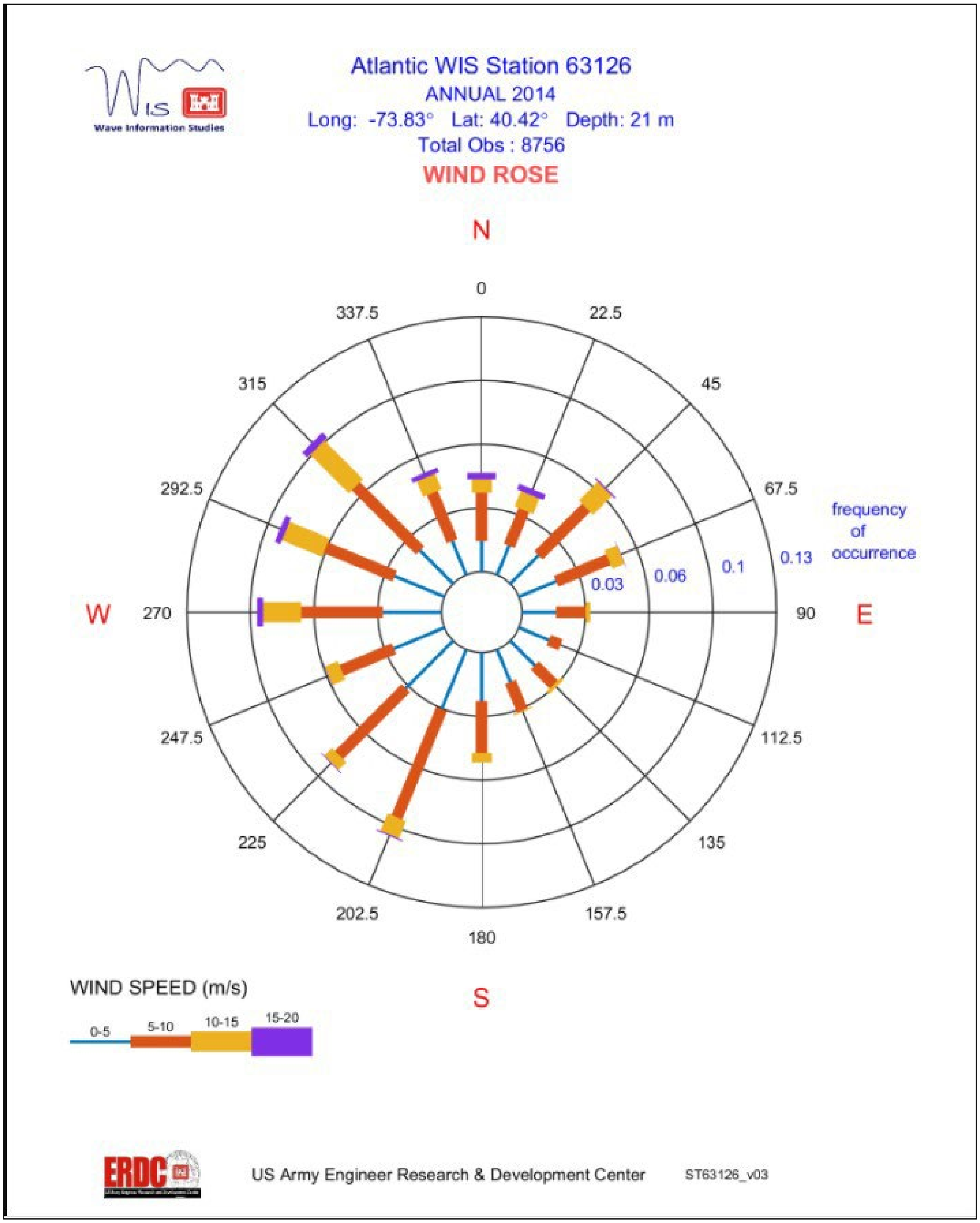

Figure 5. Wind rose Created by the USACE Wave Information Studies (WIS), Station ID 63126

A wave hindcast and wave transformation study of the waves in the Lower New York Bay area was performed by the Coastal Engineering Research Center (CERC) in support of the Dredged Material Management Plan for New York Harbor ((CERC), 1988). A summary of the nearshore wave characteristics for this study are presented below in Table 3.

Table 3. Lower New York Bay Nearshore Wave Conditions

Flood Event	Peak Wave Period [s]	Sig. Wave Height [ft.]
50%	5.4	5.8
20%	8.3	6.5
10%	9.7	7.1
4%	11.3	7.5
2%	12.3	7.9
1%	13.2	8.5
0.5%	14.5	9.0
0.2%	16.0	9.7

The Stevens Institute of Technology, on behalf of the State of New Jersey, conducted an eight-day field data collection effort in waves within the New York Harbor in 2002. Two gauges were installed near the NY Waterways Lincoln Ferry Terminal, NJ in Newark Bay (Figure 6) to obtain time series pressure records that provided a description of wave heights and wave periods found in Newark Bay. This data collection location is approximately six miles north of the HDCI study area. The data indicates a strong diurnal pattern of relatively calm overnight periods followed by very energetic periods. The highest waves in the day occur at two peak periods, corresponding to the commuter ferry morning and evening rush hours. Overnight maximum wave heights ranged from 4 to 6 inches. Peak heights were typically 12 to 16 inches. A time history of water surface elevations is presented in Figure 7.

Figure 6. Stevens Institute, Wave Data Collection Location, June 2002

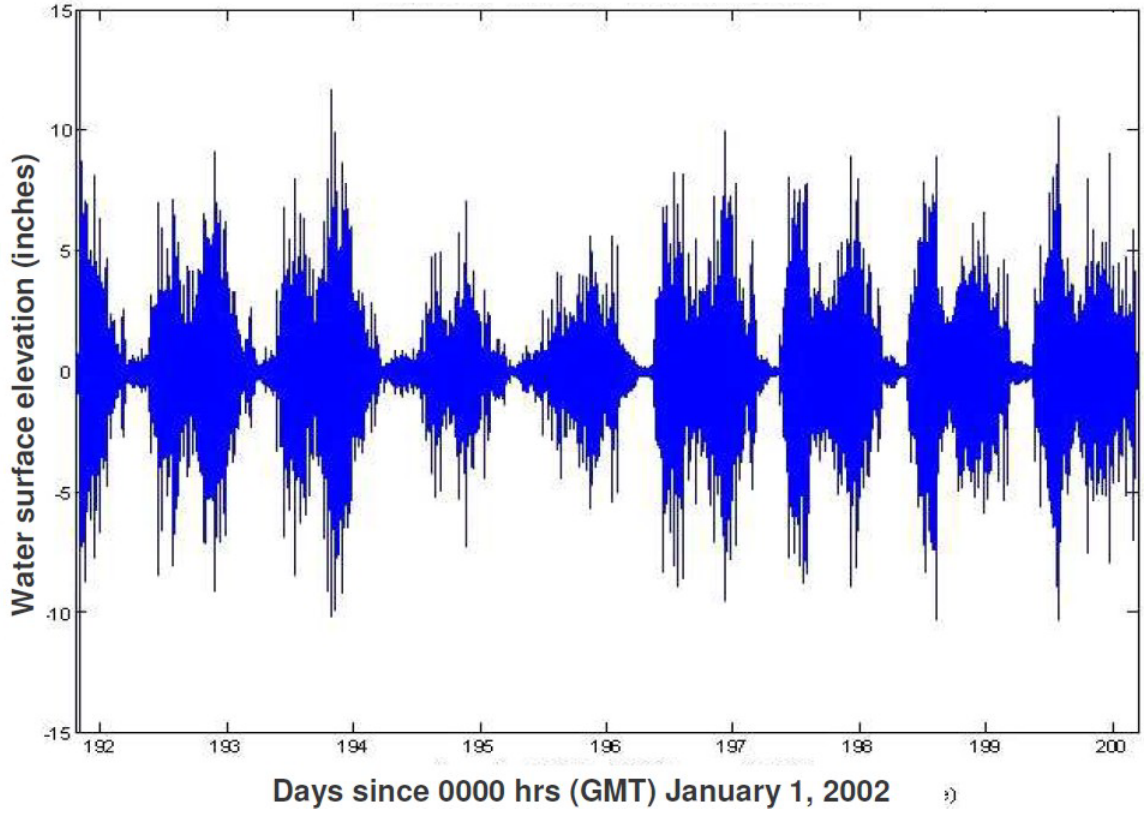

Figure 7. Time History of Water Surface Elevation 8-Day Time Span.

A histogram of wave period occurrences is provided in Figure 8. Overnight times are dominated by a wave period of 1 to 2 seconds and daytime is dominated by a wave period of 2 to 3 seconds. It is noted that boat wakes can be a source of channel side slope instability (as well as bank erosion) and that this may concern may warrant further investigation

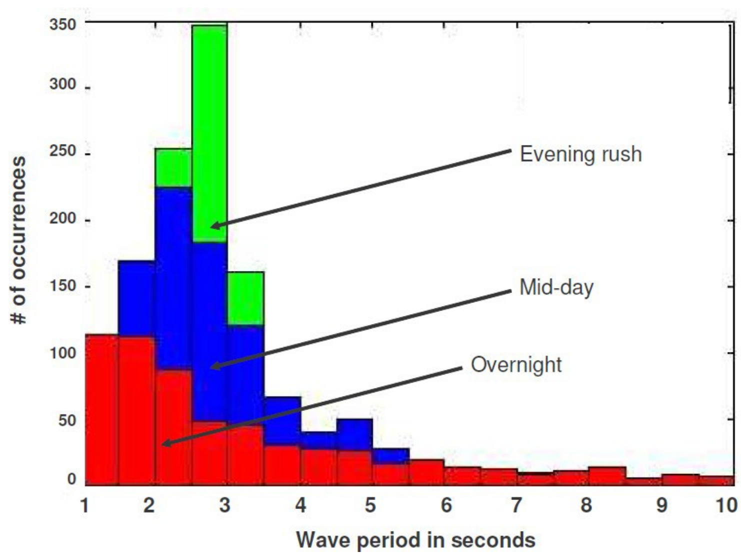

Figure 8. Histogram of Wave Period Occurrences for 8-Day Time Span

2.2.5. Geology

The project area is located near the confluence of the Manhattan Prong of the New England Uplift, the Newark Basin (Triassic Lowland) Physiographic Province, and the Atlantic Coastal Plain Physiographic Province. The stratigraphy can be divided into three major units: bedrock primarily formed during the Cambrian and Ordovician periods, Pleistocene (glacial) sediments, and Holocene sediments. Bedrock under NY & NJ Harbor south of the Kill Van Kull channel is generally buried under more than 100 feet of sediments. This bedrock is believed to consist primarily of Manhattan Schist and the Hartland Formation. The Hartland Formation consists of well-layered schist, gneiss, and amphibolite with pegmatite intrusions. The Manhattan Schist is a medium-to-dark gray, medium-to-coarse grained schist and gneiss composed primarily of biotite, muscovite, quartz, and plagioclase with local amphibolite layers. With a limited number of deep soil borings within the harbor, the locations of bedrock contacts is uncertain.

Pleistocene glacial sediments overlie the bedrock complex. During the Pleistocene epoch the area was affected by the last major glaciation (Wisconsin), which caused the erosion of rock and the deposition of glacial sediments, including lacustrian silt and clays, fluvial sands and silts, and till. The glacial sediments lay above the bedrock and are approximately 100 to 200 feet thick. The sediments range in size from microscopic clay particles to large boulders or erratics. Pleistocene sediments are normally red to brown, rarely contain shells, and are relatively dense. A layer of recent Holocene sediments has been deposited. These sediments include poorly graded sand, silty sand, slightly organic silt, and peat. The thickness of the Holocene sediments ranges from a few feet to a few hundred feet. The Holocene sediments are predominantly fine-grained silt and clay inside (north) of the Verrazano Narrows Bridge and predominantly sand-sized outside (south) of the bridge. Holocene sediments are normally gray to black and frequently contain shells. For a more detailed description of the geology in the study area, please refer to the Geotechnical Appendix, B2.

2.2.6. Sedimentation

Sedimentation and sediment transport within the New York and New Jersey Harbor is characterized by its complexity and is influenced by a host of hydrodynamic factors such as flow pathways in the system, baroclinic circulation patterns and wind driven circulation patterns. The system has areas of both cohesive (Newark Bay and portions of Upper Bay) and noncohesive (Lower Bay and portions of Upper Bay) sediment transport.

Completed in 2020, the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL) conducted a modeling study, primarily motivated by the observation that "the variability in the annual rate of dredging estimates over the differing periods and channel depths suggest that natural variability due to different river flows and meteorological conditions is more significant than the navigation channel depth." Much of the following information is taken from the study, New York/New Jersey Harbor Sedimentation Study Numerical Modeling of Hydrodynamics and Sediment Transport (McAlpin, et al. 2020) (Attachment 4).

The Hudson River is essentially a sediment storage feature that provides a temporal delay in the delivery of upper basin sediment to the estuary. Geyer et al (2001) reported that the greatest export of sediment from the Hudson River to the estuary occurs when peak river discharges coincide with spring tides. During neap tides, the sediment gets trapped within the river. Ralston and Geyer (2009) proposed that the greatest export of river sediment occurs at moderate flows, while at extreme flows the sediment delivery overwhelms the capacity of the river to transport and gets trapped. Wall, et al (2008) suggested that the tributaries downstream of Troy supply as much as 30-40 percent of the sediment supply to the estuary.

The sedimentation environment of Newark Bay has been of particular interest over that past four decades because of the presence of contaminated sediments within the lower Passaic River and Newark bay. Suszkowski (1978) did the first comprehensive analysis of the hydrodynamic and sedimentation environment of Newark Bay. Chant et al (2010) studied the sedimentation environment of the Passaic River. They found that the Passaic River has been depositional over the past 60 years but is approaching geomorphological equilibrium to the predredging conditions. Although the net tidal sediment flux is upstream into the Passaic River from Newark Bay under normal tidal conditions, when salinity driven circulation is evident, episodic river flooding dominates the overall net flux with downstream transport. The result is a net sediment flux from the Passaic River into Newark Bay.

The primary sediment source for Newark Bay is from Upper Bay through Kill van Kull (Chant, 2006; Sommerfield and Chant, 2010); around 100,000 tons per year. The Passaic and Hackensack Rivers supply approximately 17,000 and 5,000 tons per year, respectively.

Shrestha et al (2014) developed a conceptual model of the hydrodynamics and sediment transport regime in Newark Bay. They concluded:

- In the absence of strong wind forcing or large tidal gradients, the Navigation Channel displays classic estuarine, gravitational, two-layer circulation with a seaward surface flow of freshwater and a landward bottom flow of salt water. Without freshwater or atmospheric forcing, landward flow in the channels is balanced by seaward flow in the shallow tidal flats.
- A counterclockwise residual circulation is most often observed around Staten Island, although this can reverse depending on the tidal and atmospheric forcing.
- Low freshwater inputs or episodic wind and storm events can break down the classic estuarine circulation pattern generally observed in the Bay. The primary source of imported sediment to Newark Bay is the Kill van Kull, which may supply up to 140,000 metric tons per year.
- By comparison, the Passaic and Hackensack Rivers supply about an order of magnitude less sediment than the Kill van Kull, despite being the largest freshwater sources.
- Under the existing dredged configuration, most of the sediment originating from the Kill van Kull is deposited within the southern half of the Bay; most of the sediment originating from the Passaic River is deposited within the northern half of the Bay.
- Long-term average sedimentation in Newark Bay, particularly within the dredged channels, is offset by rates of maintenance dredging.
- The subtidal flats have low deposition rates and appear to be in long-term equilibrium.

- The extensive history of dredging and shoreline development that have taken place in the Newark Bay Study Area have resulted in changing historical circulation and sediment transport patterns. Historical transport patterns are likely quite different from current transport patterns.

The primary source of sediment for the inner Harbor is the Hudson River; the primary sediment source for Ambrose Channel are littoral beach sands. Sedimentation within Ambrose Channel is caused primarily by offshore wave energy that produces the westward littoral transport of sand along the south shore of Long Island as well as the northward littoral transport along the New Jersey shore and Sandy Hook. This wave energy also results in the movement of sand across the East Bank Shoal on the east side of Ambrose Channel and Romer Shoal southwest of Ambrose Channel, which deposits into Ambrose Channel. Since 1984, sand mining within or adjacent to Ambrose Channel has eliminated the need for maintenance dredging. The US Army Corps of Engineers permits up to 2,000,000 cy/year of sand mining south of the Transco Pipeline and another permit for the mining of up to 2,000,000 cy/year north of the Transco Pipeline is currently

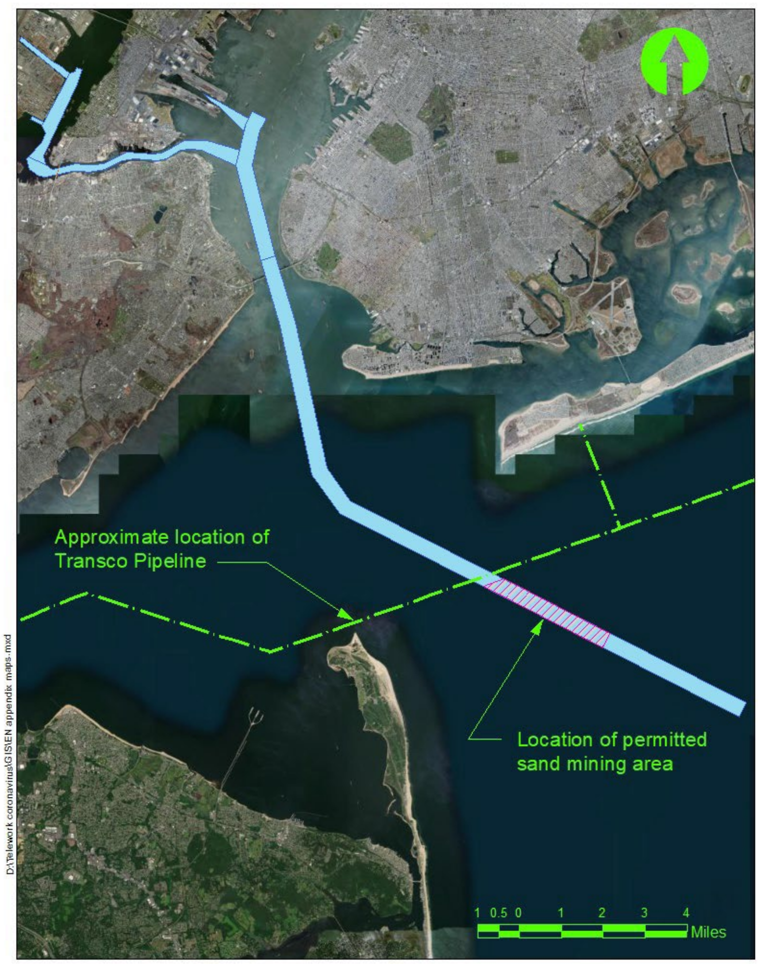

Figure 9. Transco Pipeline and Sand Mining Permit Location.

under consideration (Figure 9). A recent hydrographic survey, compiled by soundings taken between June 2020 and January 2021, shows that approximately 124,692 cubic yards of sand were mined during the most recent dredging operation.

Average annual dredging volumes were evaluated and summarized by e4sciences, under contract with CENAN (e4sciences, 2018) and are presented in McAlpin et al (2020). These data, average annual dredging volumes for the New York and New Jersey Harbor channels are presented in Table 4. The data provided included estimates of dredging for the following periods:

1. Pre-1999 dredging volumes and annual rates
2. 1999 – 2007 dredging volumes and annual rates
3. Post-2007 dredging volumes and annual rates

The pre-1999 volumes were taken from the New York and New Jersey Harbor Deepening re-evaluation report (USACE, 2004). The dredging volumes for the 1999 to 2007 period were reported with a low and a high range of annual dredging volumes based on the uncertainty in the dredging records for the duration of time between dredging activities. This data was compiled for the previous Harbor deepening project. The end year of the presented post-2007 volumes is not known and is assumed to be 2015. The post-2007 dredging volumes (columns 4 and 5 of Table 4) are shown as those volumes that were reported purely as maintenance dredging.. However, a portion of the dredging reported as "new-work" (as opposed to maintenance dredging) included material that required special upland disposal as it was unacceptable for open water disposal at the Historic Area Remediation site (HARS) placement site. These volumes could be assumed to be the result of recent deposition and are therefore considered to be a component of the maintenance volumes. These "non-HARS" volumes are included in the ranges presented in columns 6 and 7 of Table 4 (Post 2007+ non-HARS). The HARS placement site has an area of approximately 21 square and is located approximately 4 miles offshore from the Sandy Hook, NJ peninsula. (Figure 10).

The impacts on maintenance dredging for the prior deepening project are discussed in detail in McAlpin, et al, 2020 (Attachment 4). This study concluded that the prior deepening effort resulted in a 4% increase in maintenance dredging for the general HDCI footprint and a 1% increase when the navigation channels of New York and New Jersey Harbor are considered as a whole. The impact on future maintenance dredging of the deepening proposed in this study has not yet been considered in-depth and warrants further investigation in the PED phase of this study. As an initial estimate, it is, however, reasonable to infer that the impacts of the proposed deepening will be somewhat similar to the HDP project. The widenings proposed here are expected to have a greater impact. An initial estimate of the added maintenance required due to these proposed widenings is presented in section 7.3, based on sedimentation rates derived from McAlpin et al (2020).

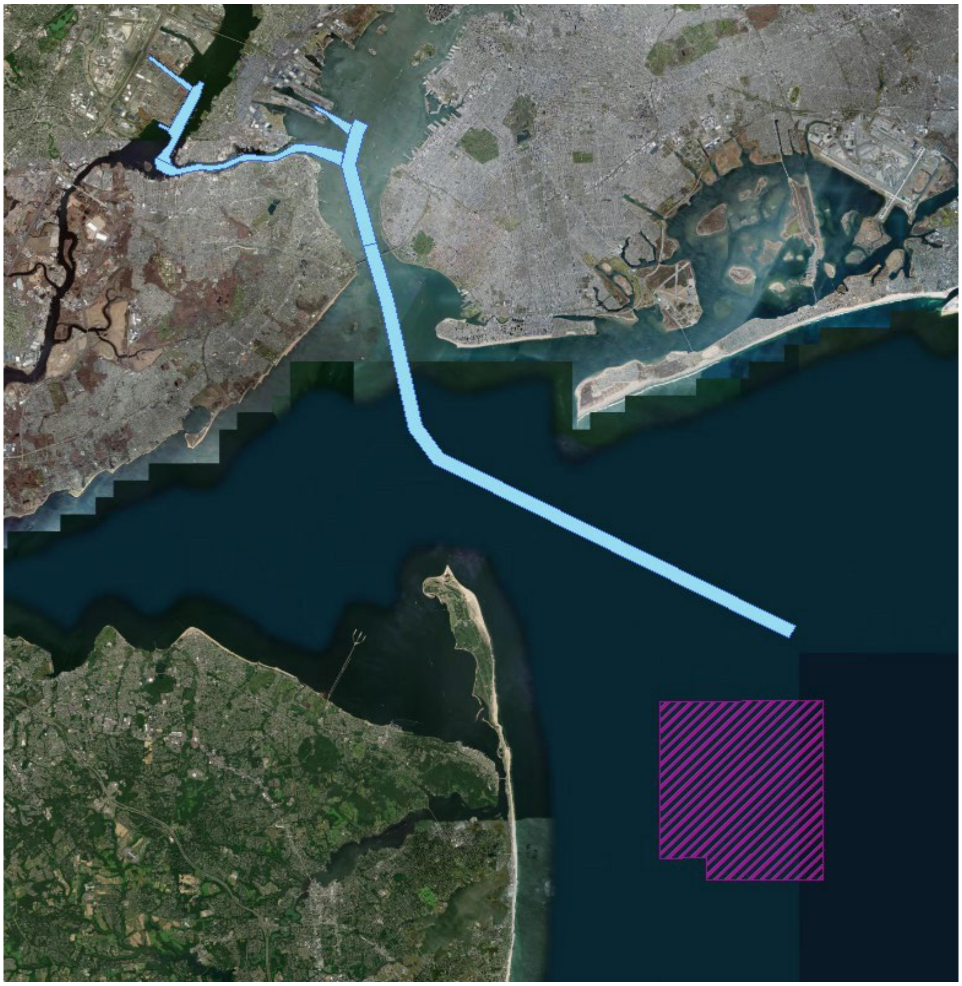

Figure 10. HARS Placement Site

Table 4. Annual Dredging Volumes (cy)

Channel	Pre-1999	1999-2007		Post 2007 (HARS Only)		Post 2007+ non-HARS (HARS + non-HARS)	
		Low range	High range	Low range	High range	Low range	High range
Ambrose	400,000	0	0	57,175	133,408	134,209	313,153
Anchorage		0	0	12,565	29,317	186,623	435,454
KVK Constable Hook	28,000	0	0	11,710	27,324	11,710	27,324
KVK Bergen Point	4,000	10,228	11,710	11,710	27,324	11,710	27,324
Newark Bay (NB) Main	211,000	65,812	92,137	0	0	160,528	374,566
NB Port Elizabeth	121,700	48,269	64,358	18,441	43,029	63,545	148,271
NB Port Newark	226,200			14,780	34,487	14,780	34,487
Port Jersey	58,000	112,089	160,220	11,368	26,525	106,299	248,031

3. Design Vessel

The design vessel is based upon economic projections of the vessels most likely to call on the ports of New York and New Jersey in the near future. The design vessel chosen for this study is Maersk Triple E class, which is in the Ultra Large Container Vessel (ULCV) class of ship. It has a minimum capacity of 14,501 TEUs and a length of 1,200 feet or longer. The dimensions of the design ship for this study are shown in Table 5 below.

Table 5. Maersk Triple-E Design Ship Dimensions

Vessel	**Maersk Triple-E container ship**
Capacity (TEU)	18,000
Length Over All (LOA)	1,309 feet
Beam	193.5 feet
Load Draft	52.5 feet

These dimensions were taken from a ship simulation study conducted at the Maritime Institute for Technology and Graduate Studies (MITAGS) in August 2016 on behalf of PANYNJ. In this study, a load draft of 49 feet was used; however, for the purpose of the Corps' channel improvements study, a design draft of 52.5 feet was used. This accounts for the anticipated evolution of the size of ships expected to call on the ports of NY & NJ Harbor over the next 20 years.

3.1. MITAGS Study (2016)

After the completion of the 50-foot deepening of the channels within the ports of New York and New Jersey, the PANYNJ and the Deep Draft Working Group of the Harbor Operations Committee commissioned a ship simulations study to help develop best practices for ULCVs to transit to the major ports within the harbor. This study was conducted on behalf of the PANYNJ at the MITAGS facility in Linthicum Heights, Maryland from 23 to 26 August 2016. Participants in the study included pilots from the Sandy Hook Pilots Association and docking and tug pilots from Moran Towing Corporation and McAllister Towing and Transportation Company.

Ships modeled for this study included the 14,000 TEU MSC Kalina and the 18,000 TEU Maersk Triple-E. The study included 27 different modeling runs with the goal of safely and consistently bring these ships into the berths at PJPAMT and EPAMT. The MITAGS study does not of course consider the improved conditions proposed here. It was, nonetheless, determined to be an appropriate preliminary reference for this early phase of this study. The needed for Ship Navigation Modeling for this study is discussed on further detail in Section 9.6

General results from the 2016 MITAGS ship simulation study are found in Table 6 below. The complete MITAGS study is provided as Attachment 5 to this appendix.

Table 6. General Results Summary of 2016 MITAGS Ship Simulation Study

18K TEU making turn at Constable Hook into the Kill Van Kull and around Bergen Point
No more than 20 knot wind
Traverse no more than approximately one hour on either side of slack water at Bergen Point
Meeting other vessels in Kill Van Kull not recommended
No meeting or overtaking except for very light boats
18K TEU ship entering Port Elizabeth
Difficult to maneuver an 18K TEU ship between two 18K TEU ships berthed on either side of channel
Should not back out between two 18K TEU ships berthed on either side of channel
18K TEU ship entering Global Terminal (Port Jersey)
Can have only one ship berthed either at Port Authority Auto Marine Terminal to north or cruise terminal to south
Can bring ship to port during slack water only
Can have no more than 20 knot wind when trying to bring in 18K TEU ship
Cruise ship passengers should not be on gangway when 18K TEU ship enters Port Jersey
General comments
Experience should first be gained with smaller ships (14K TEU) and gradually introduce 18K TEUs into port
Concerns about room for tugs to maneuver when ships on both sides of channel (Port Elizabeth)
Larger ships should avoid meeting traffic in Kill Van Kull
In some respects, 18K TEU handled better than the 14K TEU
Should not put two 18K TEUs across from each other in Port Elizabeth
18K TEU handles well for a ship of its size but load upfront obstructs pilots' view, making navigating by instruments critical
Large underwater volume displacement of these vessels my cause large surge forces on moored vessels in the confined channels like Port Jersey or Port Elizabeth. Keeping speed in check is important. Further modeling required to determine safe speed.

4. Channel Design

Numerous coordination meetings were held with the various pilot organizations (Sandy Hook Pilots, harbor pilots, docking pilots, and other stakeholders), the US Coast Guard, and local interest groups to ensure that the proposed channel improvements would provide adequate navigability for the design ship while meeting the needs of the port facilities and the maritime community. The following sections discuss a number of channel design parameters. Most of this information is based on prior studies and analyses, in keeping with Civil Works Transformation guidelines. A focused discussion of future study needs is provided in Section 9, “Further Analysis and Design Development.”

4.1. Channel Width

The channel width for an outer harbor channel such as Ambrose Channel, which is exposed to open water, is based upon guidance contained in PIANC PTC II-30. The guidance takes into account factors such as ship speed, prevailing cross winds, both cross- and longitudinal currents, significant wave height, aids to navigation, bottom surface, depth to draft ratio, cargo hazard level, bank conditions and traffic density. The previous study indicated that the existing 2000-foot width was adequate based on input from pilots and track plots from ship modeling studies. No additional widening is recommended for the Ambrose Channel for this current study.

The width of the proposed interior channels was designed in accordance with guidance contained in EM 1110-2-1613. This guidance is based upon factors such as traffic pattern (one way or two way), design vessel dimensions, channel cross section shape, current speed and direction, quality of aids to navigation and variability of channel and currents. For one-way channels, widths can vary from 2.5 times the vessel beam for a well-defined channel with minimal currents to 5.5 times the vessel beam for a variable channel with stronger currents. Two-way channels can vary from 4 to 8 times the vessel beam.

The 2016 MITAGS study indicated that the design ship is able to navigate the harbor channels in their existing condition, but with difficulty due to strong wind and tide currents at certain locations. As mentioned previously, the Kill Van Kull has 18 bends within a distance of about 5.3 miles, or on average, approximately one bend per every 1/3-mile. Given the fact that the design ship is approximately ¼-mile long, it must constantly adjust its bearing - to include crossing over the centerline - and leave enough space for one or more pilot boats to assist alongside it. Much of the Kill Van Kull is between 800 feet and 1000 feet wide, making this channel especially challenging for UCLV ships to navigate. In collaboration with harbor pilots, several locations of channel widenings within the Kill Van Kull Channel (KVK-1 and KVK-3 through KVK-5) were identified to increase the overall navigability of the design ship within this highly constrained channel. Although close attention was paid to the guidance of EM 1110-2-1613, equal weight was given to accommodating the needs of the pilots. For the most part, this study merely made adjustments to the channel designs of the previous deepening study. Further widenings, of larger scale and introduced to address a specific navigation need of the design ship were also considered. These widenings are further discussed in Section 5. With the exception of Newark Bay Channel, no modifications were made to any other channel centerline.

4.2. Channel Depth and Underkeel Clearance

The maximum channel depth is designed to permit the safe and efficient transit of a fully loaded design vessel at any phase of the tide. The determination of the navigation channel depth is based upon the loaded static summer saltwater draft of the design vessel, plus allowances for various underkeel clearances such as ship squat, water density, ship response to waves, and safety clearance. The selection of the actual project design depth is determined by economic analysis of the expected project benefits compared with the project cost at various alternative depths. Refer to the economic appendix for details of the optimization analyses.

4.2.1. Squat

Squat is the tendency of a vessel underway to sink and trim in the waterway, thereby reducing the underkeel clearance. The sinkage is due to the reduction in pressure on the ship's hull resulting from the increased water velocity passing the ship. In a shallow or confined channel, squat tends to increase because the blockage caused by the ship creates a higher water velocity around the hull, lowering the actual water surface. Another component of squat is dynamic trim, or the change in pitch of a vessel due to the forward motion. Generally, it has been found that most full-bodied ships such as tankers and bulk carriers trim down at the bow, and sleeker containerships trim down at the stern. The magnitude of the squat depends on several factors including ship speed, dimensions, ship blockage coefficient, and channel depth.

4.2.2. Ship Motion

The ship response from waves can be an important factor in the design of navigation channels. The ship motion from waves is more pronounced in entrance or bar channels which tend to be exposed to ocean waves, than it is in interior channels where wave energy is limited.

There are six types of ship motion – 3 vertical and 3 horizontal. *Only the vertical ship motions* have an effect on the underkeel clearance (Figure 11).

The 3 modes of vertical motion include:

- roll (rotation about the longitudinal axis) and
- heave (vertical displacement).
- pitch (rotation about the transverse axis),

The 3 modes of horizontal motion include:

- surge (back and forth along the longitudinal axis),
- yaw (rotation about the vertical axis), and
- sway (to and fro along the transverse axis).

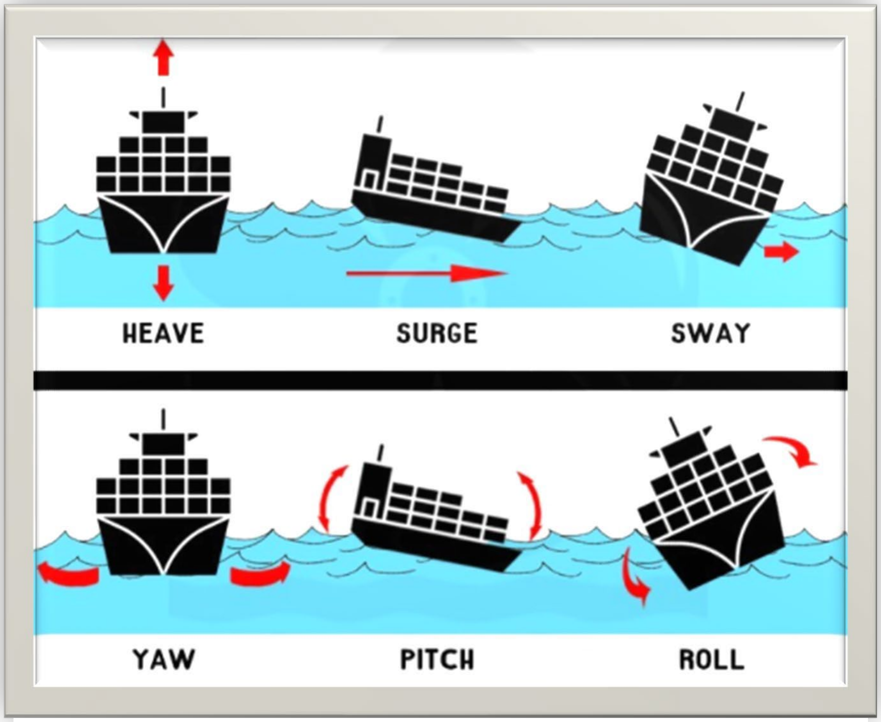

Figure 11. Types of Vertical and Horizontal Ship Motion (Credit: Thomas Smith Shipping)

4.2.2.1. Ship Motion Study

A vertical ship motion study (USACE 2011) was conducted at the USACE Waterways Experimentation Station (WES) during the previous deepening study to determine the total underkeel clearance required for the design vessels in Ambrose Channel. The study included wave modeling in the NY Bight and Lower Bay to determine incident wave conditions, a ship tracking study (utilizing DGPS receivers on board vessels inbound and outbound) to measure vertical ship motions, and a ship motion model to predict the vertical ship motion of vessels under various wave conditions.

The ship transits monitored in the ship tracking study were modeled using wave data obtained at the time of the ship transit and ship models that represented the type, size and draft of the vessels, in an attempt to reproduce the actual vertical motion of the ships in transit. Adjustment factors were determined based upon a comparison of the measured data from the tracking study and the computed data from the ship motion model. The ship motion model was then applied for design conditions, evaluating the design vessel (Susan Maersk container ship – See Table 7.) for both inbound and outbound transits, and normal as well as design (1 year) wave conditions. Although the fully loaded draft of the design ship in the 2011 vertical ship motion report was 47.5 ft, versus the current design draft of 52.5 ft, this is the best information we have during the feasibility phase of this current study.

Table 7: Susan Maersk Design Ship, from Vertical Ship Motion Study, ERDC/CHL TR-14-3

Length Overall (ft)	1138.4
Beam (ft)	140.4
Draft, Light-Loaded (ft)	46.0
Draft, Fully-Loaded (ft)	47.5

The results of the model study concluded that, for the design wave condition, the design container ship would require 7 feet of underkeel clearance. Details of the model study can be found in Draft Report “Entrance Channel Depth Design, Ambrose Channel, New York Harbor”. This same design depth was used for the current channel improvements study.

4.2.3. Salinity

No new salinity data were collected during this study; however, a sedimentation study (McAlpin et al, 2020) (Attachment 4) was performed for the New York/New Jersey Harbor (NYNJH) by the Coastal and Hydraulics Laboratory (CHL); an arm of the USACE Engineer Research and Development Center (ERDC) located in Vicksburg, Mississippi. Five simulation periods were evaluated in this study, beginning with the pre-deepened 45-foot channel in 1985 and ending with the deepened 50-foot channel in 2012. This report performed numerical modeling of hydrodynamics and sediment transport within the harbor as an effort to determine the impact of channel enlargements (width and depth) on dredging volumes.

Part of the study’s purpose was to create a numerical model to be available for future analysis of other projects, providing a way to evaluate modifications to the region in terms of hydrodynamics, salinity, and sediment transport. The results of this study show that the difference in salinity north of the Verrazano Narrows Bridge was minimal (+/- 1 part per thousand (ppt)) when excavating an additional 5 feet, from -45 feet to – 50 feet.

Seasonal salinity variations within the NY & NJ Harbor estuary are primarily a function of the variation in the freshwater discharges of the Hudson River (and Passaic and Hackensack Rivers to a lesser extent), with the lower salinity levels in the spring and summer correlating directly with the high spring runoff. In the Upper Bay, typical salinity concentrations of 25 - 28 ppt occur during low flow conditions and drop to 20 – 25 ppt during periods of higher freshwater discharges. The harbor can be considered well mixed with bottom levels slightly higher than surface concentrations. Salinity concentrations can vary by several ppt throughout the tidal cycle.

Salinity has an influence on the draft of a ship. New York Harbor is an estuary that sits at the confluence of the Hudson, Hackensack and Passaic Rivers, and the Atlantic Ocean. Ships calling on a port with fresh or brackish water will have a greater draft due to the decrease in salinity. The salinity of ocean water is approximately 33 ppt. When a vessel enters a port with brackish or fresh water, the draft of the vessel will increase in proportion to the decrease in water density. The decrease in unit weight of water, from 64.0 pounds per cubic foot (lb/cu ft) at 33 ppt to 62.4 lb/cu ft at 0 ppt, will increase the draft of a vessel by 2.6%.

4.2.4. Safety Clearance

A safety clearance is provided between the hull of the ship in transit and the design channel bottom to minimize the risk of damage to the vessel due to bottom irregularities and debris. The safety clearance also accounts for uncertainties such as tide stage, survey tolerances, etc. A safety clearance of 2 feet is provided for channels with a soft bottom; for channels consisting of rock or other hard material such as consolidated sand or clay, the safety clearance is increased to 4 feet. The additional 2 feet in safety clearance is required only for the initial construction of the navigation channel in hard material. In time, as the channel begins to shoal, a safety clearance of 2 feet will be maintained since the recently deposited material tends to be soft. Additionally, the US Coast Guard Vessel Traffic Service New York User's Manual, Revised September 2018, Appendix 7, Recommended Minimum Underkeel Clearance states "Minimum three feet under keel clearance in Ambrose Channel due to wave and sea action…"

4.2.5. Total Underkeel Clearance (UKC)

The depths proposed for the NY & NJ Harbor channels are + 5 feet from their current authorized depths, despite their deeper calculated depths. The safety of these depths will be confirmed during the PED phase, using the Channel Analysis and Design Evaluation Tool (CADET) modeling system. The total underkeel clearance (UKC) using in this study is presented below in Table 8.

Table 8. Total Underkeel Clearance for an Additional 5 Feet from Current Design Depth of 50 feet.

	Ambrose	**Anchorage**	**KVK**	**Newark Bay**	**Port Jersey**
Vessel Type	Maersk Triple E				
Capacity (TEU)	18,000 TEU				
Draft – Fully loaded (ft)	52.5 ft				
Squat (ft)	Ship Simulation Study	1.3	1.0	1.2	1.2
Wave Motion (ft)		0	0	0	0
Salinity (ft)		0.4	0.7	0.7	0.4
Safety Clearance (ft)		2	4	4	4
Total UKC (ft)	7	3.7	5.7	5.9	5.6
Req'd Channel Depth (ft, MLLW)	59.5	56.2	58.2	58.4	58.1
Design Channel Depth (ft, MLLW)	60	57	59	59	59
Proposed Channel Depth (+ 4ft, MLLW)	57	54	56	56	56
Proposed Channel Depth (+ 5ft, MLLW)	58	55	57	57	57

4.3 Ship Simulation Design Parameters

Discussed below are design parameters from the 2016 MITAGS ship simulation report. The actual parameters for this study will be developed during a later phase of the study in collaboration with the harbor pilots, docking pilots and developers of the ship simulation model.

4.3.1 Currents

It was determined that the controlling factor for currents was the transit around Bergen Point. In order for a UCLV to make the turn, the pilot would have to choose a window on either side of slack water when the currents were low. The large draft of the design ship means that the pilot could transit only during a window on either side of slack water high. For the ship simulation runs, the average high maximum current velocity was assumed to be 2.55 knots.

In order to determine which current files to use for the ship simulation model, the pilots ascertained that the changes in current velocity on either side of slack water could be represented by a percentage of the maximum current velocity during a particular tide cycle. The final result was that the most opportune time window for a UCLV to navigate around Bergen Point was between 1.5 hours before to 2.0 hours after slack water high if the current was 1.53 knots or less (approx. 60% of maximum current), and between 1.0 hour before and 1.0 hour after slack water high if the current was 1.09 knots or less (approx. 43% of maximum) (Table 9).

Table 9. Time windows that will allow transit of UCLV around Bergen Point (MITAGS study)

% Max flood current (2.55 knots)	Velocity (knots)	Time before slack water high (hours)	Time after slack water high (hours)
43%	1.53	1.5	2.0
60%	1.09	1.0	1.0

4.3.2 Wind

Wind direction and speeds were controlled by the ship simulation operator and were provided by the pilots. The most challenging combination of wind direction and speeds were tested; the maximum wind velocity tested was 30 mph

4.3.3 Waves

The MITAGS study included a supporting study in which a "target vessel" was moored at the Bayonne Terminal berths. The model calculated the theoretical forces that each vessel class would generate on the berthed vessel as it transited along the centerline of the Kill Van Kull at various speeds. It was determined that the Maersk Triple E (design ship) transiting at 4 knots generated the same wave forces as a 9,000 TEU ship transiting at 6 knots. Forces rapidly increased as the distance between the design ship and the berthed vessel decreased.

5. Channel Navigation Improvement Measures

5.1. Pathways and Reaches

Three “Pathways” were screened in the selection of the Tentatively Selected Plan. Each pathway consists of the channels through which a ship must pass, from the ocean to its destination. Each channel was divided into manageable segments, largely for simplicity in deriving excavation quantities, but also for ease in removing segments that are not included in a particular pathway. These segments were then grouped into reaches that form the pathways. Reaches are shown in Figure 12. Table 10 shows the reaches contained within each pathway. The reaches represent the largest sections of channels that are both separable in terms of plotting the screening pathways that are presented below and are reasonably homogenous in terms of material type and risk and uncertainty considerations.

The cost and benefits of the three pathways described in Section 5 were analyzed in accordance with Planning Guidance Notebook (ER 1105-2-100). This analysis is discussed in detail in Appendix C, Economic Analysis. The analysis identified the deepening of the pathways to Port Elizabeth (including South Elizabeth) and Port Jersey by 5 feet as the national economic development plan.

Figure 12. HDCI Reaches that are combined into Pathways

Table 10. Reaches that form the Three Pathways.

Pathway	Reaches										
	(1) Ambrose	(2) Anchorage South	(3) Anchorage North	(4) Port Jersey	(5) KVK	(6) Newark Bay South	(7) Newark Bay Central	(8) Newark Bay North	(9) South Elizabeth	(10) Port Elizabeth	(11) Arthur Kill
Sea to Port Jersey	X	X	X	X							
Sea to Port Elizabeth	X	X			X	X	X	X	X	X	
Sea to Arthur Kill	X	X			X	X					X

5.2. Discussion of Channel Efficiency Measures

The screening of alternatives for the Harbor Deepening & Channel Improvements (HDCI) study focused on the incremental evaluation of each of the three considered navigation pathways. The reaches discussed in Section 5.1 were initially devised to allow for flexibility in the screening of various components (i.e. for the possible consideration of the Newark Bay Pierhead separately from Port Elizabeth.) The alternative screening was, however, limited to the three pathways presented in section 5.1. The discussion of the measures considered in the alternatives screening, presented below, is, therefore, on a channel by channel basis as a consideration of each sub-reach proved to be unnecessary. Deepening quantities were initially developed in 2 feet increments up to 8 feet.

5.2.1. Ambrose Channel

Deepening alternatives for Ambrose Channel ranged from 1 to 7 feet below its current authorized depth of -53 feet, MLLW. No changes in width or channel alignment were considered. In addition to deepening, the removal of a large rubble mound, located to the north of the channel close to its mouth, was considered. Pilots use this area to bring their boats alongside the incoming and outgoing vessels for boarding and unboarding; this mound will become a hazard to navigation if it remains at its current height. Additionally, the reduction of the channel side slope to approximately 5H: 1V in the vicinity of the East Bank Shoal to reduce sloughing of sand into the channel, was considered (Figure 13). This side slope will be analyzed more closely during the PED phase to determine its adequacy for this purpose as well as for its stability. All dredged material originating from Ambrose channel was assumed to suitable for HARS disposal.

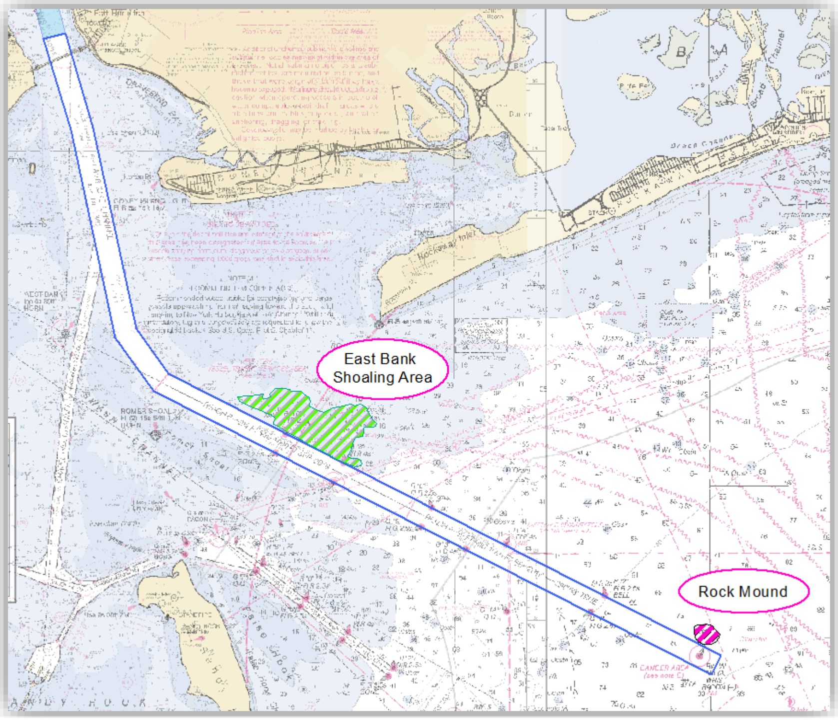

Figure 13. East Bank Shoaling Area and Rock Mound adjacent to Ambrose Channel.

5.2.2. Anchorage Channel

Deepening alternatives for Anchorage Channel ranged from 1 to 7 feet below its current authorized depth of -50 feet, MLLW. No changes in width or channel alignment were considered. The channel will be deepened for approximately 2,600 feet beyond the northern edge of the widening known as “PJ-1” at the Port Jersey Channel, which is discussed in greater detail in Section 5.2.3, Port Jersey Channel. This extended area of deepening, known as area AN-1, will allow ships to turn around after backing out of Port Jersey Channel (See Fig 14).

All dredged material originating from Anchorage Channel was assumed to be suitable for HARS disposal, with the exception of the material dredged from the area AN-1, which was assumed to be non-HARS suitable.

5.2.3. Port Jersey Channel

Deepening alternatives for Port Jersey Channel ranged from 1 to 7 feet below its current authorized depth of -52 feet, MLLW. Deepening will not occur beyond a distance of approximately 5,960 feet from the channel mouth as there is a large-diameter Passaic Valley Sewage Commission (PVSC) trunk line that crosses the channel at that location, from the northwest to the southeast. The trunk line is covered with steel plates at a depth of – 52 feet MLLW. A 150-foot buffer from the centerline of the trunk line was created to ensure that the sewer will not be at risk of movement or vessel contact during dredging. The trunk line will be thoroughly investigated for stability and adequate protection during the next phase of study. Widening along the northeast portion of Port Jersey Channel was considered to facilitate navigation of the design ship in a location where cross-currents are strong. The widening mirrors the flared configuration of Port Jersey Channel along the southeast edge, and increases the turning radius of a ship backing out into Anchorage Channel (Figure 14). All dredged material originating from Port Jersey Channel was assumed to be suitable for HARS disposal.

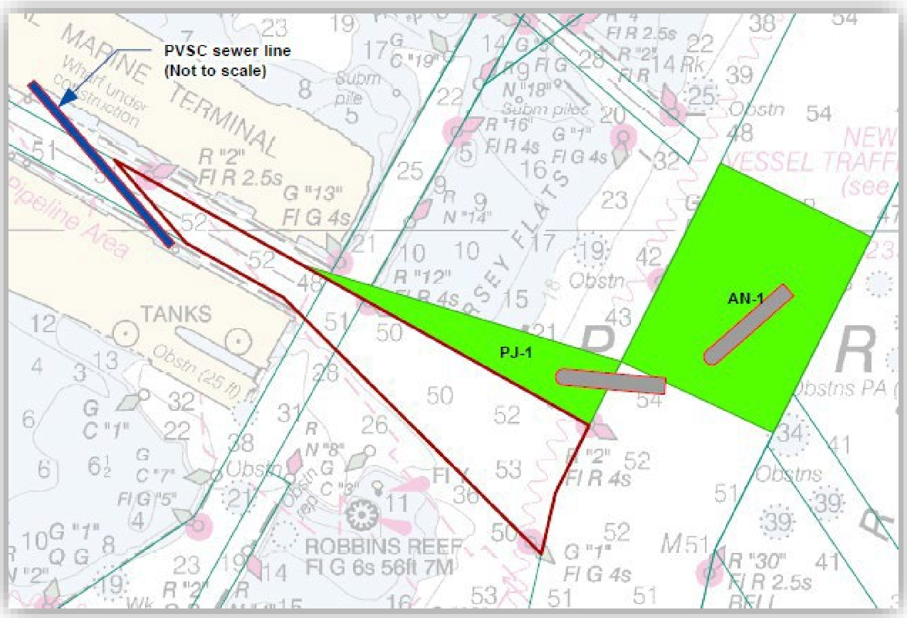

Figure 14. Port Jersey Channel, Showing Location of PVSC Trunk Line as it Crosses the Channel, Area PJ-1 and Area AN-1. (Design Ships are Shown to-Scale.)

The 2016 MITAGS report showed the pilots' successfully backing out of Port Jersey Channel without either PJ-1 or AN-1 ; however, coordination meetings with the pilot associations indicated that the high velocity wind and wave currents at the confluence of the Port Jersey and Anchorage Channels were a primary concern and this is the principal justification for these two measures.

5.2.4. Kill Van Kull Channel

Deepening alternatives for Kill Van Kull Channel ranged from 1 to 7 ft below its current authorized depth of -50 feet, MLLW. The Kill Van Kull Channel will maintain its present alignment; however, areas of widening have been added based on design ship navigation and safety considerations. Five areas were under consideration for this study: KVK-1, KVK-2, KVK-3, KVK-4 and KVK-5 (Figure 15). KVK-1 increases the turning radius of the ship's path as it leaves the Kill Van Kull Channel and into the Anchorage Channel at a location with strong cross-currents. KVK-2, an "efficiency" located along the north, was proposed to improve operational efficiency by allowing a ship to wait at this location rather than a location south of the Verrazano Narrows Bridge in the anchorages.

As mentioned previously, the Kill Van Kull has 18 bends within a distance of about 5.3 miles, or on average, approximately one bend per every 1/3-mile. The design ship is approximately ¼-mile long, and, therefore, must constantly adjust its bearing – to include crossing over the centerline – and leave enough space for one or more pilot boats to assist alongside it. Much of the Kill Van Kull is between 800 feet and 1000 feet wide, making this channel especially challenging for UCLV ships to navigate. KVK-3, KVK-4 and KVK-5 provide more room for greater maneuverability of the design ship as it passes though the very sinuous Kill Van Kull. These areas of widening <u>do not</u> remove the need for the one-way traffic restriction while the design ship navigates the channel.

Dredged material from the east side of the KVK was assumed to be HARS suitable. Dredged material from the west side of the KVK was assumed to be non-HARS suitable.

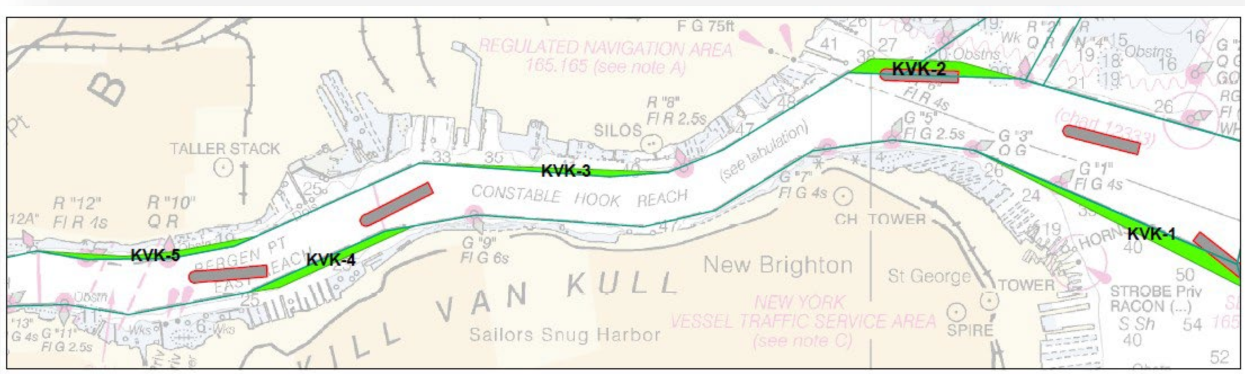

Figure 15. Areas of Widening and Efficiency (KVK-2) within the Kill Van Kull Channel (Design Ships Shown to Scale.

5.2.5. Newark Bay Channel

Deepening alternatives for the Newark Bay Channel ranged from 1 to 7 feet below its current authorized depth of 50 feet MLLW. Several areas of widening are proposed for the Newark Bay Channel. The preliminary designs for these widenings, NWK-1A and 1B, and NWK-2A, B, and C, were developed such that each is separate and corresponds to a specific function. (Figure 16).

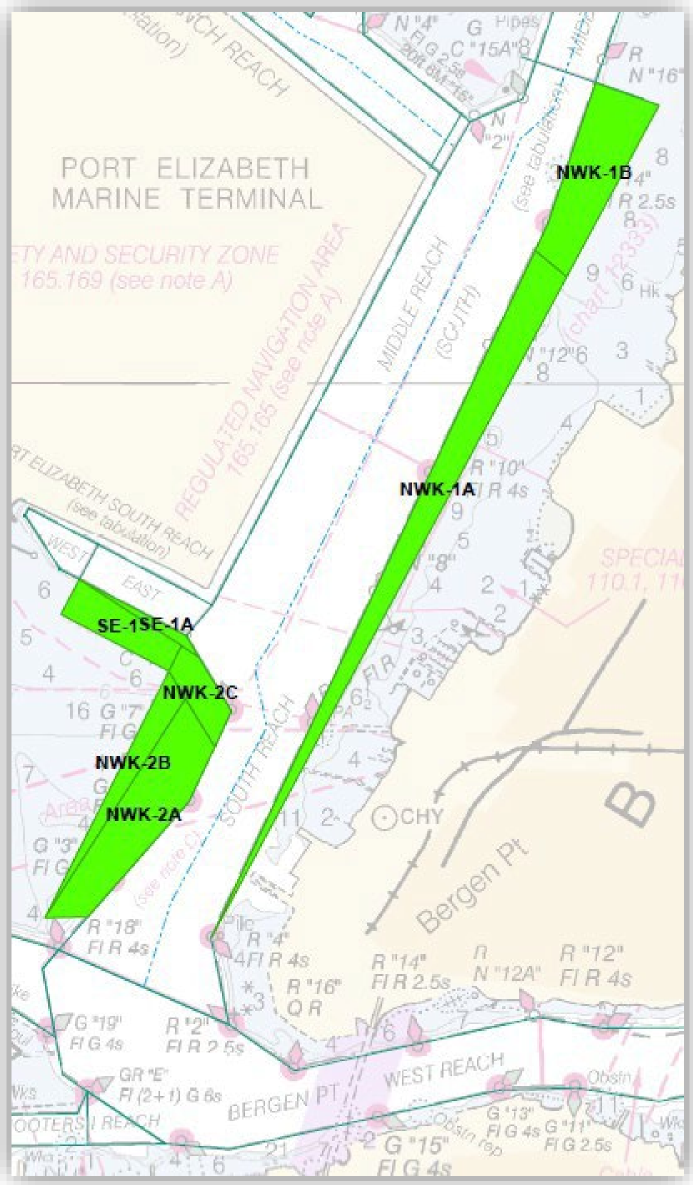

Figure 16. Newark Bay Channel with Preliminary Areas of Widening.

The primary function of widenings NWK-1A is to allow a greater swing area for a design ship leaving the berths along the western face of the Newark Bay Channel and permit it to completely turn around and proceed outbound through the Kill Van Kull Channel. The widening also help to facilitate two-way traffic through Newark Channel. It was concluded that a measure must be introduced to enable the design ship to safely exit Port Elizabeth Channel and continue outbound. Widening the Port Elizabeth Channel to the north was initially considered but there is a confined disposal facility (CDF), just north of the Port Elizabeth Channel, which contains toxic sediments from the remediation of the Passaic River superfund site. The widening of the Port Elizabeth channel to the north was ruled out due to the presence of the CDF and the widening of the Port Elizabeth Channel to the south was ruled out due the presence and continued need of berths in that area. NWK-1B is a feasible option that achieves this function as it creates a turning basin on the flats area to the east of the Newark Bay Channel, opposite its confluence with the Port Elizabeth Channel, thereby allowing for the safe exit of the design ship from the Port Elizabeth.

Proposed widenings NWK-2A, B and C are contiguous areas but each is proposed to achieve separate functions. NWK-2A will allow an inbound design ship ample area to swing around Bergen Point after passing through the Bayonne Bridge. Bergen Point is a location that has strong cross currents, making maneuvering difficult. Area NWK-2B is proposed to provide the needed swing room for a ship backing out of the Arthur Kill channel, in is proposed in conjunction with area AK-2 (See Section 5.2.7, Arthur Kill Channel). Area NWK-2C is proposed to allow a larger turning radius for a ship entering South Elizabeth Channel, coupled with areas SE-1 and SE-1A, which are discussed further in Section 5.2.6, South Elizabeth Channel. In addition to providing ample swing room for specific areas, the widenings discussed here as well the deepening of Kill Van Kull and Newark Bay Channels will serve to increase the navigation window around the bottleneck that exists at Bergen Point by expanding the tidal windows on either side of slack water high.

The preliminary designs for proposed widenings NWK-2A, B and C are somewhat artificially large so as to create the needed separability of each in accordance with their specific function. The proposed widenings included in the selected plan were subsequently streamlined (See Section 7).

All dredged material originating from Newark Bay Channel was assumed to be non HARS suitable.

5.2.6. South Elizabeth Channel

Deepening alternatives for the South Elizabeth Channel ranged from 1 to 7 feet below its current authorized depth of 50 feet MLLW. Based on the USACE Controlling Depth Report, the South Elizabeth Channel is divided into two reaches - the east reach and the west reach. This study looks at the east reach only. The east reach of the South Elizabeth channel is 500 feet wide and approximately 1600 feet long. Two areas of widening were considered for this channel, SE-1 and SE-1A, shown in Figure 17. Area SE-1 was considered in order to allow a ship berthed inland of the design ship to back out alongside the design ship and out into the Newark Bay Channel. As can be seen from Figure 17, if a design ship is berthed at South Elizabeth, there is virtually no room for another ship to berth inland, rendering area SE-1 unnecessary. Area SE-1A, in conjunction with Area NWK-2, will allow a slightly greater turning radius when entering and backing out of South Elizabeth.

All dredged material originating from South Elizabeth Channel was assumed to be non HARS suitable.

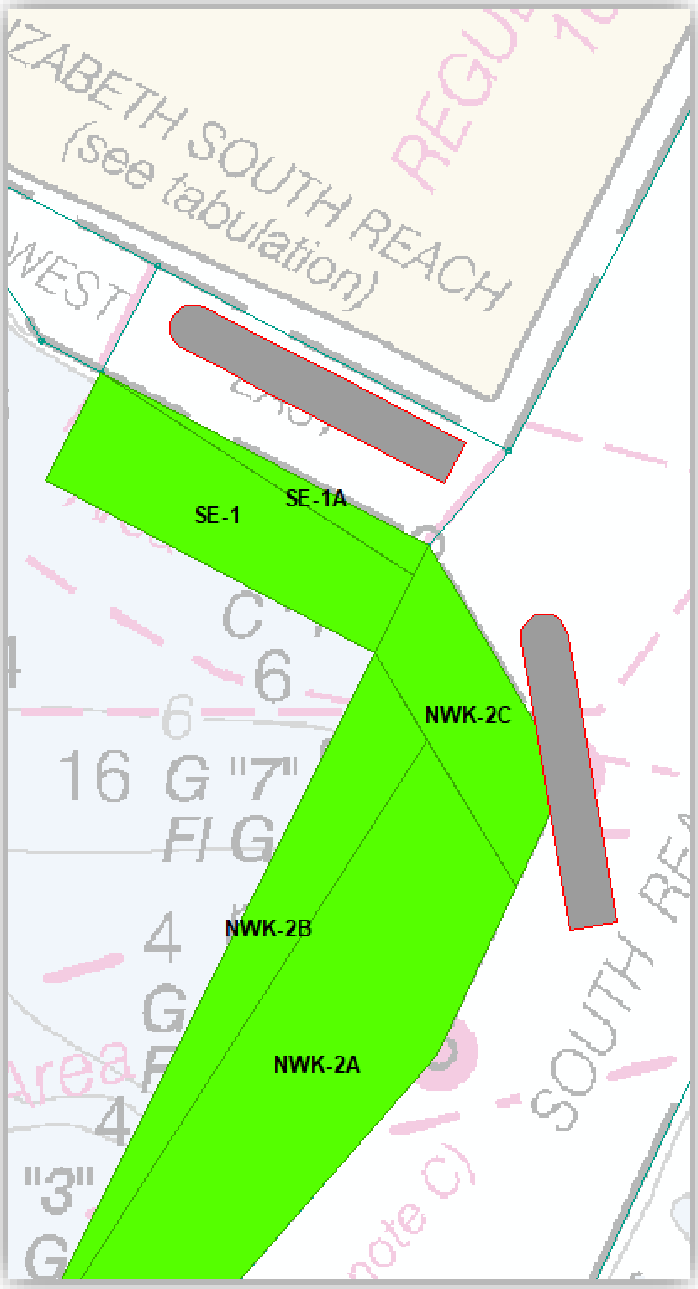

Figure 17. South Elizabeth Channel and Newark Bay South, Preliminary Widenings

5.2.7. Port Elizabeth Channel

Deepening alternatives for the Arthur Kill Channel ranged from 1 to 7 feet below its current authorized depth of 50 feet MLLW. All dredged material originating from Port Jersey Channel was assumed to be non HARS suitable.

5.2.8. Arthur Kill Channel

Deepening alternatives for the Arthur Kill Channel ranged from 1 to 7 feet below its current authorized depth of 50 feet MLLW. Two widenings were deemed necessary to accommodate the design ship in the Arthur Kill Channel, AK-1 and AK-2 (Figure 18). AK-2 extends along the northern edge of the channel from the mouth for a distance of approximately 8,000 feet. Its width varies from approximately 413 feet at the mouth to approximately 240 feet near channel centerline Station 67+00, in the vicinity of Marciante-Jackson-Millet Park to the north in Elizabethport, NJ, and Howland Hook, Staten Island, NY to the south. The combined topographic and bathymetric surveys used for this study show that AK-2 will encroach into the Marciante-Jackson-Millet Park. Additional topographic and offshore bathymetric surveys will be required to confirm this preliminary finding, as well as the extent.

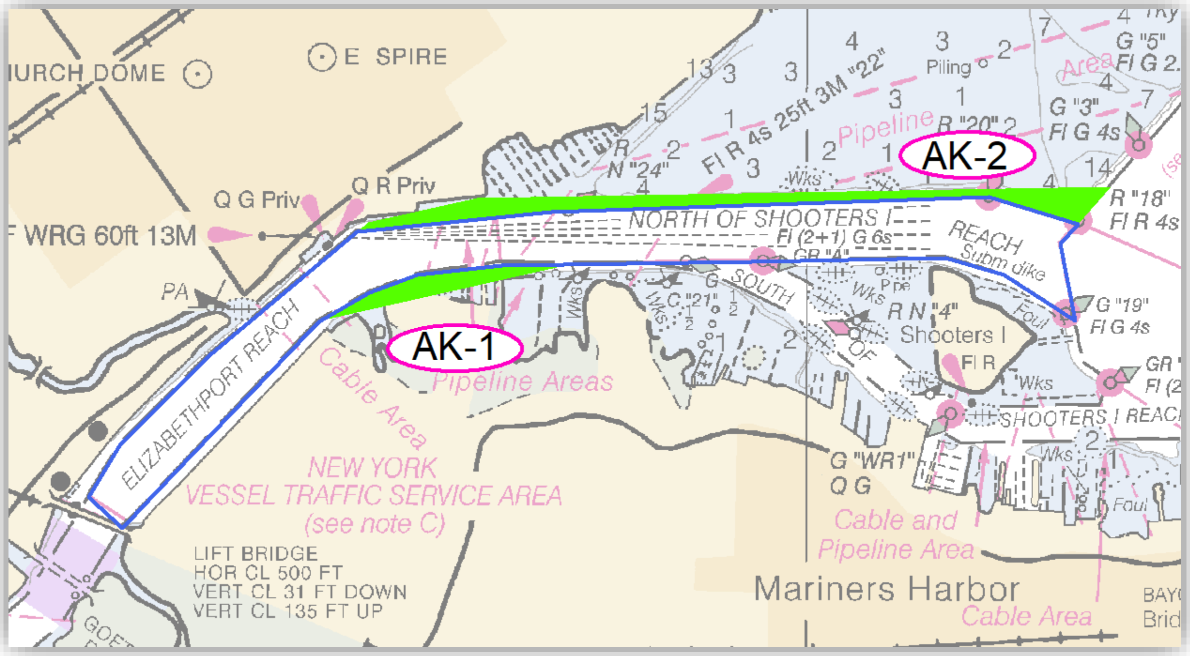

Figure 18. Arthur Kill Channel Widenings AK-1 and AK-2

Widening AK-1 extends along the southern edge of the channel for approximately 1,260 feet, reaching across open marshland on Howland Hook to a maximum width of approximately 270 feet. As with AK-2, additional topographic and offshore bathymetric surveys will be required to confirm this preliminary finding, as well as the extent.

Both widenings are designed to facilitate the maneuvering of the design vessel inbound to and outbound from the GCT-NY Marine Terminal at Howland Hook, NY. Currently, inbound vessels turn in Newark Bay Channel and then back down the Arthur Kill to the marine terminal stern first, or they will proceed to the terminal bow first and then back out of the channel, turn in Newark Bay, and proceed outbound through the Kill Van Kull Channel. The widenings will allow more room for the design vessel to enter and exit the marine terminal, and they will allow a greater turning radius for a ship to back out into Newark Bay. All dredged material originating from Arthur Kill Channel was assumed to be non HARS suitable.

6. Quantities Development

6.1. Developing a continuous Surface of NY & NJ Harbor

In order to derive excavation quantities, a complete surface of the excavation areas must be developed. Areas to be excavated are included mostly within the existing channels, but also within areas of channel widening where bathymetric data might not be available. Preliminary Quantities, used in the screening of alternatives, are provided in Attachment 2 of this appendix. Refined quantities for the TSP are provided in Attachments 3A and 3B.

6.1.1. Channel Data: eHydro Bathymetric Data

Bathymetric survey data are publicly available for all Corps maintained channels throughout the United States and can be found at the eHydro website, https://navigation.usace.army.mil/Survey/Hydro. The most recent data for each of the NY & NJ Harbor channels, at the time of download, were downloaded in the summer and fall of 2019, in preparation of the Tentatively Selected Plan (TSP) Milestone. Table 11 below shows each channel for which data were retrieved, the date of survey, the date of download, and the coordinate system of the data (NYSPLI = New York State Plane, Long Island; NJSP = New Jersey State Plane). Any data provided in NJSP was reprojected to NYSPLI; therefore, the final horizontal plane of reference for all surveys was the New York State Plane, Long Island Coordinate System, in U.S. Survey Feet, North American Datum of 1983 (NAD83). The vertical plane of reference was Mean Lower Low Water (MLLW), National Tidal Datum Epoch (NTDE) of 1983-2001, as established by the National Ocean Service (NOS).

Table 11. eHydro Bathymetric Data Survey and Download Dates

Channel	Date of Survey	Date Downloaded	Original Coordinate System
Ambrose	29 Aug 2018	12 Aug 2019	NYSPLI
Anchorage	11 Dec 2018	09 Aug 2019	NYSPLI
Arthur Kill	16 Feb 2018	09 Oct 2019	NJSP
Arthur Kill - South of Shooters Island	19 Jan 2018	16 Oct 2019	NJSP
Kill Van Kull	20 Dec 2018	31 July 2019	NJSP
Newark Bay - all	28 Feb 2019	25 Sep 2019	NJSP
Port Jersey	28 Feb 2019	18 Sep 2019	NJSP
Bay Ridge	17 Jan 2019	16 Oct 2019	NYSPLI
Port Jersey Pier Head	04 Sep 2019	16 Oct 2019	NJSP
Red Hook Flats	27 Dec 2018	16 Oct 2019	NYSPLI

6.1.2. Data Points outside of Channels

In order to develop a more complete surface of the harbor, data points from outside the channels were added using publicly available data from the National Oceanographic and Atmospheric Administration (NOAA). The data used are $1/9^{th}$ arc-second cell size and were retrieved from the Hurricane Sandy Digital Elevation Model (HSDEM), Mid-Atlantic Region, collected in 2012. The $1/9^{th}$ arc-second cell size integrates both topographic and bathymetric data at the coast and are therefore helpful in filling in the missing areas outside the channels where excavation is expected to take place. NOAA data were referenced to the same horizontal and vertical datums as the channel data. While there were many areas that evidenced good agreement between the two datasets used, there were also areas where there was evidence of considerable error in the NOAA data used. The eHydro data provides excellent accuracy along the channel bottom and for the lower portions of the channel walls. The NOAA data was found to be reasonably accurate in shallow areas, but the data was less reliable for deeper depths. This has resulted in considerable uncertainty in the dataset for the upper portions of the channel walls and where the channel walls "daylight". The cost risk implications of this are noted in section 9 of this report.

6.1.3. Projected Sedimentation Volumes

An existing condition surface was developed, and quantities were derived, from eHydro surveys conducted between January 2018 and September 2019. The projected construction start date for the deepening of the channels is 2025. The existing condition surface was modified to incorporate expected sedimentation deposits for the period between the eHydro survey dates and the construction start. This vertical channel elevation change was based on sedimentation rates calculated by McAlpin et al, 2020 (Attachment 4). In this study, five years (1985, 1995, 1996, 2011, and 2012) were simulated for a wide range of meteorological conditions including storm events. The five simulated years were then averaged to obtain a single "average" sedimentation deposition volume for each reach. An average annual vertical accretion rate was then initially calculated for the sedimentation modeling study reaches. These reaches did not conform to the HDCI study reaches and were, therefore, weighted by area to derive annual accretion rates for the HDCI reaches. Annual deposition volumes and the resulting projected elevation changes for each channel are presented in Table 12. While past dredging records (see Table 4) can provide insight into sedimentation rates, maintenance dredging will often focus on continued channel navigability and areas of pronounced shoaling and does not necessarily provide a complete estimate of sedimentation volumes. The calculated sedimentation rates produced by McAlpin et al, 2020 were therefore judged to be a better resource in developing these estimates. The inclusion of estimated future sedimentation, while necessary, introduces a source of uncertainty into the derived quantities. The cost risk of this is judged to be low given the volume of the estimated sedimentation when compared to the overall volumes.

Table 12. Deposition Volumes and Elevation Change

Channel	Annual deposition (cy)	Elevation change, annual (ft)	Elevation change, total (ft)
Ambrose	3342,09	0.046	0.31*
Anchorage	64,656	0.043	0.28
Anchorage, North of Port Jersey	26,903	0.028	0.18
Port Jersey	47,224	0.120	0.88
KVK Constable Hook	61,571	0.064	0.41
KVK Howland Hook	45,980	0.069	0.45
Newark Bay	334,269	0.368	2.33
Port Elizabeth	100,850	0.460	2.92
Port Elizabeth South	8,333	0.137	0.87

**Elevation change in Ambrose Channel assumed to be zero due to sand mining operations*

The total vertical accretion value was calculated by multiplying the annual accretion change by the number of years between the month of the eHydro survey and 01 July 2025, the approximate midpoint of the first year of construction. This vertical accretion value was then added to the ehydro Z-values in accordance with the following two constraints:

1. Only those points within the channel limits were modified
2. A maximum value of -50 feet MLLW was assumed as all deposition above this value was considered to be the responsibility of maintenance dredging.

Elevation change within Ambrose Channel was assumed to be zero due to the influence of sand mining activities. Even though sand mining activities are limited to the channel area south of the Transco Pipeline, net deposition was still assumed to be zero given the fact that up to 2 million cy/year of mining is permitted and the annual deposition is estimated to be 334.209 cy/year. It is further noted that an additional permit for sand mining north of the Transco pipeline is under consideration.

6.2. Bentley Microstation InRoads v.SS2

6.2.1. Existing Conditions Surface (projected to the Year 2025)

Survey data (both eHydro and NOAA) in x,y,z format were imported into MicroStation InRoads to create a Triangulated Irregular Network (TIN) of the entire Harbor. Extraneous triangles were eliminated from the TIN in order to create a more representative surface. It should be noted that minimal buffer areas were left between the channel data points and the NOAA data points to more intentionally interpolate these areas during the creation of the TIN. The purpose of this was to try to minimize questionable results at the boundary of these two data sets if the less-accurate NOAA data contained point elevations that were inconsistent with those of the very-accurate eHydro data. This enabled a smoother transition between the two data sets

6.2.2. Proposed Condition Surface

The proposed conditions surfaces correspond to the channel “templates” at the proposed depth(s) of excavation. The templates represent the cross-section of the proposed channels, including the proposed side slopes. Where the proposed channel is excavated through soft material such as sand, the side slope is set at 3 feet Horizontal to 1 foot Vertical (3H: 1V). Where the proposed channel is excavated through rock or across the mouth of an adjoining channel, the side slope is generally set at 1H: 1V (Figure 19), but can vary from approximately 1H:2.5 V.

. The proposed channels maintain the same footprints as the existing channels except where widenings are proposed. In the vicinity of the East Bank Shoals along the north side of Ambrose Channel, the slope has been set at 5H:1V, which is meant to prevent excessive resedimentation back into Ambrose Channel from the shoals. This slope will be evaluated in a future phase of study to determine if it is the most appropriate for this purpose. Except for the possible side slope change in the vicinity of East Bank Shoal, these are the slopes that will be maintained during future maintenance dredging operations. Proposed channel slopes are presented in Table 13.

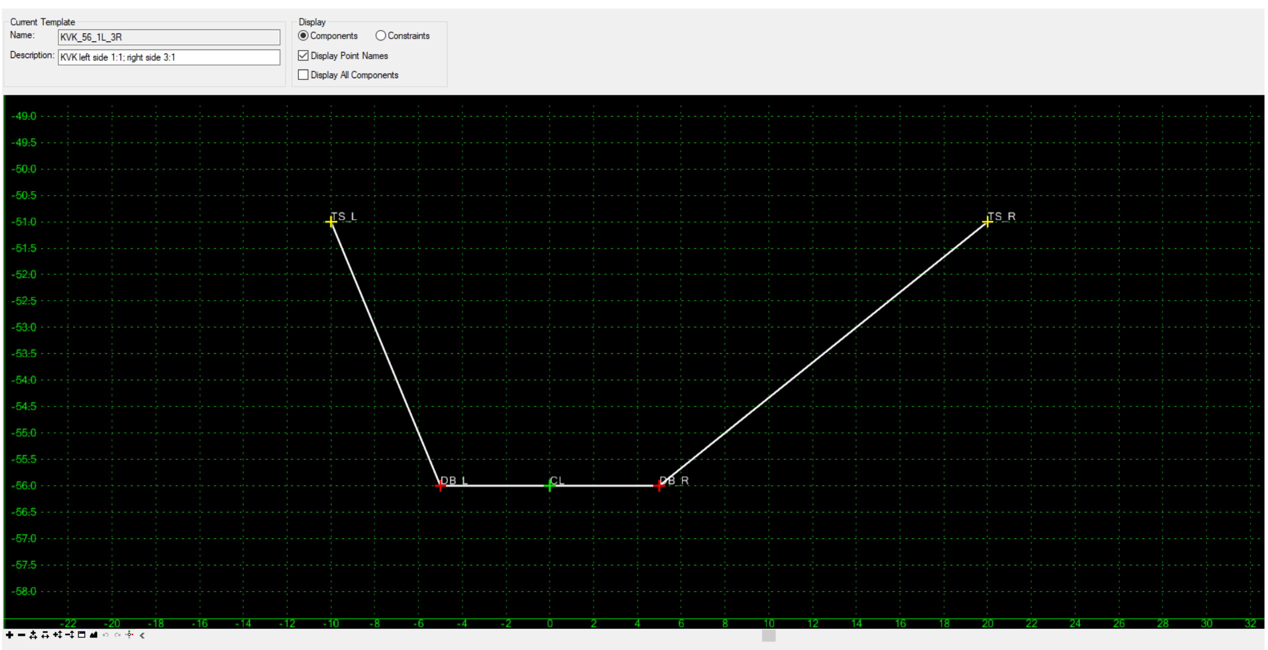

Figure 19. Sample Proposed Channel Template showing 1H: 1V Side Slope on the left; 3H: 1V Side Slope on the right

By using the Modeler feature in InRoads, templates were created for each channel and “pushed” along the channel centerline at the proposed design depth. After passing the template along the entire length of each centerline, a proposed conditions surface for each channel was created (Figure 20).

Table 13. Proposed Channel Side Slopes through each type of Material

Material	Slope
Soft material (Sand and sediment)	3H: 1V
Rock	Approx 2.5H: 1V to 1H: 1V
East Bank Shoal – Ambrose Channel	5 H: 1V

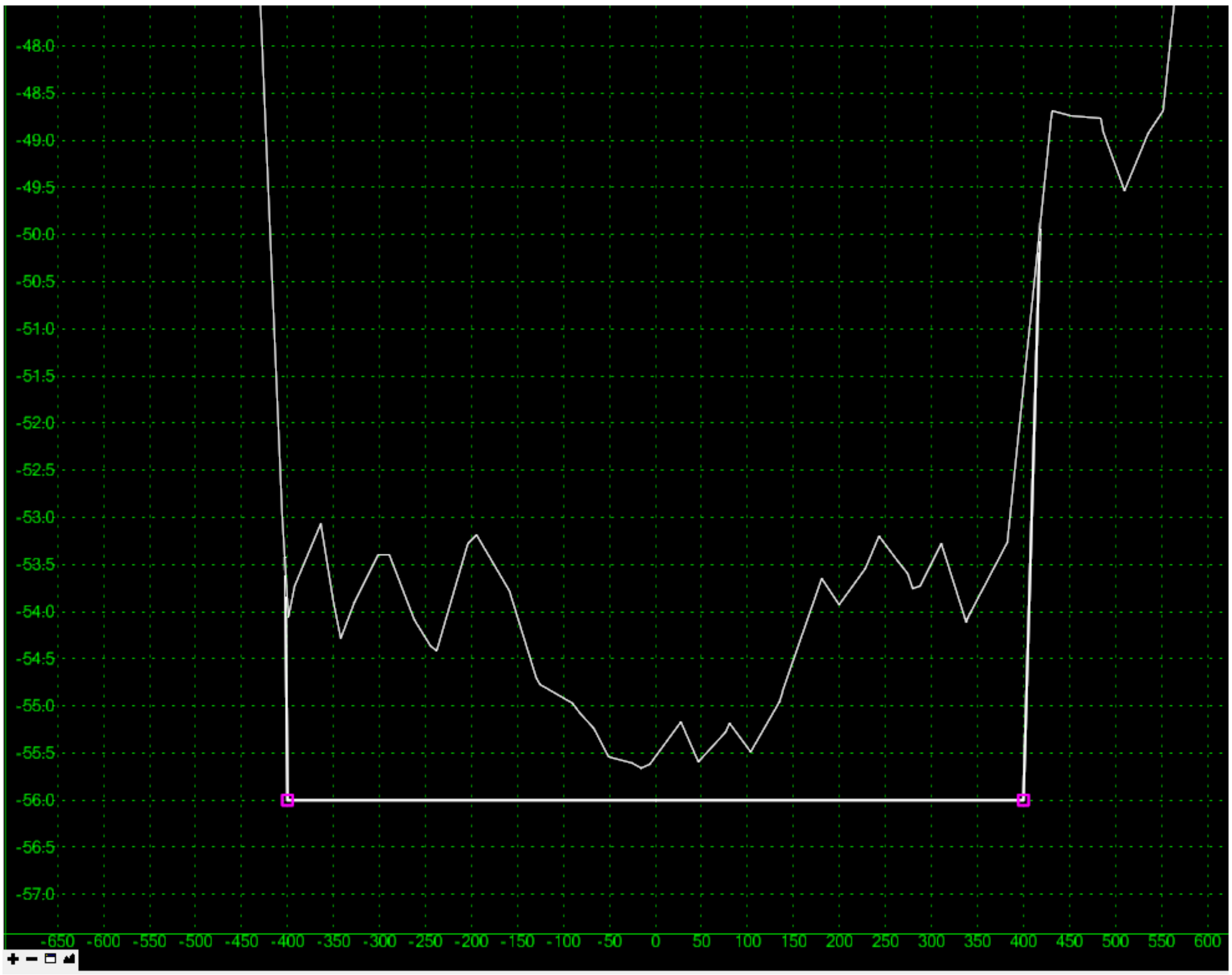

Figure 20. Proposed Channel Template being "pushed" through Existing Conditions Surface

6.3. Generating Excavation Quantities

Each channel was divided into manageable segments to simplify the process of developing excavation quantities. The gross excavation quantity for each channel segment was determined simply by subtracting the proposed conditions surface from the existing conditions surface.

6.3.1. Determining Material Composition in Channels

After the gross excavation quantities were calculated for each channel segment and channel, the material makeup of those gross quantities was determined. Because no new data were collected for this study, soil borings and MicroStation files from the previous deepening study were used to best assess the composition of the material to be excavated within the channels, side slopes and areas to be widened. HARS and Non-HARS Suitable Material. Figures 21 and 22 show approximate locations of materials that were categorized and quantified for this study.

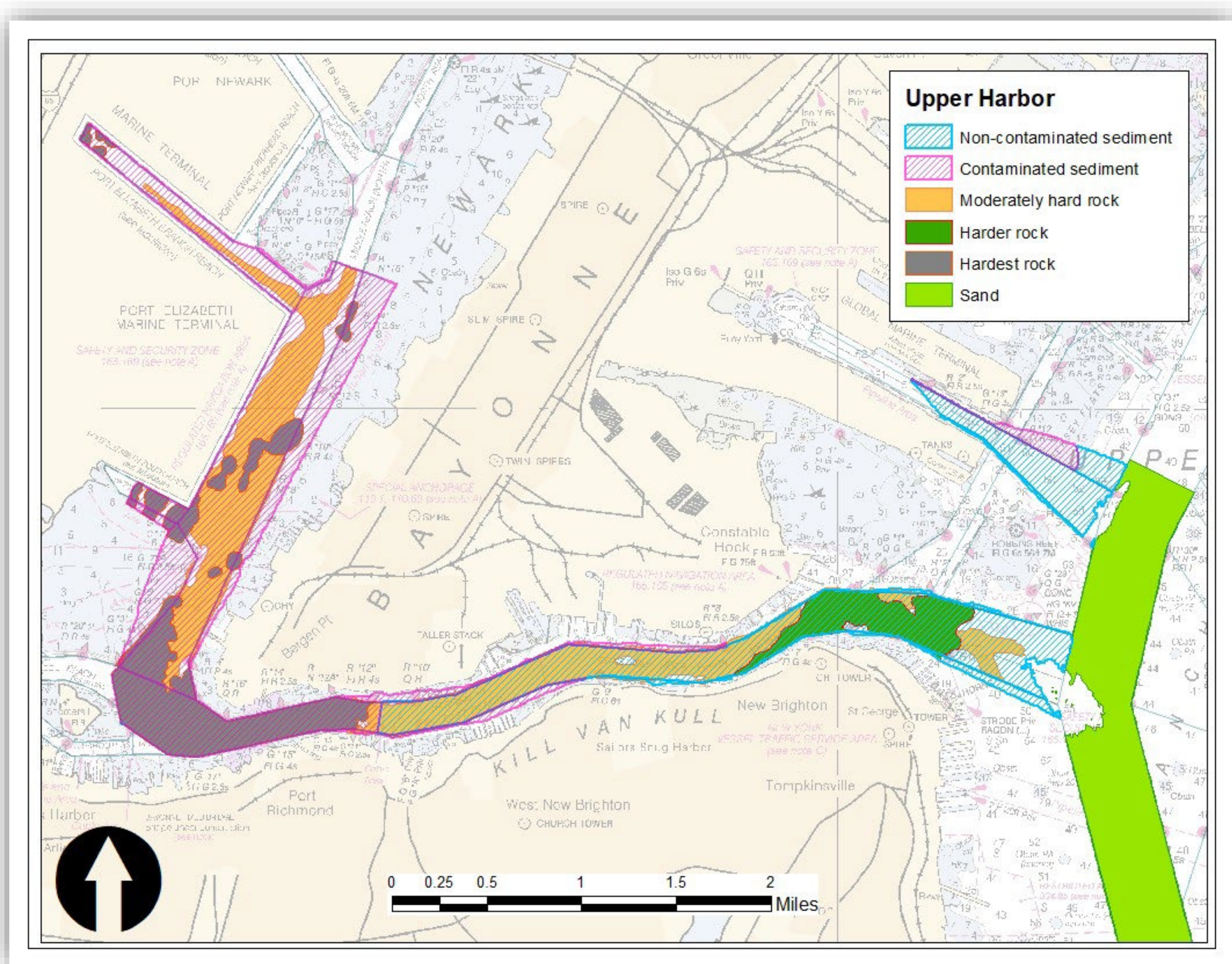

Figure 21. Approximate Locations of Various Material Types – Upper Harbor

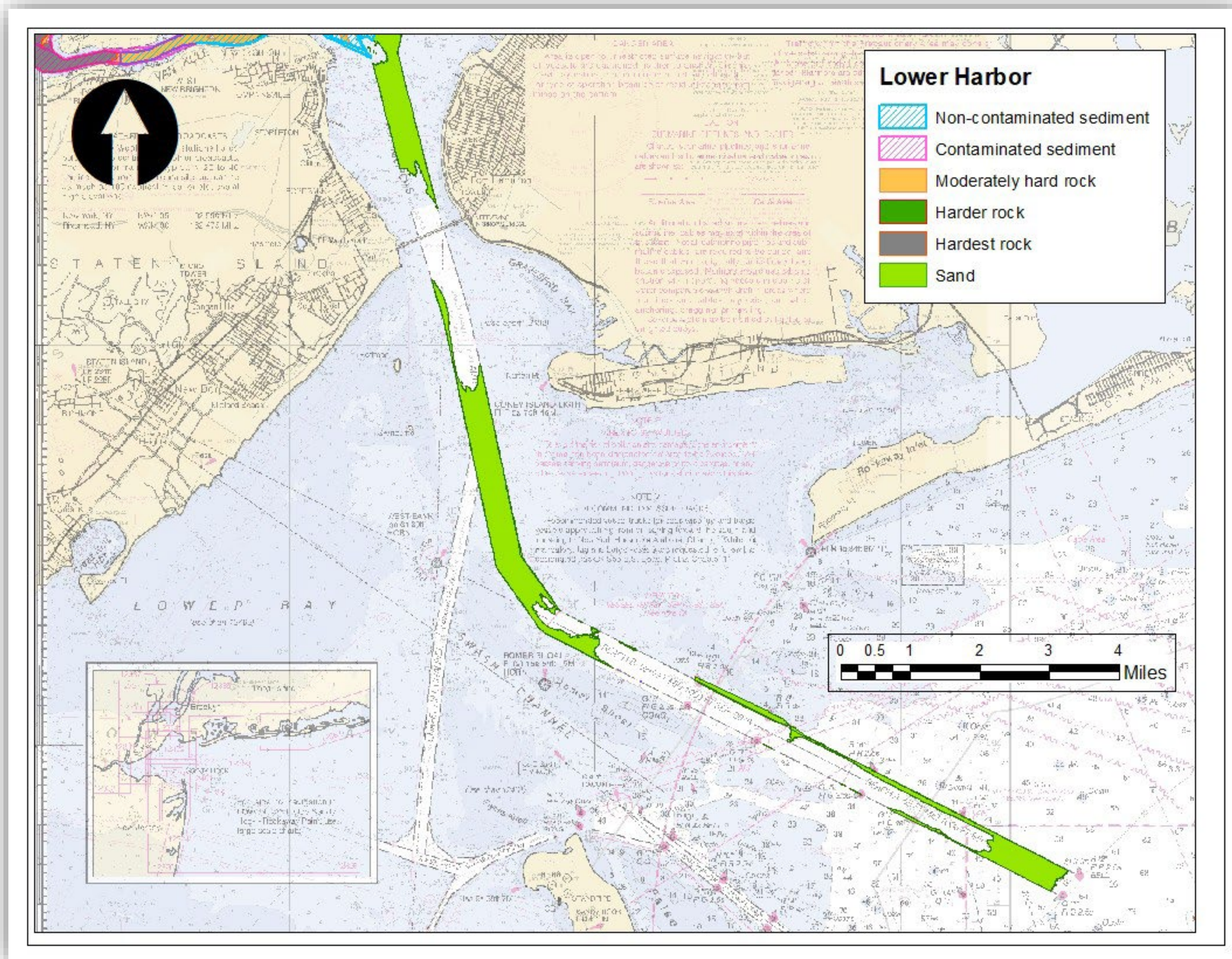

Figure 22: Approximate Locations of Various Material Types – Lower Harbor

6.3.2. HARS Suitable and non-HARS Suitable Material

Assumptions were made on the suitability of material placement based on location within the harbor. Prior testing indicates that sediments on the east side of the harbor, including those in Ambrose, Anchorage, Port Jersey and the east side of the Kill Van Kull channels, are generally HARS-suitable. Material at the northernmost end of the Anchorage Channel (area AN-1) are considered non-HARS suitable. Also, those sediments in the widened part of the Port Jersey Channel (PJ-1) that are above the Pleistocene line are considered to be non HARS-suitable. The Pleistocene limits are determined from an available data from the previous study and is shown in Figure 23. Based on eHydro channel data, on average, the existing elevation of the channel bottoms (not including the naturally deeper Ambrose and Anchorage Channels) is -53.5 feet, MLLW. Sediments above this elevation that are within the channel on the western side of the harbor, including the west end of the Kill Van Kull, the Newark Bay Channel, and Port Elizabeth and South Elizabeth channels, are automatically considered to be non-HARS suitable. These sediments are assumed have been washed down from the Passaic and Hackensack Rivers, the former of which is a known Superfund site. Non-HARS suitable material will be disposed of at an upland disposal site; HARS suitable sediments will be disposed of at the HARS.

Figure 23. Pleistocene Layer near Port Jersey Channel and the Eastern End of the Kill Van Kull Channel.

6.3.3. Rock Quantities

Rock quantities were estimated from existing data from the previous deepening study. Figure 24 below shows a snapshot of the rock areas. The missing contour lines were added based on reasonable assumptions of their placement. Rock quantities were developed using the average end area method between elevations -53.5 feet and -56 feet or -57 feet.

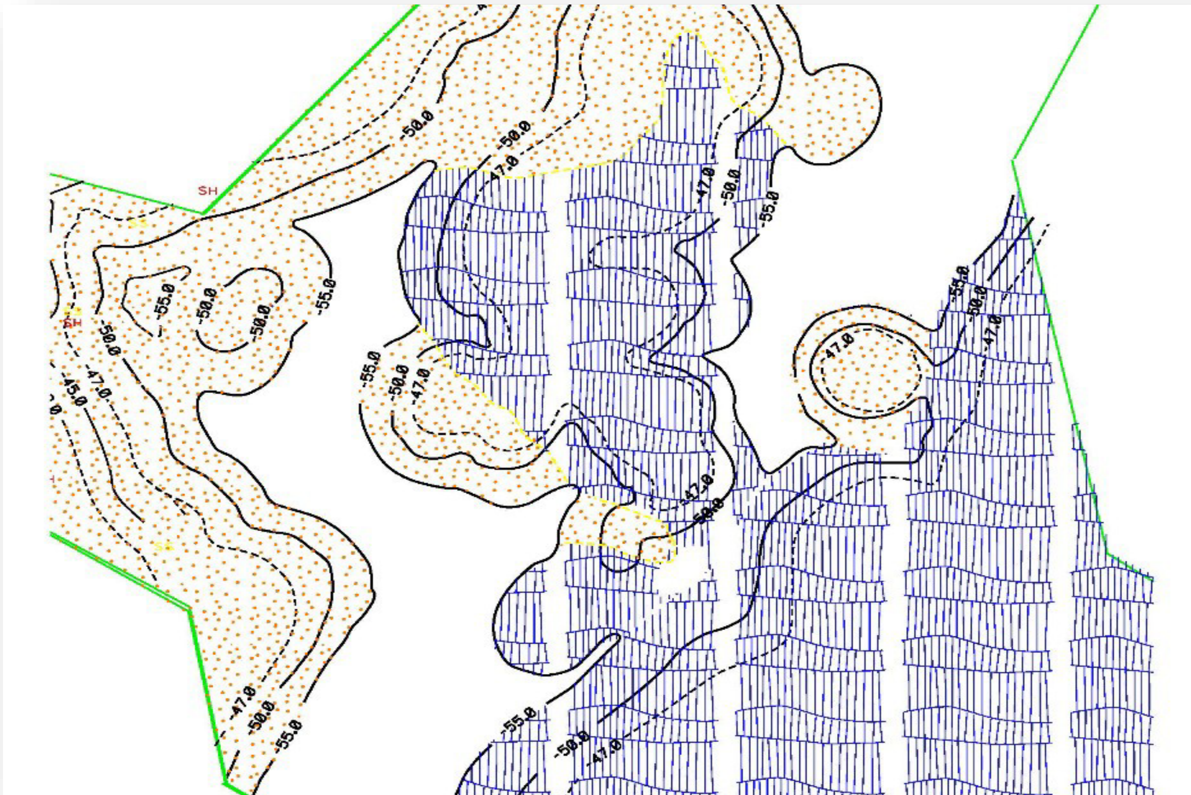

Figure 24. Sample File Showing Rock Types in the Vicinity of Bergen Point.

6.3.4. Remaining Channel Materials (Glacial Till and other materials)

After determining the volumes of sediment and rock within each channel segment, the volume of remaining materials was estimated from a rock surface from the previous study (Figure 25). Given the fact that all rock and all material above elevation -53.5 feet has been accounted for, the material outside of these limits is what remains. The rock surface was overlaid onto the channels. Any areas not already accounted for by rock were traced and a percentage of the remaining material types was determined. These percentages were multiplied by the remaining volume of each segment ((Total volume) - (non-HARS suitable/HARS suitable sediments) – (rock) = remaining volume)).

Figure 25. Sample File Showing Material Types in the vicinity of the Eastern Kill Van Kull Channel

6.4. Excavated Depth Summary

Figure 26 provides an illustration of the different dredge zones referenced in developing quantities. These horizons are defined below.

6.4.1. Existing Conditions

Based on the most recent eHydro data at the start of the study. For this study, existing conditions include a depth of sedimentation – one that is appropriate for each channel or portion of a channel – that is projected to the construction start date of 2025.

6.4.2. Maintained Depth

The maintenance quantity is the volume required to be dredged from the existing condition to the currently maintained channel dimensions

6.4.3. Authorized Depth

The authorized depth is the nominal depth used for the Plan Formulation increments and includes consideration for underkeel clearance (UKC).

6.4.4. Advanced Maintenance

Dredging contracts typically include a depth of advanced maintenance beyond the authorized depth. This depth is often greater in areas of rock than areas of sand.

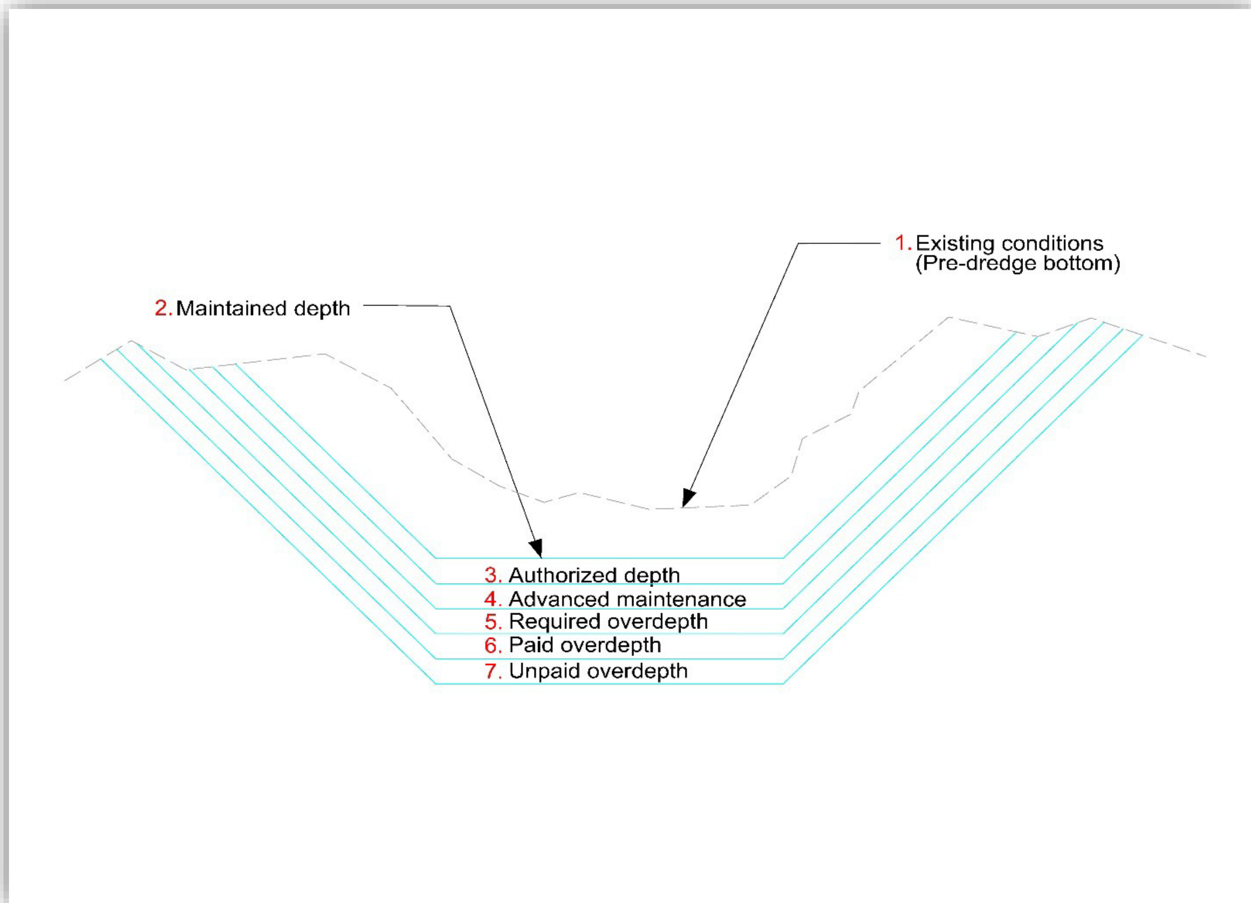

Figure 26. Typical Dredge Zones

6.4.5. Required Overdepth

Overdepth in areas where there is rock to ensure safety for clearance and future maintenance dredging.

6.4.6. Paid Overdepth

In consideration of the difficulty to dredge or blast to an exact depth, material within an agreed upon vertical distance below the authorized depth will be paid for.

6.4.7. Unpaid Overdepth

Material that is below the agreed upon paid overdepth quantity. Note that some material in this range may be paid for if it falls within the side slope area and is needed for slope stability.

7. Tentatively Selected Plan

The results of the preliminary analysis of this feasibility study identified the deepening of the pathways to Port Elizabeth (including South Elizabeth) and Port Jersey by 4 to 5 feet as the national economic development plan. The pathway to Arthur Kill was eliminated prior to the screening of the two remaining pathways as it was found that the existing configuration of the Arthur Kill channel/pathway sufficiently accommodates Howland Hook Marine Terminal's anticipated future fleet. This also resulted in the elimination of NWK-2B, the widening within Newark Bay Channel directly associated with the Arthur Kill Pathway. A three-phase screening process was then conducted where the costs and benefits for deepening each pathway by 2 to 7 feet were calculated and compared. The path and depth with the highest net benefits was then selected as the first increment (Phase 1). Phase II assumed that the pathway selected in Phase I (Sea to Port Elizabeth, deepened to 4 or 5 feet) was constructed and the costs and benefits for deepening the sea to Port Jersey pathway for depths of 2 to 7 feet were then screened. Here too, the deepening of the pathway to 4 or 5 feet was found to be cost effective and was included in the TSP. Phase III involved the screening of the only remaining efficiency, KVK-2, the widening on the north side the eastern entrance of the Kill Van Kull Channel, which was eliminated as it was determined to not be cost effective. SE-1, the widening along the south edge of South Elisabeth Channel was also eliminated when it was determined that it would not achieve its function because of the truncated extent of the deepening in South Elizabeth Channel. Finally, it is noted that, with the exception of the Newark Bay Channel, all channel centerlines, for the purpose of navigation, will remain the same as they are now. However, eHydro data collection are based on the geometric centerline of each channel, which will be determined and approved by the NY District Operations Division.

7.1. Summary

A summary of the TSP measures within each channel is provided below.

7.1.1. Ambrose Channel

Ambrose Channel will be deepened by 5 feet, from its authorized depth of -53 feet MLLW here is no plan to extend the mouth of the channel seaward as it is already deeper than the design depth. The rubble mound, located to the north of the channel close to its mouth, will be removed to a depth equal to the Ambrose Channel deepening. The channel side slope in the vicinity of the East Bank Shoal will be reduced from 3H:1V in order to prevent sloughing of sand into the channel. The side slope at this location was initially set to approximately 10H: 1V but was subsequently revised to 5H:1V during the detailed design phase of this study.

7.1.2. Anchorage Channel

Anchorage Channel will be deepened by 5 feet, from its authorized depth of -53 feet MLLW. The area AN-1 will also be deepened to an equal depth to facilitate the safe exit of the design ship from Anchorage Channel.

7.1.3. Port Jersey Channel

Port Jersey will be deepened by 5 feet from its authorized depth of -52 feet MLLW. The footprint of Port Jersey will change by the area of widening PJ-1, which will facilitate the design ship to back out from the Port Jersey Channel into the Anchorage Channel, or to back into the Port Jersey Channel from the Anchorage Channel (Figure 27)

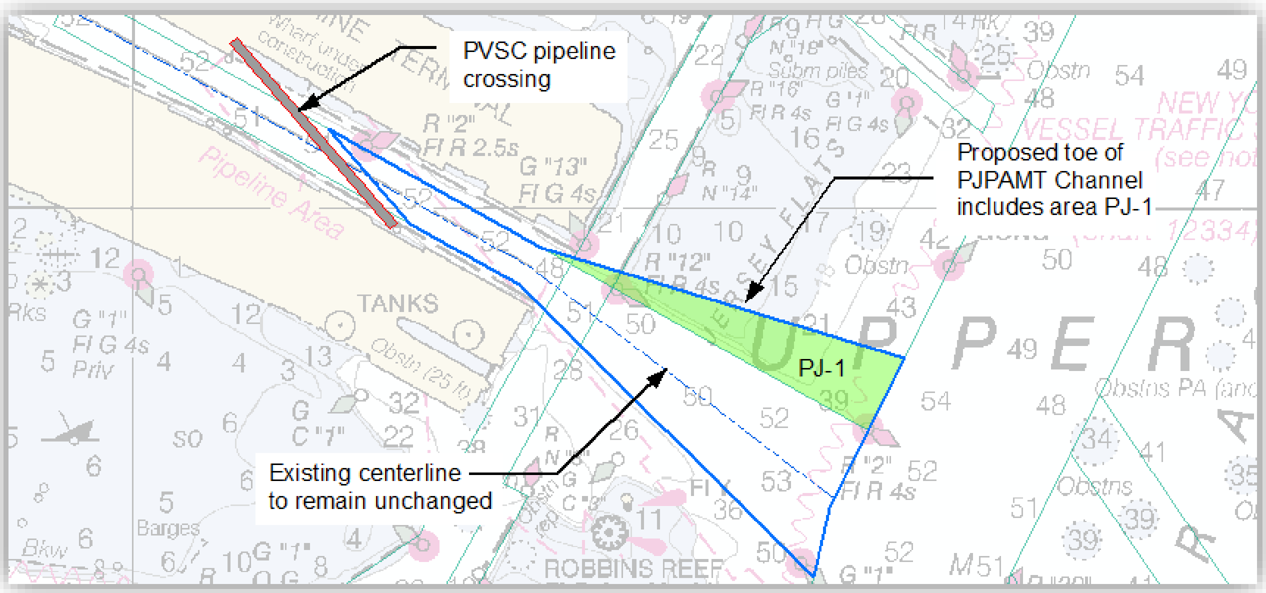

Figure 27. The Port Jersey Channel Footprint is Changed by the Addition of Area PJ-1; the Channel Centerline Remains Unchanged.

7.1.4. Kill Van Kull Channel

Kill Van Kull Channel will be deepened by 5 feet from its authorized depth of -50 feet, MLLW. The footprint of the KVK Channel will be changed to include the areas of widening: KVK-1, KVK-3, KVK-4, and KVK-5 (Figure 28). These areas will allow more room for ships to safely maneuver to and from the Newark Channel berths. The channel centerline will not change.

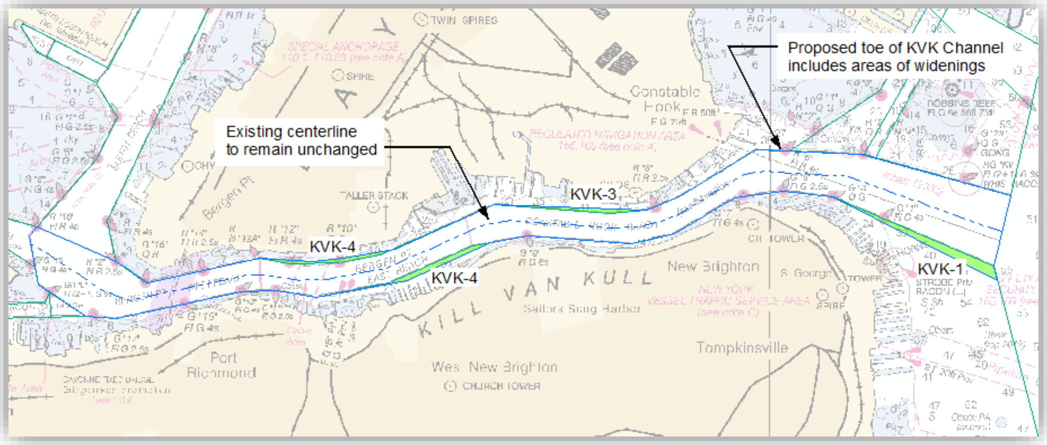

Figure 28. The KVK Channel Footprint is Changed by the Addition of Areas KVK-1, KVK-3, KVK-4, KVK-5; the Channel Centerline Remains Unchanged.

7.1.5. Newark Bay Channel

Newark Bay Channel will be deepened by 5 feet from its authorized depth of -50 feet, MLLW. Areas NWK 1A and 1B were combined into the final area NWK-1, and the areas NWK-2A and 2C were streamlined and combined to create the final area NWK-2. After further discussions with the pilots, their recommendation was to simply connect the straight line between buoys GC-1 to the north and R-18 to the south, which contained roughly the same area as that contained within combined area of NWK-2A and 2C. Collectively, the proposed channel will maintain a consistent width of approximately 2,000 feet along almost its entire length. The widenings on either side of Newark Bay Channel necessitate the relocation of the existing centerline. The proposed channel centerline is shown in Figure 29, but this relocation is subject to change and must be confirmed with and agreed to by the NY District Operations Division.

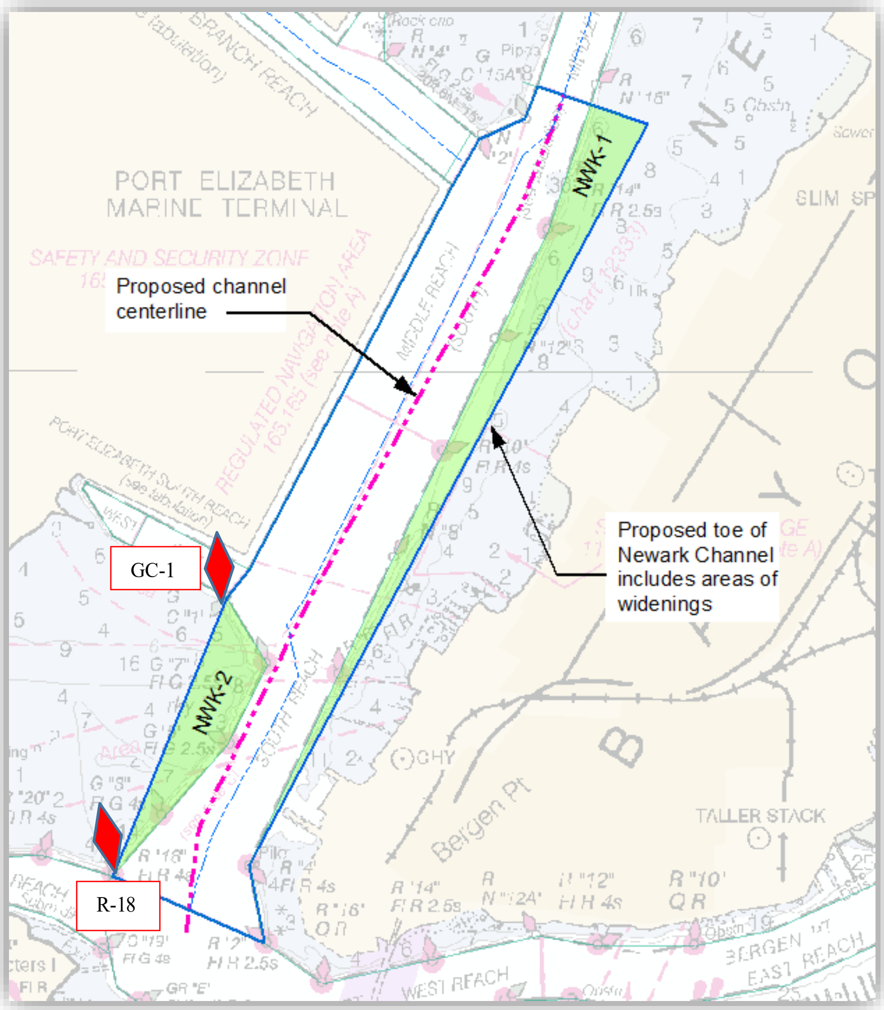

Figure 29. The Newark Bay Channel Footprint is changed by the Addition of Areas NWK-1 and NWK-2. The Proposed Channel Line is shown.

7.1.6. South Elizabeth Channel

South Elizabeth Channel will be deepened by 5 feet from its authorized depth of -50 feet, MLLW. The footprint of South Elizabeth Channel will be increased by the area of SE-1A. This area will allow more room for ships to more safely maneuver in and out of South Elizabeth Channel (Figure 30).

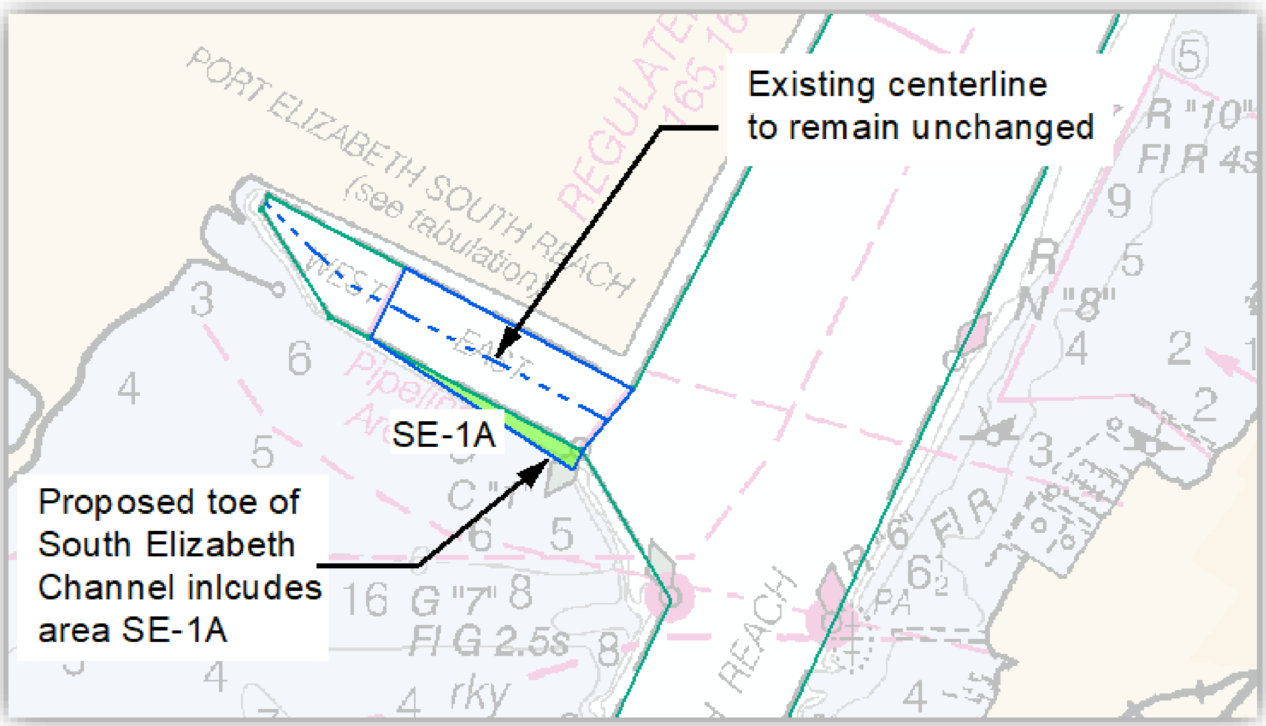

Figure 30. The Footprint of South Elizabeth Channel is Changed by the Addition of Area SE-1A; the Channel Centerline Remains Unchanged.

7.1.7. Port Elizabeth Channel

Port Elizabeth will be deepened by 5 feet from its authorized depth of -50 feet MLLW. The footprint of Port Elizabeth Channel will not be altered.

7.2. Nominal Volumes

Following the preliminary analysis that identified the TSP, more detailed excavation volumes were developed for excavation depths to 4 feet and 5 feet. This refinement reduced some of the uncertainty associated with the preliminary volumes. Developing designs for these two single depths allowed for greater accuracy than the initial effort, which covered a range of depths. Nominal volumes for the TSP are presented in Table 14. Detailed volumes can be found in Attachments 3A and 3B of this appendix.

Table 14. Tentatively Selected Plan, Nominal Volumes

Channel	4 foot Deepening (CY)	5 foot Deepening (CY)
Ambrose Channel	4,137458	5,574,568
Ambrose Rubble Mound	38.000	49,000
Anchorage Channel	2,550,869	3,800,326
Port Jersey Channel	2,743,935	3,002,932
Kill Van Kull Channel	3,237,472	4,369,451
Newark Bay Channel	13,181,145	14,147,552
South Elizabeth Channel	379,170	422,749
Port Elizabeth Channel	854,543	1,023,612

7.3. Operations & Maintenance Dredging Volumes

Estimated increases in annual channel sedimentation, and by extension, increases in O&M dredging requirements, resulting from the widenings proposed here are presented in Table 15. These estimates were calculated by simply multiplying the area of each proposed widening by the derived annual elevation change presented in Table 12, Deposition Volumes and Elevation Change. Increases in O&M dredging requirements resulting from the proposed channel deepenings were not considered here. Increases in O&M dredging requirements resulting are expected to be within the natural variability of the system. It is further noted that the estimates presented in Table 15, when compared to the maintenance dredging history (Table 4), probably represent a high-end estimate. These estimates, while sufficient for this initial phase of this study, will need be refined via sedimentation modeling during the PED phase of this study.

Table 15. Estimated Increases in Annual Channel Sedimentation.

Channel	Widenings	Widening Area (at 56 ft), Square Feet)	Annual Vertical Accretion, Feet	Added Annual Accretion (CY) (O&M increase)
Anchorage	AN-1	5,128,517	0.028	5,318
Port Jersey	PJ-1	1,667,115	0.12	7,409
Kill Van Kull	KVK-1, KVK 3 to 5	1,595,091	0.064	3,781
Newark Bay	NWK-1, NWK-2	6,358,131	0.368	86,658
South Elizabeth	SE-1A	106,447	0.137	540
[1] **Based on ERDC New York/New Jersey Harbor Sedimentation Study, 2020**				

7.4. Optimization of the selected plan

Optimization of the economic analysis found that deepening the channels by 5 feet yielded the greatest economic benefits. This optimization largely focused on the future fleet size and the expected number of ships to call on the Ports of New York and New Jersey. Following this selection, minor adjustments to the selected plan were made. Specifically, some of the side slopes of the proposed widenings within the Kill Van Kull Channel were reduced so that distance between the top of slope and the shoreline are maximized. Also, in the vicinity of the East Bank Shoal along the Ambrose Channel, the side slope was reduced from 10H:1V to 5H:1V, as noted in Section 7.1.1.

8. Relative Sea Level Change

8.1. Introduction

Climate change and global warming have been observed during the 20th and 21st centuries and have resulted in changes in localized sea levels. The 2014 Intergovernmental Panel on Climate Change (IPCC) report states that over the period of 1901 to 2010, the global mean sea level rose by 0.62 feet (IPCC 2014). The U.S. National Climate Assessment (2012) has established a range of global sea level rise predictions for the year 2100 that all predict sea level rise and range in the predicted value from 0.7 feet on the low end to 6.6 feet as a high prediction with intermediate values between the extremes (U.S. National Climate Assessment 2012).

The IPCC also predicts local sea level rise, addressing the localized factors of subsidence and oceanic currents at any particular location. Changes to relative sea level can result from a number of factors including isostatic rebound (a process by which the earth’s crust, having been compressed beneath the weight of glaciers, bounces back), faulting and consolidation of sediments in fill structures, and sediment compression caused by groundwater withdrawals (Boon 2010).

Oceanic currents influence local sea level rise on the Atlantic Coast due to temperature and salinity changes in the Atlantic Ocean, which cause pressure gradients between the Gulf Stream and coastal waters to decrease, which then cause coastal waters to rise (Sallenger et al. 2012). As a result of these factors, local, relative sea level rise (RSLR) on the mid-Atlantic Coast of the United States from North Carolina northward is occurring at approximately twice the global mean rate, and the rate of sea level rise is accelerating both globally and locally.

Observed and reasonably foreseeable global SLR means that local sea levels will continue to rise beyond the end of this century. In most locations, global SLR results in local relative SLC, which has already caused impacts such as flooding and coastal shoreline erosion to the nation's assets located at or near the ocean. These impacts will continue to change in severity. Along the U.S. Atlantic Coast alone, almost 60 percent of the land that is within a meter of sea level is planned for further development. Wise decision-making requires adequate information on the potential rates and amount of SLC. Accordingly, the risks posed by SLC motivate decision-makers to ask: “What is the current rate of SLC, and how will that impact the future conditions that affect the performance and reliability of my infrastructure, or the current and future residential, commercial, and industrial development?" To better empower data-driven and risk-informed decision-making, the USACE has developed two web-based SLC tools: the Sea Level Change Curve Calculator and the Sea Level Tracker. Both tools provide a consistent and repeatable method to visualize the dynamic nature and variability of coastal water levels at tide gauges, allow comparison to the USACE projected SLC scenarios, and support simple exploration of how SLC has or will intersect with local elevation thresholds related to infrastructure (e.g., roads, power generating facilities, dunes), and buildings. Taken together, decision-makers can align various SLR scenarios with existing and planned engineering efforts, estimating when and how the sea level may impact critical infrastructure and planned development activities (USACE, 2018b).

Engineering Pamphlet 1100-2-1, "Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation" (USACE 2019) and Engineering Regulation ER-1100-2-8162, "Incorporating Sea Level Change into Civil Works Programs" (USACE 2013), require planning studies to consider SLC in the development and assessment of planning alternatives and provide guidance on how to incorporate sea level change for civil works projects. The potential impacts of future local relative sea level change (SLC) on navigation structures and the possible adaptations that can be developed to counteract these impacts must be considered in all USACE studies and projects located in tidally influenced waters. Planning studies and engineering designs over the project life cycle, for both existing and proposed projects, should consider alternatives that are formulated and evaluated for the entire range of possible future rates of SLC. Current USACE guidance (ER 1100-2-8162 and ETL 1100-2-1) recommends that analyses assess the effects of SLC on the project at future time periods post-construction, including 20 years, 50 years, 80, and 100 years. Since the rate of future SLC (i.e. feet per century) is uncertain, the guidance specifies that the evaluation should consider the three different SLC curves (low, intermediate, and high) included in the USACE's online SLC calculator.

The use of sea level change scenarios as opposed to individual scenario probabilities underscores the uncertainty in how local relative sea levels will change in the future. At any location, changes in local relative sea level reflect the integrated effects of global mean sea level change plus local or regional changes in geologic, oceanographic, or atmospheric origin.

8.2. Sea Level Change Analysis

8.2.1. Sea Level Change Curve Calculator

The Sea Level Change Curve Calculator is designed to help with the application of the guidance found in ER 1100-2-8162 and EP 1100-2-1. The tools use equations in the regulation to produce tables and graphs for the following three SLC scenarios:

1. Baseline (or "low") estimate, which is based on historic SLR and represents the minimum expected SLC.
2. Intermediate estimate.
3. High estimate, representing the maximum expected SLC.

The calculator accepts user input—including project start date, selection of an appropriate NOAA long-term tide gauge, and project life span—to calculate projected SLCs for the respective project. The Sea Level Tracker has more functionality for quantifying and visualizing observed water levels and SLC trends and projections against existing threshold elevations for critical infrastructure and other local elevations of interest (USACE, 2018b). The start date used by the calculator is 1992, which corresponds to the midpoint of the current National Tidal Datum Epoch of 1983-2001.

The Newark Bay Main, Port Elizabeth, South Elizabeth, KVK, Arthur Kill, Port Jersey, and Anchorage channels were analyzed using data from NOAA station The Battery, NY (#8531680) tide gauge and Ambrose channel was analyzed using data from NOAA Station Sandy Hook, NJ (#8531680) tide gauge. Estimated relative SLC projections from 2020 to 2127 for each gauge used in this study, calculated with the USACE Sea Level Change Curve Calculator are illustrated on Figures 31 and 32. Each figure notes the projected construction start dates, the period of analysis for the proposed deepening (2040-2089) and the adaptation horizon (2040-2139). The adaptation horizon addresses the time of service of the project that can extend past its original design life

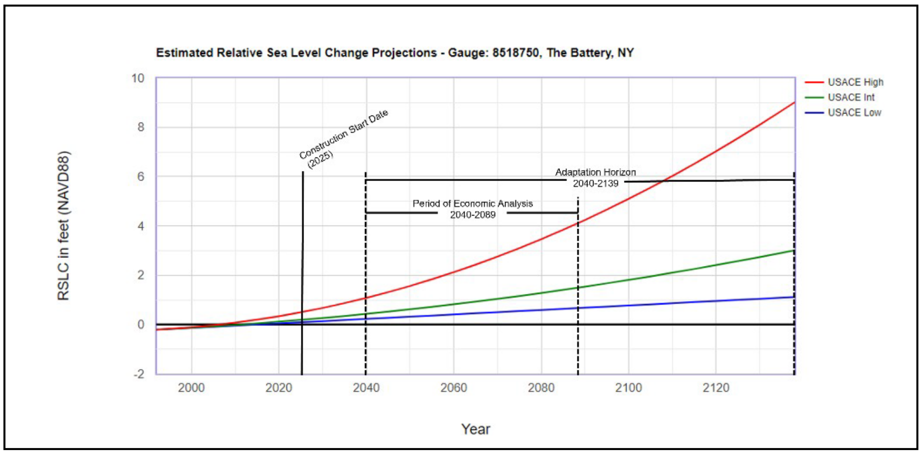

Figure 31. NOAA Gauge: The Battery, NY (#8518750) Relative Sea Level Change Projections, 1992-2139, with HDCI Construction Start Date, Period of Analysis and Adaptation Horizon.

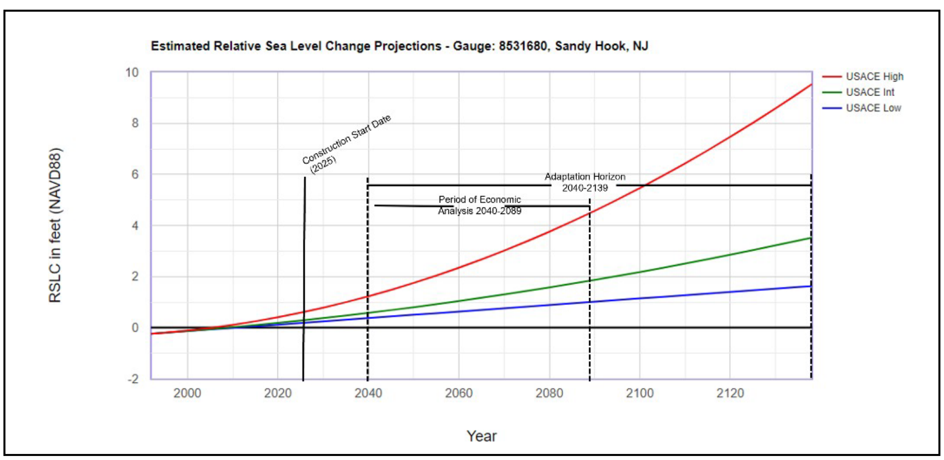

Figure 32. NOAA Gauge: Sandy Hook, NJ (#8518750) Relative Sea Level Change Projections, 1992-2139, with HDCI Construction Start Date, Period of Analysis and Adaptation Horizon.

The sea level change curve calculator data tables, with annual intervals, for each of these gauges are provided in Attachment 6. These tables were used in projecting changes in sea level rise which are applied to the tidal datums of each of the relevant NOAA tide gauges in the section below

8.2.2. Tidal Datum Change Projections

Table 16 shows the projected low, intermediate and high rates of sea level change at The Battery, NY gauge as applied to the 1992 Datums for this NOAA station. Table 17 shows the projected low, intermediate and high rates of sea level change at Sandy Hook, NJ gauge as applied to the 1992 Datums for this NOAA station. The tables note tidal datums in 1992, projected tidal datums for 2025 (the estimated construction start date) and the years 2040, 2059, 2089, 2119 and 2139, which represent years 1, 20, 50, 80 and 100 respectively.

Table 16. Tidal Datum Predictions at NOAA Station The Battery, NY Gauge for the Low, Intermediate and High Rates of Sea Level Change.

Datum	1992	2025 (ft, NAVD88)			2040 (ft, NAVD88)			2059 (ft, NAVD88)		
		LOW	INT	HIGH	LOW	INT	HIGH	LOW	INT	HIGH
MHHW	2.28	2.58	2.68	2.98	2.72	2.98	3.57	2.89	3.29	4.55
MHW	1.96	2.26	2.36	2.66	2.40	2.60	3.25	2.57	2.97	4.23
MTL	-0.30	0.00	0.10	0.4	0.14	0.34	0.99	0.31	0.71	1.97
MLW	-2.57	-2.27	-2.17	-1.87	-2.13	-1.93	1.28	-1.96	-1.56	-0.30
MLLW	-2.77	-2.47	-2.37	-2.07	-2.33	-2.13	-1.48	-2.16	-1.76	-0.50
Datum	**1992**	**2089 (ft, NAVD88)**			**2119 (ft, NAVD88)**			**2139 (ft, NAVD88)**		
		LOW	INT	HIGH	LOW	INT	HIGH	LOW	INT	HIGH
MHHW	2.28	3.16	4.00	6.65	3.43	4.87	9.41	3.62	5.54	11.62
MHW	1.96	2.84	3.68	6.33	3.11	4.55	9.09	3.30	5.22	11.30
MTL	-0.30	0.58	1.42	4.07	0.85	2.29	6.83	1.04	2.96	9.04
MLW	-2.57	-1.69	-0.85	1.80	-1.42	0.02	4.56	-1.23	0.69	6.77
MLLW	-2.77	-1.89	-1.05	-1.60	1.62	-0.18	4.36	-1.43	0.49	6.57

Table 17. Tidal Datum Predictions at NOAA Station Sandy Hook, NJ Gauge for the Low, Intermediate and High Rates of Sea Level Change.

Datum	1992	2025 (ft, NAVD88)			2040 (ft, NAVD88)			2059 (ft, NAVD88)		
		LOW	INT	HIGH	LOW	INT	HIGH	LOW	INT	HIGH
MHHW	2.41	2.83	2.93	3.24	3.02	3.23	3.88	3.27	3.67	4.93
MHW	2.08	2.50	2.60	2.91	2.69	2.9	3.55	2.94	3.34	4.60
MTL	-0.27	0.15	0.25	0.56	0.34	0.55	1.20	0.59	0.99	2.25
MLW	-2.62	-2.2	-2.1	-1.79	-2.01	-1,80	-1.15	-1,76	-1.36	-0.10
MLLW	-2.82	-2.40	-2.30	-1.99	-2.21	-2.00	-1.35	-1.96	-1.56	-0.30
Datum	**1992**	**2089 (ft, NAVD88)**			**2119 (ft, NAVD88)**			**2139 (ft, NAVD88)**		
		LOW	INT	HIGH	LOW	INT	HIGH	LOW	INT	HIGH
MHHW	2.41	3.65	4.49	7.14	4.04	5.47	10.02	4.29	6.21	12.29
MHW	2.08	3.32	4.16	6.81	3.71	5.14	9.69	3.96	5.88	11.96
MTL	-0.27	0.97	1.81	4.46	1.36	2.79	7.34	1.61	3.53	9.61
MLW	-2.62	-1.38	-0.54	2.11	-0.99	0.44	4.99	-0.74	1.18	7.26
MLLW	-2.82	-1.58	-0.74	1.91	-1.19	0.24	4.79	-0.94	0.98	7.06

8.3. Potential Impacts of Sea Level Change

Potential Impacts of sea level change on a number of project features are discussed below. Further analysis is, however, recommended during the PED phase to better understand the possible impacts of climate change in general and sea level change in particular. An inland hydrology analysis is also recommended (see section 9.5) as this may have impacts on sedimentation and other concerns.

8.3.1. Potential Impacts on TSP Depth Selection

Sea level change could theoretically impact the depth of the selected plan as the cumulative increases in channel depths brought about by sea level change may negate the need for additional deepening, particularly in the latter years of the project's period of analysis. The proposed project and all channel depths are, however, referenced to MLLW, which will rise along with rising seas. In addition to this, consideration of sedimentation is critical to this question as it will largely serve to offset any 'benefits" of SLC; if the annual rate of vertical accretion eclipses the rate of SLC, there will be no realized benefit.

The impact of sea level change, which increases channel depth, and sedimentation, which decreases channel depth, on the TSP, were compared for selected channels. When sedimentation is considered, it is concluded that sedimentation outpaces SLC, in all channels, for the low and intermediate curve and outpaces the high curve for all channels within the inner harbor. The rate of SLC for the high curve outpaces sedimentation only in Anchorage and Ambrose channels. SLC, therefore, does not serve to provided additional clearance in almost all instances and has little to no impact on the final selection of the Tentatively Selected Plan.

Calculated elevation changes due to both accretion and SLC are shown in Table 18 for Kill Van

Kull, Anchorage, Anchorage North and Ambrose Channels for Years 20 and 50 of this study. The comparison of elevation change for Kill Van Kull shows that the accretion rate outpaces SLC under all scenarios (low, intermediate and high). While SLC will presumably lessen the volumes and/or frequency of maintenance dredging, SLC changes have no impact on the selection of the-selected plan, as there will be no net gain of clearance realized. The remaining channels that were considered all have calculated accretion rates greater than Kill Van Kull. The same conclusion can, therefore, be applied to these channels.

Table 18. Kill Van Kull Channel Calculated Accretion Elevation Change and Sea Level Change

	KVK accretion, vertical elevation change, total (ft)	Ambrose accretion vertical elevation change, total (ft)	Anchorage accretion, vertical elevation change, total (ft)	Anchorage North accretion, vertical elevation change, total (ft)	SLC, WSE elevation change, total, ft		
					LOW	INT	HIGH
Year 20	1.34	0.92	0.86	0.56	0.17	0.37	0.98
Year 50	3.35	2.3	2.15	1.4	0.44	1.08	3.08

For Anchorage, Anchorage North and Ambrose Channels the calculated net accretion at years 20 and 50 is greater than the predicted SLC changes under the low and intermediate curves. For these channels, SLC changes under the high curve do outpace accretion but not at a rate that would yield any appreciable gains in clearance, particularly during the early part of the study period. (i.e the net gain for Anchorage Channel at year 20 is 0.1 ft and is 0.86 ft at year 50).

It is acknowledged that the above analysis is an oversimplification as accretion in the channels does not result in consistent elevation changes but this does not negate the conclusion; just as sedimentation will occur in a complex and irregular manner, any benefits gained for sea level change will be equally inconsistent. It is, therefore, concluded that this project cannot reasonably expect to realize SLC benefits at a time scale and consistency that would impact the selection of the TSP, given the fact that sedimentation outpaces SLC in a large majority of the study area, under most of the range considered by the SLC curves. Further, even if sedimentation were neglected the additional underkeel clearance would be in later years of the project. Thus, when annualized, they would contribute little to the net benefits.

A fuller analysis of both sedimentation and the impacts of the proposed actions on future maintenance volumes will need to be conducted during PED. This is noted in Section 9 of the Channel Design Appendix (Further Analysis and Design Development Needs).

8.3.2. Potential Impacts on O&M Maintenance Requirements

As previously noted, it is anticipated that SLC will yield an incremental decrease in O&M dredging requirements given the fact that all authorized depths are referenced to MLLW. MLLW will increase with rising sea levels yielding a theoretical decrease in O&M dredging requirements (dredging volumes and frequency) that is proportional to the volume of water added within the project channel area. The actual realized decrease in O&M maintenance dredging is also expected to be less due to the complex shoaling patterns observed in maintenance surveys. Projected decreases in O&M dredging requirements were not calculated due to this fact as well the wide possible range of sea level change seen in the three curves.

8.3.3. Potential Impacts on Bridge Clearance and Trafficability

RSLC can also have a negative impact on trafficability under bridges as rising sea levels decrease bridge clearance. The design vessel, the Maersk Triple E, has a total height of 239.5 ft and a fully loaded water draft of 52.5 ft. This results in a total air draft is 187 feet. Clearance at the Verrazano bridge is 228 ft MHW, resulting in an air gap of 41 ft at MHW. The sea level change calculator for Sandy Hook, indicates an absolute water surface elevation change of 1.24, 2.08 and 4.73 ft, at year 50 (2089), respectively for the low, intermediate, and high curves, relative to 1992, the mid-point of the NOAA 1982-2001 Epoch. At year 100 (2139), the sea level change calculator indicates an absolute water surface elevation change of 1.88, 3.80, and 9.88 ft. This indicates that future RSLC will not impact the trafficability of the Maersk Triple E under the Verrazano Bridge for the period of analysis and adaptation horizon. The Bayonne Bridge has a maximum clearance of 215 ft MHW, resulting in an air gap of 28 ft at MHW. The sea level change calculator for The Battery, indicates an absolute water surface elevation change of 0.88, 1.72 and 4,37 ft, at year 50 (2089), respectively for the low, intermediate, and high curves. At year 100 (2139), the sea level change calculator indicates an absolute water surface elevation change of 1.34, 3.26, and 9.34 ft, relative to 1992, the mid-point of the NOAA 1982-2001 Epoch. This indicates that future RSLC will not impact the trafficability of the Maersk Triple E under the Bayonne Bridge for the for the period of analysis and adaptation horizon.

8.3.4. Potential Impacts on Dockside Infrastructure

As noted previously, the potential impacts of future local relative sea level change (SLC) on

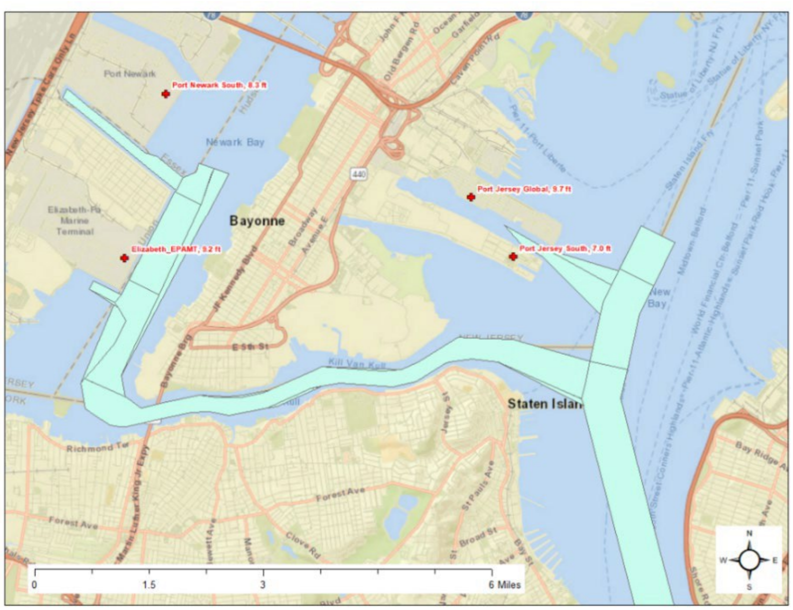

Figure 33. HDCI Wharves with Base Elevations, ft, NAVD88

navigation structures and the possible adaptations that can be developed to counteract these impacts must be considered in all USACE studies and projects located in tidally influenced waters. The proposed improvements provide deepened access to four wharves within NY Harbor. These wharves and the base elevation of each of these are shown in Figure 33. Figure 34 illustrates the base elevation of the lowest two of these wharves, Port Jersey South (Base elevation of 7.0 ft NAVD88) and Port Newark South (Base elevation of 8.3 ft NAVD88) in relation to the three projected sea level curves for NOAA

As can be seen in Figure 34, there will be no impacts to the dockside infrastructure if the low or intermediate projected curves are realized. In addition to producing the projected curves and RSLC change tables, the Sea Level Change Curve Calculator produces a curve intersection table that outputs the year that each curve intersects with the critical elevations input by the user, which in this instance is the base elevation of Port Jersey South and Port Newark South. This output is presented in Table 19 and shows that if the projected high curve is realized, MSL will intersect the base elevation of Port Jersey South in 2119 and Port Newark South in 2131. These dates are well outside of the projects period of analysis which is projected to end on or around 2089. SLC impacts are however projected to occur within the 100-year adaptation horizon which is projected to end in 2139.

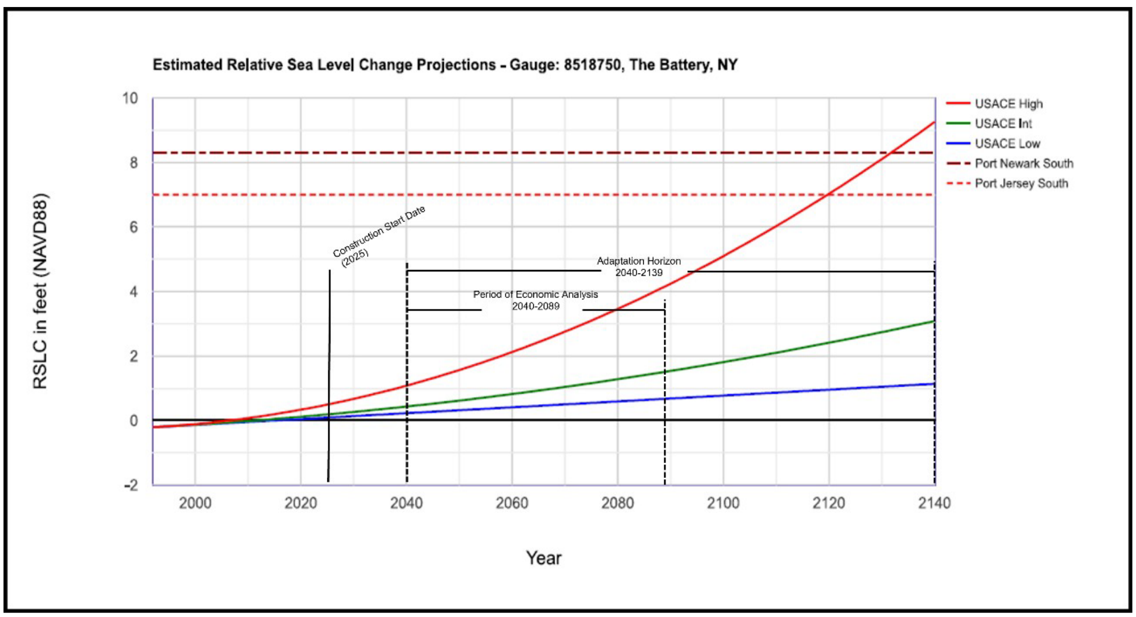

Figure 34. NOAA Gauge: The Battery, NY (#8518750) Relative Sea Level Change Projections, 1992-2140, with select NY Harbor Wharf Elevations.

Table 19. Sea Level Change Calculator Curve Intersection Output

Curve	Port Jersey South (yr)	Port Newark South (yr)
USACE High	2119	2131
USACE Intermediate	2230	2254
USACE Low	N/A	N/A

Table 20 presents the years that, if the projected high curve is realized, MHHW, MHW and MSL will intersect with the base elevations of these selected wharves. The earliest of these dates, 2096 for Port Jersey South and 2210 for Port Jersey South provide an approximate date when mitigation strategies for each of these locations must by fully implemented if RSLC in NY Harbor tracks along the high curve.

Table 20. Projected High Curve Datum and Base Elevation Intersection Dates for selected NY Harbor Wharves

Datum	Port Jersey South (yr)	Port Newark South (yr)
MHHW	2096	2110
MHW	2100	2114
MSL	2119	2131

The impacts of sea level change on shore side infrastructure is explicitly considered in the PANYNJ's Sustainability Policy which directs the Authority to "develop strategies that reduce the risk posed by climate change to its facilities and operations and, in collaboration with other regional stakeholders, develop strategies that mitigate the risk to the region posed by climate change in a manner that will promote a sustainable environment." The PANYNJ has also issued climate resilience design guidelines and sustainable infrastructure guidelines in their effort to extend project life cycles, reduce future operational costs and develop resiliency strategies. One resilience strategy to be implemented by PANYNJ is to reconstruct wharves with greater structural strength at the time of replacement, thereby imbuing the structure with capacity to adapt to sea level change in the future. Should the high rate of sea level change be realized, possible mitigation strategies at Port Jersey South and Port Newark South include elevating the deck and/or constructing a perimeter floodwall, which would be supported by the previously reinforced wharf structure. Additional measures include backflow preventers on drainage outfalls and stormwater pumps. PANYNJ will also protect continuity of terminal operations by mitigating flood risk from sea level change-intensified storm surge events by elevating or floodproofing critical electrical and mechanical equipment throughout the sites

9. Further Analysis and Design Development Needs

No new data were collected for this feasibility study, commensurate with risk informed decision-making. Data from the prior harbor deepening study were located from the NY District archives and utilized to the fullest extent possible. Data collection and analysis to be conducted during the PED phase are discussed below. The design development concerns discussed are limited to those efforts related to channel design. This discussion of data and analysis needs should therefore not be considered comprehensive.

9.1. Topographic & Bathymetric Surveys

eHydro surveys are collected with multi-beam sonar equipment that provide high-density point coverage of the entire area within the channels. Equally high-resolution data for the channel walls and the flats areas directly adjacent to the channels are also needed. Topographic survey points should be taken along and inside the shoreline, and bathymetric survey points should be taken offshore for those channels in developed areas (with the exception of Ambrose Channel and Lower Anchorage Channel). For this study, the ehydro data was supplemented with publicly available 1/9th arc-second data (discussed in Section 6.1.2) The cost risk of the uncertainty associated with the use of public bathymetric data is judged to be significant and will be greatly mitigated by the collection of high-resolution data during the PED phase.

9.2. Geotechnical

Additional borings and geotechnical surveys (i.e seismic, electrical resistivity, magnetic, and sidescan sonar) will be needed to more accurately determine excavated material type. This is especially true for areas outside of the existing channel limits where little to no data is available. Additional data on material type and condition is also needed for the lower limits of proposed excavation and in certain areas of channel walls.

It is expected that significant quantities of consolidated rock that were previously too compacted to be dredged without pretreatment will be found ready for excavation, already fractured, as a result of prior blasting efforts during the previous harbor deepening effort. Some if this material will therefore be clearable without any drilling or blasting and will be easily broken and scraped with a backhoe prior to new blasting. Additional investigations may identify these locations of looser material, potentially saving cost and environmental consequences. Test pits may also provide a better understanding of the depth of this fractured rock. These geotechnical considerations are a source of significant uncertainty and represent a significant cost risk to the present conclusions of this study.

9.3. Hazardous, Toxic and Radioactive Waste (HTRW)

Assumptions as to whether the excavated material is HARS-suitable or in need of upland disposal were based on data collected from the prior deepening project. It was assumed that any sediment on the eastern half of the KVK was considered to be HARS-suitable; any sediment on the western half was considered to be non-HARS suitable. Additional data collection will be needed to verify these assumptions. As with the geotechnical data, there is little to no available data for ears outside of the federal channel limits, so this will need to be an area of focused data collection. As with the geotechnical data, there is a significant cost risk due to the need for better HTRW data.

9.4. Hydrodynamic Data Collection

The collection of water surface elevation, current velocity data, and wind velocity data may be warranted to both provide insight at critical project locations and to support the validation of an updated hydrodynamic and sediment model. The necessity and distribution of this data collection effort should be considered and developed in collaboration with harbor and docking pilots, and the developers of both the recommended hydrodynamic and sediment model (discussed below) and ship navigation models (discussed below).

9.5. Inland Hydrology

As previously noted, climate induced changes to inland hydrology may significantly alter the flows received by the study area. For NY Harbor this encompasses the Hudson River as well as all the tributaries that feed into it. For Newark Bay, this includes the Passaic and Hackensack Rivers. A more detailed analysis of the hydrologic trends observed in these areas is therefore warranted. A qualitative analysis using the suite of tools developed by USACE (including nonstationarity detection, climate hydrology assessment and vulnerability assessment), in accordance with ECB 2018-14, is required during the PED phase as well as a quantitative assessment of flow and resulting sedimentation changes using the modeling tools discussed in Section 9.6.

9.6. Hydrodynamic and Sediment Modeling and Analysis

A comprehensive hydrodynamic modeling study of the NY & NJ Harbor was conducted by the USACE Engineer Research and Development Center's Coastal Hydraulics Laboratory (USACE ERDC-CHL, November, 2020) to capture the with and without project conditions of the previous harbor deepening study, completed in 2012. Numerical simulation modeling was conducted to determine the effects of deepening the harbor channels to their current depths. The modeling results were examined to ascertain those locations within the channels that might experience increases or decreases in sediment transport and deposition. The results indicated that the increase in channel depth had an insignificant increase in sediment deposition due to the increased channel depths.

An updated model will be necessary, using the current channel depths as the existing conditions, as well as the measures proposed here as the improved condition. The model will be provide need water velocity data for the ship navigation modeling effort discussed in Section 9.6. The model will be further needed to determine the impacts of the proposed measures on the sediment transport and deposition patterns of the current system and the changes to the spatial and temporal distribution of salinity within the study area. Hydrodynamic and wave modeling will also be necessary to fully understand the impacts of the proposed widening and deepening actions on wave-surge, storm surge, and erosion within the project area and adjacent areas. Changes in hydrodynamics and salinity both will affect how the design ship responds to further deepening of the channels, as well as how aquatic organisms respond.

The model might also be used to explore the impact of climate change on the future with project condition as changes to inland hydrology (increases in flow) and precipitation may have adverse impacts in terms of sedimentation, salinity, and scour at critical areas.

A thorough analysis of the impacts of the proposed measures on the sedimentation and deposition processes in the study area will be needed to gauge the changes in maintenance dredging that can be expected and to the analyze impacts of the proposed measures on the sedimentation and deposition processes in the study area. The model will also provide insight into the appropriate excavation methods to remove material from the existing channels and areas of widening. The churning and suspension of sediments generated by the dredging operations can have a negative effect on aquatic organisms that pass through the suspended sediments in the water column. Additionally, these sediments can settle in the habit areas of vertebrate and invertebrate species, which can potentially be harmful to those organisms.

In a dynamic tidal environment such as NY & NJ Harbor, suspended sediments can possibly be carried for great distances from the dredging operations. This is of particular concern, especially for those channels in which excavated material is considered to be non-HARS suitable. Suspended sediments from these channels can potentially be carried to those channels whose sediments are considered to be HARS-suitable.

Sedimentation modeling will be conducted during the PED phase of study to address Total Suspended Solids (TSS) and other characteristics. While hydrodynamic, sediment and salinity modeling are clearly needed to fully analyze this project, the risk pf proceeding to the PED phase without this analysis is judged to be low.

9.7. Ship Navigation Modeling

Ship navigation modeling was initially planned for the preliminary portion of this feasibility study. Navigation modeling was to be conducted at the ERDC Ship/Tow simulator in Vicksburg, MS with assistance from members of the various harbor and docking pilots associations within NY and NJ Harbor. Pilots were planned to pilot a simulated Maersk Triple E class ship at the ERDC facility to determine whether the proposed channel widenings are sufficient for a range of weather, current, tide and traffic scenarios. Approximately 40 modeling inbound and outbound scenarios are proposed. It was, however, determined that, given the array of alternatives being considered, the results of this modeling would not impact the selection of the tentatively selected plan. It was decided that this modeling could be prudently postponed and is now recommended for the PED phase of this study. Although the widenings take into account suggestions made by the pilots to address the projected navigational difficulties they would experience within the existing channels, it is possible that efficiencies may be found, yielding decrease in excavation volumes and project costs. Ship Navigation Modeling must fully consider the hydrodynamic impacts of the proposed deepening and widenings and analyze the performance of the design vessel in this improved condition environment.

Prior to the navigation modeling at the ERDC Ship/Tow simulator in Vicksburg, MS, SHIPMA by Marin (Delft) may prove useful. SHIPMA is a fast-time simulation program that uses auto-pilot and algorithms for tugs and additional maneuvering devices such as bow and stern thrusters, allowing for the rapid simulation of proposed measures under a variety of different environmental. The use of this tool prior to physical simulations may reduce the number of scenarios needed during Piloted simulations.

In addition to the ship navigation modeling, a vertical ship motion study using the Channel Design Analysis and Design Tool (CADET) is recommended. The CADET model will be used to predict vertical ship motions due to wave-induced heave, pitch and roll; squat and underkeel clearances will also be evaluated. The outputs of the model will be used to make informed judgments about the optimum channel depths for the ship loading conditions.

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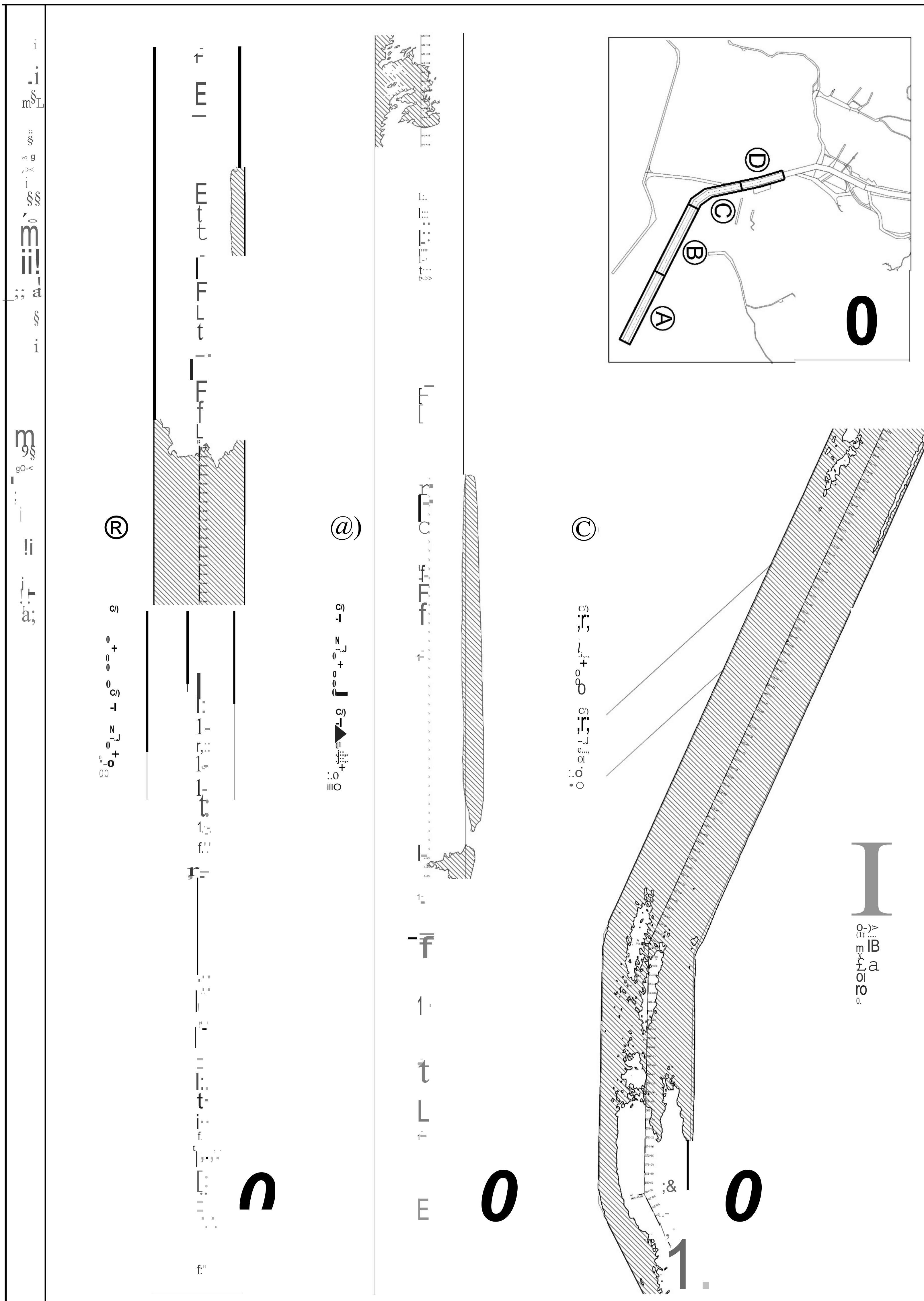
ATTACHMENT 1

CHANNEL DESIGNS AND CROSS-SECTIONS



HUDSON RIVER CHANNEL IMPROVEMENTS PROJECT

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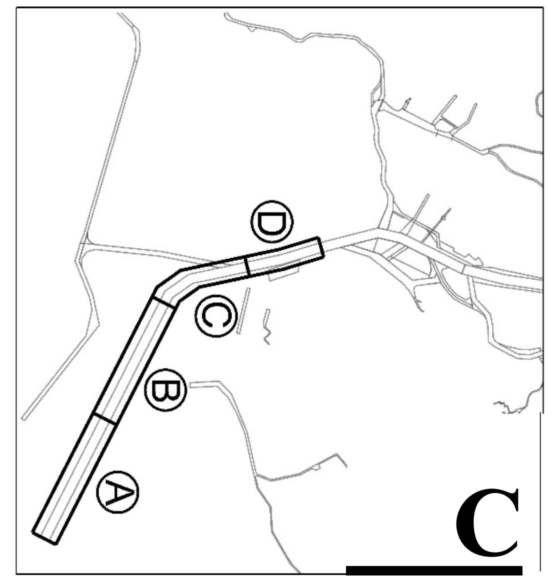

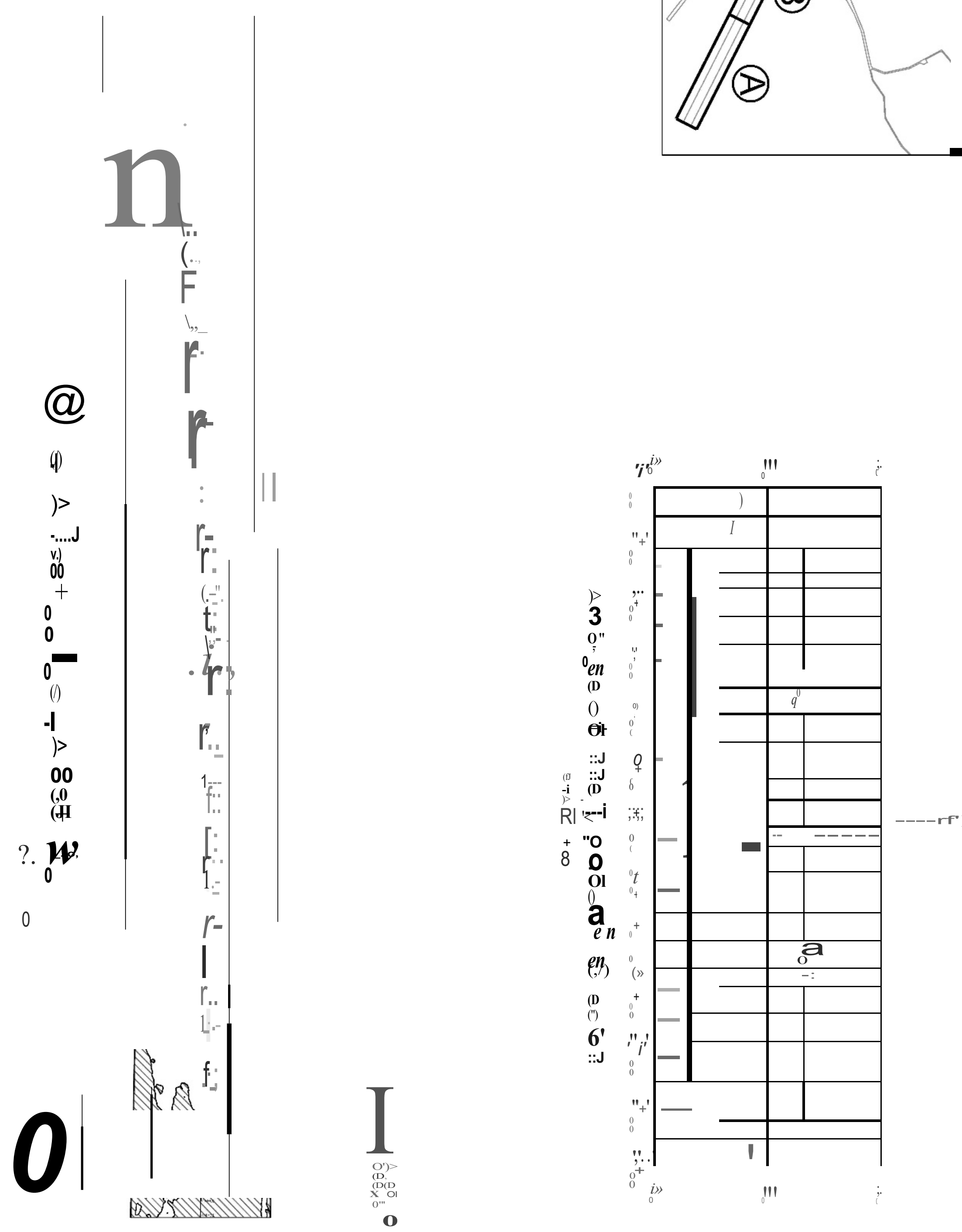

HUDSON RIVER CHANNEL IMPROVEMENTS PROJECT

AMBROSE CHANNEL

NEW YORK & NEW JERSEY HARBOR, USA

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DESIGNED BY GSW

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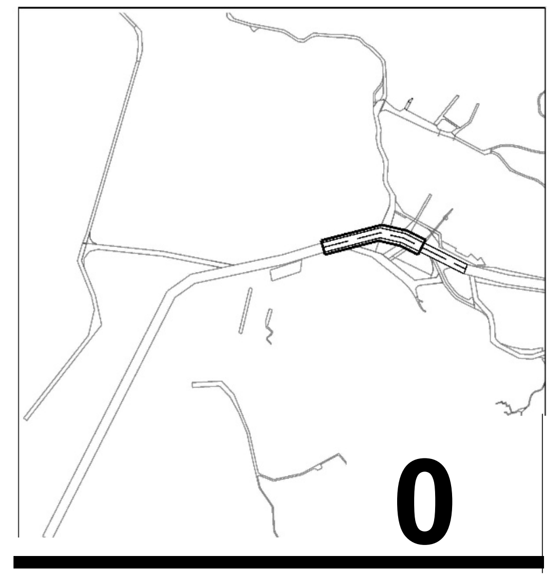

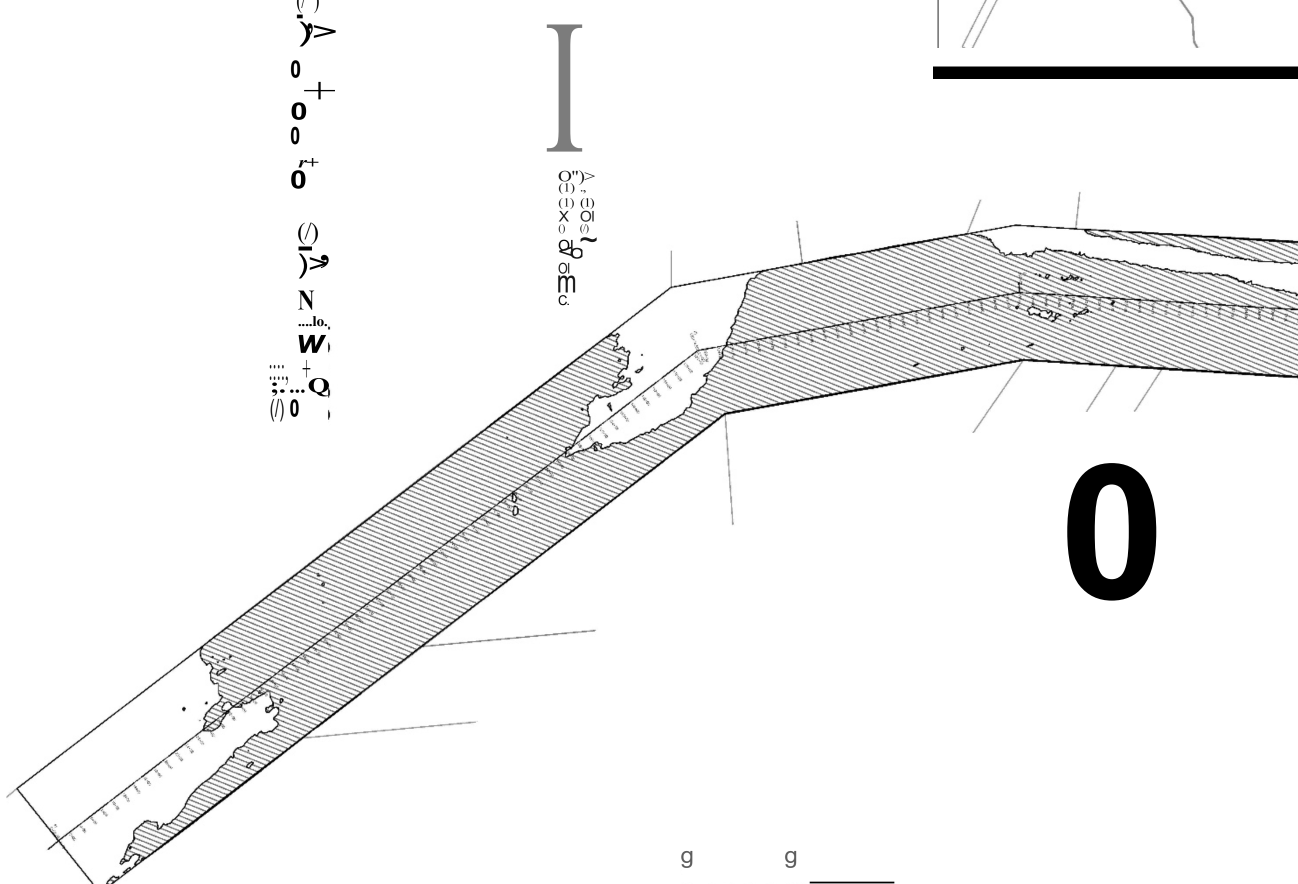

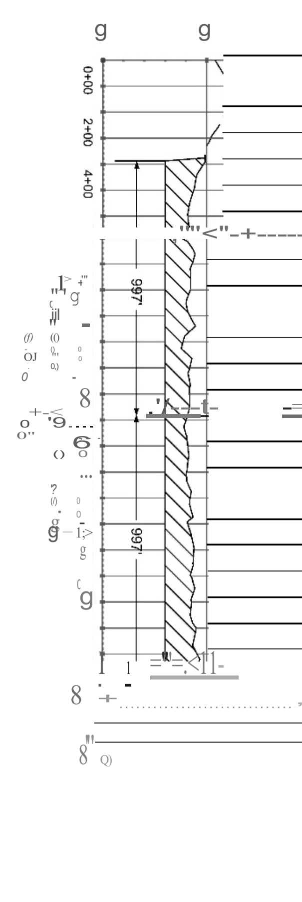

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CIVIL RESOURCES BRANCH

ECOSYSTEM RESTORATION TEAM

CENAN-EN-H

DESCRIPTION

DATE

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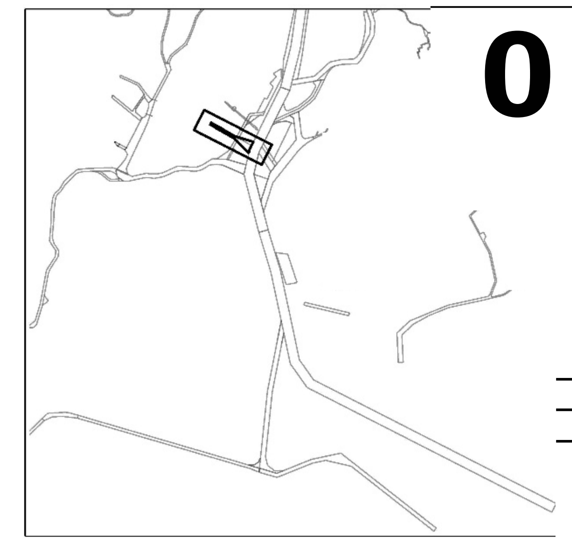

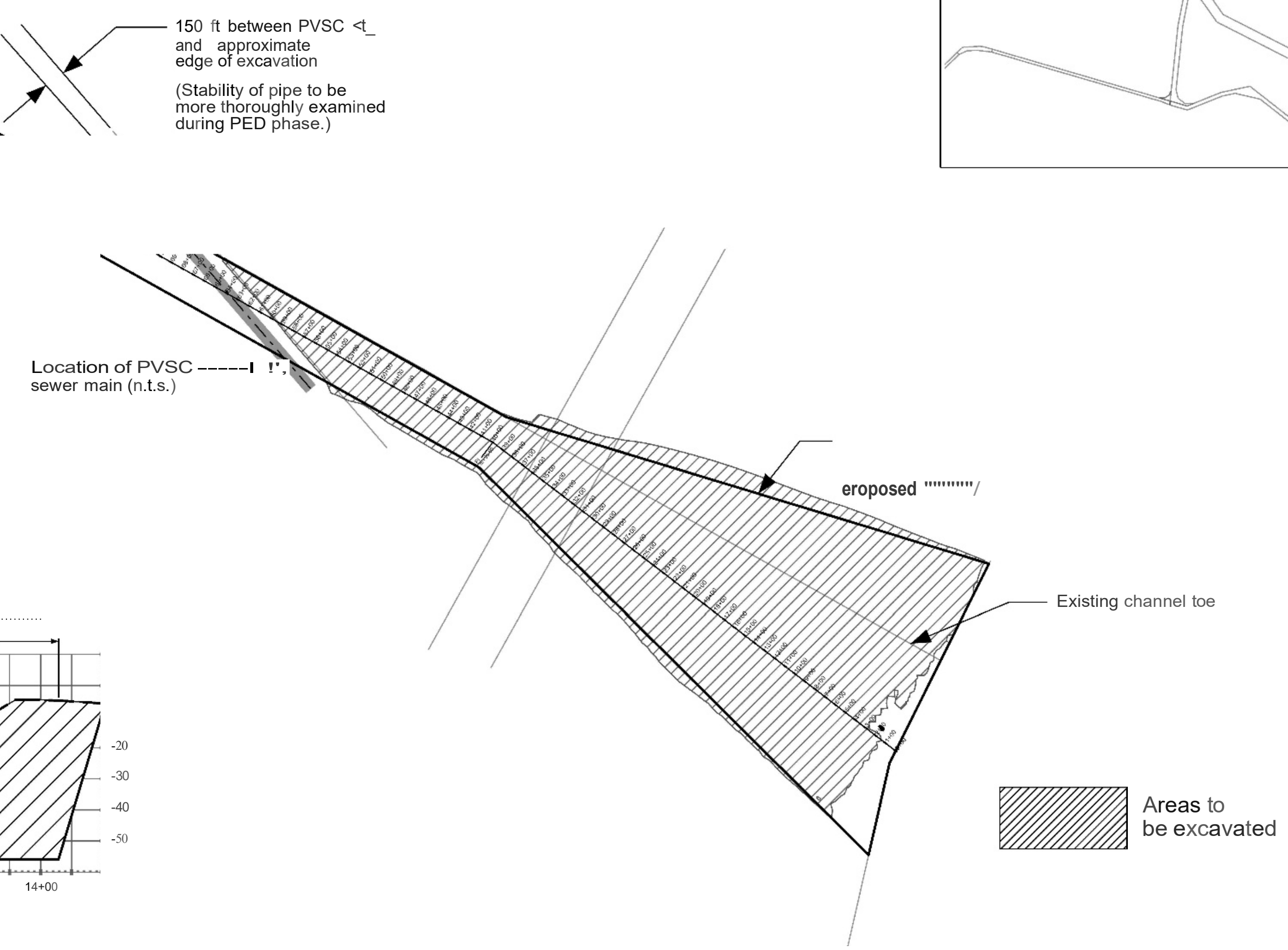

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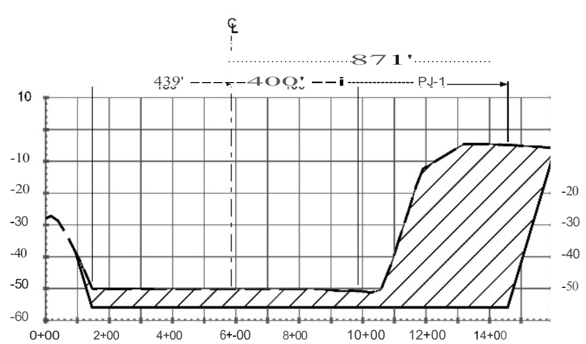

Typical Cross-Section
STA 23+00

A

US Army Corps
of Engineers
New York District

IMPROVEMENTS PROJECT

NEW YORK & NEW JERSEY HARBOR, USA

SHEET
REFERENCE
NUMBER

ALL DIMENSIONS & EXISTING CONDITIONS SHOWN SHALL BE CHECKED AND VERIFIED BY THE CONTRACTOR AT THE SITE. ANY DISCREPANCIES SHALL BE IMMEDIATELY REPORTED TO THE GOVERNMENT FOR CLARIFICATIONS. DRAWINGS SHALL NOT BE SCALED TO OBTAIN DIMENSIONS OR DISTANCES.

MAY 2009 NYD BORDER

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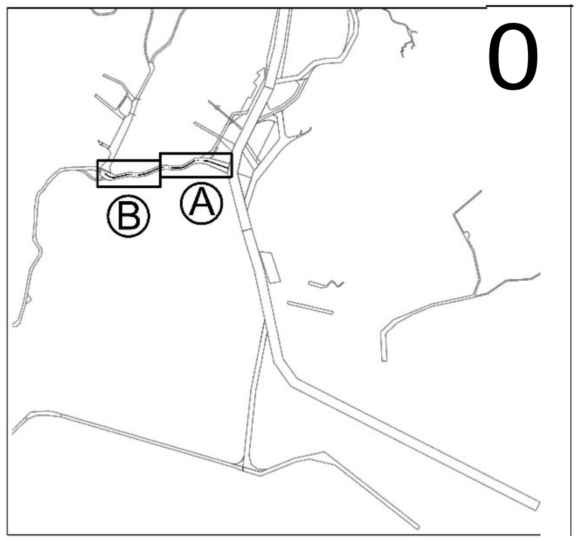

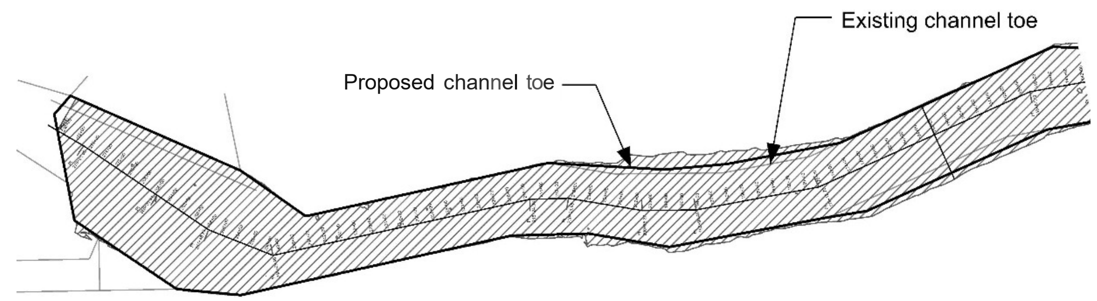

Ⓡ **STA 144+00 to STA 280+47**

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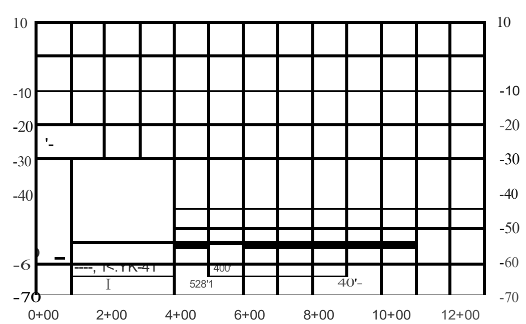
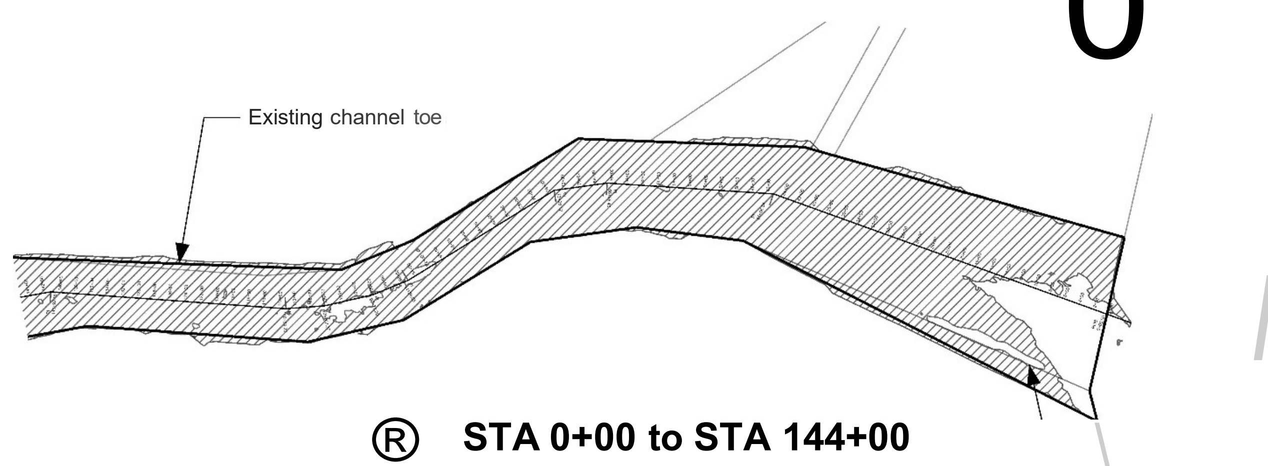


Kill Van Kull
Typical Cross Section
STA 162+00

Areas to be excavated



Ⓡ **STA 0+00 to STA 144+00**

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ALL DIMENSIONS EXISTING CONDITIONS SHOWN SHALL BE CHECKED AND VERIFIED BY THE CONTRACTOR AT THE SITE. ANY DISCREPANCIES SHALL BE IMMEDIATELY REPORTED TO THE GOVERNMENT FOR CLARIFICATIONS. CAUTION: SHALL NOT BE SCALED TO OBTAIN DIMENSIONS OR DISTANCES.

US Army Corps of Engineers
New York District

SHEET REFERENCE NUMBER

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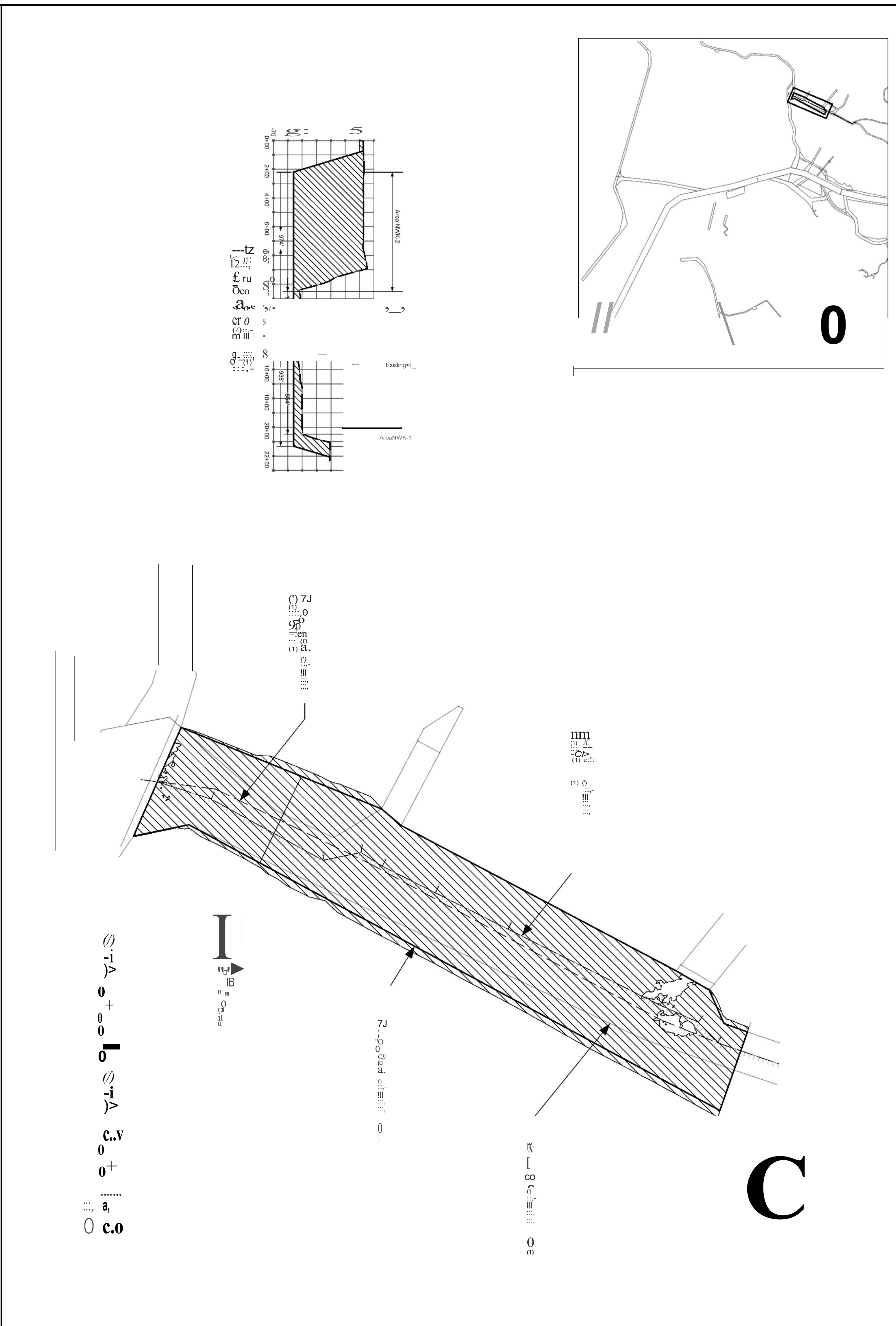

HUDSON RIVER CHANNEL IMPROVEMENTS PROJECT

NEWARK BAY CHANNEL

NEW YORK & NEW JERSEY HARBOR, USA

NEW YORK

http://www.nan.usace.army.mil

CIVIL RESOURCES BRANCH
ECOSYSTEM RESTORATION TEAM
CENAN-EN-H

MAY 2009 NYD BORDER

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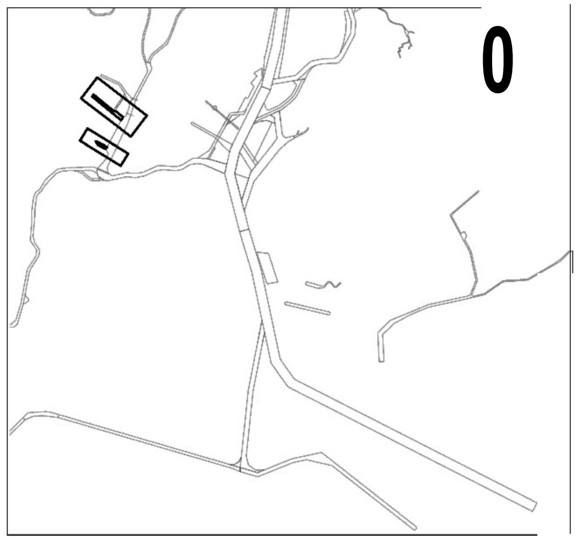
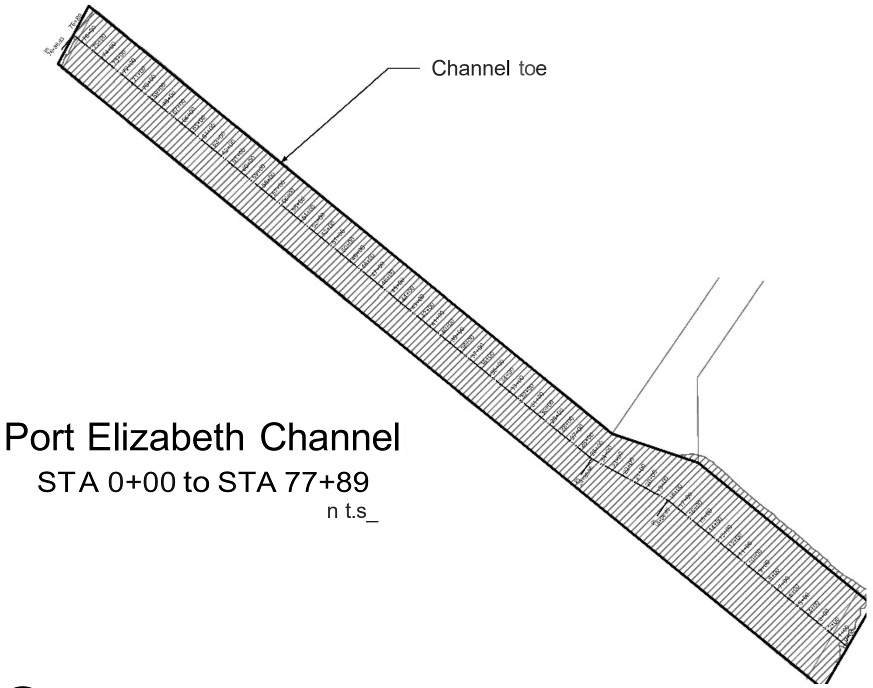
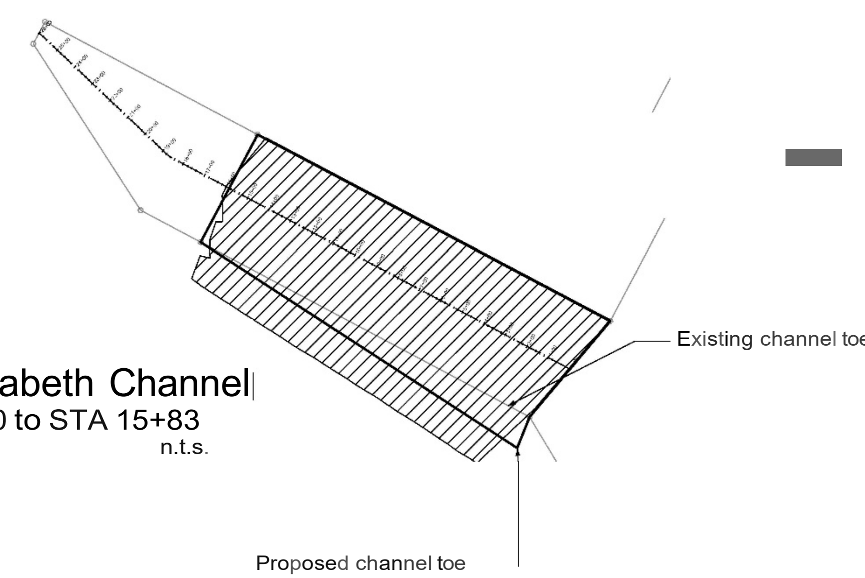


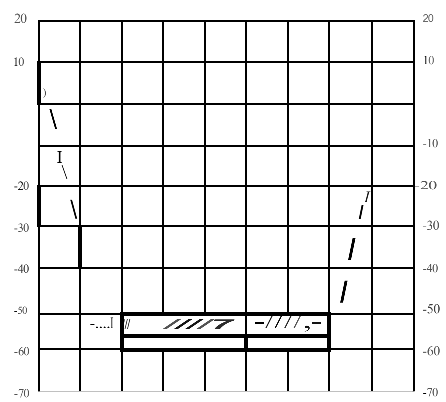


Port Elizabeth Channel
STA 0+00 to STA 77+89
n.t.s.

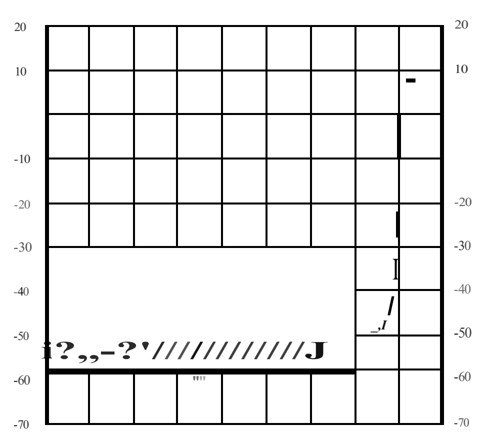


South Elizabeth Channel
STA 0+00 to STA 15+83
n.t.s.

Areas to be excavated



Port Elizabeth Typical Cross Section
STA 38+00



South Eliz.abeth Typical Cross Section
STA6+00

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US Army Corps
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New York District

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ATTACHMENT 2

PRELIMINARY QUANTITIES

Ambrose Channel

Channel Segment	Station Begin Sta	Station End Sta	54 ft Volume (cy)	56 ft Volume (cy)	58 ft Volume (cy)	60 ft Volume (cy)	
			Total excavation volumes from MLLW=0 to the depth indicated				
A	0	5000	-	-	-	-	-
B	5000	10000	-	-	-	-	
C	10000	15000	-	40,901	258,688	601,183	
D	15000	20000	1,502	163,862	734,028	1,408,763	
E	20000	25000	10,923	51,373	178,724	397,140	
F	25000	30000	90	13,653	93,524	279,229	
G	30000	35000	829	10,165	47,180	118,427	
H	35000	40000	67,883	104,272	164,970	254,424	
I	40000	45000	98,438	133,075	176,633	230,799	
J	45000	50000	-	-	848	2,781	
K	50000	55000	4,216	37,430	207,593	491,950	
L	55000	60000	17,522	147,649	515,009	1,018,791	
M	60000	65000	16,811	280,834	935,792	1,699,169	
N	65000	70000	86,984	252,249	996,910	1,762,902	
O	70000	75000	442	79,261	747,414	1,505,023	
P	75000	80000	3,187	21,252	123,288	332,222	
Q	80000	85000	15,379	52,137	140,583	277,871	
R	85000	90000	-	1,633	6,105	13,332	
Total			324,207	1,389,742	5,327,290	10,394,005	

Ambrose Rock Mound 54.0 ft is average as-built-elevation

Volume above Grade

Ambrose Rock Mound 40 27' 50.4" N, 73 50' 7.5" W	Design Depth	Total Area above Grade (sf)	Total Area above Grade (ac)	Total	Contaminated sediment	Non-contaminated sediment	Sandstone (Hardest)	Other Rock (Hardest) (REEF DISPOSAL)	Recent Black Silt	Pleistocene Silt and Clay (Moderately Hard)		Moderately hard Rock	Harder rock	Hardest rock
Ambrose Rock Mound	**52'**	**910,000**	**20.89**	**-**	**-**			-						-
	53'			**-**	**-**			-						-
	54'			**2,000**	**-**			**2,000.00**						**2,000**
	56'			**25,000**	**-**			**25,000.00**						**25,000**
	58'			**49,000**	**-**			**49,000.00**						**49,000**
	60			**68,000**	**-**			**68,000.00**						**68,000**
Projected Future														

						Volume above Grade (cumulative)					
Channel	**Reach**	**Reach-specific Geotech Notes**	**Design Depth**	**Total Area above Grade (ac)**		**Total**	**Contaminated sediment (non-HARS)**	**Non-contaminated sediment**	**Moderately hard Rock**	**Harder rock**	**Hardest rock**
				SQ FT	**ACRES**						
ANCHORAGE	Anchorage A	Homgenous, Sand	**52'**	2,384,010	55	**155,862**		**155,862**			
			54'	4,828,752	111	**319,326**		**319,326**			
			56'	6,271,614	144	**677,866**		**677,866**			
			58'	10,419,552	239	**1,148,042**		**1,148,042**			
			60'	10,018,800	230	**1,733,763**		**1,733,763**			
	Anchorage B	Homgenous, Sand	**52'**	10,099,289	232	**293,035**		**293,035**			
			54'	12,617,525	290	**986,034**		**986,034**			
			56'	13,058,820	300	**1,903,959**		**1,903,959**			
			58'	13,500,115	310	**2,881,035**		**2,881,035**			
			60'	12,980,880	298	**3,864,509**		**3,864,509**			
	Anchorage Bend Lower	Homgenous, Sand	52	2,484,011	57	**107,653**		**107,653**			
			54'	3,161,441	73	**280,802**		**280,802**			
			56'	4,403,408	101	**513,926**		**513,926**			
			58'	4,892,659	112	**832,050**		**832,050**			
			60'	4,704,480	108	**1,183,652**		**1,183,652**			
	Anchorage Bend Upper	Homgenous, Sand	52'	5,693,285	131	**396,632**		**396,632**			
			54'	7,039,872	162	**814,769**		**814,769**			
			56'	7,361,928	169	**1,337,791**		**1,337,791**			
			58'	7,610,803	175	**1,875,601**		**1,875,601**			
			60'	7,318,080	168	**2,423,802**		**2,423,802**			
	Anchorage C	Homgenous, Sand	52'	1,037,808	24	**108,167**		**108,167**			
			54'	2,239,559	51	**193,337**		**193,337**			
			56'	2,497,800	57	**358,061**		**358,061**			
			58'	2,582,237	59	**541,553**		**541,553**			
			60'	2,482,920	57	**732,089**		**732,089**			
	Anchorage AN-1	Homgenous, Sand	52'	3,678,178	84	**291,820**	**291,820**				
			54'	4,961,755	114	**559,032**	**559,032**				
			56'	5,083,152	117	**910,839**	**910,839**				
			58'	5,255,078	121	**1,293,390**	**1,293,390**				
			60'	5,052,960	116	**1,625,612**	**1,625,612**				

Channel	Reach	Reach-specific Geotech Notes	Pre-treatment notes	Design Depth	Total Area above Grade SQ FT	Total Area above Grade ACRES	Volume above Grade: Total	Contaminated sediment (non-HARS)	Non-contaminated sediment	Moderately hard Rock	Harder rock	Hardest rock
ANCHORAGE	Port Jersey Channel			52'	4,226,376	97.02	750,482.00		750,482.00			
				54'	5,121,270	117.57	1,043,244.00		1,043,244.00			
				56'	5,040,420	115.71	1,419,227.00		1,419,227.00			
				58'	4,959,570	113.86	1,826,364.00		1,826,364.00			
				60'	4,878,720	112.00	2,251,355.00		2,251,355.00			
	Port Jersey Widening (PJ-1)	Holocene = Non-HARS Pleistocene = HARS		52'	1,560,960	35.83	1,621,049.00	1,222,756.58	398,292.42			
				54'	1,584,540	36.38	1,762,170.00	1,313,467.96	448,702.04			
				56'	1,608,120	36.92	1,898,719.38	1,440,831.13	457,888.25			
				58'	1,631,700	37.46	2,028,671.00	1,491,700.02	536,970.98			
				60'	1,655,280	38.00	2,140,526.00	1,563,649.00	576,877.00			

Kill Van Vull Channel	Design Depth	Total Area above Grade (sf)	Total Area above Grade (ac)	Total	Contaminated sediment	Non-contaminated sediment	Serpentenite HARDER	Schist HARDER	Shale NONE	Sandstone HARDEST	Gneiss	Diabase HARDEST	Glacial Till MODERATELY		Moderately hard Rock	Harder rock	Hardest rock
KVK A-0'	52'	10,494	0.24	2,411	-	2,411	-	-		-		-	-		-	-	-
	53.5'	24,972	0.57	2,411	-	2,411	-	-		-		-	-		-	-	-
	54'	30,919	0.71	2,411	-	2,411	-	-		-		-	-		-	-	-
	56'	46,810	1.07	2,411	-	2,411	-	-		-		-	-		-	-	-
	58'	56,054	1.29	2,411	-	2,411	-	-		-		-	-		-	-	-
	60	60,204	1.38	2,411		2,411	-	-		-		-	-		-	-	-
KVK-A	52'	646,435	14.84	206,211		206,211	-			-		-	-		-	-	-
	53.5'	1,914,134	43.94	244,674		244,674	-			-		-	-		-	-	-
	54'	2,424,400	55.66	271,763		244,674	-	-		-		-	27,089		27,089	-	-
	56'	3,820,809	87.71	475,088		244,674	-	-		-		-	230,414		230,414	-	-
	58'	4,657,839	106.93	775,639		244,674	-	-		-		-	530,965		530,965	-	-
	60'	5,066,208	116.30	1,131,533		244,674	-	-		-		-	886,859		886,859	-	-
KVK-B	52	354,440	8.14	78,882		78,882	-	-		-		-	-		-	-	-
	53.5'	502,799	11.54	95,311		95,311	-	-		-		-	-		-	-	-
	54'	744,986	17.10	102,248		95,311	904	3,326				-	2,707		2,707	4,230	-
	56'	1,174,192	26.96	173,502		95,311	10,535	39,495				-	28,161		28,161	50,030	-
	58'	1,165,246	26.75	264,338		95,311	23,151	86,735				-	59,141		59,141	109,886	-
	60'	1,156,300	26.54	355,351		95,311	35,913	134,067				-	90,060		90,060	169,980	-
KVK-C	52'	311,335	7.15	72,746		72,746	-	-		-		-	-		-	-	-
	53.5'	467,570	10.73	86,760		86,760	-	-		-		-	-		-	-	-
	54'	713,839	16.39	92,855		86,760	5,980	-		-		-	115		115	5,980	-
	56'	1,017,751	23.36	159,025		86,760	71,598	-		-		-	667		667	71,598	-
	58'	1,009,459	23.17	240,543		86,760	152,776	-		-		-	1,007		1,007	152,776	-
	60	1,001,167	22.98	320,088		86,760	232,313	-		-		-	1,015		1,015	232,313	-
KVK-D	52'	579,087	13.29	124,011		124,011	-	-		-		-	-		-	-	-
	53.5'	1,292,115	29.66	151,720		151,720	-	-		-		-	-		-	-	-
	54'	1,949,801	44.76	167,812		151,720	12,201	-		-		-	3,891		3,891	12,201	-
	56'	2,679,958	61.52	328,367		151,720	140,029	-		-		-	36,618		36,618	140,029	-
	58'	2,653,420	60.91	532,838		151,720	306,665	-		-		-	74,453		74,453	306,665	-
	60'	2,626,882	60.30	740,411		151,720	475,829	-		-		-	112,862		112,862	475,829	-
KVK-E	52'	85,522	1.96	39,127		39,127	-	-		-		-	-		-	-	-
	53.5'	398,942	9.16	47,241		47,241	-	-		-		-	-		-	-	-
	54'	627,684	14.41	52,491		47,241	5,125	-		-		-	125		125	5,125	-
	56'	985,882	22.63	110,915		47,241	63,053	-		-		-	621		621	63,053	-
	58'	974,926	22.38	188,803		47,241	140,927	-		-		-	635		635	140,927	-
	60'	963,970	22.13	267,630		47,241	219,754	-		-		-	635		635	219,754	-
KVK-F	52'	124,128	2.85	92,484		92,484	-	-		-		-	-		-	-	-
	53.5'	576,495	13.23	99,884		99,884	-	-		-		-	-		-	-	-
	54'	1,066,985	24.49	106,822		99,884	2,709	-		-		-	4,229		4,229	2,709	-
	56'	2,149,325	49.34	240,803		99,884	57,285	-		-		-	83,634		83,634	57,285	-
	58'	2,224,151	51.06	432,405		99,884	136,910	-		-		-	195,611		195,611	136,910	-
	60'	2,193,119	50.35	630,935		99,884	219,415	-		-		-	311,636		311,636	219,415	-
KVK-G	52'	320,861	7.37	99,443		99,443	-	-		-		-	-		-	-	-
	53.5'	1,052,954	24.17	104,384		104,384	-	-		-		-	-		-	-	-
	54'	1,985,849	45.59	114,298		104,384	-	-		-		-	9,914		9,914	-	-
	56'	4,193,488	96.27	317,173		104,384	-	-		-		-	212,789		212,789	-	-
	58'	4,262,441	97.85	650,319		104,384	-	-		-		-	545,935		545,935	-	-
	60'	4,202,483	96.48	1,019,746		104,384	-	-		-		-	915,362		915,362	-	-
KVK-H	52'	766,351	17.59	98,424	98,424		-	-		-		-	-		-	-	-
	53.5'	828,586	19.02	106,417	106,417		-	-		-		-	-		-	-	-
	54'	2,455,947	56.38	117,751	106,417		-	-		-		-	11,334		11,334	-	-
	56'	4,295,360	98.61	349,017	106,417		-	-		-		-	242,600		242,600	-	-
	58'	4,234,400	97.21	675,887	106,417		-	-		-		-	569,470		569,470	-	-
	60'	4,173,440	95.81	1,009,171	106,417		-	-		-		-	902,754		902,754	-	-
KVK-I	52'	96,656	2.22	15,583	15,583		-	-		-		-	-		-	-	-
	53.5'	96,656	2.22	21,389	21,389		-	-		-		-	-		-	-	-
	54'	242,912	5.58	23,427	21,389		-	-		-		868	1,170		1,170	-	868
	56'	667,691	15.33	59,130	21,389		-	-		-		16,835	20,906		20,906	-	16,835
	58'	667,691	15.33	115,389	21,389		-	-		-		43,069	50,931		50,931	-	43,069
	60'	667,691	15.33	171,193	21,389		-	-		-		69,390	80,414		80,414	-	69,390
KVK-J	52'	221,499	5.08	40,268	40,268		-	-		-		-	-		-	-	-
	53.5'	221,499	5.08	41,343	41,343		-	-		-		-	-		-	-	-
	54'	276,873	6.36	46,334	41,343		-	-		-		4,991	-		-	-	4,991
	56'	678,083	15.57	126,342	41,343		-	-		-		84,999	-		-	-	84,999
	58'	1,725,330	39.61	258,286	41,343			-		-		216,943	-		-	-	216,943
	60'	1,725,330	39.61	392,943	41,343		-	-		-		351,600	-		-	-	351,600
KVK-K	52'	425,138	9.76	52,176	52,176		-	-		-		-	-		-	-	-
	53.5'	468,640	10.76	57,515	57,515		-	-		-		-	-		-	-	-
	54'	901,816	20.70	69,794	57,515		-	-		-		12,279.00	-		-	-	12,279
	56'	2,235,540	51.32	172,955	57,515		-	-		-		115,440.00	-		-	-	115,440
	58'	2,235,540	51.32	341,454	57,515		-	-		-		283,939.00	-		-	-	283,939
	60'	2,235,540	51.32	517,961	57,515		-	-		-		460,446.00	-		-	-	460,446
KVK-L	52'	535,796	12.30	45,543	45,543		-	-		-		-	-		-	-	-
	53.5'	669,745	15.38	50,136	50,136		-	-		-		-	-		-	-	-
	54'	1,070,081	24.57	78,763	50,136		-	-				28,627			-	-	28,627
	56'	1,951,324	44.80	182,679	50,136		-	-				132,543			-	-	132,543

Kill Van Vull Channel	Design Depth	Total Area above Grade (sf)	Total Area above Grade (ac)	Total	Contaminated sediment	Non-contaminated sediment	Serpentenite HARDER	Schist HARDER	Shale NONE	Sandstone HARDEST	Gneiss	Diabase HARDEST	Glacial Till MODERATELY		Moderately hard Rock	Harder rock	Hardest rock
	58'	1,951,324	44.80	328,818	50,136		-	-				278,682			-	-	278,682
	60'	1,951,324	44.80	475,253	50,136		-	-				425,117			-	-	425,117
KVK-M	52'	755,928	17.35	40,723	40,723		-	-		-		-	-		-	-	-
KVK-M	53.5'	795,714	18.27	41,417	41,417		-	-		-		-	-		-	-	-
KVK-M	54'	884,127	20.30	51,067	41,417		-	-		2,780		2,235	4,635		4,635	-	5,015
KVK-M	56'	1,744,825	40.06	140,530	41,417		-	-		31,324		25,387	42,402		42,402	-	56,711
KVK-M	58'	1,744,825	40.06	269,970	41,417		-	-		75,108		60,936	92,509		92,509	-	136,044
KVK-M	60'	1,744,825	40.06	399,807	41,417		-	-		119,589		96,594	142,207		142,207	-	216,183
KVK-M-0'	52'	18,770	0.43	1,045	1,045		-	-				-	-		-	-	-
KVK-M-0'	53.5'	18,770	0.43	1,045	1,045		-	-				-	-		-	-	-
KVK-M-0'	54'	22,686	0.52	1,263	1,045		-	-		218		-	-		-	-	218
KVK-M-0'	56'	44,770	1.03	4,106	1,045		-	-		3,061		-	-		-	-	3,061
KVK-M-0'	58'	44,770	1.03	7,425	1,045		-	-		6,380		-	-		-	-	6,380
KVK-M-0'	60'	44,770	1.03	10,745	1,045		-	-		9,700		-	-		-	-	9,700
KVK-1 (Widening)	52'	931,006	21.37	181,614	14,644.00	131,798.00	35,172	-				-			-	35,172	-
KVK-1 (Widening)	54'	959,626	22.03	234,808	14,644.00	177,822.00	42,342	-				-			-	42,342	-
KVK-1 (Widening)	56'	988,246	22.69	293,305	14,644.00	228,403.00	50,258	-				-	-		-	50,258	-
KVK-1 (Widening)	58'	1,016,866	23.34	359,544	14,644.00	286,007.00	58,893	-				-	-		-	58,893	-
KVK-1 (Widening)	60'	1,045,486	24.00	427,818	14,644.00	344,902.00	68,272	-				-	-		-	68,272	-
KVK-3 (Widening)	52'	355,454	8.16	96,549	22,065.00		-	-				-	74,484.00		74,484	-	-
KVK-3 (Widening)	54'	380,354	8.73	96,549	22,065.00		-	-				-	74,484.00		74,484	-	-
KVK-3 (Widening)	56'	405,254	9.30	128,548	22,065.00		-	-				-	106,483.00		106,483	-	-
KVK-3 (Widening)	58'	430,154	9.87	162,809	22,065.00		-	-				-	140,744.00		140,744	-	-
KVK-3 (Widening)	60'	455,054	10.45	198,795	22,065.00		-	-				-	176,730.00		176,730	-	-
KVK-4 (Widening)	52'	475,718	10.92	240,574	168,402.00		-	-				-	72,172.00		72,172	-	-
KVK-4 (Widening)	54'	493,088	11.32	240,574	168,402.00		-	-				-	72,172.00		72,172	-	-
KVK-4 (Widening)	56'	510,458	11.72	283,253	168,402.00		-	-				-	114,851.00		114,851	-	-
KVK-4 (Widening)	58'	527,828	12.12	329,464	168,402.00		-	-				-	161,062.00		161,062	-	-
KVK-4 (Widening)	60'	545,198	12.52	377,669	168,402.00		-	-				-	209,267.00		209,267	-	-
KVK-5 (Widening)	52'	509,120	11.69	261,706	93,319.00		-	-				-	168,387.00		168,387	-	-
KVK-5 (Widening)	54'	531,320	12.20	261,706	93,319.00		-	-				-	168,387.00		168,387	-	-
KVK-5 (Widening)	56'	553,520	12.71	321,359	93,319.00		-	-				1,308	226,732.00		226,732	-	1,308
KVK-5 (Widening)	58'	575,720	13.22	399,060	93,319.00		-	-				17,207	288,534.00		288,534	-	17,207
KVK-5 (Widening)	60'	597,920	13.73	465,713	93,319.00		-	-				19,070	353,324.00		353,324	-	19,070
															-	-	-
KVK-2 (EFFICIENCY)	52'	708,647	16.27	409,929	55,902.00		-	-				-	354,027		354,027	-	-
KVK-2 (EFFICIENCY)	54'	725,747	16.66	461,209	55,902.00		1,710	-				-	403,597		403,597	1,710	-
KVK-2 (EFFICIENCY)	56'	742,847	17.05	510,418	55,902.00		9,044	-				-	445,472		445,472	9,044	-
KVK-2 (EFFICIENCY)	58'	759,947	17.45	552,774	55,902.00		13,422	-				-	483,450		483,450	13,422	-
KVK-2 (EFFICIENCY)	60'	777,047	17.84	590,742	55,902.00		16,352	-				-	518,488		518,488	16,352	-

				Volume above Grade					
Reach	Area (sft)	Area (ac)	Design Depth	**Total**	**Contaminated sediment (non-HARS) (Upland Disposal**	**Non-contaminated sediment (HARS DISPOSAL)**	**Moderately hard Rock**	**Fractured Rock**	**Hardest rock**
	495,828	11.38	-52	78,827	78,827				
	740,041	16.99	-54	178,247	141,450	5,018	14,217	14,217	3,345
AK-A	1,217,375	27.95	-56	299,367	141,450	5,018	14,217	14,217	124,465
	1,217,375	27.95	-58	423,865	141,450	5,018	14,217	14,217	248,963
	1,217,375	27.95	-60	551,272	141,450	5,018	14,217	14,217	376,370
	653,968	15.01	-52	95,496	95,496				
	976,072	22.41	-54	201,526	170,431	4,664	16,325	10,106	-
AK-B	976,072	22.41	-56	300,211	170,431	4,664	96,212	10,106	18,798
	976,072	22.41	-58	401,982	170,431	4,664	179,184	10,106	37,597
	976,072	22.41	-60	505,765	170,431	4,664	264,169	10,106	56,395
	855,878	19.65	-52	97,484	97,484				
	1,320,718	30.32	-54	231,881	200,873	4,651	16,279	10,078	-
AK-C	1,403,079	32.21	-56	375,083	200,873	4,651	159,481	10,078	-
	1,403,079	32.21	-58	524,924	200,873	4,651	309,323	10,078	-
	1,403,079	32.21	-60	677,960	200,873	4,651	462,358	10,078	-
	206,639	4.74	-52	27,547	27,547				
	303,881	6.98	-54	51,382	44,404	1,047	3,245	2,268	419
AK-D	354,339	8.13	-56	86,580	44,404	1,047	17,849	2,268	21,012
	354,339	8.13	-58	122,953	44,404	1,047	32,923	2,268	42,312
	354,339	8.13	-60	161,079	44,404	1,047	48,698	2,268	64,662
	175,905	4.04	-52	32,221	32,221				
	418,821	9.61	-54	92,656	72,615	3,006	8,518	6,513	2,004
AK-E	720,614	16.54	-56	164,105	72,615	3,006	8,518	6,513	73,454
	720,614	16.54	-58	241,048	72,615	3,006	8,518	6,513	150,396
	720,614	16.54	-60	320,123	72,615	3,006	8,518	6,513	229,471
	175,186	4.02	-52	40,556	40,556				
	417,109	9.58	-54	164,769	100,949	9,573	27,124	20,742	6,382
AK-F	1,045,887	24.01	-56	283,373	100,949	9,573	27,124	20,742	124,986
	1,152,873	26.47	-58	404,314	100,949	9,573	27,124	20,742	245,927
	1,152,873	26.47	-60	531,672	100,949	9,573	27,124	20,742	373,285
	42,945	0.99	-52	15,560	15,560				
	195,205	4.48	-54	142,508	142,508	-	-	-	-
AK-G	823,025	18.89	-56	223,177	142,508	-	-	-	80,669
	888,507	20.40	-58	309,566	142,508	-	-	-	167,058
	888,507	20.40	-60	397,412	142,508	-	-	-	254,904
	330,434	7.59	-52	35,723	35,723				
	493,186	11.32	-54	120,637	88,797	4,776	13,532	10,348	3,184
AK-H	981,464	22.53	-56	211,347	88,797	4,776	13,532	10,348	93,894
	981,464	22.53	-58	303,941	88,797	4,776	13,532	10,348	186,488
	981,464	22.53	-60	398,592	88,797	4,776	13,532	10,348	281,139
	959,905	22.04	-52	1,075,736	197,394	380,167	129,442	185,479	183,255
	976,609	22.42	-54	1,146,840	268,498	380,167	129,442	185,479	183,255
AK-1 (WIDENING)	993,229	22.80	-56	1,176,920	270,587	380,167	129,442	185,479	211,245
	1,009,849	23.18	-58	1,208,024	272,723	380,167	129,442	185,479	240,214
	1,026,469	23.56	-60	1,236,859	274,906	380,167	129,442	185,479	266,865
	2,144,329	49.23	-52	4,175,030	1,019,774		1,938,352	798,476	418,428
	2,659,129	61.05	-54	4,333,869	1,178,613		1,938,352	798,476	418,428
AK-2 (WIDENING)	2,710,159	62.22	-56	4,408,956	1,213,555		1,938,352	798,476	458,573
	2,761,189	63.39	-58	4,497,467	1,248,953		1,938,352	798,476	511,686
	2,812,219	64.56	-60	4,576,329	1,284,819		1,938,352	798,476	554,682

Newark Bay Channel

Average as-built elevation assumed to be -53 ft

Volume above Grade

Reach	Design Depth	Total Area above Grade (sf)	Total Area above Grade (ac)	Total	Contaminated sediment (Non-HARS Disposal)	Non-Contaminated Sediment (HARS Disposal)	Pleistocene Silt and Clay (Moderately Hard)	Other Rock (Hardest)	Serpentenite (Harder)	Sandstone (Hardest)	Diabase (Hardest)	Moderately hard Rock	Harder rock	Hardest rock
NWK-A	52'	1,972,320	45.28	236,335	236,335			-	-	-	-	-	-	-
	53	1,960,720	45.01	250,757	250,757			-	-	-	-	-	-	-
	54'	1,958,400	44.96	265,179	252,010		2,784.9	-	-	4,913	5,470	2,784.94	-	10,383.84
	56'	1,944,480	44.64	374,887	260,483		21,614.1	-	-	44,293	48,497	21,614.13	-	92,789.51
	58'	1,930,560	44.32	527,699	269,753		42,212.5	-	-	103,848	111,885	42,212.48	-	215,732.90
	60	1,916,640	44.00	690,614	277,566		59,576.6	-	-	171,227	182,244	59,576.57	-	353,470.98
NWK-B	52'	1,902,684	43.68	232,586	232,586	-		-	-	-	-	-	-	-
	53	1,886,534	43.31	260,524	260,524	-		-	-	-	-	-	-	-
	54'	1,883,304	43.23	288,462	260,524	3,169	16,901	-	-	7,868	-	16,901.07	-	7,867.98
	56'	1,863,924	42.79	402,364	260,524	15,574	83,059	-	-	43,208	-	83,058.94	-	43,207.50
	58'	1,844,544	42.34	535,608	260,524	29,131	155,363	-	-	90,590	-	155,363.19	-	90,590.21
	60'	1,825,164	41.90	670,874	260,524	42,129	224,687	-	-	143,534	-	224,686.80	-	143,534.42
NWK-C	52	4,509,192	103.52	442,831	442,831	-		-	-	-	-	-	-	-
	53	4,479,092	102.83	494,438	494,438			-	-	-	-	-	-	-
	54'	4,473,072	102.69	546,044	499,065	8,545	34,107	773	618	2,936	-	34,107.26	618	3,708.25
	56'	4,436,952	101.86	826,719	523,717	54,055	215,769	5,950	4,334	22,894	-	215,768.86	4,334	28,843.80
	58'	4,400,832	101.03	1,150,386	551,053	104,522	417,217	14,164	9,060	54,370	-	417,216.94	9,060	68,533.53
	60'	4,364,712	100.20	1,472,269	577,139	152,679	609,443	24,466	14,230	94,311	-	609,443.23	14,230	118,777.77
NWK-D	52'	4,988,268	114.51	565,634	565,634			-	-	-	-	-	-	-
	53	4,959,093	113.85	637,270	637,270			-	-	-	-	-	-	-
	54'	4,953,258	113.71	708,906	643,170		49,902	2,253	-	13,581	-	49,902.42	-	15,833.29
	56'	4,918,248	112.91	1,032,512	667,826		258,429	15,299	-	90,958	-	258,429.33	-	106,256.89
	58'	4,883,238	112.10	1,402,043	692,101		463,741	35,123	-	211,077	-	463,741.29	-	246,200.57
	60	4,848,228	111.30	1,827,293	716,482		669,943	61,158	-	379,710	-	669,943.25	-	440,868.03
NWK-E	52'	3,657,264	83.96	522,033	522,033			-	-		-	-	-	-
	53	3,634,039	83.43	588,684	588,684			-	-		-	-	-	-
	54'	3,629,394	83.32	655,333	611,876		43,457	-	-		-	43,457.10	-	-
	56'	3,601,524	82.68	863,971	684,479		179,492	-	-		-	179,492.14	-	-
	58'	3,573,654	82.04	1,112,075	770,816		341,259	-	-		-	341,258.93	-	-
	60'	3,545,784	81.40	1,376,567	862,855		513,712	-	-		-	513,711.59	-	-
NWK-F	52'	2,000,856	45.93	288,273	288,273			-	-		-	-	-	-
	53	1,988,756	45.66	324,620	324,620			-	-		-	-	-	-
	54'	1,986,336	45.60	360,967	337,524		22,188	-	-		1,255	22,188.20	-	1,255.03
	56'	1,971,816	45.27	442,692	366,305		71,678	-	-		4,709	71,678.49	-	4,709.15
	58'	1,957,296	44.93	548,478	402,923		134,643	-	-		10,912	134,643.26	-	10,911.56
	60'	1,942,776	44.60	672,449	445,397		206,732	-	-		20,320	206,732.29	-	20,320.41
NWK-G	52'	350,256	8.04	61,994	61,994			-	-		-	-	-	-
	53	346,256	7.95	76,239	76,239			-	-		-	-	-	-
	54'	345,456	7.93	90,484	84,486		5,998	-	-		-	5,997.89	-	-
	56'	340,656	7.82	120,704	101,982		18,722	-	-		-	18,722.11	-	-
	58'	335,856	7.71	153,994	121,255		32,739	-	-		-	32,738.95	-	-
	60'	331,056	7.60	185,064	139,243		45,821	-	-		-	45,821.05	-	-
NWK-1A	52	2,193,371	50.35	5,535,818	3,699,678	587,893	881,965	366,282				881,965.43	-	366,281.58
	54'	2,250,371	51.66	5,809,279	3,766,150	653,694	881,965	507,470				881,965.43	-	507,469.71
	56'	2,307,371	52.97	6,096,467	3,842,134	715,821	881,965	656,547				881,965.43	-	656,547.41
	58'	2,364,371	54.28	6,294,351	3,842,134	757,918	881,965	812,334				881,965.43	-	812,334.16
	60'	2,421,371	55.59	6,544,442	3,842,134	848,026	881,965	972,317				881,965.43	-	972,317.18
NWK-1B	52'	2,135,987	49.04	3,266,783	1,658,942	244,441	1,290,431	72,968				1,290,431.41	-	72,967.55
	54'	2,149,247	49.34	3,426,288	1,663,764	274,540	1,342,049	145,935				1,342,048.67	-	145,935.11
	56'	2,162,507	49.64	3,674,553	1,685,700	314,673	1,382,310	291,870				1,382,310.13	-	291,870.22
	58'	2,175,767	49.95	3,888,266	1,685,700	354,805	1,409,956	437,805				1,409,956.33	-	437,805.33
	60	2,189,027	50.25	4,051,284	1,685,700	364,838	1,417,006	583,740				1,417,006.11	-	583,740.43
NWK-2A	52'	1,757,168	40.34	3,596,100	639,751	303,431	2,302,193	350,725				2,302,193.13	-	350,725.32
	54'	1,776,668	40.79	3,769,122	647,018	307,708	2,329,151	485,246				2,329,150.93	-	485,245.77
	56'	1,796,168	41.23	4,116,924	663,731	333,602	2,494,221	625,370				2,494,221.27	-	625,369.64
	58'	1,815,668	41.68	4,113,119	661,551	315,854	2,368,062	767,652				2,368,061.89	-	767,652.29
	60'	1,835,168	42.13	4,290,940	668,818	319,927	2,389,022	913,174				2,389,021.58	-	913,173.84
NWK-2B	52'	527,494	12.11	1,463,912	487,511	94,060	620,016	262,325				620,015.56	-	262,324.63
	54'	548,194	12.58	1,544,203	494,778	98,338	645,226	305,861				645,225.99	-	305,861.41
	56'	568,894	13.06	1,803,274	511,491	124,232	813,131	354,420				813,130.59	-	354,419.99
	58'	589,594	13.54	1,708,737	509,311	106,484	687,597	405,345				687,596.80	-	405,345.01
	60'	610,294	14.01	1,794,105	516,578	110,557	707,836	459,135				707,836.50	-	459,134.52
NWK-2C	52'	442,134	10.15	966,590	211,796		749,972	4,822				749,972.36	-	4,821.76
	54'	449,094	10.31	1,013,791	214,026		792,565	7,200				792,565.47	-	7,200.42
	56'	456,054	10.47	1,061,489	216,256		835,159	10,075				835,158.58	-	10,074.64
	58'	463,014	10.63	1,109,682	218,486		877,752	13,444	-		-	877,751.69	-	13,444.42
	60'	469,974	10.79	1,158,370	220,716		915,145	22,510	-		-	915,144.80	-	22,509.76

Port Elizabeth Channel 53.0 ft is average as-built-elevation

							Volume above Grade								
Reach	**Design Depth**	**Total Area above Grade (sf)**	**Total Area above Grade (ac)**	**Total**	**Contaminated sediment (UPLAND)**	**Non-contaminated sediment**	**Sandstone (REEF)**	**Other Rock (REEF)**	**Diabase (REEF)**	**Glacial Till (HARS DISPOSAL)**	**Pleistocene Silt and Clay (HARS DISPOSAL)**		**Moderately hard Rock**	**Harder rock**	**Hardest rock**
South Eliz A	**52'**	**873,492**	**20.05**	**49,791**	**49,791**		-	-			-		-	-	-
	53'	**863,949**	**19.83**	**56,458**	**100,153**		-	-			-		-	-	-
	54'	**854,406**	**19.61**	**129,216**	**110,162**		**7,274**	**2,302.81**			**9,477**		**9,477**	-	**9,576**
	56'	**835,320**	**19.18**	**188,166**	**126,577**		**27,665**	**8,906.49**			**25,018**		**25,018**	-	**36,571**
	58'	**816,234**	**18.74**	**247,190**	**138,588**		**54,435**	**17,776.22**			**36,391**		**36,391**	-	**72,211**
	60	**797,148**	**18.30**	**306,214**	**147,369**		**85,882**	**28,258.63**			**44,704**		**44,704**	-	**114,141**
South Eliz A1	**52'**	**80,208**	**1.84**	**165,379**	**165,379**								-		-
	53'	**85,428**	**1.96**	**180,217**	**172,493**		**4,055**	**771.74**			**2,897**		**2,897**		**4,827**
	54'	**90,648**	**2.08**	**195,054**	**179,496**		**8,241**	**1,568.29**			**5,749**		**5,749**		**9,809**
	56'	**101,088**	**2.32**	**221,853**	**189,877**		**18,482**	**3,517.40**			**9,976**		**9,976**		**22,000**
	58'	**111,528**	**2.56**	**251,545**	**198,237**		**33,544**	**6,383.80**			**13,380**		**13,380**		**39,928**
	60	**121,968**	**2.80**	**282,084**	**205,334**		**50,810**	**9,669.67**			**16,270**		**16,270**		**60,479**
South Eliz PE-1 (EFFICIENCY)	**52'**	**735,021**	**16.87**	**1,451,724**	**521,758**			**11,597**		**233,357**	**685,012**		**918,369**		**11,597**
	54'	**744,213**	**17.08**	**1,504,858**	**522,599**			**40,436**		**256,811**	**685,012**		**941,823**		**40,436**
	56'	**753,405**	**17.30**	**1,556,842**	**523,440**			**78,215**		**270,175**	**685,012**		**955,187**		**78,215**
	58'	**762,597**	**17.51**	**1,608,260**	**524,281**			**119,913**		**279,054**	**685,012**		**964,066**		**119,913**
	60	**771,789**	**17.72**	**1,658,700**	**525,122**			**163,793**		**284,773**	**685,012**		**969,785**		**163,793**

Port Elizabeth Channel (-53.5 ft is average as-built elevation)

							Volume above Grade						
Reach	**Design Depth**	**Total Area above Grade (sf)**	**Total Area above Grade (ac)**	**Total**	**Contaminated sediment (UPLAND DISPOSAL)**	**Non-contaminated sediment (HARS DISPOSAL)**	**Other Rock (REEF DISPOSAL)**	**Recent Black Silt (UPLAND DISPOSAL)**	**Pleistocene Silt and Clay (HARS DISPOSAL)**		**Moderately hard Rock**	**Harder rock**	**Hardest rock**
Eliz A	52'	1,290,240	29.62	88,027	88,027			-	-		-	-	-
	53.5'	1,273,725	29.24	120,208	120,208			-	-		-	-	-
	54'	1,270,422	29.16	133,139	127,721				5,418		5,418	-	-
	56'	1,250,604	28.71	205,906	169,998				35,908		35,908	-	-
	58'	1,230,786	28.25	298,696	223,908				74,788		74,788	-	-
	60	1,210,968	27.80	400,709	283,177				117,532		117,532	-	-
Eliz B	52'	1,826,100	41.92	103,035	103,035.00				-				
	53.5'	1,795,050	41.21	124,161	124,161.00				-				
	54'	1,788,840	41.07	135,871	132,510.00				3,361		3,361		
	56'	1,751,580	40.21	240,970	207,445.00				33,525		33,525		
	58'	1,714,320	39.36	373,245	301,755.00				71,490		71,490		
	60'	1,677,060	38.50	508,673	398,314.00				110,359		110,359		
Eliz C	52	930,180	21.35	71,151	71,151.00			-	-		-		
	53.5'	913,355	20.97	111,586	111,586.00			-	-		-		
	54'	909,990	20.89	117,858	113,389.00				4,469		4,469		
	56'	889,800	20.43	147,530	120,851.00				26,679		26,679		
	58'	869,610	19.96	270,689	128,539.00				142,150		142,150		
	60'	849,420	19.50	346,873	136,656.00				210,217		210,217		
Eliz-D	52'	704,568	16.17	68,299	68,299.00		-	-	-				
	53.5'	692,093	15.89	103,463	103,463.00		-	-	-				
	54'	689,598	15.83	115,434	110,965.00		4,469		-				4,469
	56'	674,628	15.49	164,269	137,590.00		26,679		-				26,679
	58'	659,658	15.14	213,715	160,798.00		52,917		-				52,917
	60	644,688	14.80	260,638	180,934.00		79,704		-				79,704

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ATTACHMENT 3A

TSP QUANTITIES

4-FOOT DEEPENING

Ambrose 57 ft (Deepen by 4)

				Total Area above Grade		Volume above Grade (cy)					
Ambrose Channel Reach	**Reach-specific Geotech Notes**	**Pre-treatment notes**	**Design Depth**	**Area (sf)**	**Area (ac)**	**Total Volume (cy)**	**Contaminated sediment (non-HARS)**	**Non-contaminated sediment**	**Moderately hard Rock**	**Harder rock**	**Hardest rock**
A			**57'**	-	-	-		-			
B			**57'**	-	-	-		-			
C			**57'**	2,962,951.2	68.0	136,060		136,060.0			
D			**57'**	7,873,905.6	180.8	424,179		424,179.0			
E			**57'**	1,735,866.0	39.9	100,576		100,576.0			
F			**57'**	985,762.8	22.6	36,822		36,822.0			
G			**57'**	415,126.8	9.5	19,837		19,837.0			
H	Includes excavation of shoaling areas		**57'**	1,816,016.4	41.7	630,054		630,054.0			
I			**57'**	1,700,582.4	39.0	653,377		653,377.0			
J			**57'**	13,939.2	0.3	370		370.0			
K			**57'**	2,117,451.6	48.6	70,547		70,547.0			
L			**57'**	5,300,380.8	121.7	328,380		328,380.0			
M			**57'**	9,261,727.2	212.6	594,910		594,910.0			
N			**57'**	10,235,293.2	235.0	618,625		618,625.0			
O			**57'**	9,555,757.2	219.4	376,797		376,797.0			
P			**57'**	1,387,386.0	31.9	58,658		58,658.0			
Q			**57'**	1,190,494.8	27.3	88,086		88,086.0			
R			**57'**	8,276.4	0.2	180		180.0			
						4,137,458					

Anchorage 54 ft (Deepen by 4)

Anchorage Channel Reach	Reach-specific Geotech Notes	Pre-treatment notes	Design Depth	Total Area above Grade		Volume above Grade (cy)					
				Area (sf)	Area (ac)	Total Volume (cy)	Contaminated sediment (non-HARS)	Non-contaminated sediment	Moderately hard Rock	Harder rock	Hardest rock
A			**54'**	4,202,233	96	218,878		218,878			
B			**54'**	11,594,365	266	921,328		921,328			
BEND-L			**54'**	2,838,370	65	239,887		239,887			
BEND-U			**54'**	6,983,104	160	584,295		584,295			
C			**54'**	2,078,248	48	112,814		112,814			
AN-1			**54'**	4,203,104	96	473,667	473,667				
						2,550,869					

Port Jersey 56 ft (Deepen by 4)

Port Jersey Reach	Design Depth	Total Area above Grade		Volume Above Grade (cy)					
				Total (cy)	Contaminated sediment (non-HARS)	Non-contaminated sediment	Moderately hard Rock	Harder rock	Hardest rock
		SQ FT	ACRES						
Port Jersey channel	**56'**	4,857,811.2	111.52	**896,184**		896,184			
PJ-1	**56'**	2,010,294.0	46.15	**1,847,751**	1,324,143	523,608			

2,743,935

Kill Van Vull Channel 56 ft (Deepen by 4)

(-53.5 ft is average as-built elevation)

Volume above Grade | **Disposal Location Midpoint Coordinates**

Reach	Design Depth	Total Area above Grade (sf)	Total Area above Grade (ac)	Total	Contaminated sediment	Non-contaminated sediment	Serpentenite HARDER	Schist HARDER	Shale NONE	Other Rock HARDEST	Gneiss	Diabase HARDEST	Glacial Till MODERATELY		Moderately hard Rock	Harder rock	Hardest rock		Disposal Description	Northing	Easting	Additional Notes
A	56'	**3,920,400**	90.0	336,909		264,436							72,473		72,473	-	-					
B	56'	**1,186,574**	27.24	122,492		28,728	17,328	64,903					11,532		11,532	82,232	-					
C	56'	**1,012,334**	23.24	107,760		12,787	94,973								-	94,973	-					
D	56'	**2,750,814**	63.15	255,951		5,504	250,447								-	250,447	-					
E	56'	**976,615**	22.42	76,831		7,135	69,696								-	69,696	-					
F	56'	**2,193,682**	50.36	145,563		2,817	99,123						43,623		43,623	99,123	-					
G	56'	**4,274,107**	98.12	279,617		22,423							257,194		257,194	-	-					
H	56'	**4,315,054**	99.06	314,553	15,676								298,877		298,877	-	-					
I	56'	**727,452**	16.70	46,750	3,809							3,168	39,773		39,773	-	3,168					
J	56'	**1,775,941**	40.77	111,979	2,473							85,628	23,878		23,878	-	85,628					
K	56'	**2,272,961**	52.18	151,485	14,245							137,240			-	-	137,240					
L	56'	**1,964,992**	45.11	159,300	25,852							104,812	28,636		28,636	-	104,812					
M	56'	**1,778,555**	40.83	126,127	17,649							2,027	106,451		106,451	-	2,027					
KVK-1	56'	**835,045**	19.2	228,670	-	94,145	8,794			11,516			114,214		114,214	8,794	11,516					
KVK-3	56'	**463,914**	10.65	157,320									157,320		157,320	-	-					
KVK-4	56'	**561,053**	12.88	277,029									277,029		277,029	-	-					
KVK-5	56'	**669,517**	15.37	339,136								5,759	333,377		333,377	-	5,759					
A KVK-1		**617,245**	14.2	152,017		65,015				7,969			79,033									
B KVK-1		**113,692**	2.61	52,480		21,927	1,210			2,688			26,655									
C KVK-1		**46,609**	1.07	21,530		7,014	5,130			860			8,526									
D KVK-1		**57,499**	1.32	2,643		189	2,454															
				-																		
G KVK-3		**463,914**	10.65	157,320									157,320									
				-																		
G KVK-4		**11,326**	0.26	3,503									3,503									
H KVK-4		**549,727**	12.62	273,526									273,526									
				-																		
H KVK-5		**510,959**	11.73	262,507									262,507									
I KVK-5		**135,036**	3.10	69,224									69,224									
J KVK-5		**23,522**	0.54	7,405								5,759	1,646									

Port Elizabeth Channel 56 ft (Deepen by 4)
(-53.5 ft is average as-built elevation)

Reach	Design Depth	Total Area above Grade (sf)	Total Area above Grade (ac)	Total	Volume above Grad (cy) Contaminated sediment (UPLAND DISPOSAL)	Non-contaminated sediment (HARS DISPOSAL)	Other Rock (REEF DISPOSAL)	Sediment in channel above 53.5 ft (UPLAND DISPOSAL)	Recent Black Silt (UPLAND DISPOSAL)	Pleistocene Silt and Clay (HARS DISPOSAL) (Moderate)	"Other" Rock (Hardest)		Moderately hard Rock	Harder rock	Hardest rock
A	56'	1,270,645.20	29.17	**223,002**	176,141			102,460	73,681	46,861	-		46,861		-
B	56'	1,727,154.00	39.65	**301,980**	257,979			141,628	116,351	44,001	-		44,001		-
C	56'	877,734.00	20.15	**187,363**	178,894			105,710	73,184	8,469	-		8,469		-
D	56'	651,657.60	14.96	**142,198**	111,625			83,915	27,710	-	30,573		-		30,573
				854,543											

South Elizabeth Channel 56 ft (Deepen by 4)

53.0 ft is average as-built-elevation

Reach	Design Depth	Total Area above Grade (sf)	Total Area above Grade (ac)	Total	Contaminated sediment (UPLAND)	Non-contaminated sediment	Sandstone (REEF)	Other Rock (REEF)	Diabase (REEF)	Glacial Till (HARS DISPOSAL)	Pleistocene Silt and Clay (HARS DISPOSAL) Moderate		Moderately hard Rock	Harder rock	Hardest rock
South Eliz A	**56'**	789,307.2	18.1	**161,917.0**	108,330		-	36,324.20			17,262		17,262	-	36,324
SE-1A Widening	**56'**	383,328.0	8.8	**217,253.0**	43,223			28,640.5		41,631.23	103,758		145,389.53		28,640.5
				379,170.0											

The heading "Volume above Grade" is printed above the columns from Sandstone (REEF) to Hardest rock.

Newark Bay Channel

Average as-built elevation assumed to be -53.5 ft

					Volume above Grade									Totals by Rock Hardness		
Reach	Design Depth	Total Area above Grade (sf)	Total Area above Grade (ac)	Total	Contaminated sediment (Non-HARS Disposal)	Non-Contaminated Sediment (HARS Disposal)	Pleistocene Silt and Clay (Moderately Hard)	Pleistocene Sand & Gravel (Moderate)	Till (Moderate)	Serpentenite (Harder)	Other Rock (Hardest)	Sandstone (Hardest)	Diabase (Hardest)	Moderately hard Rock	Harder rock	Hardest rock
A	56'	**1,842,588.00**	42.30	**245,204**	64,167		6,496	2,285				92,973	79,283	8,781	-	172,256
B	56'	**1,817,758.80**	41.73	**316,803**	142,213		115,018					59,572		115,018	-	59,572
C	56'	**4,382,136.00**	100.60	**745,155**	352,730		288,168	53,832		6,871	5,510	30,232	7,812	341,999	6,871	43,555
D	56'	**4,888,303.20**	112.22	**871,540**	445,283		293,544					132,713		293,544	-	132,713
E	56'	**3,545,784.00**	81.40	**621,377**	397,789		223,588							223,588	-	-
F	56'	**1,605,186.00**	36.85	**243,301**	152,628		78,622						12,052	78,622	-	12,052
G	56'	**368,953.20**	8.47	**80,666**	66,900		13,766							13,766	-	-
														-	-	-
(Widenings: Total quantites summed from all sections)														-	-	-
NWK-1	56'	**5,397,886**	124	**6,278,505**	2,864,068	987,094	700,308	737,125	-	-	989,909	-	-	1,437,433	-	989,909
NWK-2	56'	**2,779,564**	64	**3,778,594**	576,720	55,068	2,271,816	-	330,367	-	544,624	-	-	2,602,183	-	544,624
(Widenings: quantities separated per section)																
A NWK-1	56'	**15,612**	0.36	**3,165**		1,865	1,240	60						1,299	-	-
B NWK-1	56'	**178,160**	4.09	**91,001**	8,731	47,012	23,170	12,089						35,259	-	-
C NWK-1	56'	**860,310**	19.75	**749,715**	263,198	200,722	170,148	42,537			73,111			212,685	-	73,111
D NWK-1	56'	**1,288,505**	29.58	**1,254,782**	783,142	210,593	31,370	212,786			16,891			244,156	-	16,891
E NWK-1	56'	**1,370,398**	31.46	**1,765,248**	1,134,296	311,931		233,949			85,072			233,949	-	85,072
F NWK-1	56'	**1,302,444**	29.90	**1,867,846**	386,911	133,912	296,483	235,704			814,835			532,188	-	814,835
G NWK-1	56'	**382,457**	8.78	**546,748**	287,791	81,060	177,897							177,897	-	-
				-										-	-	-
A NWK-2	56'	**187,308**	4.30	**176,046**		55,068	31,101		34,810		55,068			65,910	-	55,068
B NWK-2	56'	**1,276,308**	29.30	**1,831,170**	330,896		870,609		295,557		334,108			1,166,166	-	334,108
C NWK-2	56'	**1,315,948**	30.21	**1,771,378**	245,824		1,370,107				155,447			1,370,107	-	155,447

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ATTACHMENT 3B

TSP QUANTITIES

5-FOOT DEEPENING

Ambrose Channel 58 ft (deepen by 5)

				Total Area above Grade		Volume above Grade (cy)					
Ambrose Channel Reach	**Reach-specific Geotech Notes**	**Pre-treatment notes**	**Design Depth**	**Area (sf)**	**Area (ac)**	**Total Volume (cy)**	**Contaminated sediment (non-HARS)**	**Non-contaminated sediment**	**Moderately hard Rock**	**Harder rock**	**Hardest rock**
A			**58'**	-	-	-		-			
B			**58'**	-	-	-		-			
C			**58'**	3,777,087.6	86.7	261,115		261,115.0			
D			**58'**	8,678,894.4	199.2	731,965		731,965.0			
E			**58'**	2,325,232.8	53.4	176,856		176,856.0			
F			**58'**	2,068,228.8	47.5	95,594		95,594.0			
G			**58'**	767,091.6	17.1	43,092		43,092.0			
H	Includes excavation of shoaling areas		**58'**	2,021,184.0	27.4	286,697		698,778.0			
I			**58'**	1,805,997.6	23.4	315,901		717,647.0			
J			**58'**	41,817.6	0.5	1,277		1,950.0			
K			**58'**	3,160,713.6	72.6	162,428		162,428.0			
L			**58'**	6,310,101.6	144.9	542,168		542,168.0			
M			**58'**	10,171,260.0	233.5	951,987		951,987.0			
N			**58'**	10,295,841.6	236.4	998,441		998,441.0			
O			**58'**	10,174,744.8	233.6	744,782		744,782.0			
P			**58'**	2,073,020.4	47.6	122,950		122,950.0			
Q			**58'**	1,538,103.6	35.3	138,652		138,652.0			
R			**58'**	16,117.2	0.4	663		663.0			

6,389,068

Anchorage Channel 55 ft (deepen by 5)

Anchorage Channel Reach	Reach-specific Geotech Notes	Pre-treatment notes	Design Depth	Total Area above Grade: Area (sf)	Total Area above Grade: Area (ac)	Volume above Grade (cy): Total Volume (cy)	Volume above Grade (cy): Contaminated sediment (non-HARS)	Volume above Grade (cy): Non-contaminated sediment	Volume above Grade (cy): Moderately hard Rock	Volume above Grade (cy): Harder rock	Volume above Grade (cy): Hardest rock
A			**55'**	5,031,180	115.5	391,270		391,270			
B			**55'**	12,811,432	294.1	1,373,260		1,373,260			
BEND-L			**55'**	3,189,463	73.2	351,393		351,393			
BEND-U			**55'**	7,122,060	163.5	845,619		845,619			
C			**55'**	2,340,043	53.7	193,340		193,340			
AN-1			**55'**	5,066,464	116.3	645,444	645,444				
						3,800,326					

Port Jersey Channel 57 ft (Deepen by 5)

Port Jersey Reach	Design Depth	Total Area above Grade		Volume Above Grade (cy)					
				Total (cy)	Contaminated sediment (non-HARS)	Non-contaminated sediment	Moderately hard Rock	Harder rock	Hardest rock
		SQ FT	ACRES						
Port Jersey channel	**57'**	4,937,526.0	113.35	**1,079,544**		1,079,544			
PJ-1	**57'**	2,033,816.4	46.69	**1,923,388**	1,367,900	555,488			

3,002,932

Kill Van Vull Channel (-53.5 ft is average as-built elevation)

Volume above Grade

Reach	Design Depth	Total Area above Grade (sf)	Total Area above Grade (ac)	Total	Contaminated sediment	Non-contaminated sediment	Serpentenite HARDER	Schist HARDER	Shale NONE	Other Rock HARDEST	Gneiss	Diabase HARDEST	Glacial Till MODERATELY		Moderately hard Rock	Harder rock	Hardest rock
A	57'	**4,493,214**	103.2	481,886		382,781							99,105		99,105	-	-
B	57'	**1,188,317**	27.28	166,541		47,673	17,687	64,545					36,636		36,636	82,232	-
C	57'	**1,012,334**	23.24	145,416		12,295	133,121								-	133,121	-
D	57'	**2,750,814**	63.15	359,961		5,504	354,457								-	354,457	-
E	57'	**976,615**	22.42	112,975		7,135	105,840								-	105,840	-
F	57'	**2,193,682**	50.36	227,963		2,817	132,164						92,982		92,982	132,164	-
G	57'	**4,274,107**	98.12	476,971		31,875							445,096		445,096	-	-
H	57'	**4,421,340**	101.50	474,742	15,676								459,066		459,066	-	-
I	57'	**705,672**	16.20	68,559	5,441							4,858	58,259		58,259	-	4,858
J	57'	**1,775,941**	40.77	177,579	2,473							137,156	37,950		37,950	-	137,156
K	57'	**2,272,961**	52.18	235,294	14,245							221,049			-	-	221,049
L	57'	**1,964,992**	45.11	231,943	25,852							162,003	44,088		44,088	-	162,003
M	57'	**1,778,555**	40.83	192,992	23,048							3,151	166,793		166,793	-	3,151
KVK-1	57'	**836,352**	19.2	258,045		117,797	419			6,475			133,354		133,354	419	6,475
KVK-3	57'	**463,914**	10.65	174,008									174,008		174,008	-	-
KVK-4	57'	**561,053**	12.88	298,655									298,655		298,655	-	-
KVK-5	57'	**596,772**	13.70	285,921								6,113	279,809		279,809	-	6,113
A KVK-1		**617,245**	14.2	175,745		75,163				9,213			91,369				
B KVK-1		**113,692**	2.61	56,498		23,339	1,928			2,861			28,371				
C KVK-1		**46,609**	1.07	23,137		6,970	6,841			854			8,472				
D KVK-1		**57,499**	1.32	2,665		189	2,476										
G KVK-3		**463,914**	10.65	174,008									174,008				
G KVK-4		**11,326**	0.26	2,786									2,786				
H KVK-4		**549,727**	12.62	295,869									295,869				
H KVK-5		**510,959**	11.73	281,202									281,202				
I KVK-5		**135,036**	3.10	73,343									73,343				
J KVK-5		**23,522**	0.54	8,150								6,113	2,038				

Newark Bay Channel 57 ft (Deepen by 5)

(-53.5 ft is average as-built elevation)

Reach	Design Depth	Total Area above Grade (sf)	Total Area above Grade (ac)	Total	Volume above Grade: Contaminated sediment (Non-HARS Disposal)	Non-Contaminated Sediment (HARS Disposal)	Pleistocene Silt and Clay (Moderately Hard)	Pleistocene Sand & Gravel (Moderate)	Till (Moderate)	Serpentenite (Harder)	Other Rock (Hardest)	Sandstone (Hardest)	Diabase (Hardest)	Totals by Rock Hardness: Moderately hard Rock	Harder rock	Hardest rock
A	57'	**1,887,019.20**	43.32	**308,767**	64,167		7,943	2,425				128,728	105,504	10,368	-	234,232
B	57'	**1,825,164.00**	41.90	**385,377**	142,213		161,643					81,522		161,643	-	81,522
C	57'	**4,382,136.00**	100.60	**904,563**	360,247		394,500	73,695		11,412	10,567	40,870	13,272	468,195	11,412	64,708
D	57'	**4,890,481.20**	112.27	**1,061,536**	462,093		407,956					191,487		407,956	-	191,487
E	57'	**3,554,496.00**	81.60	**756,249**	435,159		321,090							321,090	-	-
F	57'	**1,605,186.00**	36.85	**306,825**	169,730		119,614						17,480	119,614	-	17,480
G	57'	**368,953.20**	8.47	**94,506**	75,659		18,847							18,847	-	-
														-	-	-
(Widenings: Total quantites summed from all sections)														-	-	-
NWK-1	57'	**5,419,300**	124	**6,472,395**	2,923,050	1,010,241	720,914	759,400	-	-	1,058,790	-	-	1,480,314	-	1,058,790
NWK-2	57'	**2,779,564**	64	**3,857,334**	582,293	55,068	2,292,986	-	333,371	-	593,617	-	-	2,626,356	-	593,617
(Widenings: quantities separated per section)																
A NWK-1	57'	**15,682**	0.36	**3,598**		2,111	1,403	84						FALSE	-	-
B NWK-1	57'	**187,308**	4.30	**98,307**	9,261	49,866	24,577	14,604						39,180	-	-
C NWK-1	57'	**872,507**	20.03	**785,573**	270,510	206,298	174,875	48,637			85,252			223,513	-	85,252
D NWK-1	57'	**1,288,505**	29.58	**1,300,490**	801,857	215,625	32,119	217,871			33,018			249,991	-	33,018
E NWK-1	57'	**1,370,398**	31.46	**1,812,497**	1,155,377	317,729		238,296			101,095			238,296	-	101,095
F NWK-1	57'	**1,302,444**	29.90	**1,911,213**	393,810	136,300	301,770	239,908			839,425			541,678	-	839,425
G NWK-1	57'	**382,457**	8.78	**560,717**	292,236	82,312	186,169							186,169	-	-
	57'			-										-	-	-
A NWK-2	57'	**187,308**	4.30	**176,046**		55,068	31,101		34,810		55,068			65,910	-	55,068
B NWK-2	57'	**1,276,308**	29.30	**1,875,741**	334,258		879,456		298,561		363,465			1,178,017	-	363,465
C NWK-2	57'	**1,315,948**	30.21	**1,805,547**	248,035		1,382,429				175,083			1,382,429	-	175,083

Port Elizabeth Channel 57 ft (Deepen by 5)

(-53.5 ft is average as-built elevation)

Volume above Grade (cy)

Reach	Design Depth	Total Area above Grade (sf)	Total Area above Grade (ac)	Total	Contaminated sediment (UPLAND DISPOSAL)	Non-contaminated sediment (HARS DISPOSAL)	Other Rock (REEF DISPOSAL)	Sediment in channel above 53.5 ft	Recent Black Silt (UPLAND DISPOSAL)	Pleistocene Silt and Clay (HARS DISPOSAL) (Moderate)	"Other" Rock (Hardest)		Moderately hard Rock	Harder rock	Hardest rock
A	57'	1,302,008.40	29.89	**271,309**	206,345			102,460	103,885	64,964	-		64,964		-
B	57'	1,737,172.80	39.88	**366,095**	304,856			141,628	163,228	61,239	-		61,239		-
C	57'	881,654.40	20.24	**219,888**	208,098			105,710	102,388	11,790	-		11,790		-
D	57'	659,934.00	15.15	**166,329**	122,834			83,915	38,919	-	43,495.5		-		43,495
				1,023,621											

South Elizabeth Channel 57 ft (Deepen by 5)

(-53.5 ft is average as-built elevation)

Reach	Design Depth	Total Area above Grade (sf)	Total Area above Grade (ac)	Total	Contaminated sediment (UPLAND)	Non-contaminated sediment	Sandstone (REEF)	Other Rock (REEF)	Diabase (REEF)	Glacial Till (HARS DISPOSAL)	Pleistocene Silt and Clay (HARS DISPOSAL) Moderate		Moderately hard Rock	Harder rock	Hardest rock
							Volume above Grade								
South Eliz A	**57'**	790,178	18.14	**191,543.0**	123,814		-	38,671.60			29,057		29,057	-	38,672
SE-1A Widening	**57'**	388,991	8.93	**231,206.0**	44,930			39,024.7		43,341.52	103,910		147,251.29		39,024.7
				422,749.0											

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ATTACHMENT 4

ERDC/CHL SEDIMENTATION STUDY

ERDC TR-20-15

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Engineer Research and Development Center

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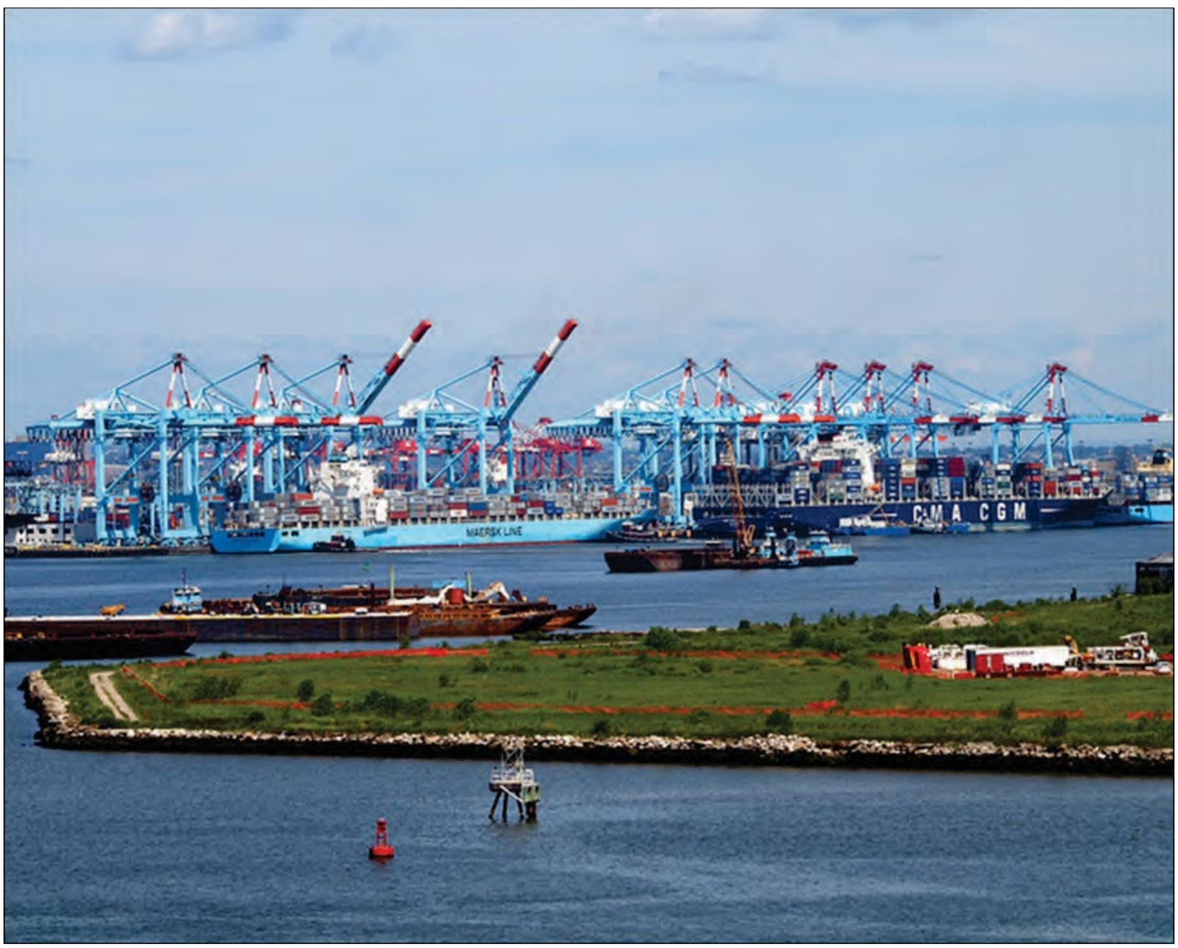
New York/New Jersey Harbor Sedimentation Study

Numerical Modeling of Hydrodynamics and Sediment Transport

Tate O. McAlpin, Joseph V. Letter, Jr., Mary Bryant, Anthony G. Emiren, Gary L. Brown, Gaurav Savant, Bryce W. Wisemiller, Jamal A. Sulayman, and Corey J. Trahan

August 2020



Engineer Research and Development Center

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New York/New Jersey Harbor Sedimentation Study

Numerical Modeling of Hydrodynamics and Sediment Transport

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New York, NY 10278

Final report

Prepared for US Army Corps of Engineers, New York District
New York, NY 10278

Under Work Item Code 1J186F, “ERDC Sedimentation Modeling”

Abstract

The New York/New Jersey Harbor (NYNJH) is a vital economic resource for both the local economy and the entire US economy due to the vast quantity of imports and exports handled by the numerous ports in this waterway. As with most ports, there is a significant, recurring expense associated with dredging the navigation channels to the authorized depths. In an effort to determine the impact of channel enlargements ("the project") on dredging volumes, a numerical model study was performed. The advantage of a numerical model study is the ability to isolate individual system modifications and associated impacts in terms of dredging volumes. Five years (1985, 1995, 1996, 2011, and 2012) were simulated for both the with- and without-project conditions to determine the impact of the channel deepening on the dredging requirements for a wide range of meteorological conditions including storm events. The numerical model results were analyzed to provide insight into which locations will experience increased/decreased deposition and quantify the amount of increase/decrease for a given channel reach. The model results indicate a relatively minor increase in the total dredge volumes for the NYNJH with the increase being insignificant in comparison to the natural variability in dredge volumes across years.

Contents

Figures and Tables

Figures

Tables

Preface

The work documented in this report was conducted for the US Army Corps of Engineers, New York District, under the "ERDC Sedimentation Modeling" Work Item Code 1J186F. The New York District oversight was provided by Mr. Jamal A. Sulayman, and Mr. Bryce W. Wisemiller served as the Program Manager.

At the time of publication of this report, Mr. David P. May was Acting Chief, Riverine and Estuarine Engineering Branch; and Dr. Carey Talbot was Chief, Flood and Storm Protection Division. The Deputy Director of the US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL), was Mr. Jeffery Eckstein, and the Director was Dr. Ty V. Wamsley.

Participants in the study included multiple branches and laboratories, with the primary work being completed within the Riverine and Estuarine Engineering Branch of ERDC-CHL.

The authors acknowledge the contributions of e4sciences in compiling bathymetric data, sediment data, and historical dredge volume information in addition to its thorough review and valuable consultation throughout this study. The authors specifically acknowledge the contributions of Dr. William Murphy III, Dr. W. Bruce Ward, and Dr. Daniel Rosales Roche.

COL Teresa A. Schlosser was the Commander of ERDC, and the Director was Dr. David W. Pittman.

1 Introduction

Background

The New York/New Jersey Harbor (NYNJH) is a vital resource for both the local economies of New York and New Jersey as well as the entire US economy. The Port of New York and New Jersey is the third busiest port in the United States with approximately 60.9 million tons of bulk cargo at a value of almost 48 billion US dollars (PANYNJ 2010) with 5,000 ship arrivals per year (Caplow et al. 2003). The Port supports 279,200 jobs with wages of over 11 billion US dollars and contributes more than 19 billion US dollars to the New York/New Jersey gross regional product (PANYNJ 2010).

NYNJH includes numerous navigation channels and various ports resulting in a complex system of navigation channels extending from offshore, inland to the individual ports of call. Over the years, NYNJH has evolved continuously with numerous channels being deepened and widened to better facilitate navigational safety and efficiency. One such alteration is the latest harbor deepening project to a 50 ft* channel depth (USACE 2007). The 50 ft harbor deepening project is considered the "with-project" condition analyzed in this study with the "pre-project" representing the conditions for the 45 ft channel configuration. While a typical Panamax containership could be accommodated by a 35 ft (10 m) channel, the new generation of post-Panamax containerships requires a channel depth between 42 and 52 ft (13–16 m) (Rodrigue 2004). This necessitates the deepening of the navigation channels to accommodate these larger vessels and maintain the Port of New York/New Jersey as one of the busiest ports in the United States.

The complexity of the system includes various important processes. These processes are critical to the overall circulation within the harbor, which are

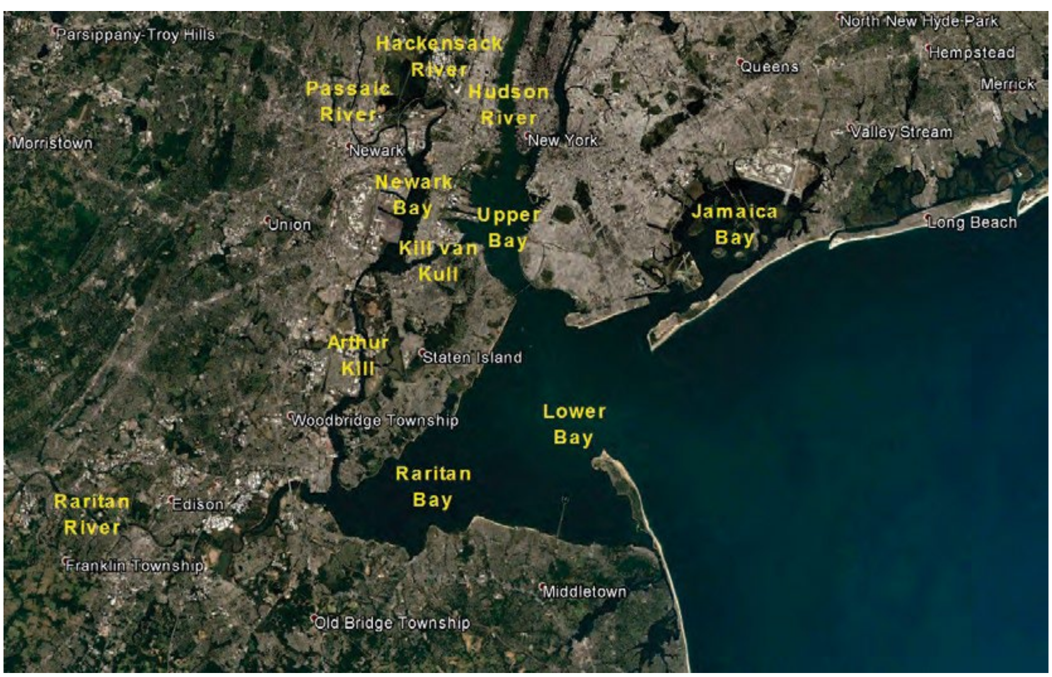
* For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248-52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

coupled strongly to the sediment transport and fate. Some of these include the following:

- numerous inflows (Hudson River, Passaic River, Hackensack River, Raritan River, etc.)
- large sewage outfalls
- complex hydrodynamic conditions with multiple flow pathways
- three-dimensional (3D) salinity transport
- cohesive and noncohesive sediment transport
- organic sediments with cohesive properties
- extreme storm events
- along-shore currents and sediment transport
- regular dredging operations
- deep-draft ship transit and associated bow waves.

Figure 1 provides a general study area map of the system. The inter-connectivity between the various areas and the general complexity of the system make accurate numerical modeling extremely challenging. This report will detail the numerical modeling completed as part of this study and associated results and conclusions.

Figure 1. Study area.



Objective

The purpose of this study is to provide insight into the impact of the 50 ft channel deepening project on the dredging requirements in the NYNJH system as compared to the previously authorized 45 ft channel depth. The variability in the annual rate of dredging indicates significant natural variability due to irregularity in river flows and meteorological conditions. This is the primary motivation for the current numerical model study, which can isolate the navigation channel depth impacts by simulating the same conditions (tides, flows, winds, pressures, etc.) for both the pre- and post-deepening channel configurations. Analysis will include total dredge volume changes and the spatial variation in dredge requirements on a reach-by-reach basis. The resulting numerical model will also be available for future analysis for other projects as well, providing a means of evaluating system modifications in terms of hydrodynamics, salinity, and sediment transport.

Approach

A 3D numerical model was developed for hydrodynamic, salinity, and sediment transport. Observational data were utilized to validate the model properly replicates the observed behavior in the real system. Five years (1985, 1995, 1996, 2011, and 2012) were simulated for both the pre- and post-deepened conditions to evaluate both the impact of the deepened navigation channels and the impact of the varying forcing conditions on yearly dredge volumes. The five years simulated high/low river flows along with large storm events (Hurricanes Gloria, Irene, and Sandy) providing a range of results for varying channel depths and forcing conditions.

2 Description of Hudson-Raritan Estuary

History of navigation improvements

The NYNJH has supported commercial shipping for over 300 years (Wakeman et al. 2007). After construction of the Erie Canal in 1825, NYNJH experienced phenomenal growth, becoming one of the leading ports in the United States (Parkman 1983). In the 1880s, the steady (and still ongoing) increases in ship sizes limited trans-Atlantic vessels to flood-tide transits into the harbor, necessitating the deepening of the main ship channel to 30 ft with a width of 1,000 ft (Parkman 1983). This quickly became inadequate and was again enlarged in 1899 with the construction of the Ambrose channel at a depth of 40 ft with a 2,000 ft width (Parkman 1983). During World War II, the Ambrose Channel was deepened to 45 ft along with improvements to the New York and New Jersey Channels that pass through Raritan and Newark Bays (Parkman 1983). Since then, navigation channels have been maintained and/or deepened throughout the estuary's rivers and bays, resulting in over 250 mi of established channels and berthing areas (USACE 2016). USACE (2007) provides a detailed listing of the historical deepening projects for the Kill van Kull, Arthur Kill, and Newark Bay channels. The latest authorized project included deepening of the main shipping channels within the harbor to a 50 ft depth with the exception of the Ambrose Channel, which was deepened to a 53 ft depth (CENAN 2007). The deepening was implemented in a consolidated approach with the previous authorization (45 ft depth) as detailed in USACE CENAN (2004) in an effort to reduce time and costs for completion. This study investigates the impact of this latest deepening project in terms of dredging requirements and associated changes in dredge volumes as compared to the previously authorized 45 ft channel configuration.

Previous analysis

The importance of the NYNJH is illustrated by the numerous studies that have been completed to better understand this complex system. There have been many data collection efforts to understand the hydrodynamics, salinity, and sediment transport of the NYNJH and surrounding areas (Caplow et al. 2003; Chant 2006; Coch 2016; Clarke et al. 2015; Woodruff et al. 2001). These data collection efforts have provided much information about the system that has significantly improved the understanding of this complex area. The data collected as part of these studies have also proved instrumental in improving the numerical models that have been utilized.

Some of the initial 3D hydrodynamic and salinity transport numerical modeling of the NYNJH system was documented in Blumberg et al. 1999. Additional subsequent studies have tended to focus on smaller spatial domains with increased model resolution. These studies have also shifted to incorporate sediment transport over smaller domains (Wakeman et al. 2007; Hellweger et al. 2004; Ralston and Geyer 2009). The study documented here attempts to model the hydrodynamics, salinity, and sediment transport over the entire NYNJH system and adjacent areas of importance.

Processes of importance

Attempting to develop a numerical model of the sediment transport in the NYNJH system is an extremely challenging task due to the numerous processes impacting the sediment movement and deposition/erosion. These include hydrodynamic processes (tides, winds, pressure fields, riverine inflows, etc.) that will ultimately impact the salinity and sediment transport.

Tidal energy

The NYNJH experiences semidiurnal tides with a mean tide range of approximately 5 ft. These tide ranges tend to dominate the hydrodynamic behavior in the system barring significant meteorological events. A 5 ft tide also equates to approximately 10% of the channel depth and equates to more than a 10% volume of water being overturned twice a day. This exchange of water can result in relatively high velocities in some locations like the Kill van Kull channel (surface velocities > 1.0 m/s).

River inflows

The NYNJH system has several riverine freshwater inflows. The largest freshwater inflow impacting the system is the Hudson River. The Passaic, Raritan, and Hackensack flows are significantly smaller than that of the Hudson (based on US Geological Survey [USGS DOI 2020] surface water data at https://waterdata.usgs.gov/nwis/sw?). Additional smaller inflows were included in the modeling for thoroughness, including the Third River, Saddle River, South River, Rahway River, and Lawrence Brook. The locations of these inflows are shown in Figure 2 and Figure 3. These stations have long periods of record allowing for extensive analysis of the seasonal flow behavior for these locations. The USGS provides daily minimum, maximum, and certain percent exceedance values for these locations for each day of the year. This information is plotted for these rivers in Figure 4 through Figure 12 to illustrate the seasonal variation in the riverine flows and also to illustrate the variability across years. Note that log plots cannot show 0.0 cfs discharges, so some minimum curves and even some of the lower percentile curves are not observed in the plots due to the very low discharges represented. The Hackensack River is a prime example of this.

Figure 2. River inflow locations.

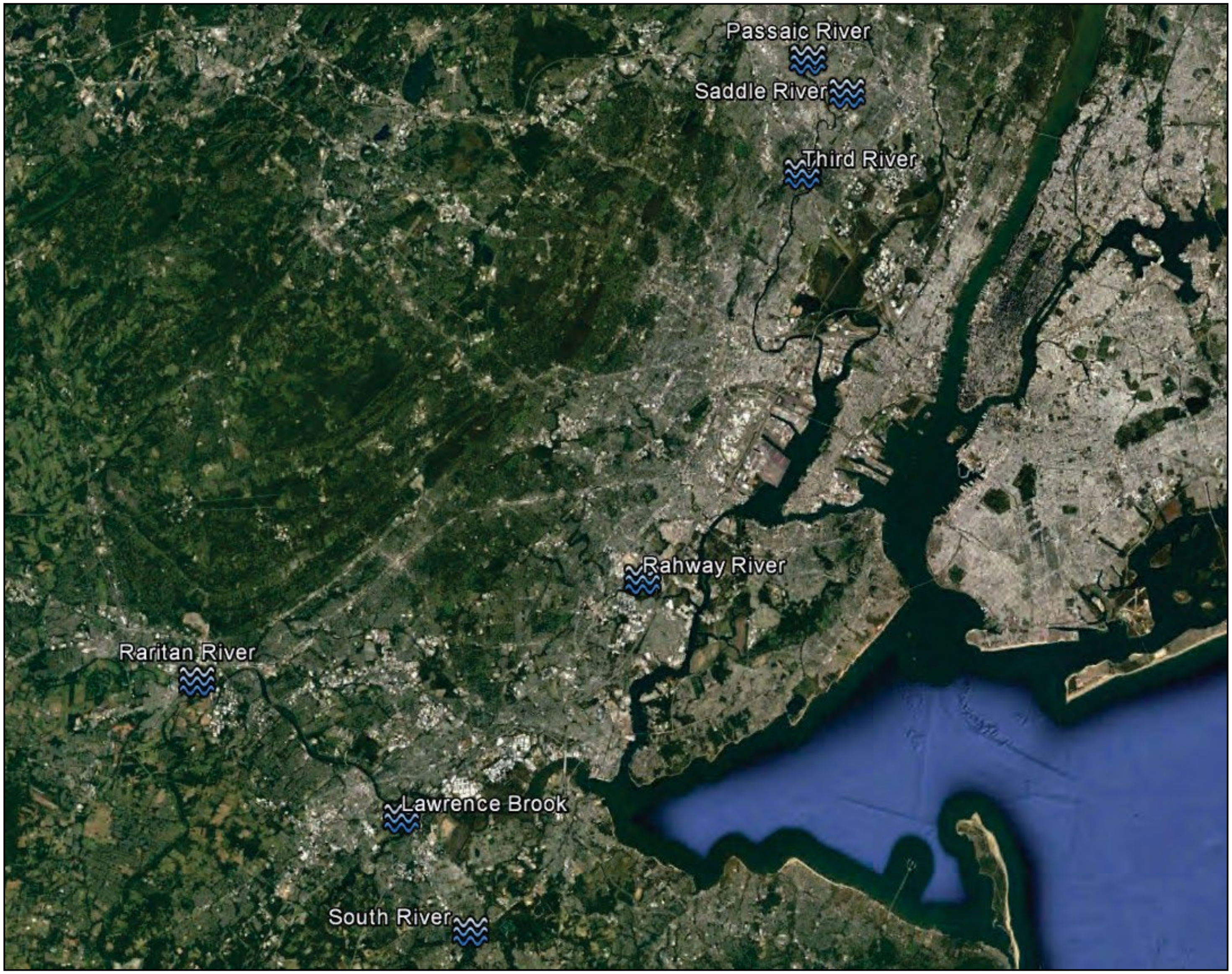


Figure 3. River inflow locations, including the Hudson River.

Figure 4. Average daily river inflow statistics for the Hudson River at Green Island.

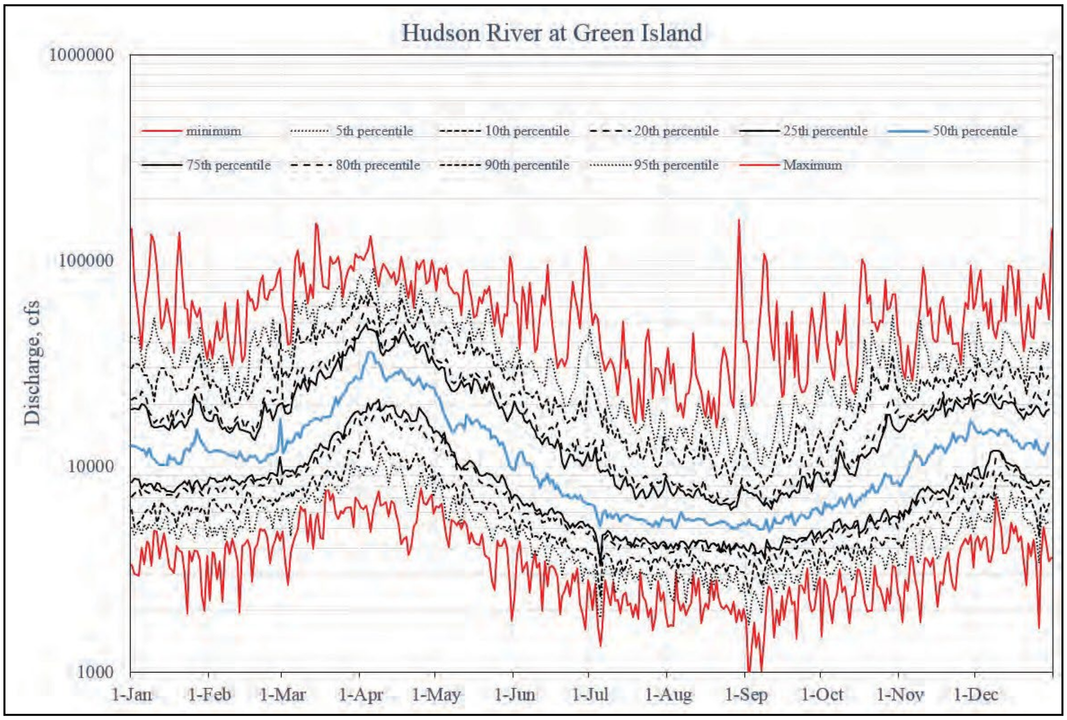


Figure 5. Average daily river inflow statistics for the Hackensack River.

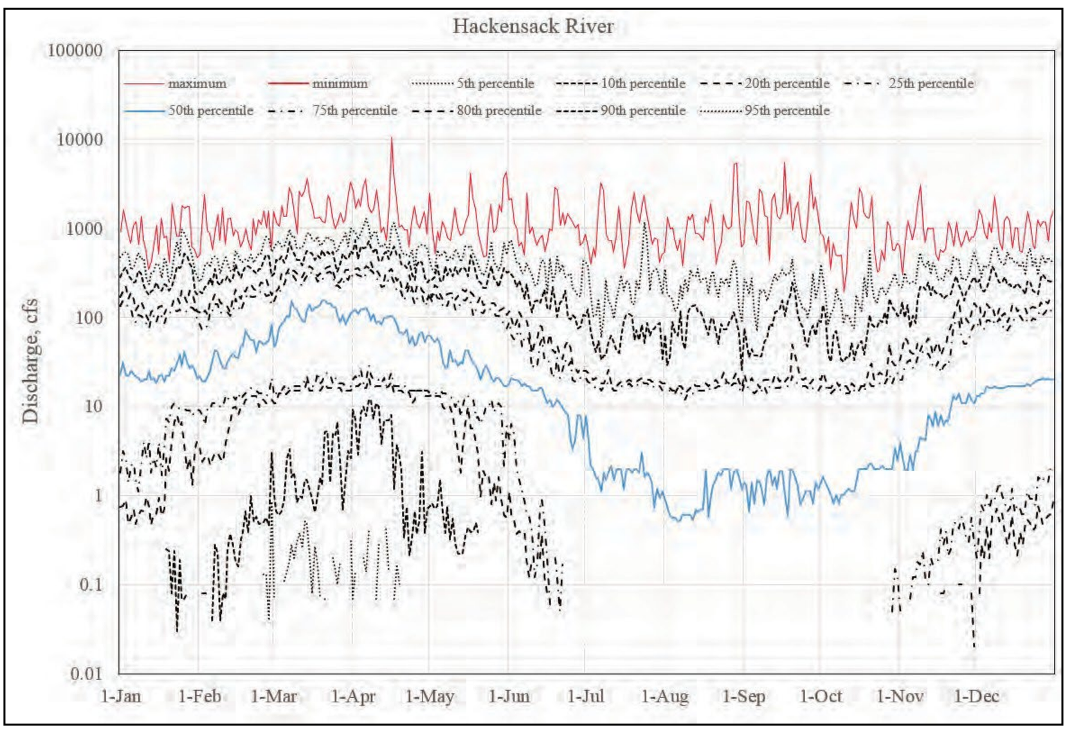


Figure 6. Average daily river inflow statistics for the Passaic River.

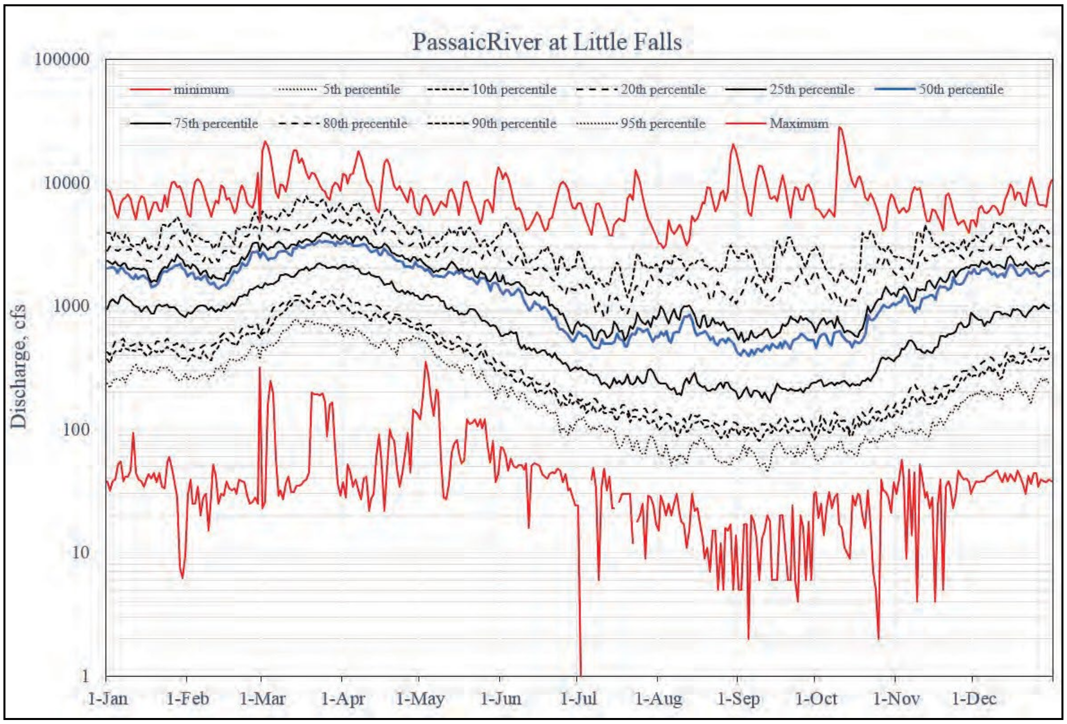


Figure 7. Average daily river inflow statistics for the Saddle River.

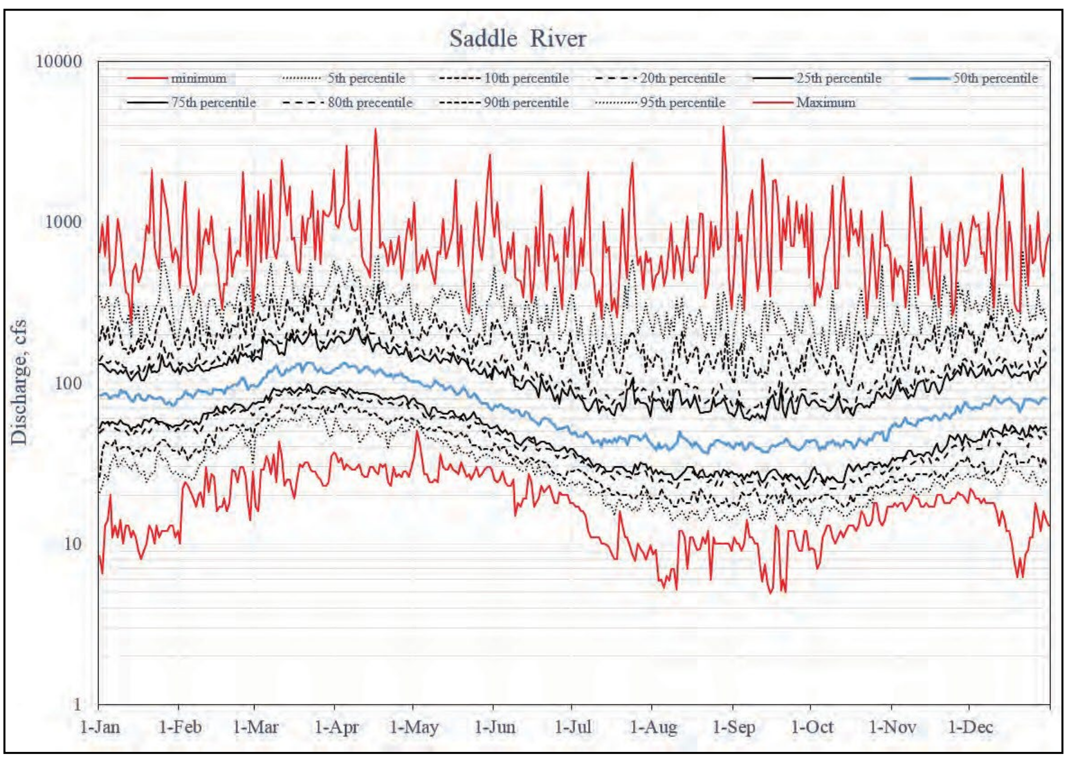


Figure 8. Average daily river inflow statistics for the Third River.

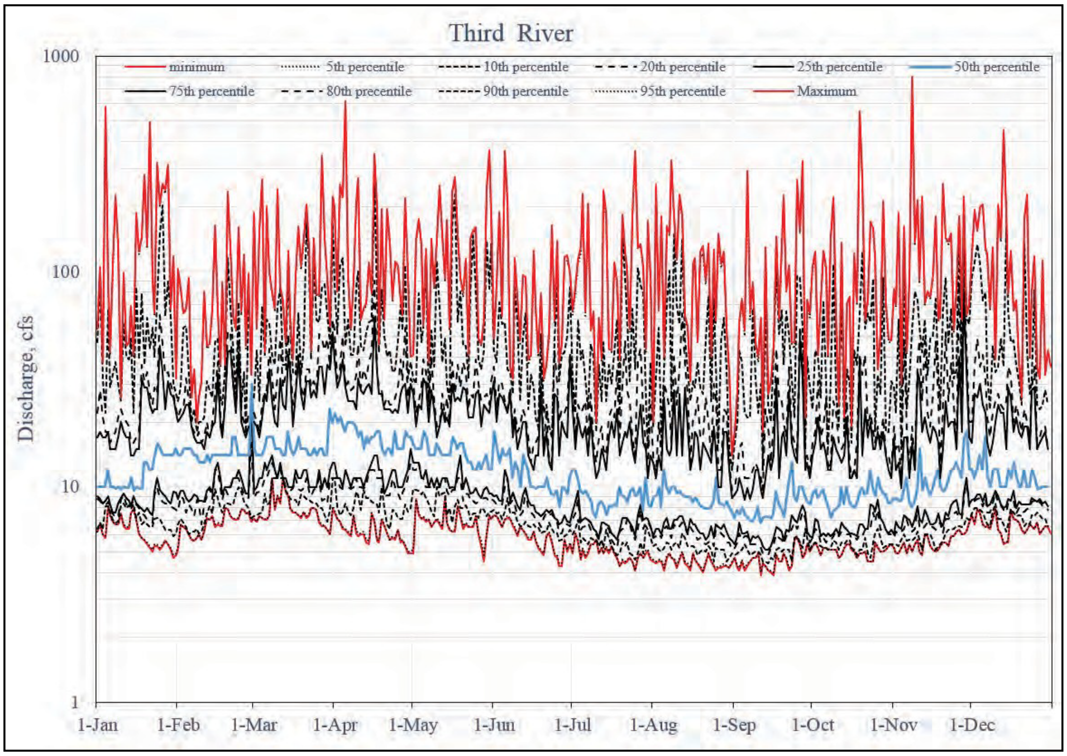


Figure 9. Average daily river inflow statistics for the Rahway River.

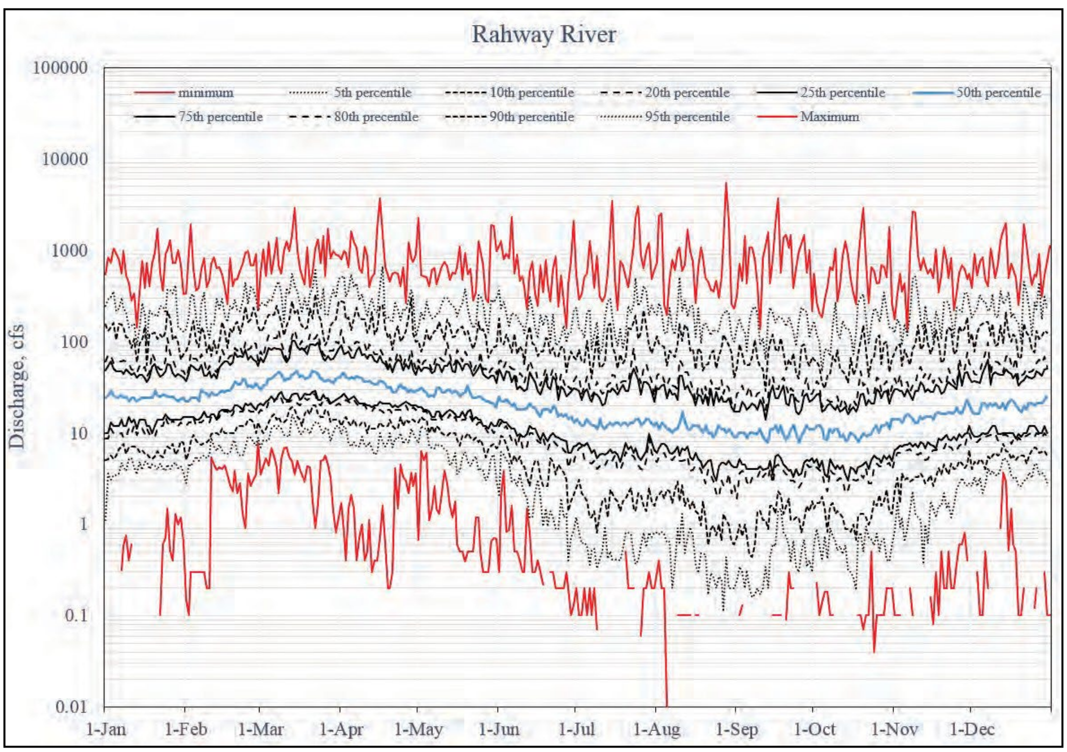


Figure 10. Average daily river inflow statistics for the Raritan River.

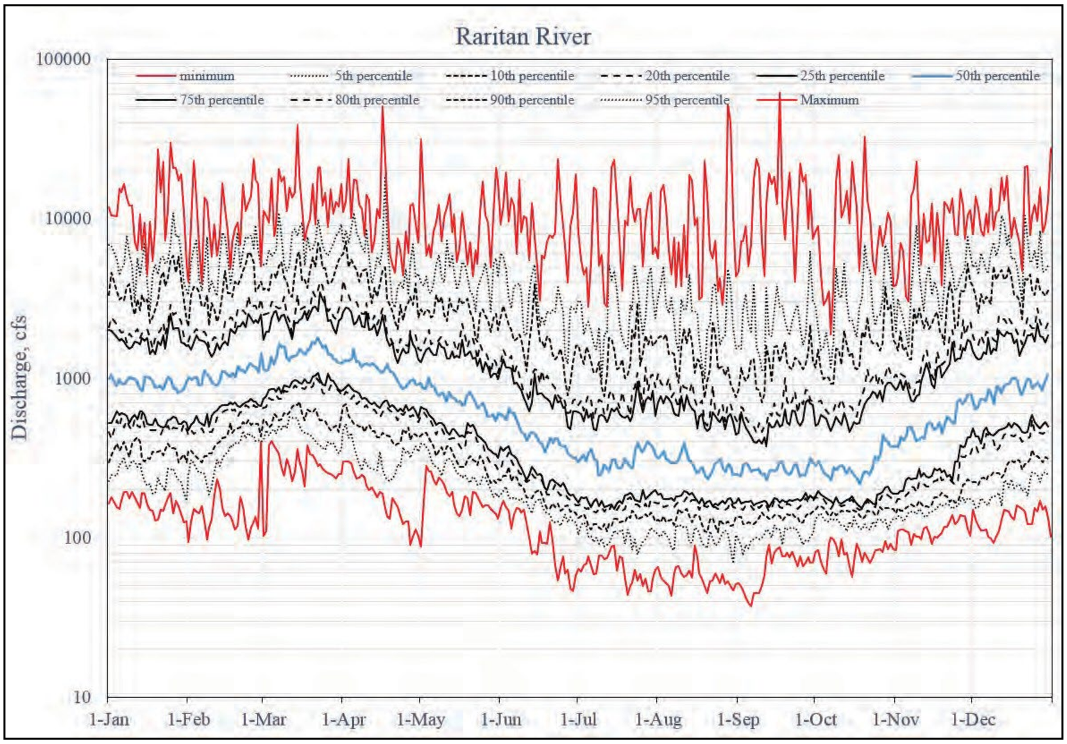


Figure 11. Average daily river inflow statistics for the South River.

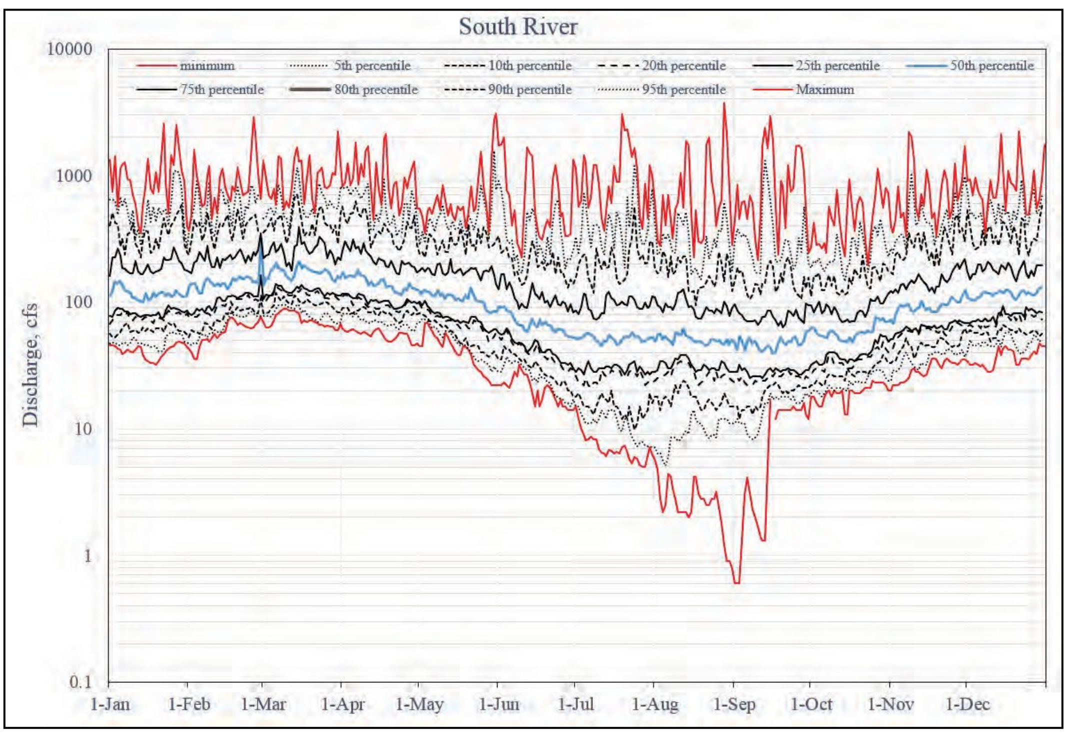
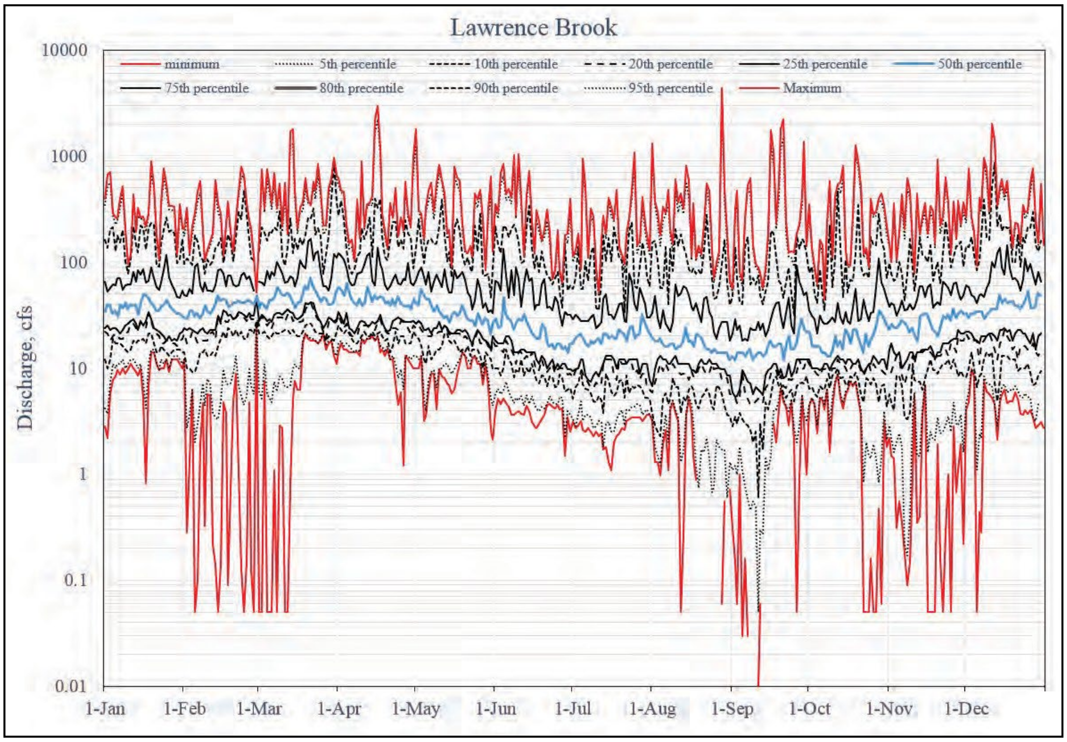


Figure 12. Average daily river inflow statistics for Lawrence Brook.



Municipal wastewater treatment facility discharges

The New York/New Jersey area is a very densely populated region. As such, the discharges from Municipal Wastewater Treatment Facilities (MWTFs) can be significant. Therefore, it was deemed essential the numerical model account for the presence of these flows.

Ship traffic impacts

The NYNJH system experiences a large volume of deep-draft navigation. The presence of these vessels can have a significant impact on the hydrodynamics and sediment suspension and transport. A vessel can create sediment resuspension due to the blockage of the channel, the propellor wash, and the bow wave generated during transit. Tate et al. (2014) investigated the impact of vessels for Galveston Bay and discovered that ship traffic is a significant contributor to the dredge volumes in the channel. The magnitude of the impact of ship traffic on the dredge volumes in the NYNJH system is unknown but should be recognized as a contributor to sediment resuspension and movement.

Salinity intrusion and baroclinic circulation

The NYNJH is a partially mixed estuary that can transition from relatively high levels of stratification to completely mixed over short periods of time. The tide range (~5 ft) and currents increase the vertical mixing in the system and thereby prevent excessive levels of stratification (greater than 20 ppt), but stratification levels are high enough to create density driven circulation patterns. The salinity levels are highly dependent on the freshwater inflows, which can vary significantly during a given year.

Sedimentation regimes

The NYNJH is a very complex area in terms of sediment transport. The system has areas of both cohesive (Newark Bay and portions of Upper Bay) and noncohesive (Lower Bay and portions of Upper Bay) sediment transport.

There are various hydrodynamic factors (flow pathways in the system, baroclinic circulation patterns, wind driven circulation patterns, etc.) that make it extremely challenging to accurately predict the sediment transport in the NYNJH system. This is in addition to the complex nature of sediment transport in general.

The Hudson River is essentially a sediment storage feature that provides a temporal delay in the delivery of upper basin sediment to the estuary. Geyer et al. (2001) reported that the greatest export of sediment from the Hudson River to the estuary occurs when peak river discharges coincides with spring tides. During neap tides, the sediment gets trapped within the river. Ralston and Geyer (2009) proposed that the greatest export of river sediment occurs at moderate flows while at extreme flows, the sediment delivery, which is cubic with discharge, overwhelms the capacity of the river to transport and gets trapped. Wall et al. (2008) suggested that the tributaries downstream of Troy (Hudson River inflow location in Figure 3) supply as much as 30%–40% of the sediment supply to the estuary.

The sedimentation environment of Newark Bay has been of particular interest over the past 4 decades because of the presence of contaminated sediments within the lower Passaic River and Newark Bay. Suszkowski (1978) did the first comprehensive analysis of the hydrodynamic and sedimentation environment of Newark Bay.

Chant et al. (2011) studied the sedimentation environment of the Passaic River. They found that the Passaic River has been depositional over the past 60 years but is approaching geomorphological equilibrium to the pre-dredging conditions. Although the net tidal sediment flux is upstream into the Passaic River from Newark Bay under normal tidal conditions, when salinity driven circulation is evident, episodic river flooding dominates the overall net flux with downstream transport. The result is a net sediment flux from the Passaic River into Newark Bay.

The primary sediment source for Newark Bay is from Upper Bay through Kill van Kull (Chant 2006; Sommerfield and Chant 2010) and estimated at approximately 100,000 tons per year. The Passaic and Hackensack Rivers supply approximately 17,000 and 5,000 tons per year, respectively.

Shrestha et al. (2014) developed a conceptual model of the hydrodynamics and sediment transport regime in Newark Bay. They concluded the following:

1. In the absence of strong wind forcing or large tidal gradients, the navigation channel displays classic estuarine, gravitational, two-layer circulation with a seaward surface flow of freshwater and a landward bottom flow of salt water. Without freshwater or atmospheric forcing, landward flow in the channels is balanced by seaward flow in the shallow tidal flats.
2. A counterclockwise residual circulation is most often observed around Staten Island, although this can reverse depending on the tidal and atmospheric forcing.
3. Low freshwater inputs or episodic wind and storm events can break down the classic estuarine circulation pattern generally observed in the bay.
4. The primary source of imported sediment to Newark Bay is the Kill van Kull, which may supply up to 140,000 MT/year.
5. By comparison, the Passaic and Hackensack Rivers supply approximately an order of magnitude less sediment to Newark Bay than the Kill van Kull, despite being the largest freshwater sources.
6. Under the existing dredged configuration, most of the sediment originating from the Kill van Kull is deposited within the southern half of Newark Bay; most of the sediment originating from the Passaic River is deposited within the northern half of the bay.

7. Long-term average sedimentation in Newark Bay, particularly within the dredged channels, is offset by rates of maintenance dredging.
8. The subtidal flats in Newark Bay have low deposition rates and appear to be in long-term equilibrium.
9. The extensive history of dredging and shoreline development that have taken place in the Newark Bay study area have resulted in changing historical circulation and sediment transport patterns. Historical transport patterns are likely quite different from current transport patterns.

3 Technical Approach

Hydrodynamics

The hydrodynamics for the project were simulated using the 3D baroclinic version of the Adaptive Hydraulics (AdH) model (Savant et al. 2014). The model is based on the hydrostatic assumption and gradually varying flow. The governing momentum equations include terms for temporal variation (unsteady flow), advection, turbulent diffusion, bottom friction, vegetative friction, ice friction, Coriolis, wind stress, wave radiation stress, barometric pressure and pressure gradients, including density driven effects. Vertical turbulent diffusion is handled by Mellor-Yamada 2.0 (Mellor and Yamada 1982) closure with vertical mixing reduced based on Richardson number for cases of stratification (Savant 2015). The model also includes specification of rainfall and volumetric inflows (rivers, sewage discharges, etc.).

The hydrodynamic solution includes the simulation of salinity transport, which can induce density driven circulation patterns that are important to some critical aspects of sedimentation within the harbor.

Sediment transport

The sediment transport module within AdH is invoked by using the sediment transport algorithms of SEDLIB (Brown 2008a,b), which include cohesive and non-cohesive sedimentation processes. These processes are combined with the constituent transport solvers within AdH, with a constituent for each sediment size class simulated. The model includes both cohesive and noncohesive transport.

The current 3D version of AdH does not explicitly resolve bed load transport. It performs a total load calculation, and instead of distributing the total load between bedload and suspended load components, the total load is placed into suspension in the water column. Given the nature of bed material (large fall velocities), it is expected the bed material placed in suspension will quickly fall from suspension and return to the bed. This approach would tend to overestimate the transport of bed material in terms of travel distance and underestimate travel times, but given this is a tidally driven system, the overall impact is expected to be minimal. Sensitivity simulations with the two-dimensional (2D) version of AdH (which includes bed-load transport) also indicated that bed-load transport was significantly less than the suspended load. Note that bed-load transport would only be important in sand-dominated areas. Cohesive sediment areas would not possess bed-load transport.

Wave energy

The purpose of applying nearshore wave models is to describe quantitatively the change in wave parameters (wave height, period, direction, and spectral shape) between the offshore and the shoreline. As waves travel from the offshore through the surf zone, they shoal and break due to the shallower depths found in nearshore areas, leading to significant variations in wave conditions within relatively small areas. Offshore wave information obtained from wave buoys or global- or regional-scale wave hindcasts and forecasts is transformed through the nearshore coastal region using these models.

The nearshore wave model Steady-State spectral WAVE (STWAVE) was applied as part of the shoaling analysis for the navigation channel deepening in NYNJH. One STWAVE grid, previously developed as part of the North Atlantic Coast Comprehensive Study (NACCS), was updated for this modeling effort (Cialone et al. 2015).

To rigorously represent the hydrodynamic processes of the study area, tight two-wave coupling between AdH and STWAVE was facilitated with the CSTORM-MS, a physics-based modeling capability. During the two-way coupling process, AdH passes spatially variable water elevations, current velocities, and wind fields to STWAVE. When STWAVE completes its instance, it passes spatially variable wave radiation stress gradients to AdH to drive wave-induced water level changes (e.g., wave setup and setdown) and currents. These wave-generated currents can transport sediment onshore, offshore, and alongshore.

Meteorological impacts

The impacts of meteorology on hydrodynamics and sedimentation processes within the harbor are addressed both directly and indirectly. The direct impacts are handled by specifying the wind and pressure field over the model domain to be used for the wind stresses on the water surface and the spatial variation in the barometric pressure within the hydrodynamic model. Indirect impacts are addressed by the wind-wave generation calculations in STWAVE, which provide the radiation stress gradients that drive littoral currents to the AdH model. Indirect meteorological impacts are also included in the time-series boundary conditions for river discharges after major rainfall events and the associated induced suspended sediment influxes as well as the residual tidal signal across the open ocean boundary. Direct precipitation/evaporation within the harbor and drainage areas downstream of gaging stations were not included for this study. The tributary inflows are considered to be the primary response to precipitation. Local precipitation could result in some localized runoff and short-term variations in the salinity field but should have minimal effect on the long term model results.

Extreme events

Major meteorological events such as tropical storms and winter storms (Nor'easters) were modeled directly within the AdH model. The tidal boundary forcing for extreme events was taken from the ADCIRC NACCS results and embedded in the tidal boundary specification.

Model simulation approach

The conditions — hydrodynamic, salinity, and especially sediment — at a particular spatial location and time are impacted by the behavior prior to that time. Examples would be a large flow providing a significant amount of fine sediment to the system or a large storm event supplying coastal sand to the system. These types of events can result in system impacts for long periods of time and can significantly complicate efforts to replicate observations in the field. This study simulated five discrete years independently of each other. During these simulation time periods, the hydrodynamics, salinity, and sediment transport (including deposition and erosion) progress temporally with the bed elevations being updated during the simulation by erosional and depositional processes. The simulations were performed on the years independently to provide indicators of the relative shoaling intensity and potential dredging requirements. Since dredging activities prevent significant variations from the authorized depths, longer-term simulations could diverge from a realistic indicator of the dredging requirements as channel infilling could reduce depositional volumes.

The model simulations were completed with a probabilistic mindset. That is, given the deepened channel condition, what would be the sedimentation patterns during the next year for a range of potential forcing conditions? In general, the cumulative changes in erosion/deposition for multiple years would not be linear. As significant shoals form, the current velocities would be impacted, and nonlinear morphological changes could become important. However, the period of time for such significant changes is assumed to be much longer than the period between dredging cycles. Therefore, the linear superposition on the probabilistic yearly simulations is believed to be a valid indicator of the long-term dredging impacts for the deepening.

4 Numerical Models

Adaptive Hydraulics (AdH)

AdH is a US Army Engineer Research and Development Center (ERDC) developed modular Finite Element Method code capable of simulating 2D (AdH-2DSW) and 3D (AdH-3DSW) Shallow Water (SW) flow, Reynolds Averaged Navier Stokes flow, Saturated and Unsaturated Groundwater flow, and Overland flow computations. Both AdH-2DSW and AdH-3DSW were used in the execution of this study.

AdH-2DSW is the depth-averaged module of the AdH code utilized for mass conservative vertically averaged hydrodynamic and transport computations for a wide variety of domains such as riverine flows, estuarine flows, dam and levee break flows, etc. (Savant et al. 2011; Tate et al. 2012; Savant and Berger 2012; Martin et al. 2011; McAlpin et al. 2013).

AdH-3DSW is the hydrostatic 3D module of the AdH code utilized for mass and momentum conservative hydrodynamic and transport computations in regions where the vertical distribution of velocities is sufficiently different such that the depth-averaged behavior is not equivalent to the 3D behavior of the system. AdH-3DSW represents a state of the art in the numerical simulation of 3D hydrostatic flows (Savant and Berger 2015) and a few of its features are the following:

1. Linear triangle-based meshing allows for an accurate representation of bathymetry.
2. Vertical meshing that is neither Sigma nor Z-grid based and hence is not encumbered by the drawbacks of either.
3. Run-time adaption in the horizontal and vertical allows for improved representation of hydrodynamics as well as transport.
4. Internal time-step size adaption allows for time-step changes to capture rapidly changing physics during run time.
5. Fluid and constituent mass are conserved.
6. Easy transition from the 2D realm to the 3D realm.
7. Availability of several turbulence options such as Mellor-Yamada (Level 2 and 2.5), K-e, and Smagorinski along with turbulence suppression options.

Sediment transport library (SEDLIB)

SEDLIB is a sediment transport library developed at ERDC (Brown 2012a,b). It is capable of solving problems consisting of multiple grain sizes, cohesive and cohesionless sediment types, and multiple discrete bed layers. It calculates erosion and deposition processes simultaneously and simulates bed processes such as armoring, consolidation, and discrete depositional strata evolution.

The SEDLIB system is designed to link to any appropriate hydrodynamic code. The hydrodynamic code must be capable of performing advection-diffusion calculations for a constituent. SEDLIB interacts with the parent code by providing sources and sinks to the advection diffusion solver in the parent code. The sources and sinks are passed to the parent code via an explicit bed sediment flux for each grain class.

STWAVE

STWAVE is a finite-difference, phase-averaged spectral wave code based on the wave action balance equation. STWAVE computes nearshore wave growth, propagation, and transformation, including refraction, shoaling, and breaking.

Code description

The STWAVE code uses the governing equation for steady-state conservation of spectral wave action along a wave ray (Jonsson 1990):

$$(C_g)_i \frac{\partial}{\partial x_i} \frac{C C_g \cos(\alpha) E(\omega,\alpha)}{\omega} = \sum \frac{S}{\omega} \tag{1}$$

where:

C_g = group celerity
C = wave celerity
i = tensor notation for x- and y-coordinates
α = wave orthogonal direction
E = wave energy density divided by the density of water ρ_w and the acceleration of gravity g
ω = angular frequency
S = energy source and sink terms.

The angular frequency is related to the wave number *k* by the dispersion relation

$$\omega^2 = gk \tanh(kd) \tag{2}$$

with celerity, C, and group celerity, C_g, given by

$$C = \frac{\omega}{k} \tag{3}$$

$$C_g = 0.5C\left(1 + \frac{2kd}{\sinh(2kd)}\right) \tag{4}$$

Source and sink mechanisms include surf-zone breaking in the form of the Miche criterion (Miche 1951), the flux of input energy due to wind (Resio 1988; Hasselmann et al. 1973), energy redistribution through wave-wave interactions (Resio and Perrie 1989) and whitecapping (Resio 1987, 1988), and energy losses due to bottom friction (Hasselmann et al. 1973; Padilla-Hernandez 2001; Holthuijsen 2007). Radiation stress gradients are calculated based on linear wave theory and provide wave forcing to external circulation models. The full equations for these source terms and additional technical details are provided in Massey et al. (2011a).

Execution

STWAVE has two modes available, half-plane and full-plane. Half-plane allows wave energy to propagate only from the offshore towards the nearshore (± 87.5 deg from the x-axis of the grid). In other words, all waves traveling in the negative x-direction, such as those generated by offshore blowing winds, are neglected. Full-plane allows wave transformation and generation on the full 360 deg plane. All simulations were executed in full-plane to allow a more complete representation of the wave climate affecting sediment transport.

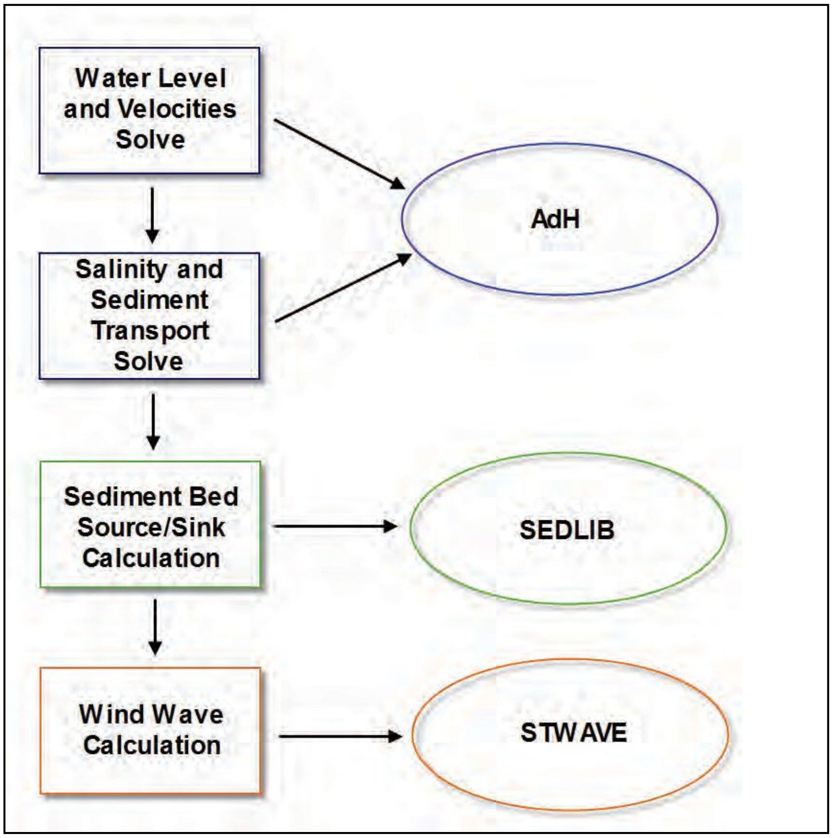
The full-plane version of STWAVE uses an iterative solution process that requires user-defined convergence criteria to signal a suitable solution. Boundary spectra information is propagated from the boundary during the initial iterations. Once the initial stage converges, winds and water levels are added to the forcing, and this final stage iteratively executes until it also reaches a convergent state. The convergence criteria for both stages include the maximum number of iterations to perform per instance, the relative difference in significant wave height between iterations, and the minimum percentage of cells that must satisfy the convergence criteria (i.e., have values less than the relative difference). Convergence parameters were selected based on a previous study by Massey et al. (2011a) in which the sensitivity of the solution to the final convergence criteria was examined. The relative difference was defined as 0.1 and 0.05 for the initial iterations and the final iterations, respectively. The minimum cell percentage was defined as 100.0 for the initial iterations and 99.8 for the final iterations. The maximum number of initial iterations to perform was 17 whereas the maximum number of final iterations was 22.

Full-plane requires considerably more memory with longer run times than half-plane. Thus, parallel computing was utilized to optimize the run time of the simulations. STWAVE was set up with parallel in-space execution whereby the computational grid was divided into different partitions in both the x and y directions, with each partition residing on a different computer processor. This application utilized 136 processors for the STWAVE solve.

Model coupling

The simulation of the processes necessary for the sedimentation analysis within the harbor was accomplished by coupling of the hydrodynamics, sediment transport, salinity transport, and wave generation and propagation within a single computer simulation. The coupling involved specification of the wind fields generated as part of the Wave Information Study (WIS) (http://wis.usace.army.mil/). This linkage of the waves to the AdH hydrodynamics and sediment transport was accomplished using the CSTORM-MS system (Massey et al. 2011b). An overview of the solution process is provided in Figure 13. The AdH (hydrodynamics and transport) and SEDLIB (sediment source/sink calculation) are solved at each time-step in the order shown. The STWAVE calculation is performed every 3 hours to reduce the computational burden due to the wave generation and propagation calculations.

Figure 13. Diagram of the solution steps.



5 Model Development

Mesh development

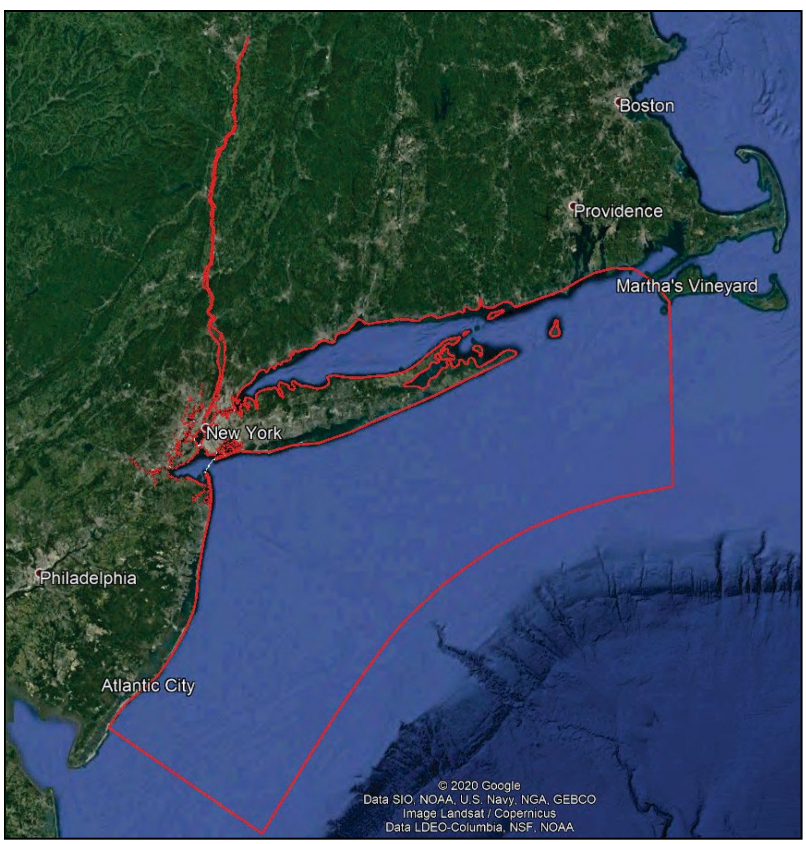
The numerical model requires a numerical model mesh for computations. The mesh specifies the model domain or computational area. It is imperative the model domain be large enough to prevent a prescribed result in the project area from the model boundary conditions. It is also important to include an appropriate level of model resolution and accurate bathymetric values to obtain useful model results.

Model domain

Hydrodynamic/salinity/sediment transport model

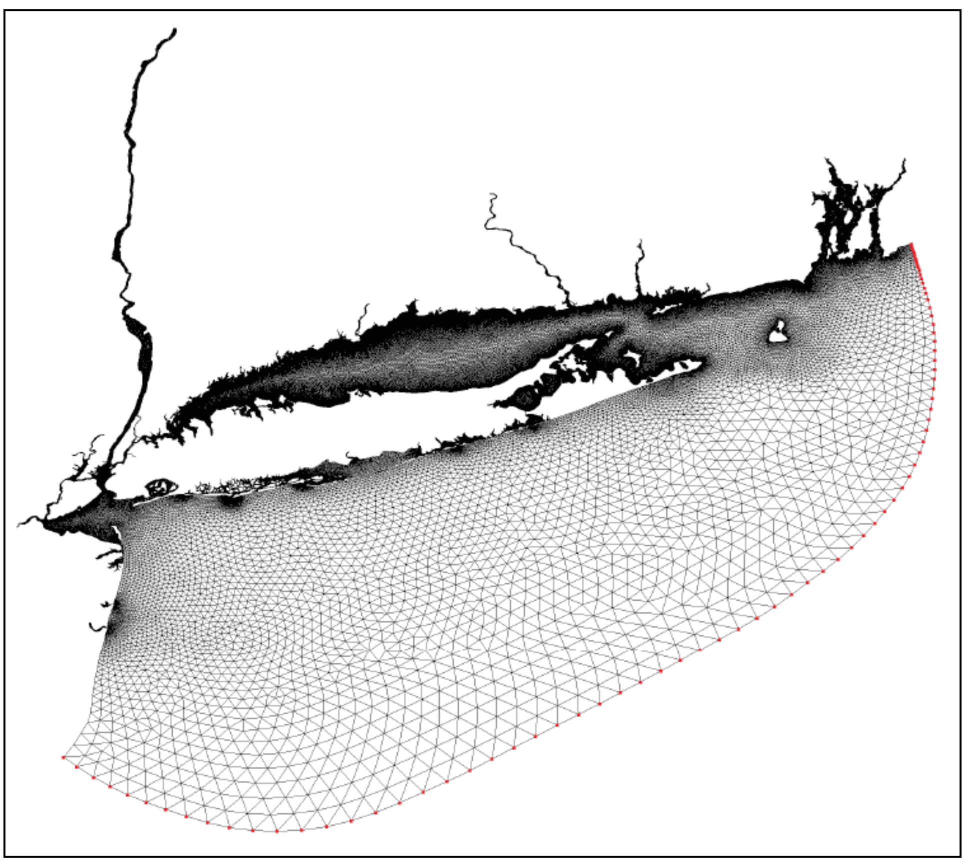
The numerical model domain for this study needs to be large enough to encompass the areas impacting the study area. For this complex system, that includes the previously discussed rivers along with the offshore areas. The model domain for this study is shown by the red line in Figure 14.

Figure 14. Model domain outlined with red line.



Previous studies completed at the ERDC Coastal and Hydraulics Laboratory consisted of a smaller domain due to computational constraints. This strategy began on the physical scale model of the harbor, when the domain was critical to the cost of construction. Previous numerical modeling efforts also included two tidal boundaries, one in the Long Island Sound and one offshore in the Atlantic Ocean. Proper specification of the phase variation between these two boundaries was an obvious source of error in the modeling but was unavoidable at the time for computational reasons. Given the advancements in numerical modeling and computational resources, this AdH model was able to avoid this complication. The choice of a proper model domain for this study area was reinforced by comparing the chosen AdH model domain to the domain utilized by National Oceanic and Atmospheric Administration (NOAA) (NOAA 2008) for its vertical tidal datum analysis (Figure 15). This model domain was also utilized by HydroQual (Blumberg et al. 1999; HydroQual 2008) model studies within the harbor and by pre-ERDC modeling of New York Bight (Scheffner et al. 1994), which was not focused within the harbor.

Figure 15. NOAA model domain used for development of vertical tidal datum in New York area (NOAA 2008).



Wave model

The wave impacts are incorporated into the model by linking the hydrodynamic and salinity and sediment transport model to a wave model (STWAVE) using the CSTORM-MS system (Massey et al. 2011b). This linkage consists of passing flow information to the wave model with the wave model passing back wave radiation stress gradients, which impact the flow conditions. This information is needed only for locations where wind waves impact the study area. The STWAVE model does not solve on the same mesh as the AdH model and as such allows for the wave model domain to be reduced for computational savings. The domain of the wave model is shown by the red box in Figure 16.

Figure 16. STWAVE model domain.

Mesh resolution

Excessive mesh resolution can result in extreme simulation times, and too little resolution can result in a reduction in the computational accuracy of the model results. Therefore, extreme care must be taken when choosing the spatial and vertical resolution in a numerical model. This issue is significantly reduced with AdH as it is an adaptive model whereby the resolution (horizontal and vertical) can be increased during the model simulation to better resolve the physics of the hydrodynamic and/or transported quantities. This added resolution is removed when no longer needed resulting in increased accuracy without significantly increasing the computational burden. However, the horizontal mesh resolution must be sufficient to capture all important features in the bathymetry, since horizontal adaption linearly interpolates the bottom elevation. The initial unadapted 3D mesh had approximately 220,000 nodes and approximately 750,000 elements.

Horizontal resolution

AdH model meshes are unstructured allowing increased resolution in the study area with significantly less resolution in the offshore areas. This allows the AdH mesh to possess approximately 50 to 100 m nodal spacing in and near the ship channels with approximately 18 km nodal spacing at the tidal boundary. The numerical formulation of AdH does not have a constraint on the mesh dimensions, as with classical finite difference formulations. Structured meshes would either be forced to have more resolution offshore where it is not needed or less resolution in the study area where it is required. Figure 17, Figure 18, and Figure 19 show the AdH horizontal mesh resolution.

Figure 17. AdH numerical model mesh.

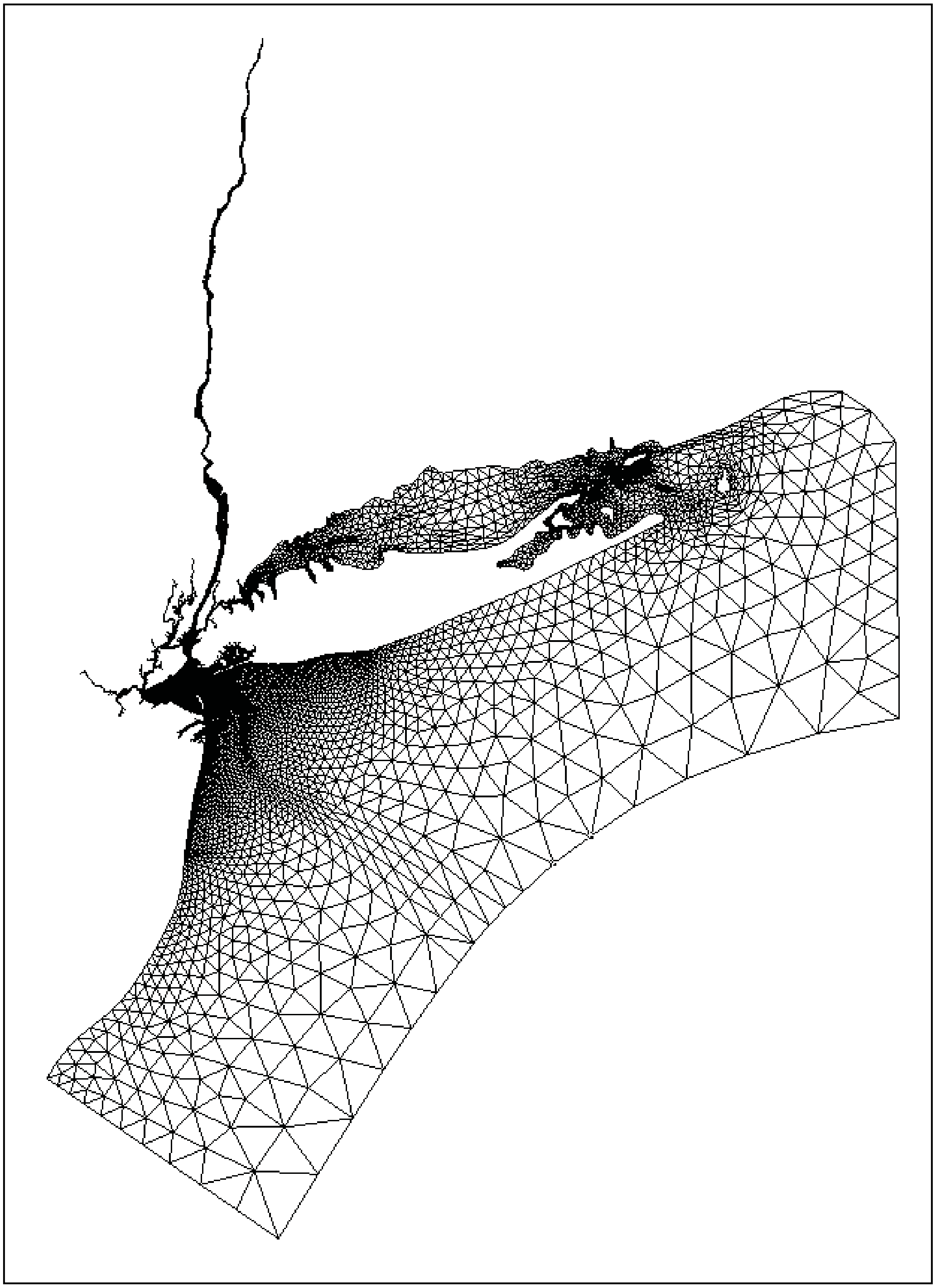


Figure 18. Mesh resolution in the NYNJH area.

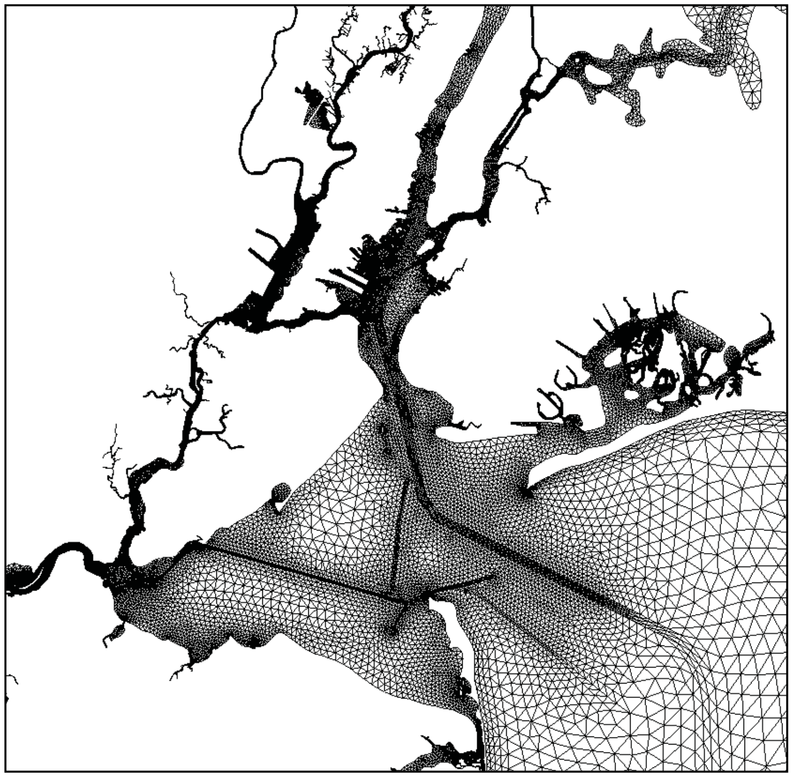
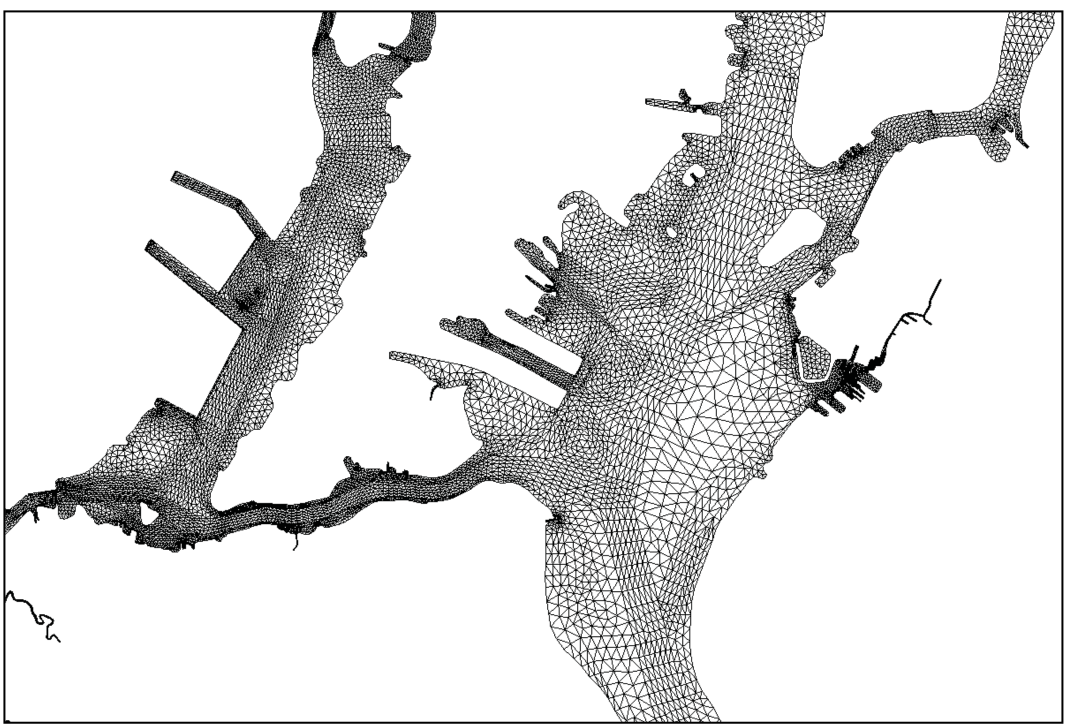


Figure 19. Mesh resolution in the Upper Bay and Newark Bay area.



Vertical resolution

The vertical resolution is illustrated in Figure 20 and Figure 21. AdH is unstructured in the horizontal and columnar in the vertical with the ability for the user to specify the number of vertical layers spatially. The vertical resolution ranges from one layer (2 nodes) in shallow areas and areas outside the study area to as much as five layers (6 nodes) in the ship channels. The adaptive capability in AdH allows this resolution to increase as needed during the model simulation to better resolve the hydrodynamics, salinity and sediment transport.

Figure 20. Vertical mesh resolution.

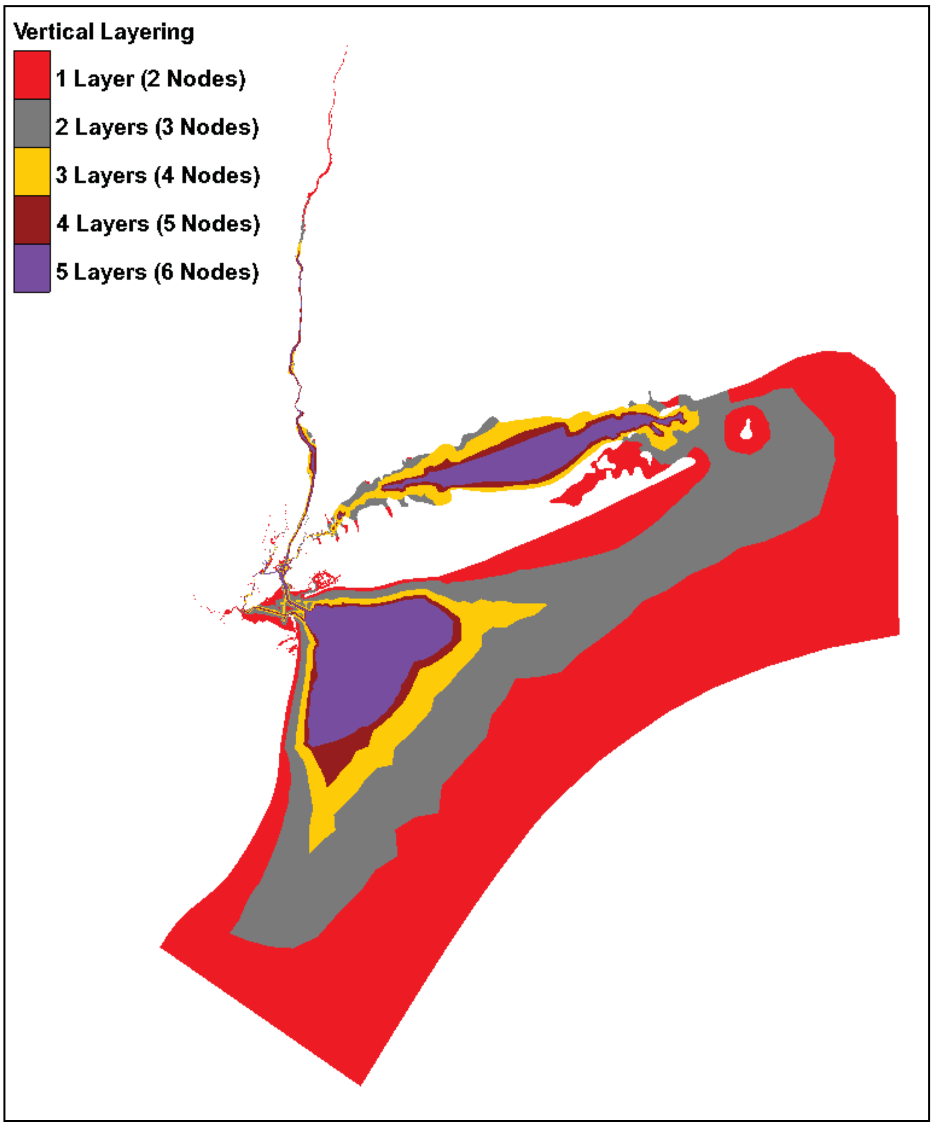
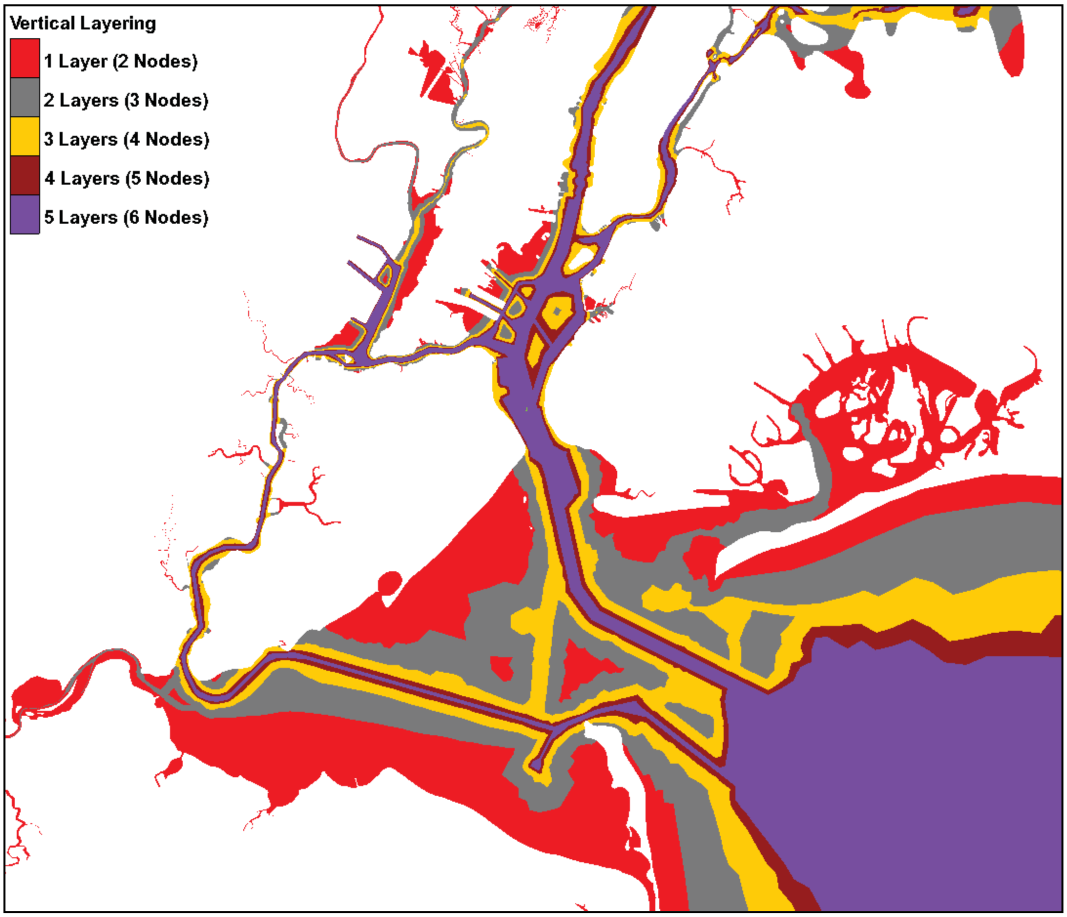


Figure 21. Vertical mesh resolution in the study areas.



Adaption

The AdH numerical code has the capability to adapt the numerical mesh during the simulation to better resolve the hydrodynamics and transport. The adaption levels vary based on regions or material types. Supplemental areas (offshore areas and upstream areas on the rivers) were specified to have zero adaption as the near field accuracy of the model in these areas is not vital in obtaining accurate results in the study area. The regions in and near the ship channel were allowed to adapt each element twice; additional areas (shallower tidal flats and other off channel areas) were allowed to adapt once. As an example of the resolution possibilities with adaption, one level of adaption can result in both a doubling of the vertical resolution (e.g., from 5 layers to 10 layers) and also a doubling of the horizontal resolution. Additional discussion of the 3D adaption in AdH is provided in Savant et al. (2017).

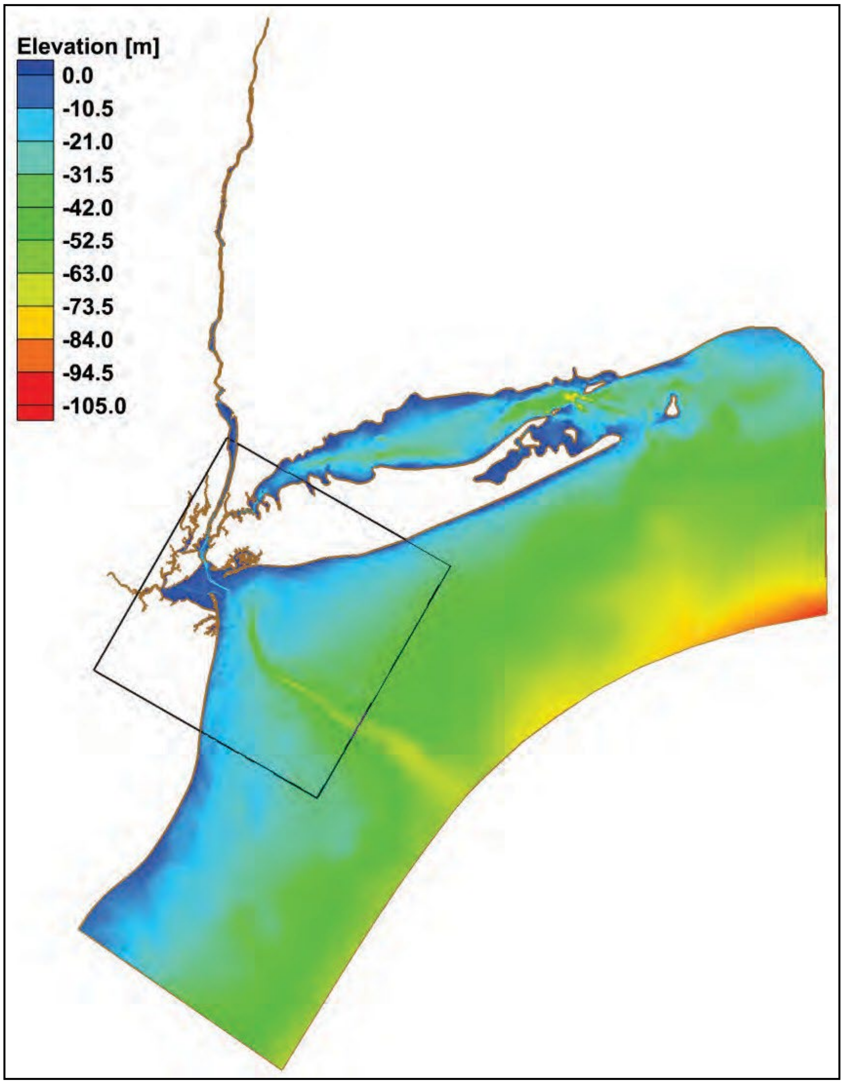
Wave model resolution

STWAVE is formulated on a Cartesian grid, with the x-axis oriented in the cross-shore direction (I) and y-axis oriented alongshore (J), often parallel with the shoreline. Angles are measured counterclockwise with respect to the grid x-axis. The grid encompassing the study area was previously developed as part of the NACCS (Cialone et al. 2015). The grid was projected from Universal Transverse Mercator Zone 18 to State Plane Coordinate System New Jersey (FIPS 2900) to be consistent with the AdH projection. The grid properties are shown in Table 1, and the location of the STWAVE grid with respect to the AdH domain is shown in Figure 22. The grid's offshore boundary remained at approximately 40 m, the same as the NACCS. Wave interactions with the bed at this offshore extent are relatively small, particularly in comparison to the importance of wave generation by wind. The grid resolution of 200 m also remained the same as that defined in the NACCS. This resolution has demonstrated good agreements with measurements for the NACCS (e.g., Hurricanes Gloria, Sandy, and Irene) and previous studies of Hurricane Rita, Katrina, Gustav, and Ike (Dietrich et al. 2011; Hope et al. 2008; Bunya et al. 2010; Dietrich et al. 2010; Bender et al. 2013).

Table 1. STWAVE grid properties.

Projection	Grid Origin (x,y) (m)	Azimuth (deg)	$\Delta x \backslash \Delta y$ (m)	Number of Cells	
				I	J
State Plane 2900	297382.3, 195032.8	150.2	200.0	569	593

Figure 22. STWAVE domain indicated by black box overlaid on AdH domain.



Bathymetric data

The accuracy of the model results is directly tied to the accuracy of the bathymetric data incorporated into the model. For this large model domain, multiple data sources were utilized in the specification of the bed elevations. The primary study area was specified utilizing data accumulated and merged by a district contractor (e4sciences*; Please note: The footnote below will serve for all mentions of this unpublished document throughout this report.). The remaining data consisted of

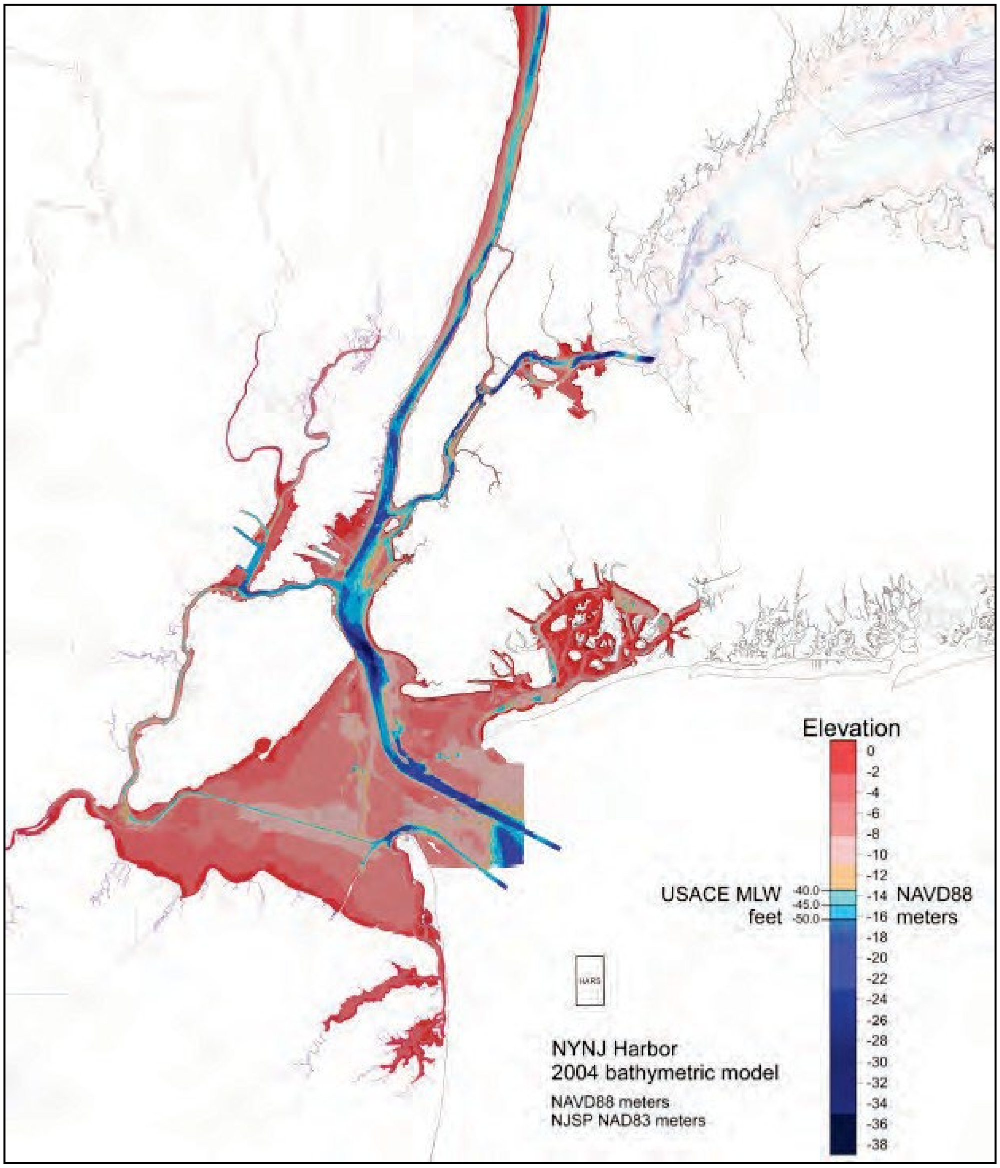
* e4sciences. 2018. Unpublished report. Contract #W912DS-13-D-0002: Task Order #0004. *New York New Jersey Harbor Deepening Project Sedimentation Study*. Draft Report for the Department of the Army, New York District Corps of Engineers, April 2018.

offshore areas and was specified based on the data from the ADCIRC model utilized in the NACCS (Cialone et al. 2015).

e4sciences bathymetric model

e4sciences coalesced available data to create the most accurate representation of the NYNJH bathymetry for 2004 (Figure 23) and 2015. The vertical datum of the provided bathymetry was in meters, NAVD88. Initial model simulations were completed on the 2004 bathymetry dataset, but portions of the 50 ft NYNJH deepening project were already constructed in 2004, and therefore 2004 was not considered an appropriate without-project bathymetry set. As such, the 2004 bathymetry dataset provided by e4sciences was modified to remove any components of the project deepening already constructed in 2004. This was primarily limited to the Kill van Kull area. The with-project configuration is discussed more in subsequent chapters but primarily consisted of modifying the without-project bathymetry to incorporate the project deepening. Therefore, areas not altered due to the construction of the project are the same in both the with- and without-project bathymetry sets. This makes with-project versus without-project comparisons more appropriate as there are no mesh modifications outside the project deepening influencing the model results.

Figure 23. Bathymetric model for 2004 from e4sciences.



ADCIRC bathymetric model

The e4sciences dataset did not cover the entire model domain. Therefore, additional bathymetric data were required for the remaining areas of the mesh. The NACCS (Cialone et al. 2015) ADCIRC mesh was available for these outlying areas. The ADCIRC mesh resolution is provided in Figure 24. The bathymetric data associated with that mesh is shown in Figure 25.

Figure 24. ADCIRC comprehensive model mesh resolution in the Delaware Bay to Nantucket area including New York Bight.

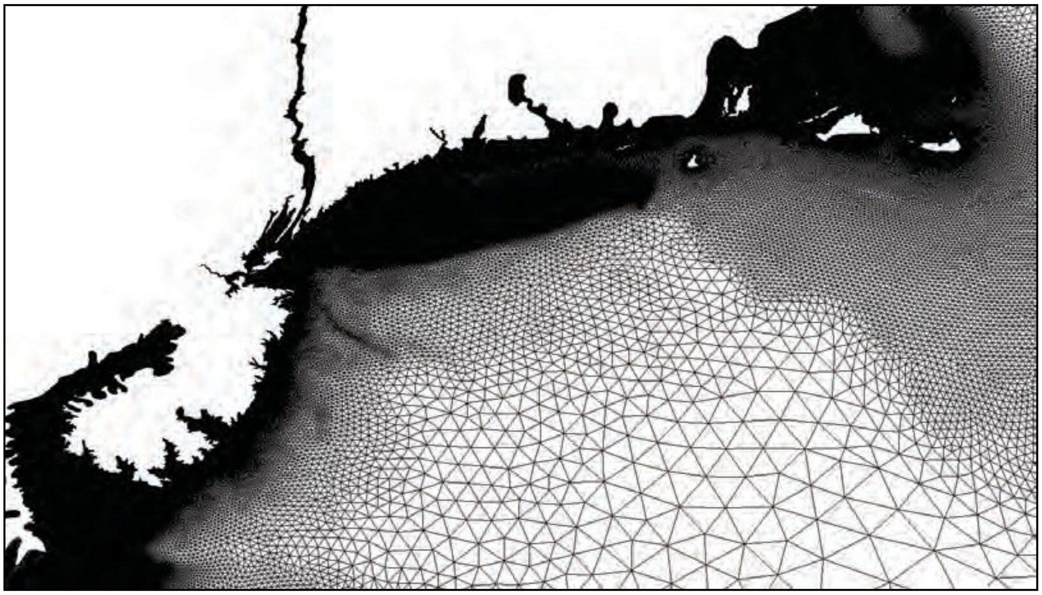
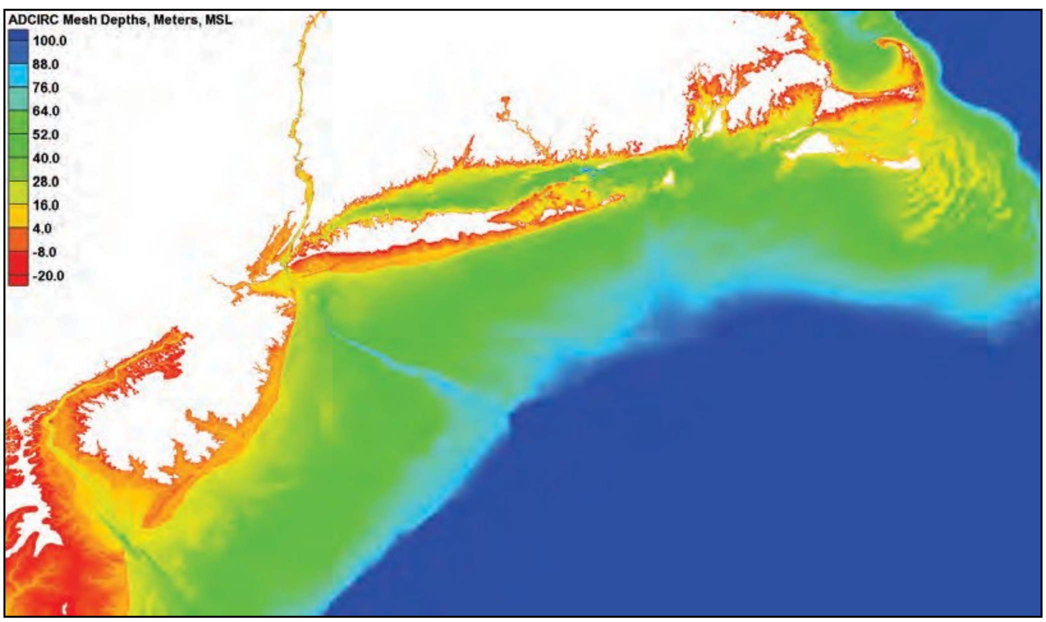


Figure 25. ADCIRC comprehensive model depths, from -20 m mean sea level (MSL) (red) to 100 m (blue).



Adaptive hydraulics mesh bathymetry

The two previously discussed datasets were converted to the same vertical and horizontal datums and combined with the e4sciences dataset having priority over the NACCS data. The resulting merged dataset was then incorporated into the numerical model mesh with any components of the channel deepening being removed, resulting in the bathymetry shown in Figure 26 and Figure 27.

For consistency in coupling of the hydrodynamic model, the wave model and the NACCS offshore boundary conditions, the vertical datum for the AdH model was selected as MSL as defined at Sandy Hook.

Figure 26. AdH mesh bathymetry.

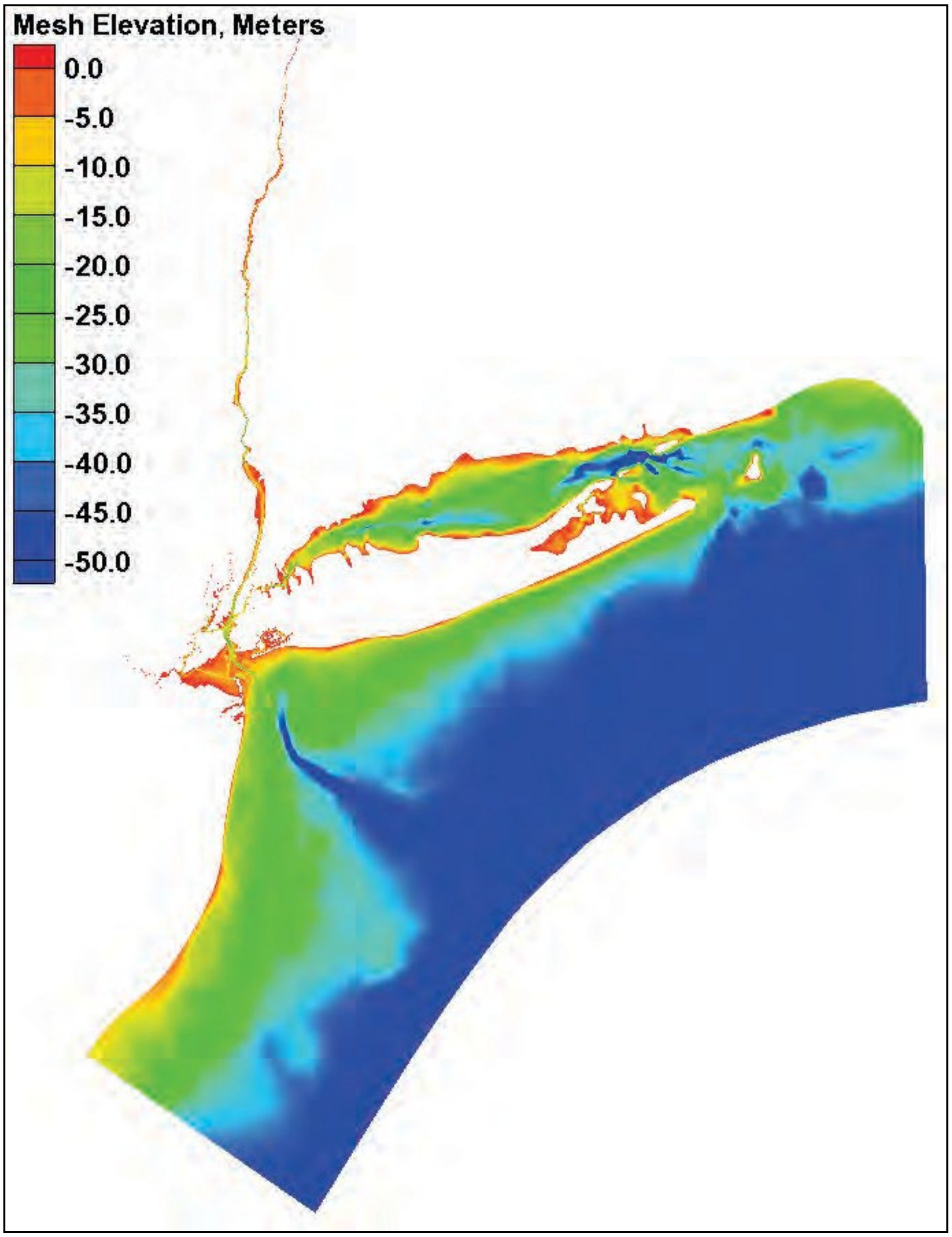
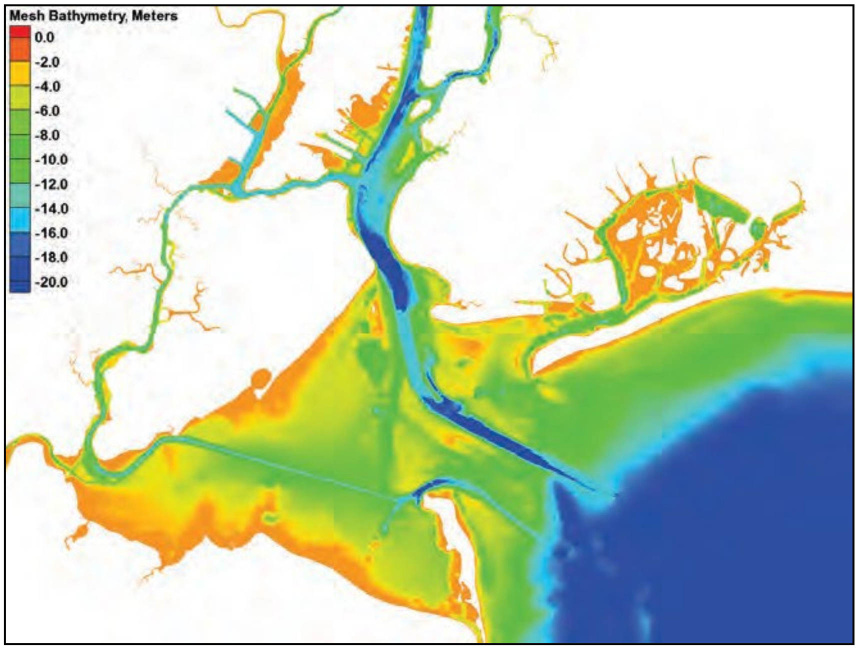


Figure 27. AdH without-project mesh bathymetry in the NYNJH.



STWAVE mesh bathymetry

The bathymetry was interpolated from the AdH mesh to populate the STWAVE domain with land based values obtained from the ADCIRC mesh.

Boundary conditions

The purpose of the numerical model is to perform very complex computations that amount to balancing the water, salt, and each sediment size class over the complete domain of the model and report on the tendencies for various sediment classes to fall into the navigation channels. To perform those balances, the inflowing water, salt, and sediment must be defined as boundary time-series conditions at all tributary inflows and tidal boundaries.

Comparison of the numerical model to long-term field experience necessitates that the model be simulated for a sufficient variety of environmental forcing conditions to make the comparisons appropriate. This is particularly true for sedimentation results. Consequently, five specific calendar years (1985, 1995, 1996, 2011, and 2012) were chosen for model simulation to provide a range of hydrologic inflows and meteorological conditions, including both tropical and extra-tropical storms.

Riverine flows

The time series for each tributary for the years simulated are presented in Figure 28 through Figure 36, along with the minimum and maximum daily flows during the year. Note that 0.0 values cannot be plotted on log plots. The Hackensack River in particular does not have a minimum line as the minimum flows are 0.0 cfs. The Hudson River is an order of magnitude larger than any of the remaining flows and as such tends to dominate the system. The mean annual discharges for the Hudson River for each of the five simulated years are compared to the cumulative frequency of the mean annual discharge derived from data for 1947 through 2014 in Figure 37. Calendar year 2011 was the year with the highest mean annual discharge (640 cms or 22,570 cfs) while 1995 was the lowest Hudson River discharge year. Table 2 shows the statistics for the included rivers for each of the five simulated years. Table 3 provides the mean flows for the Hudson River for the five simulated years along with an approximate return period for each year.

Figure 28. Annual river discharges for Hudson River for simulation years 1985, 1995, 1996, 2011, and 2012 compared to the minimum and maximum discharges.

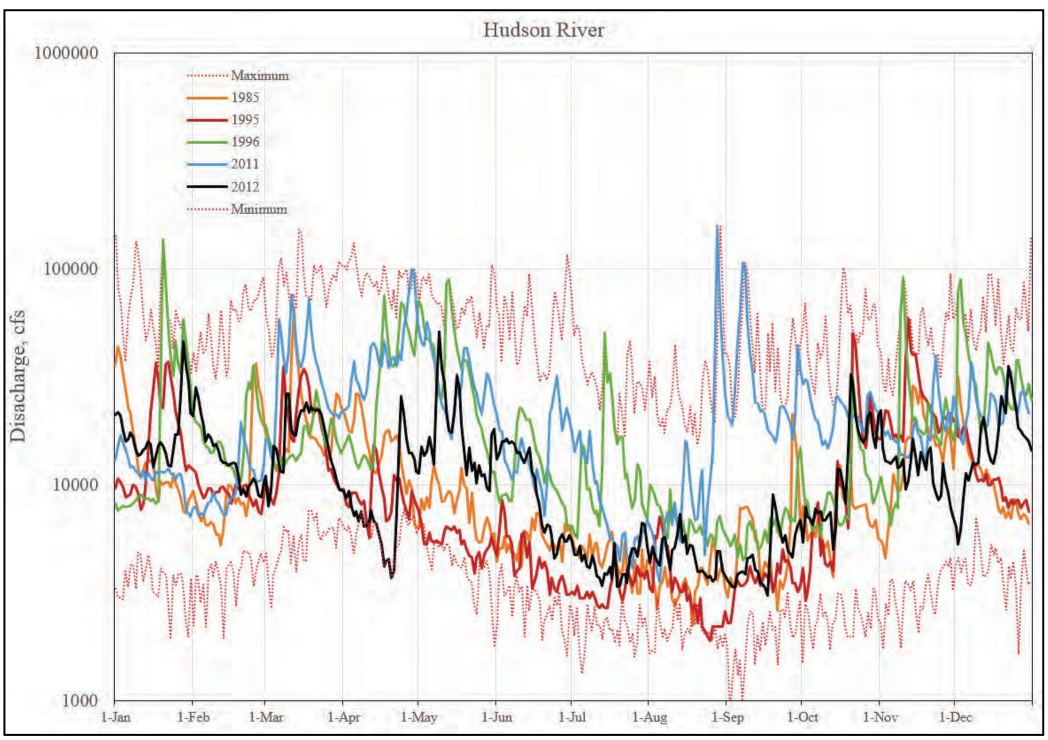


Figure 29. Annual river discharges for Hackensack River for simulation years 1985, 1995, 1996, 2011, and 2012 compared to the minimum and maximum discharges.

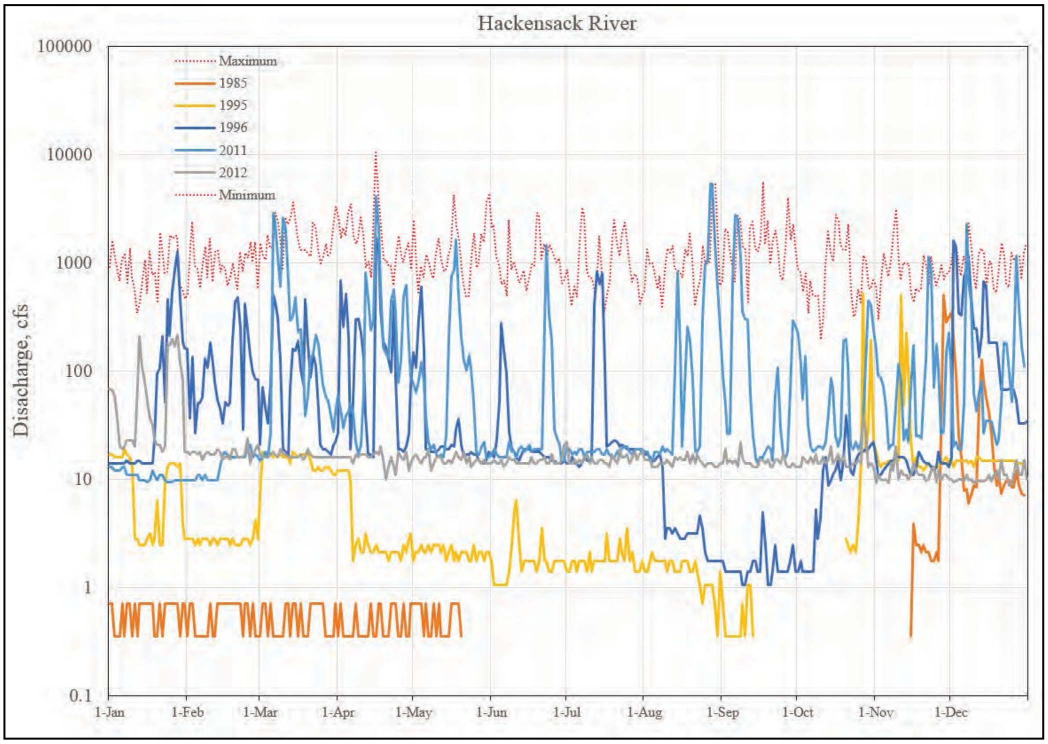


Figure 30. Annual river discharges for Passaic River for simulation years 1985, 1995, 1996, 2011, and 2012 compared to the minimum and maximum discharges.

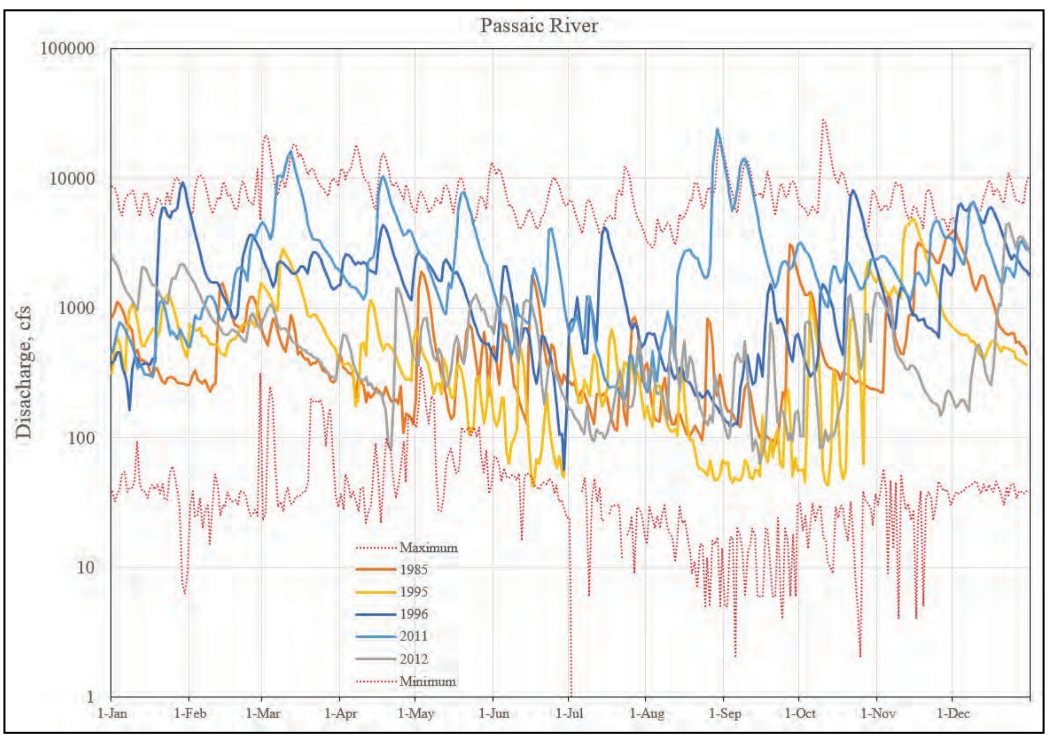


Figure 31. Annual river discharges for Saddle River for simulation years 1985, 1995, 1996, 2011, and 2012 compared to the minimum and maximum discharges.

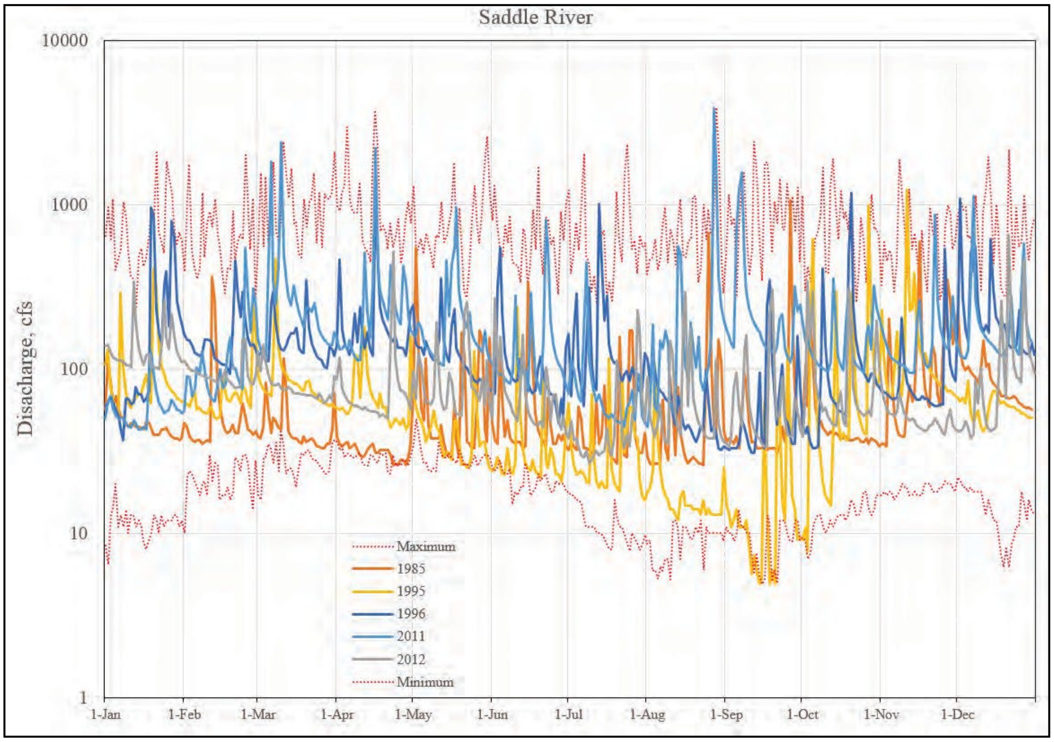


Figure 32. Annual river discharges for Third River for simulation years 1985, 1995, 1996, 2011, and 2012 compared to the minimum and maximum discharges.

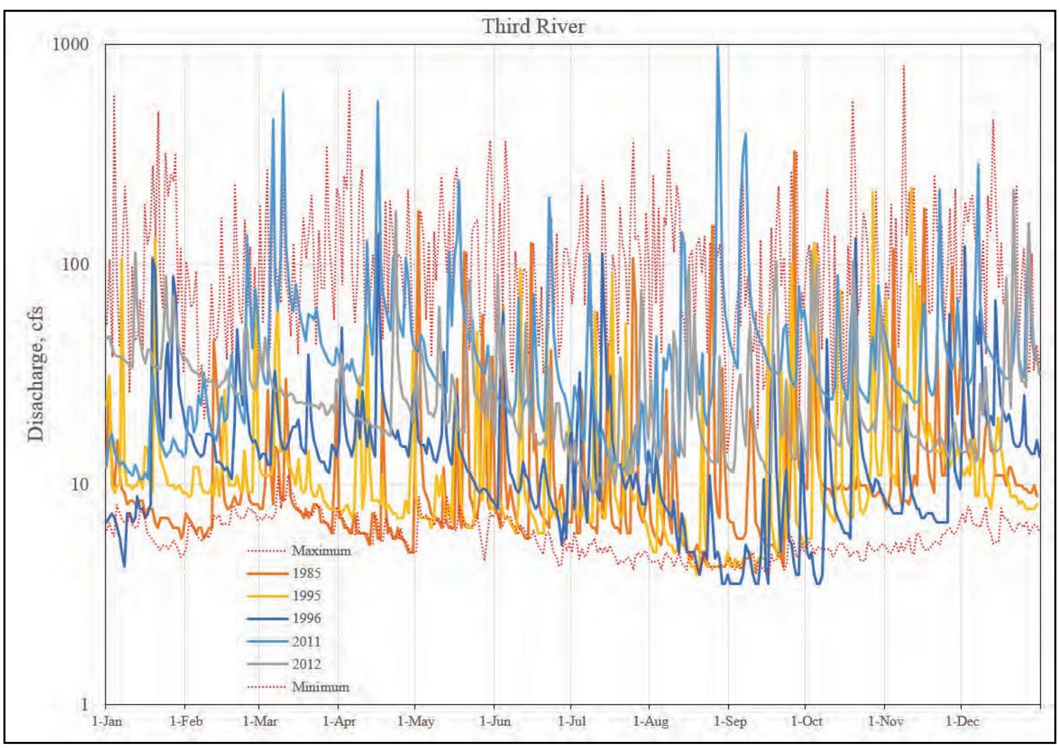


Figure 33. Annual river discharges for Rahway River for simulation years 1985, 1995, 1996, 2011, and 2012 compared to the minimum and maximum discharges.

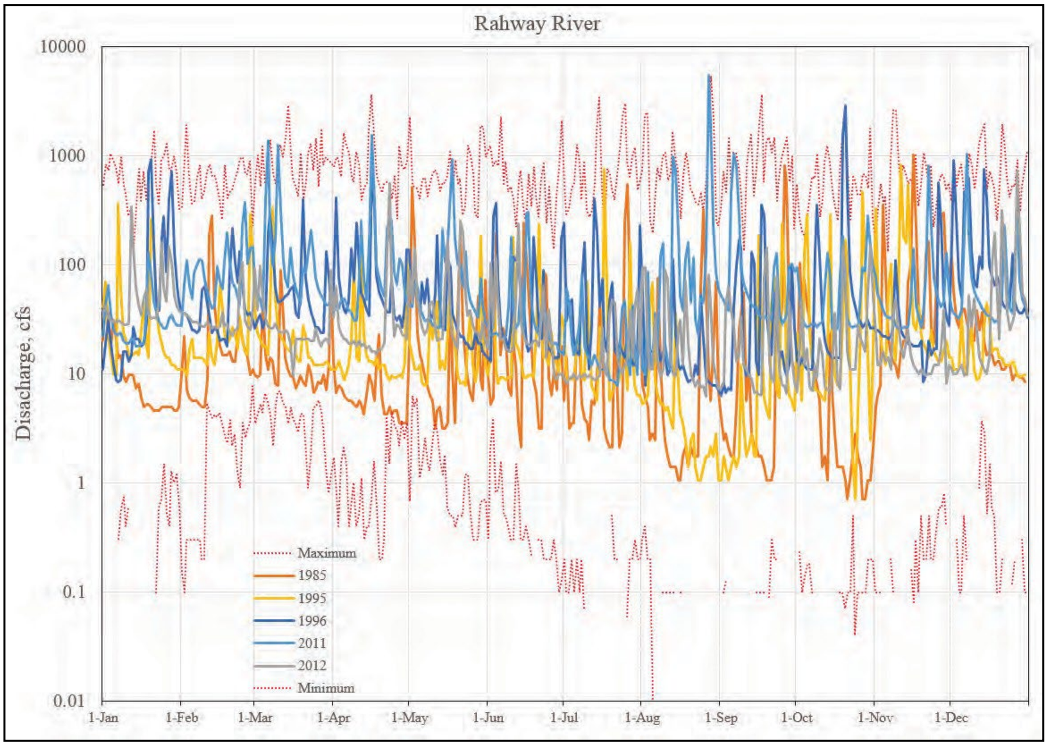


Figure 34. Annual river discharges for Raritan River for simulation years 1985, 1995, 1996, 2011, and 2012 compared to the minimum and maximum discharges.

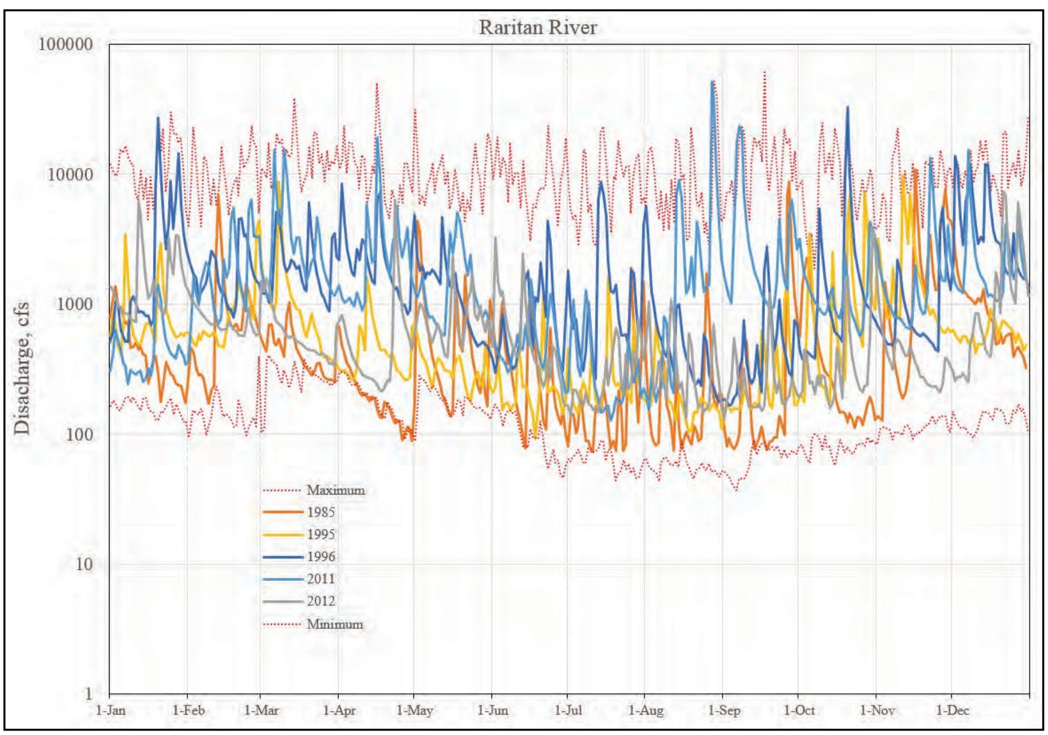


Figure 35. Annual river discharges for Lawrence Brook for simulation years 1985, 1995, 1996, 2011, and 2012 compared to the minimum and maximum discharges.

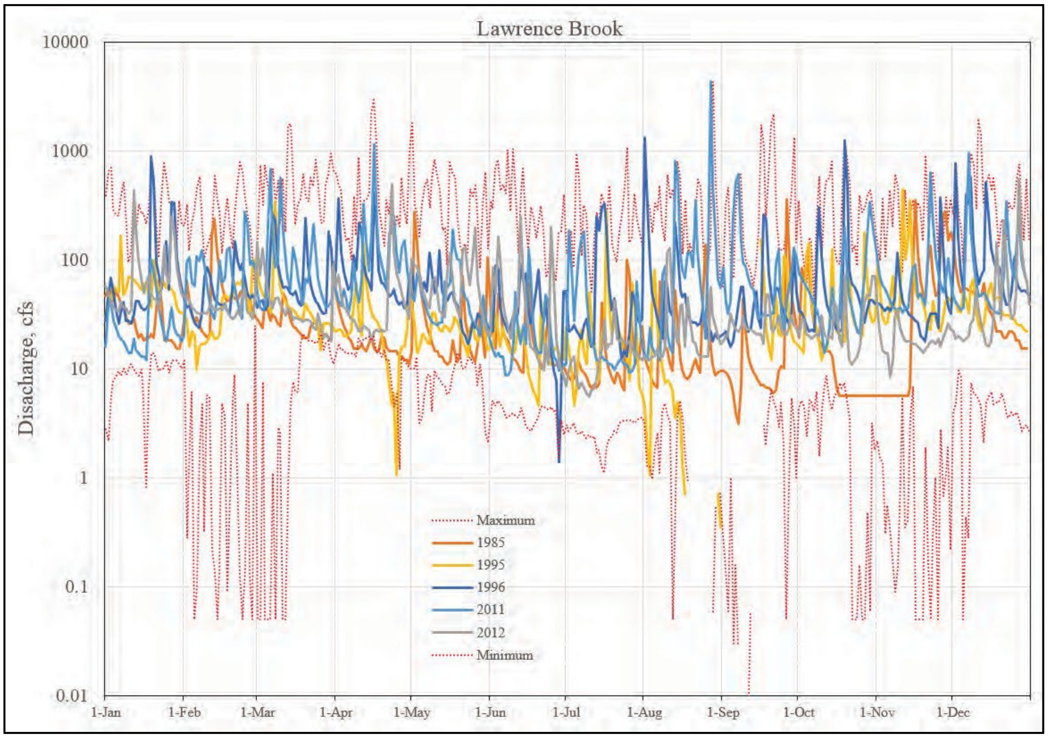


Figure 36. Annual river discharges for the South River for simulation years 1985, 1995, 1996, 2011, and 2012 compared to the minimum and maximum discharges.

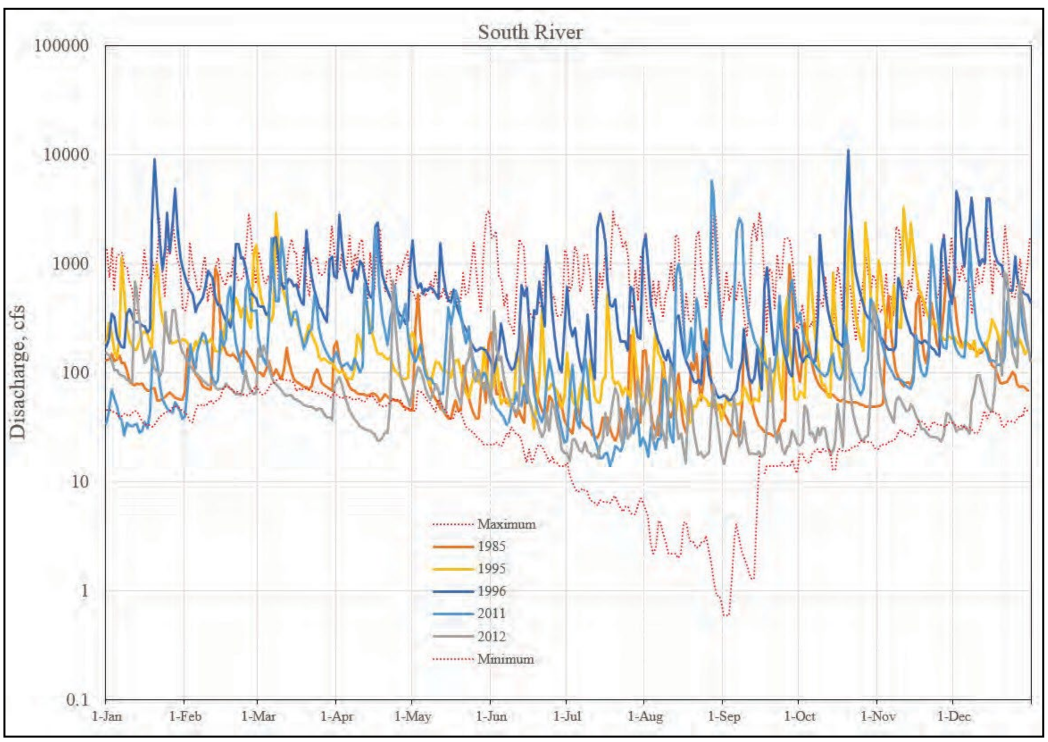


Figure 37. Cumulative frequency of average annual Hudson River discharge from 1947 through 2014 compared to model simulation years.

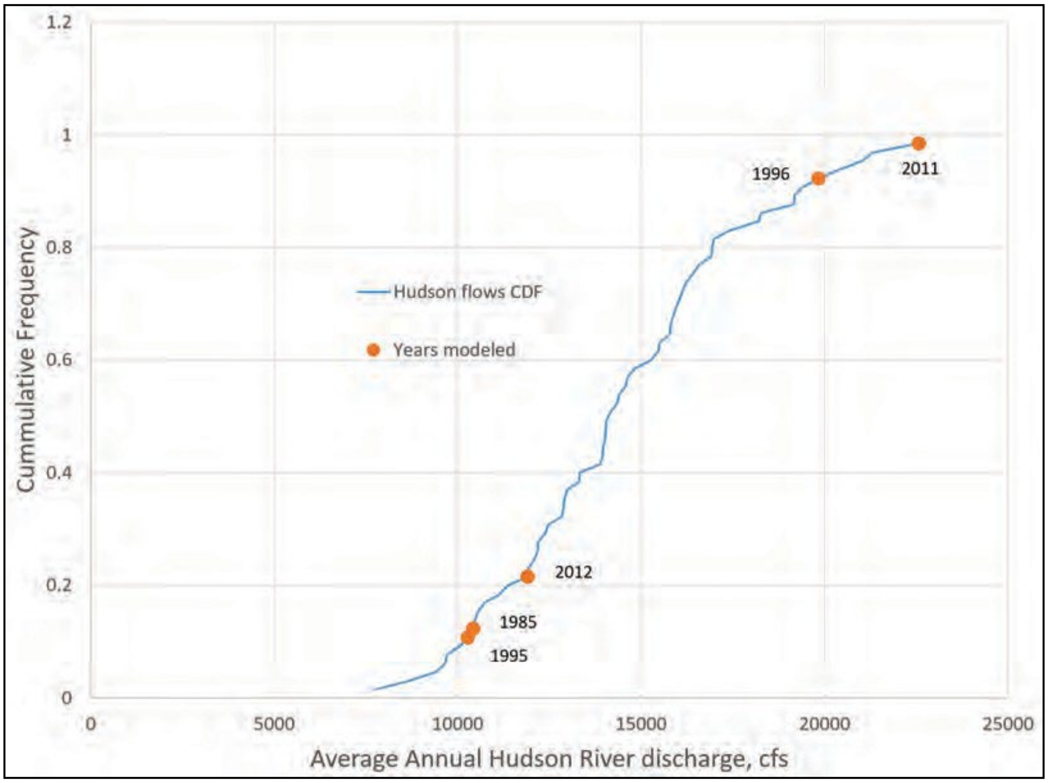


Table 2. Statistics of tributary inflows for simulation years (in cms)

Calendar Year	Statistic	Tributary								
		Hudson	Passaic	Raritan	Hackensack	South	Lawrence	Rahway	Saddle	Third
1985	Peak	1,869.0	111.8	305.8	14.24	27.52	10.28	28.60	30.30	9.20
	Minimum	63.4	2.5	2.1	0.00	0.68	0.09	0.02	0.74	0.12
	Average	296.8	18.4	18.9	0.19	3.06	0.91	0.97	1.86	0.42
	Std Dev	225.6	20.8	33.0	1.17	3.41	1.26	2.67	2.45	0.74
1995	Peak	1,667.9	137.6	277.8	14.67	92.60	12.54	23.22	35.11	6.34
	Minimum	53.8	1.2	2.6	0.00	0.87	0.00	0.02	0.14	0.11
	Average	290.6	17.2	21.1	0.29	7.04	1.00	1.01	1.96	0.43
	Std Dev	250.1	21.0	31.9	1.16	10.64	1.25	2.38	2.87	0.67
1996	Peak	3,879.6	262.5	926.0	47.86	308.66	37.38	81.84	35.11	3.90
	Minimum	127.4	1.6	4.7	0.03	1.58	0.04	0.18	0.88	0.10
	Average	560.9	50.9	57.5	2.89	19.16	2.24	2.46	4.14	0.46
	Std Dev	498.2	48.8	86.2	6.42	28.74	3.78	5.93	4.44	0.49
2011	Peak	4,474.2	674.0	1,461.2	152.35	162.36	122.90	154.05	110.72	27.68
	Minimum	100.0	5.3	3.6	0.27	0.40	0.25	0.22	1.22	0.30
	Average	638.4	81.3	63.9	5.99	7.10	2.64	3.25	5.74	1.43
	Std Dev	489.1	92.8	123.5	17.03	13.72	7.21	9.85	9.19	2.30
2012	Peak	1,452.7	127.7	209.3	6.12	23.25	15.66	20.50	18.58	6.19
	Minimum	87.2	1.8	3.7	0.25	0.41	0.16	0.18	0.76	0.25
	Average	337.8	19.1	20.8	0.56	2.31	1.20	1.06	2.41	0.80
	Std Dev	207.5	19.8	26.6	0.70	2.95	1.56	1.74	1.91	0.64

Table 3. Return periods for mean annual Hudson River inflows for simulation years

Calendar Year	Mean Annual Discharge		Return Period (years)
	cfs	cms	
1985	10,420	295.1	1.14
1995	10,270	290.8	1.12
1996	19,830	561.5	13
2011	22,570	639.1	65
2012	11,900	337.0	1.3

River inflow sediment concentrations

The data needs for the upstream sediment boundary conditions are based on the numerical approach used at the boundary. There are two general approaches that have been used in AdH for other sediment transport studies. The most direct is to specify the inflowing sediment concentrations by sediment size class, with the summation of all size classes being the total concentration. The primary problem with this method is insufficient data to specify either the size distribution or even the total concentration as a function of time. The second approach was developed to compensate for these data deficits.

This method is usually best applied to riverine conditions that are in relative equilibrium. The assumption of equilibrium in the transport is only applicable to sand transport. A section of the model adjacent to the boundary and some distance downstream is treated in a special way. The bottom bed surface elevation is fixed. The bed sediment distribution is initialized and the bed thickness set as a deep reservoir of sediment. The boundary concentration is set to a low value, commonly zero. As the flow enters, the model sediment entrainment occurs, providing enough sediment supply, until at the downstream end of this initialization section the sediment concentrations are near equilibrium based on the hydrodynamic conditions. This method does not work well for fines or wash load. Also, tidal rivers provide further complications. This study utilized a combination of the two aforementioned approaches. The specification of the inflowing concentrations was directly specified while the upstream riverine sections were specified with a fixed bottom bed surface elevation to allow the model to adjust to inconsistencies in the inflowing concentrations. The issues regarding data deficits in determining an accurate incoming sediment concentration at all times for each grain class is still present but reduced with this methodology.

Hudson River

The primary source of sediment for the estuary is the Hudson River for the inner harbor and littoral beach sands for Ambrose Channel. The upstream limit of the numerical model was chosen as the Troy Lock and Dam. The gaging station used for the Hudson River inflows is primarily at Green Island, which is approximately a mile downstream of Troy Lock and Dam. There are only limited measurements of suspended sediment at the Green Island gaging station and none for the simulated time periods.

Upstream of Troy Lock and Dam on the Hudson River is the Waterford gaging station with suspended sediment concentrations (SSC) available for 2011 and 2012, but not for the other 3 years (1985, 1995, and 1996). Between the Waterford gaging station and the Green Island station, the Mohawk River enters the Hudson from the west, approximately 0.8 mi above Troy Lock and Dam. A schematic of this confluence is provided in Figure 38. An aerial image of the confluence is provided in Figure 39. Suspended sediment and discharge data are available for the Mohawk River at Cohoes, NY, for some years but not others. When no suspended sediment concentration data were available for the Hudson River at Green Island, an estimate could be made, provided there were SSC data at both the Mohawk River at Cohoes and for the Hudson at Waterford.

Figure 38. Schematic of confluence of Mohawk River and Hudson River.

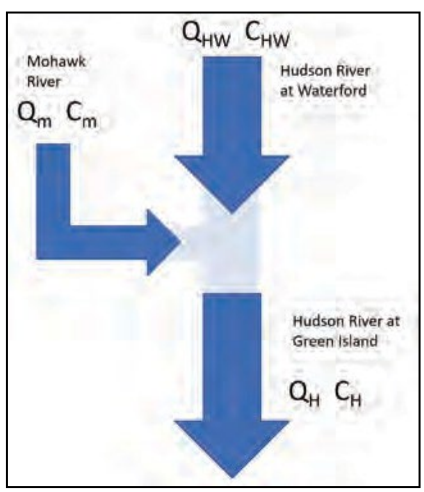


Figure 39. Aerial Image of confluence of Mohawk and Hudson Rivers.

The estimate (Equation 5) was made assuming that the SSC does not interact with the bed between the upstream gaging station and the station at Troy (which is aliased as Green Island data).

$$CC_{HH} = \frac{CC_{MM}QQ_{MM}+CC_{HHHH}QQ_{HHHH}}{QQ_{HH}} \tag{5}$$

where

C_H = SSC at Green Island
C_M = SSC of Mohawk River at Cohoes
C_{WH} = SSC of Hudson River at Waterford
Q_H = Hudson River discharge at Green Island
Q_M = Mohawk River discharge at Cohoes
Q_{HW} = Hudson River discharge at Waterford.

The percentiles of available SSC data for the Hudson River at Waterford are presented in Figure 40. The peak SSC was approximately 800 ppm by weight. The percentiles of SSC for the Mohawk River at Cohoes are presented in Figure 41. The maximum SSC for the Mohawk River was approximately 2,500 ppm. The sediment concentrations on the Mohawk are generally higher than on the Hudson.

The Hudson River also has ungauged flows that enter below Troy Lock and Dam. This modeling effort neglected these flows as they were not deemed significant and would have minimal impact on the model results. Appendix A details the magnitude of these additional flows.

Figure 40. Percentiles of sediment concentration for Hudson River at Waterford.

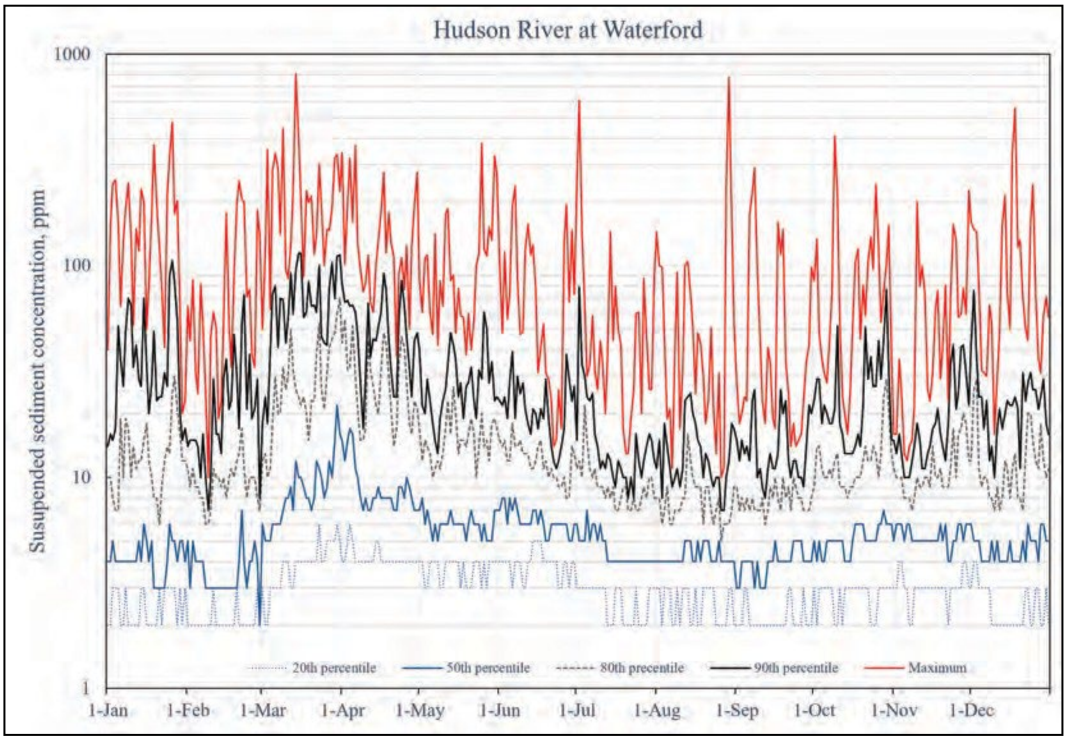
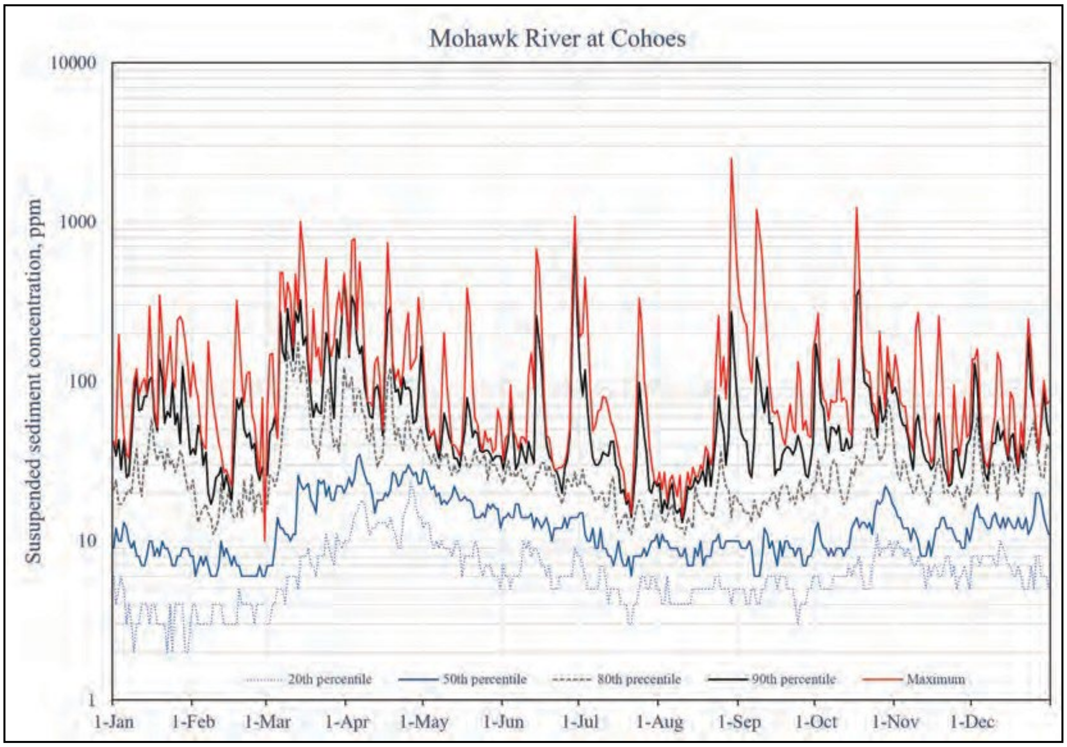
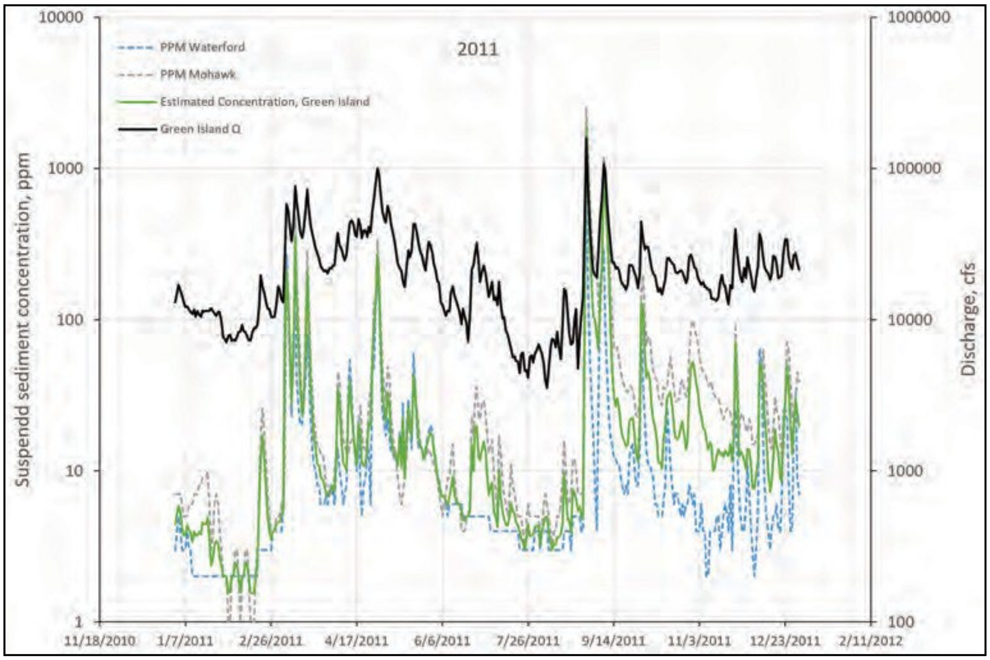


Figure 41. Percentiles of sediment concentration for Mohawk River at Cohoes, NY.



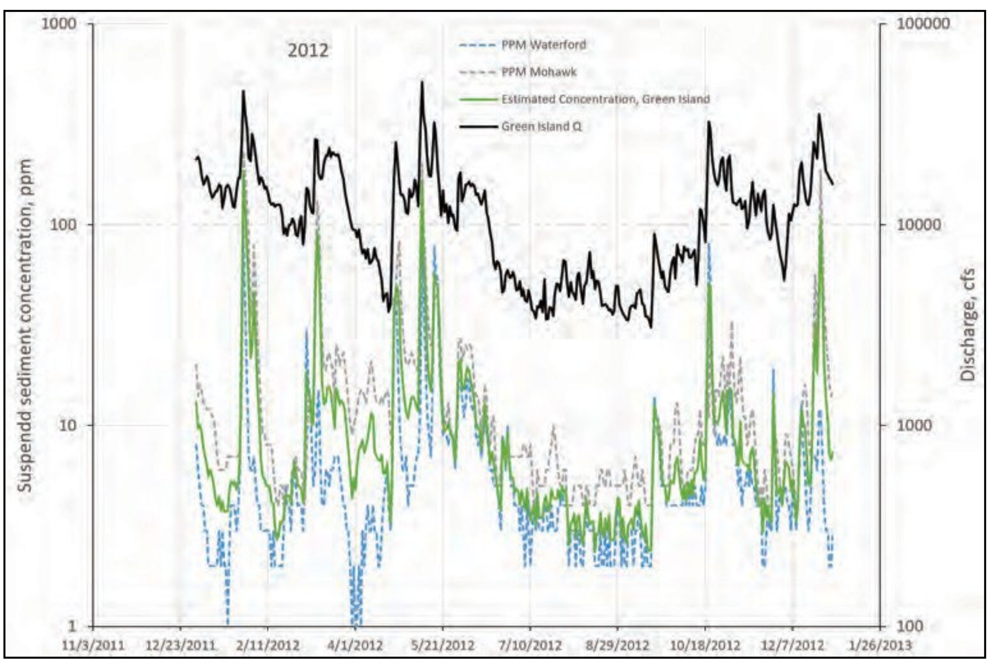
For calendar year 2011, the approximation technique of Equation 5 for the SSC of the Hudson River at Green Island is presented in Figure 42 and compared to the SSC data for the Mohawk at Cohoes and the Hudson River at Waterford. The maximum concentrations in early September are associated with the heavy rains of Hurricane Irene, which produced significant sediment load on the Mohawk River. As expected, because Equation 5 is essentially a weighted averaging, the estimated SSC for Green Island lies between the values at Waterford and Cohoes. The maximum SSC for 2011 at Green Island was estimated to be 1,841 ppm.

Figure 42. Estimation of 2011 SSC at Hudson River at Green Island via Equation 5.



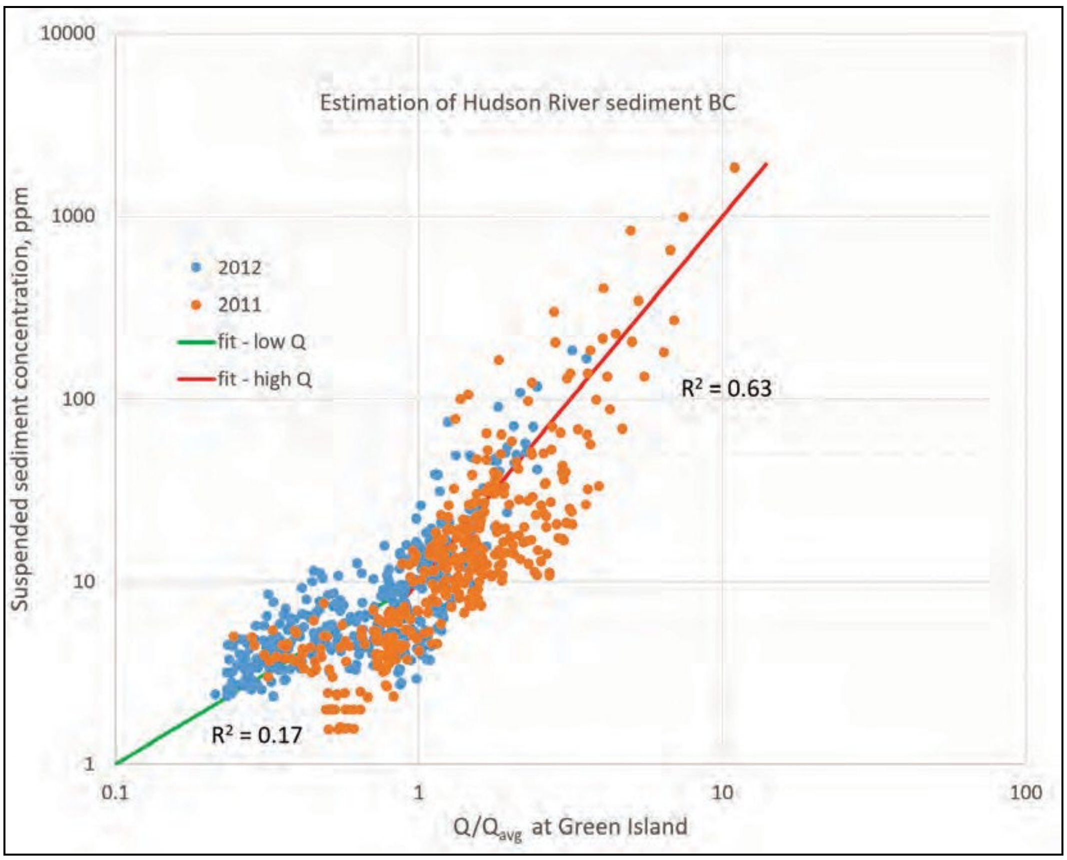
The estimation for calendar year 2012 is presented in Figure 43. Similar averaging of results is seen for 2012. The maximum SSC at Green Island was estimated at 185 ppm for 2012.

Figure 43. Estimation of 2012 SSC at Hudson River at Green Island via Equation 5.



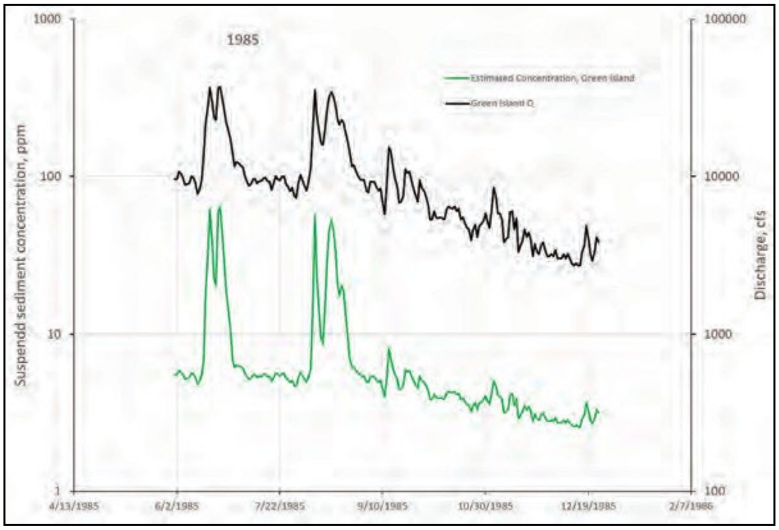
For calendar years 1985, 1995, and 1996, SSC data were not available for both the Mohawk River at Cohoes and the Hudson River at Waterford; therefore, making use of Equation 5 was not an option. Also, SSC data were not available at the Hudson River at Green Island. As an alternative, a relationship was sought between the Hudson River discharge at Green Island and the estimated SSC for 2011 and 2012. It was found that an effective independent variable for the SSC is the nondimensional discharge (Q/Q_{avg}). A plot of the SSC versus the nondimensional discharge is shown in Figure 44 for the estimated SSC for years 2011 and 2012. A regression was performed for the nondimensional discharges above and below 1.0. The upper data showed the SSC to be dependent on the square of the discharge and the lower data linear with discharge. At higher flood flows (nondimensional discharge > 1), the SSC is transport capacity controlled. At lower flows the SSC may be sediment supply limited.

Figure 44. Relationship of flow-weighted suspended sediment concentration with nondimensional river discharge for the Hudson River at Green Island.



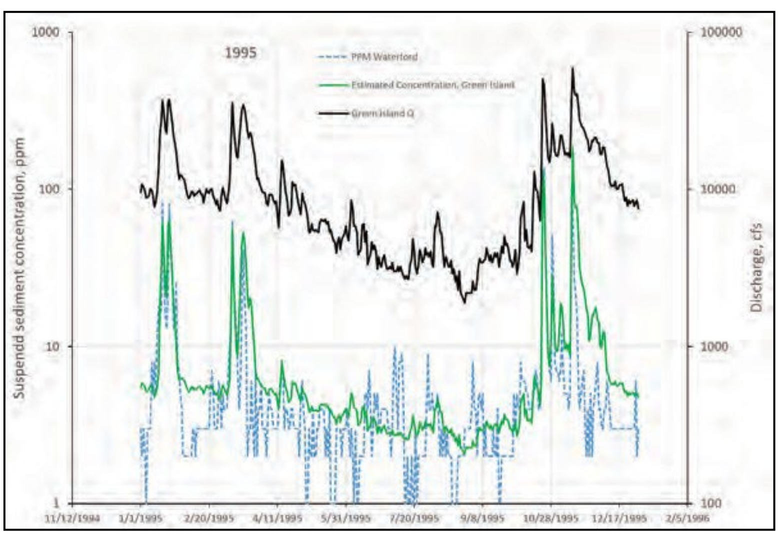
Using the regression fits shown in Figure 44, the SSC for the Hudson River at Green Island were estimated for the calendar year 1985 (Figure 45). The correlation is clear, showing the trends in SSC directly following the variation in the river discharge.

Figure 45. Estimation of the SSC for 1985 using the regression shown in Figure 44.



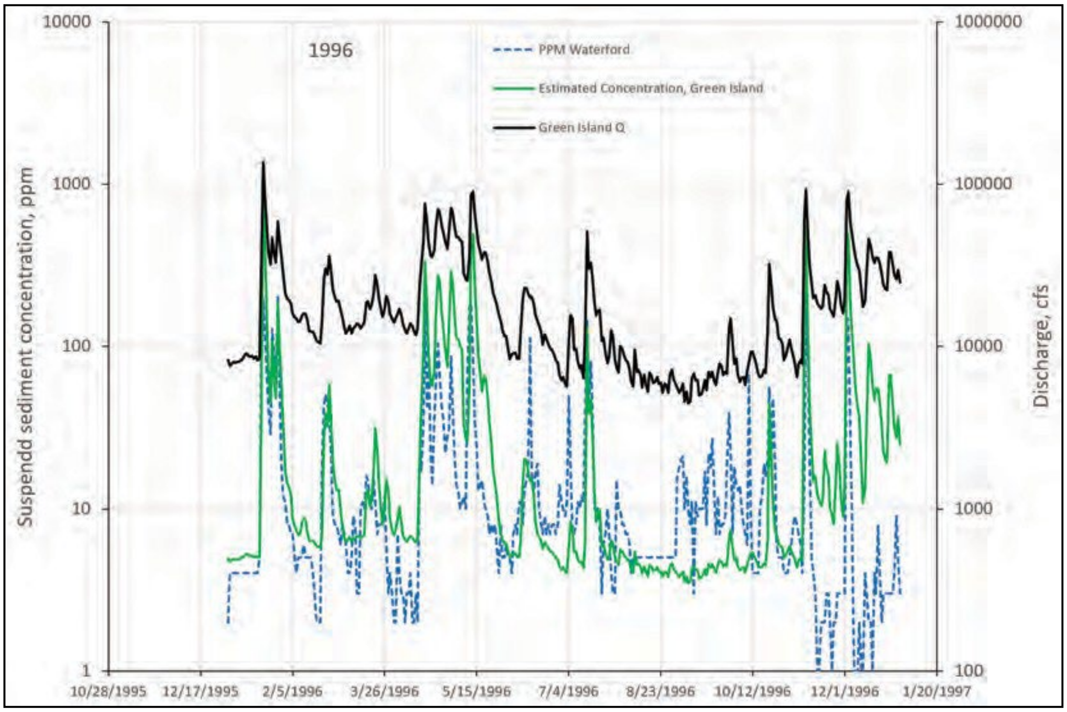
The application of the relationship of Figure 44 for calendar year 1995 is presented in Figure 46. For 1995, SSC data were available at Waterford on the Hudson, which follows very closely the regression-estimated sediment concentrations for Green Island.

Figure 46. Estimation of the SSC for 1995 using the regression shown in Figure 44.



The estimated SSC for calendar year 1996 is shown in Figure 47. For 1996, data were again available at Waterford. The estimated Green Island SSC follows the trends of the Waterford SSC very well through August but shows some deviation in the fall.

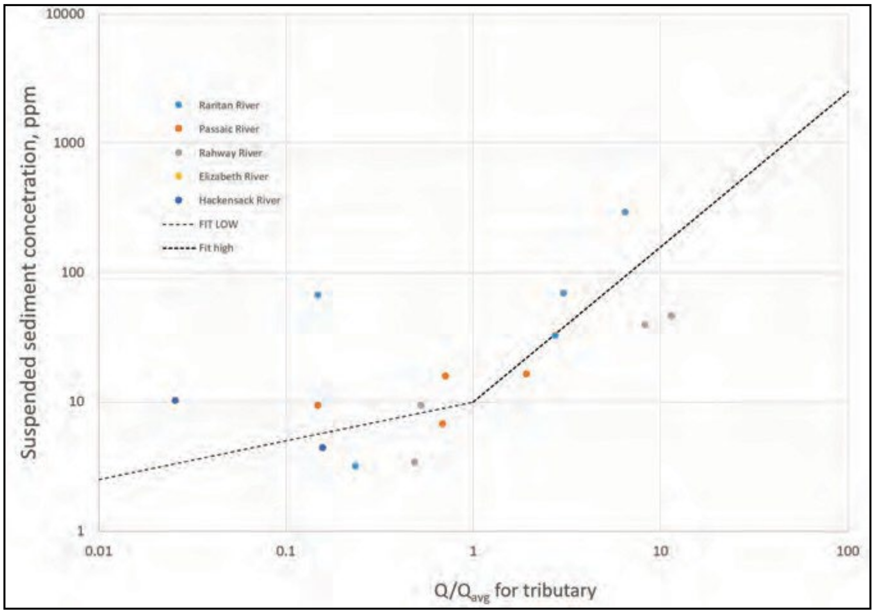
Figure 47. Estimation of the SSC for 1996 using the regression shown in Figure 44.



Remaining tributaries

For the secondary tributaries discharging into the harbor, there are very limited SSC data. Many of these tributaries are regulated, and there is not significant sediment load. Taking all of the limited measurements of SSC from these tributaries and plotting them against the nondimensional discharges for each tributary yields the relationship shown in Figure 48.

Figure 48. Secondary tributary SSC data as a function of the nondimensional river discharge.



Applying the relationship of Figure 48 to the individual river flows on the secondary tributaries gives the overall estimated SSC time series for 2012 as shown in Figure 49. Comparable time series were developed for the remaining years of simulation. The sediment inflows from the smaller tributaries are small primarily because the discharges are relatively small. However, each sediment inflow can have localized impact on the sedimentation environment. Note that the uncertainty in these inflow concentrations is significant and could result in increased uncertainty in the model results. The data fit shown in Figure 48 exhibits a scatter of approximately an order of magnitude for a given non-dimensional discharge.

The estimated grain size distribution of the inflows is shown in Figure 50. The development of the distribution curves for sediment concentrations was based on the fact that as the river discharge increases, the shear stresses will increase and the range of grain sizes that can be mobilized from the bed and entrained will become coarser. The use of relative river flows includes an assumption that each of the tributary systems has reached some sort of equilibrium in the balance between the morphology of the river channels and the hydrology. Therefore, doubling the discharge from the mean flow would have a similar impact on each tributary in terms of entrainment of coarser material. Note that as the relative discharge increases, the finest fraction is fixed, and the other percentiles become progressively coarser.

The coarsest grain size that is in suspension increases in response to increases in the shear stresses associated with increased discharge. Below the mean flow, the flows are confined to the river channel, so the increase in velocities are more linear with the ratio of the discharge. At flood flows, the response is less dramatic on the flow velocities due to increased water depths and flows in the overbanks. The grain size distributions in Figure 50 reflect this sensitivity. For flows less than the mean, the proportion was linear while above the mean flows, the coarsest grain size ratio was assumed proportional to the flow ratio to the one-third.

Also note that the actual distribution curve used is interpolated between the plotted curves based on the actual nondimensional discharge. The curve for a nondimensional discharge of 100 is very rarely used because for the majority of tributaries the peak nondimensional discharge is below 10. The only tributaries with high nondimensional discharges tend to be the small tributaries.

Because most of the tributaries have long river channel reaches before entering the estuary, it is assumed that the bed interaction along the tributaries within the model domain will make adjustments to the sediment distribution.

Figure 49. Time series of suspended sediment inflow boundary conditions for the 2012 simulation year.

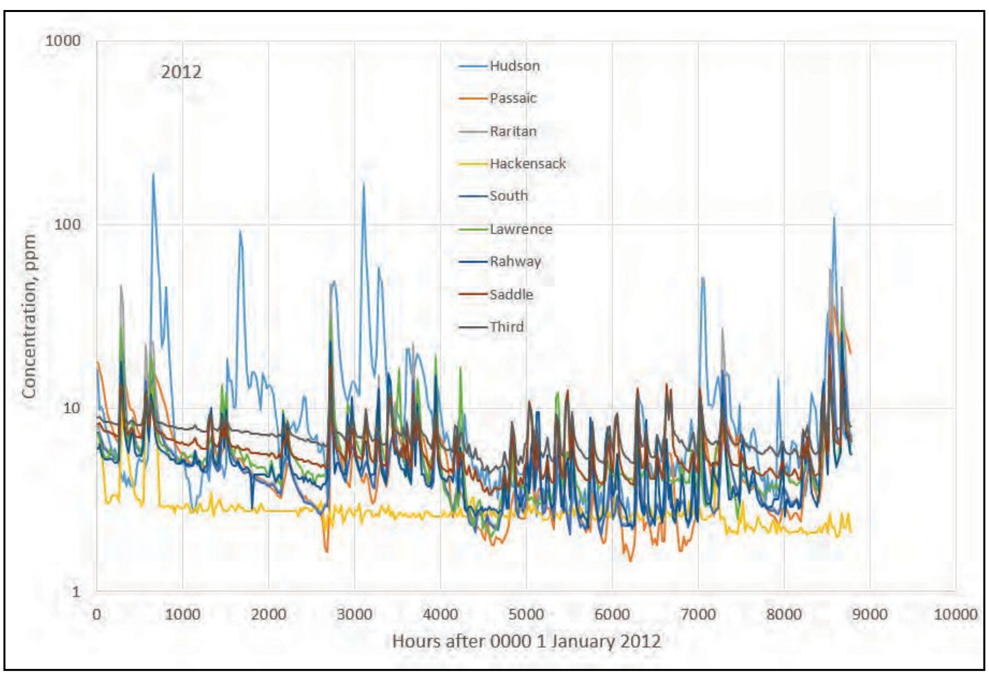
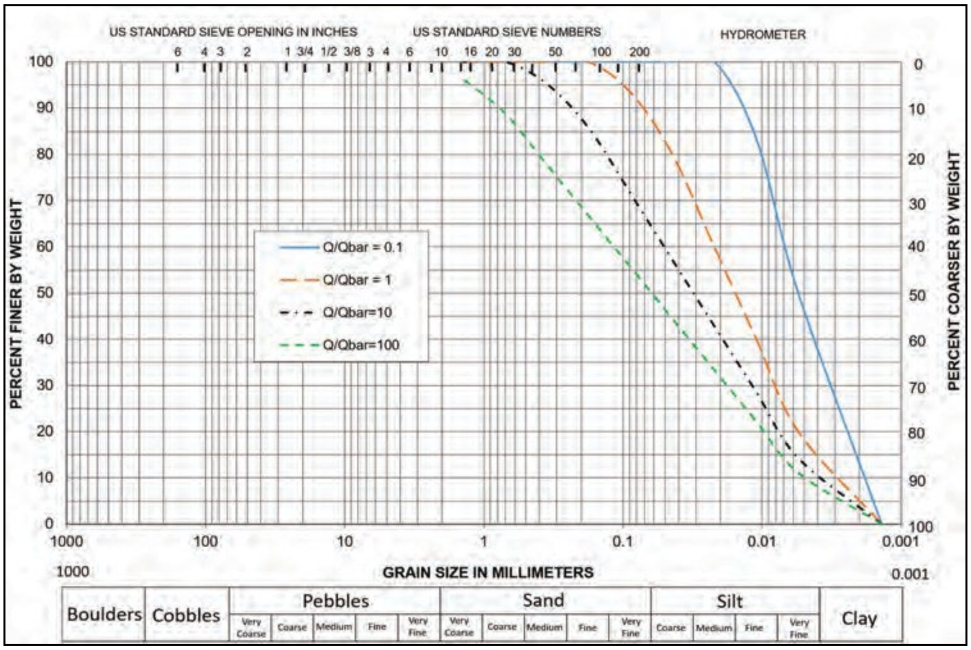


Figure 50. Grain size distribution used in the tributary inflows as a function of the nondimensional discharge.



Wastewater treatment facility flows

NYNJH Estuary Program, 2008, details the New Jersey wastewater treatment facilities along with approximate flowrates. This consisted of 12 facilities with a total flowrate of 612.7 MGD or 26.84 cms. The New York City Department of Environmental Protection (n.d.) details the New York wastewater treatment facilities along with approximate flowrates. This consisted of 14 facilities with a total flowrate of 1,805 MGD or 79.1 cms. At times, the cumulative flow of wastewater treatment facilities can rival the riverine freshwater flows (see Table 4 and Figure 28 to Figure 36). The locations of all the New York and New Jersey MWTFs are shown in Figure 51. The locations and flowrates are provided in Table 4.

Figure 51. Wastewater facility discharge locations.

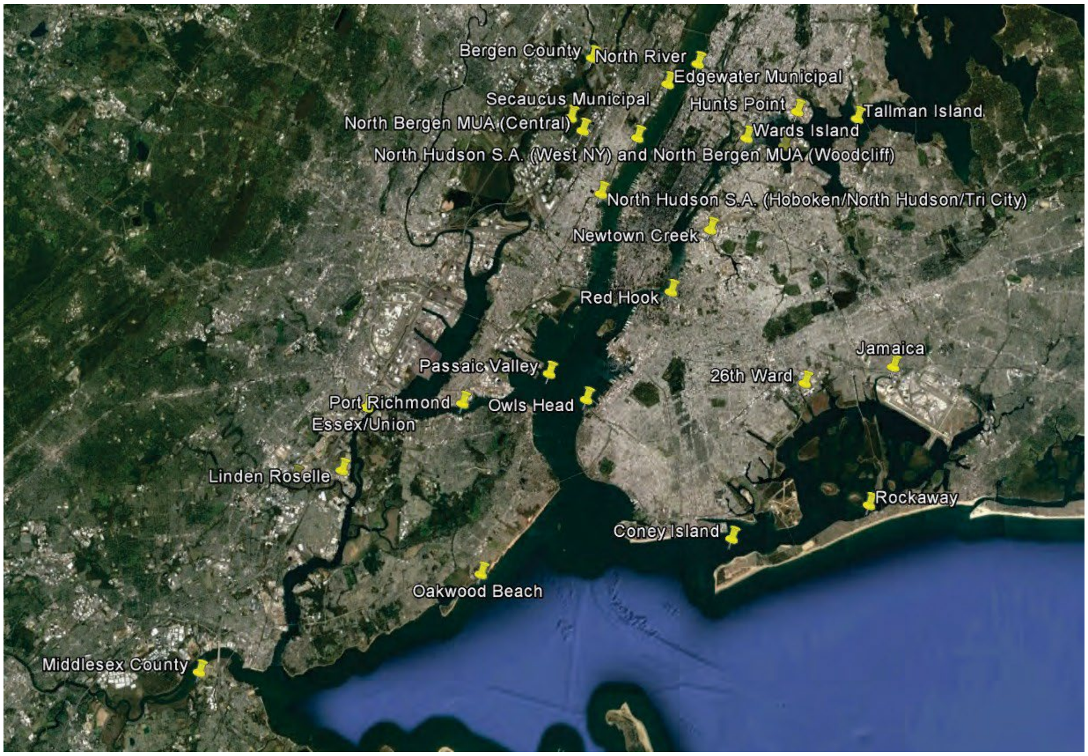


Table 4. Wastewater treatment discharge locations and flow rates.

Wastewater Treatment Locations and Discharges			
Wastewater Treatment Facility	Location (decimal degrees)		Discharge (cms)
	Latitude	Longitude	
Passaic Valley (NJ)	40.7084	74.1209	12.4
Middlesex County (NJ)	40.4922	74.3177	5.0
Bergen County (NJ)	40.8314	74.0320	3.0
Essex/Union (NJ)	40.6386	74.1961	2.6
Rahway Valley (NJ)	40.5999	74.2482	1.1
Linden Roselle (NJ)	40.6038	74.2141	0.6
North Hudson S.A. (Hoboken/North Hudson/Tri City) (NJ)	40.7565	74.0257	0.9
North Bergen MUA (Central) (NJ)	40.7913	74.0389	0.3
North Hudson S.A. (West NY) and North Bergen MUA (Woodcliff) (NJ)	40.7874	73.9991	0.6
Secaucus Municipal (NJ)	40.7985	74.0477	0.1

Wastewater Treatment Locations and Discharges			
Wastewater Treatment Facility	Location (decimal degrees)		Discharge (cms)
	Latitude	Longitude	
Edgewater Municipal (NJ)	40.8170	73.9769	0.1
Bowery Bay (NY)	40.7827	73.8919	6.6
Hunts Point (NY)	40.8017	73.8825	8.8
Tallman Island (NY)	40.7977	73.8388	3.5
Wards Island (NY)	40.7871	73.9195	12.0
Newtown Creek (NY)	40.7366	73.9461	13.6
North River (NY)	40.8281	73.9550	7.4
Oakwood Beach (NY)	40.5466	74.1130	1.8
Port Richmond (NY)	40.6408	74.1265	2.6
Red Hook (NY)	40.7024	73.9747	2.6
26th Ward (NY)	40.6518	73.8774	3.7
Coney Island (NY)	40.5898	73.9308	4.8
Jamaica (NY)	40.6607	73.8131	4.4
Owls Head (NY)	40.6430	74.0364	5.3
Rockaway (NY)	40.5846	73.8309	2.0

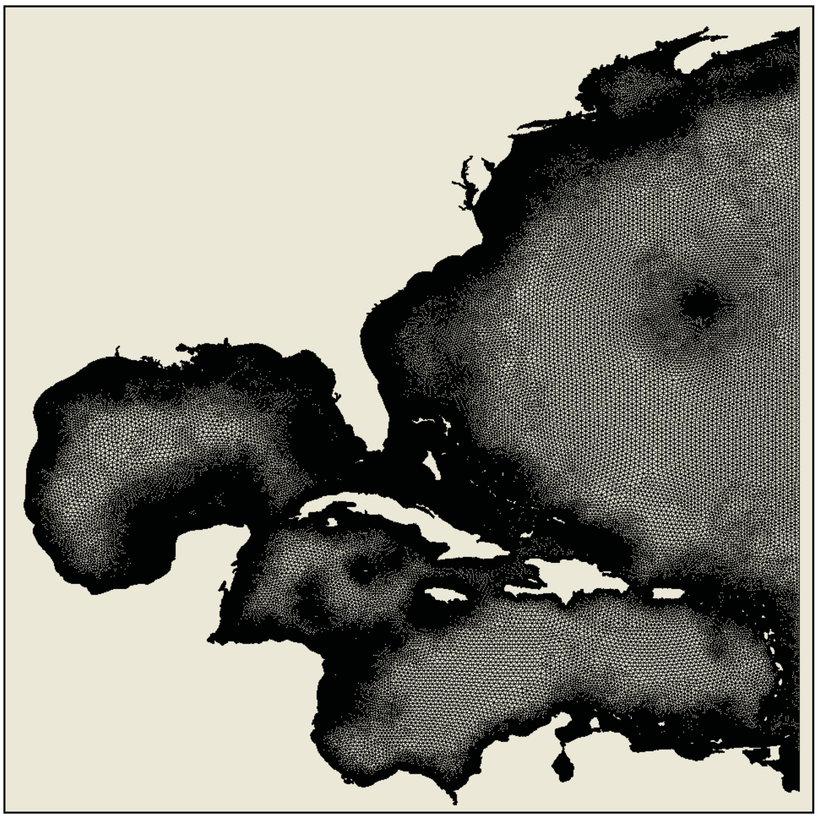
Tidal specification

Tidal harmonics

The development of tidal boundary conditions along the ocean boundary was conducted so that the model can be simulated both with and without meteorological forcing. The limits of the AdH model were previously shown in Figure 14. The southern limit of the ocean boundary is approximately at Atlantic City, NJ, and extends perpendicular to the New Jersey shore offshore to the edge of the continental shelf at a depth of approximately 75 m (250 ft). The offshore boundary then follows the edge of the shelf northeastward to south of Martha's Vineyard, then north to Martha's Vineyard.

The primary tidal harmonics (largest nine constituent amplitudes) have been modeled extensively and documented within the ADCIRC East Coast tidal harmonic database. The overall modeled domain for the ADCIRC tidal harmonic model is presented in Figure 52. The domain includes the western Atlantic Ocean and the Gulf of Mexico, covering all of the eastern shoreline of the United States. The AdH ocean boundary conditions are believed to be sufficiently posed to simulate extreme events and generally matches the previously shown NOAA model domain (Figure 15).

Figure 52. ADCIRC East Coast tidal database model grid.



The AdH ocean water surface elevation boundary conditions are enforced along each individual finite element face as represented by the 36 small black squares in Figure 53. The harmonic amplitudes extracted from the ADCIRC model were for the 37 nodes along the boundary with the edge values being a simple average of the two participating computational nodal water level values. The extracted harmonic amplitudes are presented in Figure 54 at each node from the southern end to the northern end of the model boundary. The greatest variability is in the over-tides (M_4 and M_6 harmonics). For the remaining constituents, the amplitudes are relatively uniform.

Figure 53. Boundary condition locations (squares) for extraction of tidal harmonics from ADCIRC Tidal Database.

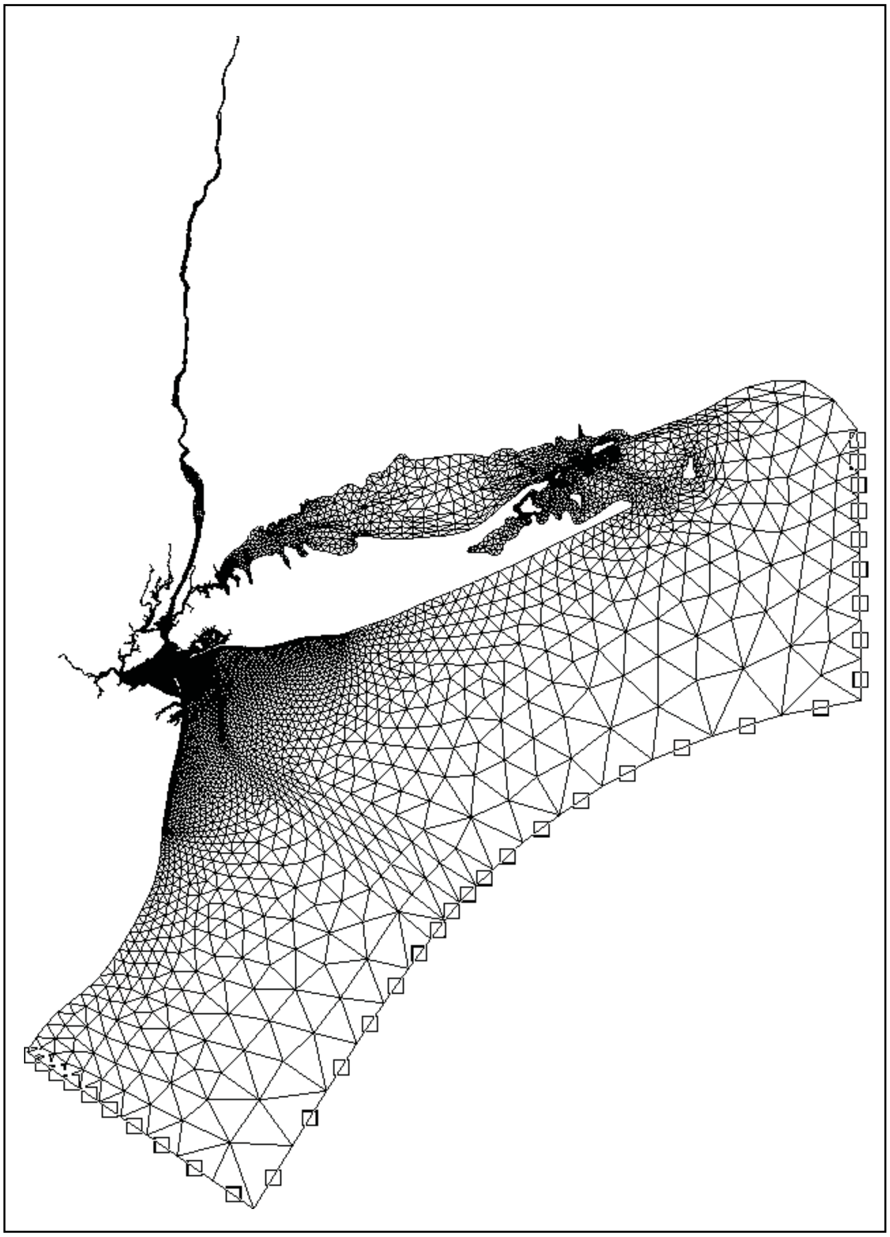
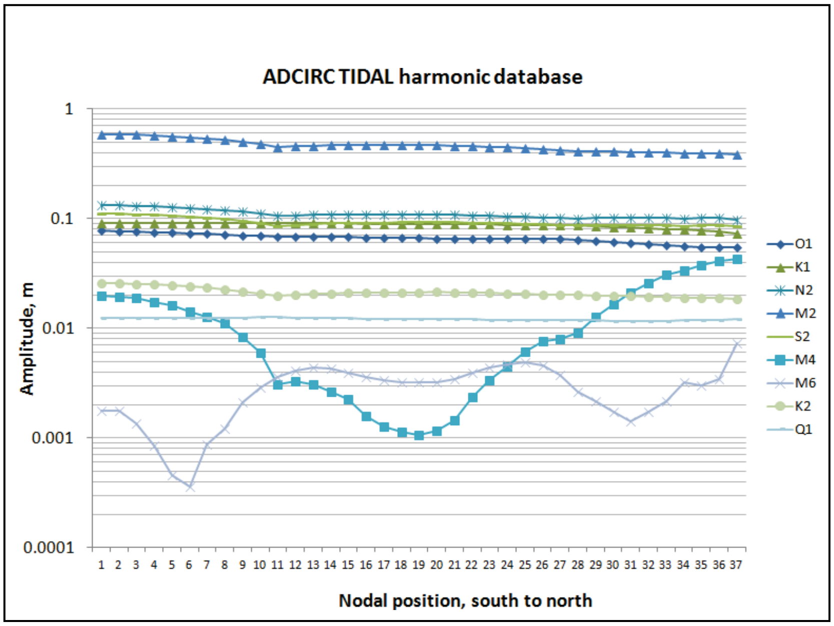
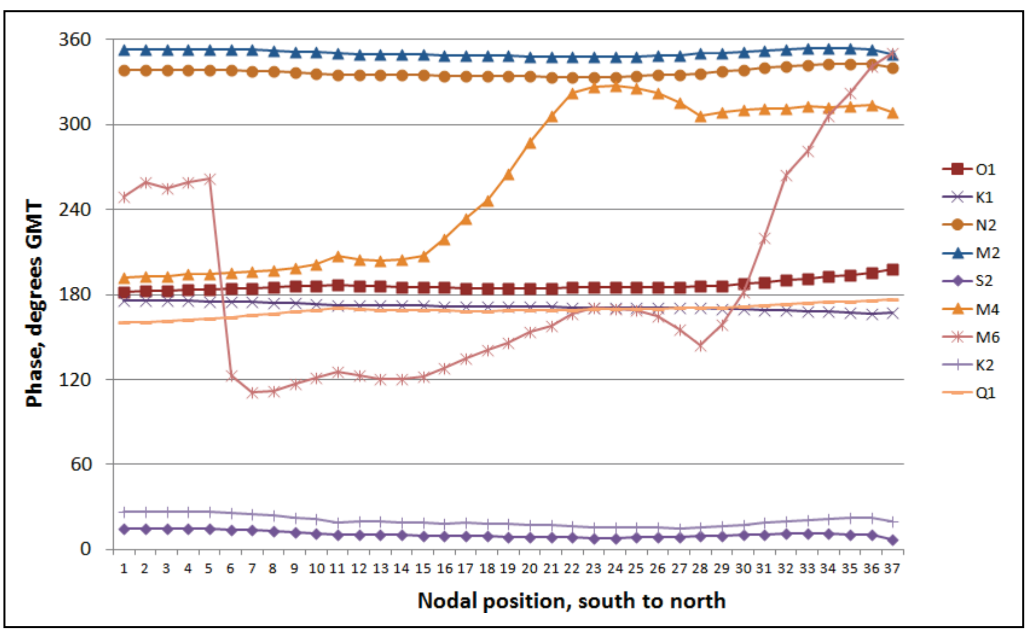


Figure 54. Variation of the nine ADCIRC tidal harmonic amplitudes along the AdH model boundary.



The tidal constituent phases along the AdH ocean boundary are presented in Figure 55. The phases are again most variable for the M_4 and M_6 overtides, and the remainder have relatively uniform phases.

Figure 55. Variation in the nine ADCIRC tidal harmonic phases along the AdH ocean tidal boundary.



The NOAA standard 37 harmonic constituents were obtained at all of the available tide stations in the study area. The three primary gages of interest near the AdH model boundary are Atlantic City, Montauk Point, and Woods Hole. The remaining 28 constituents (9–37) not available from the ADCIRC database are presented in Figure 56 and Figure 57 for the amplitudes and phases, respectively. None of the remaining constituents have amplitudes greater than 0.07 m (0.23 ft) with the majority less than 0.01 m (0.03 ft). The phases of the 28 constituents are relatively constant, particularly between Atlantic City and Woods Hole. The large difference for the NU2 constituent is not as great when it is recognized that a 340 deg phase is the same as a -20 deg phase.

Figure 56. Variation in the NOAA tidal harmonic amplitudes for the tidal constituents not included in the ADCIRC database.

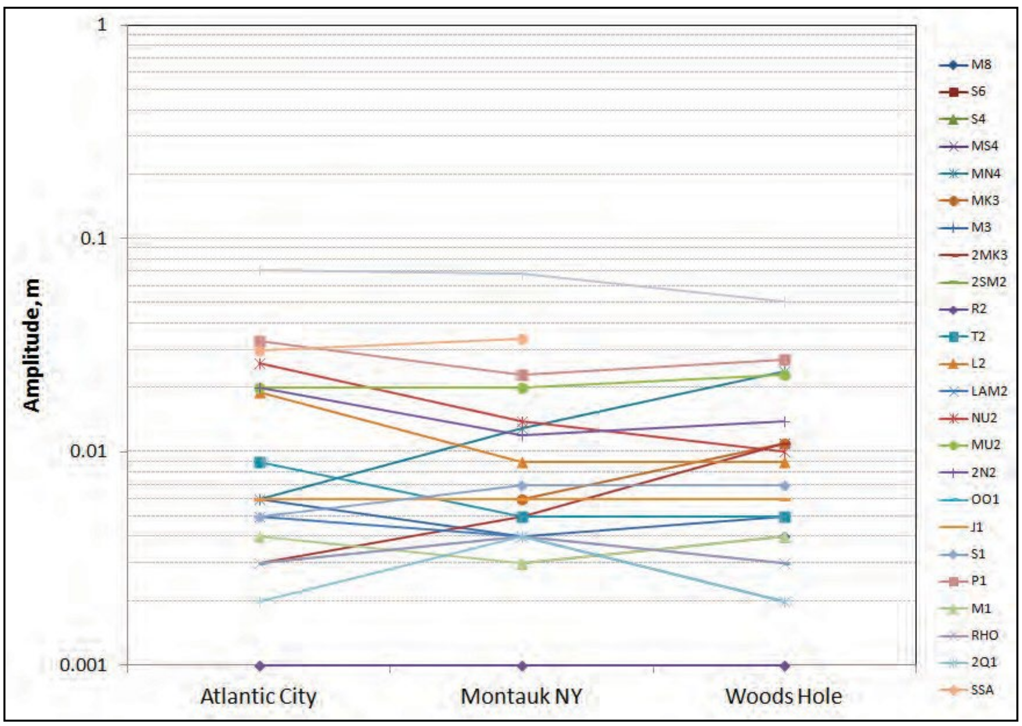
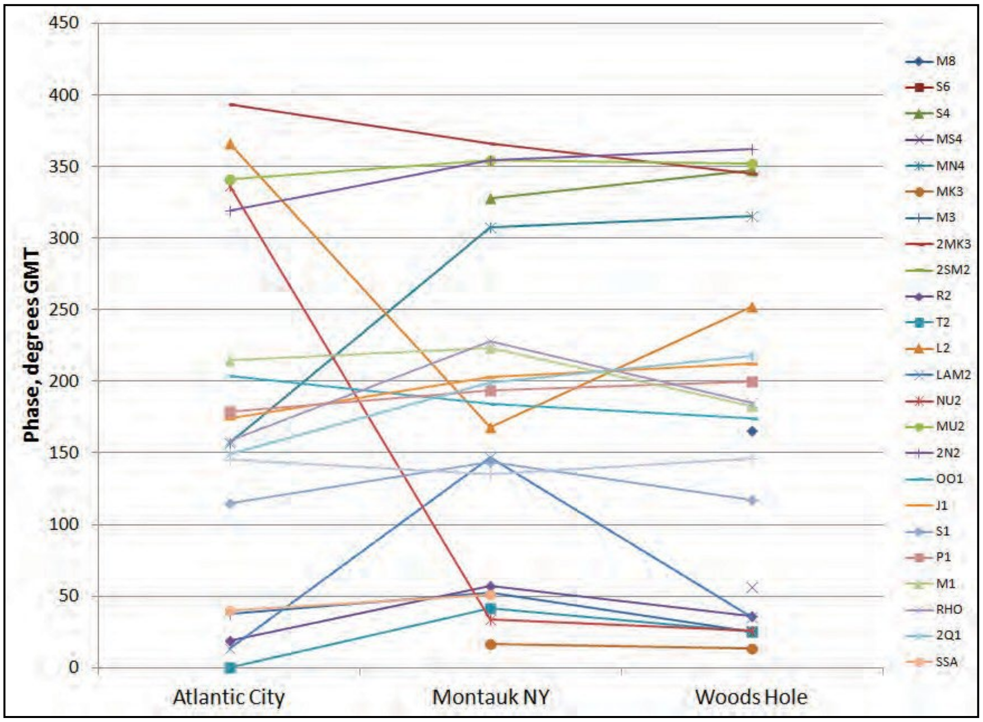


Figure 57. Variation in the NOAA tidal harmonic phases for the tidal constituents not included in the ADCIRC database.



For the purposes of developing tidal harmonic conditions along the ocean boundary, the average amplitudes and phases between Atlantic City and Woods Hole were used with constant amplitudes and phases along the 37 nodes of the AdH boundary for these minor harmonics. The nine harmonics included in the ADCIRC database vary along the boundary as appropriate in both amplitude and phase.

Tidal/meteorological residuals

For the second task of the AdH model tidal validation, the model was simulated for the period of 1995 with the meteorological influences included in the model boundary conditions. For that simulation, the observed tidal signals at Atlantic City and Nantucket were compared to the predicted harmonic tides to obtain a residual tidal signal representing the meteorological influence at each end of the model ocean boundary. The tidal comparison for the full year is presented in Figure 58 and for the month of January and early February in Figure 59. The meteorological residual tides follow the same general trends but have some localized differences that are significant.

Figure 58. Comparison of tidal elevation time series in 1995 between Atlantic City, NJ, and Nantucket Island, MA, for the purpose of extracting the tidal residual series.

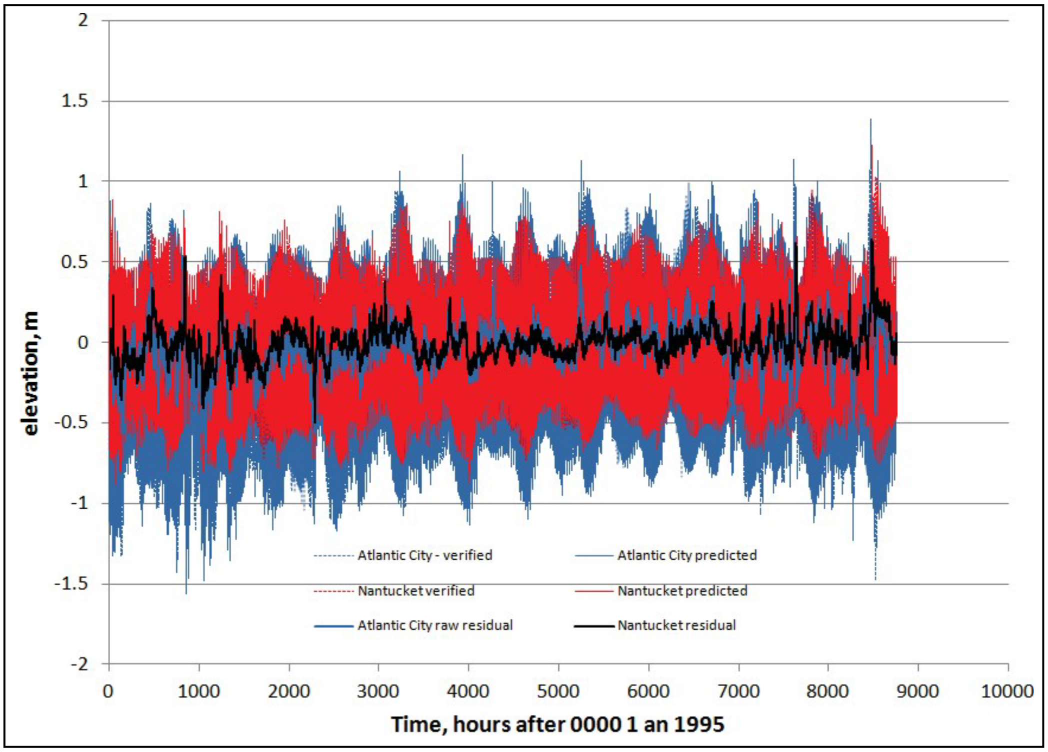
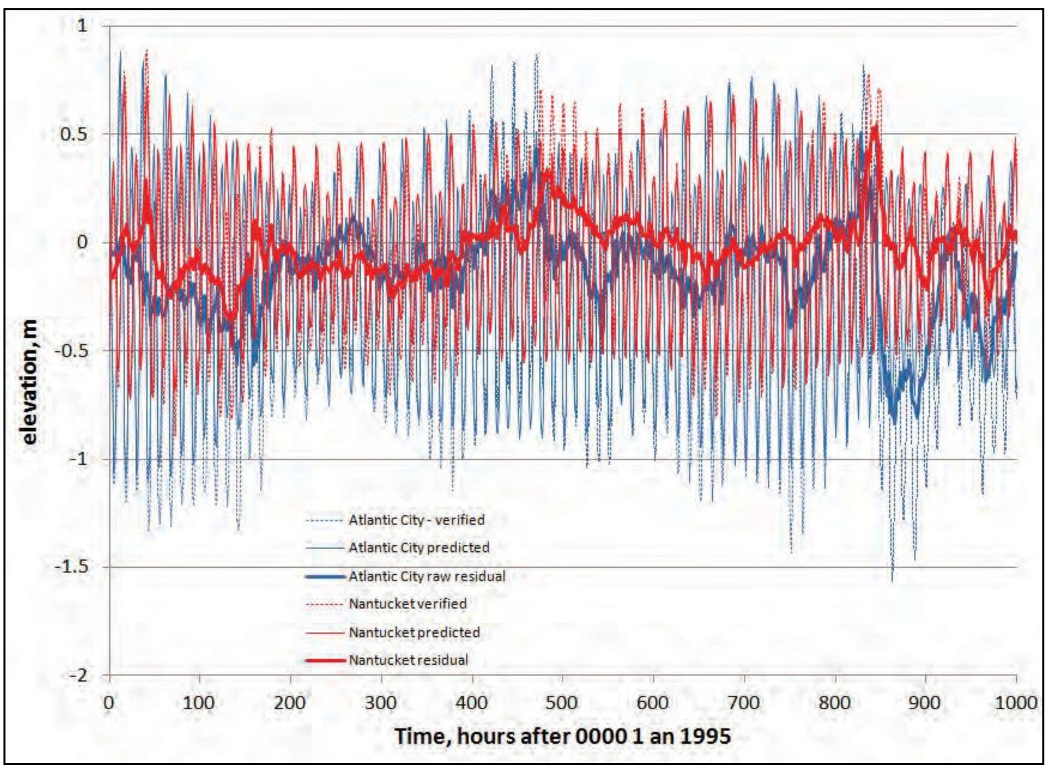
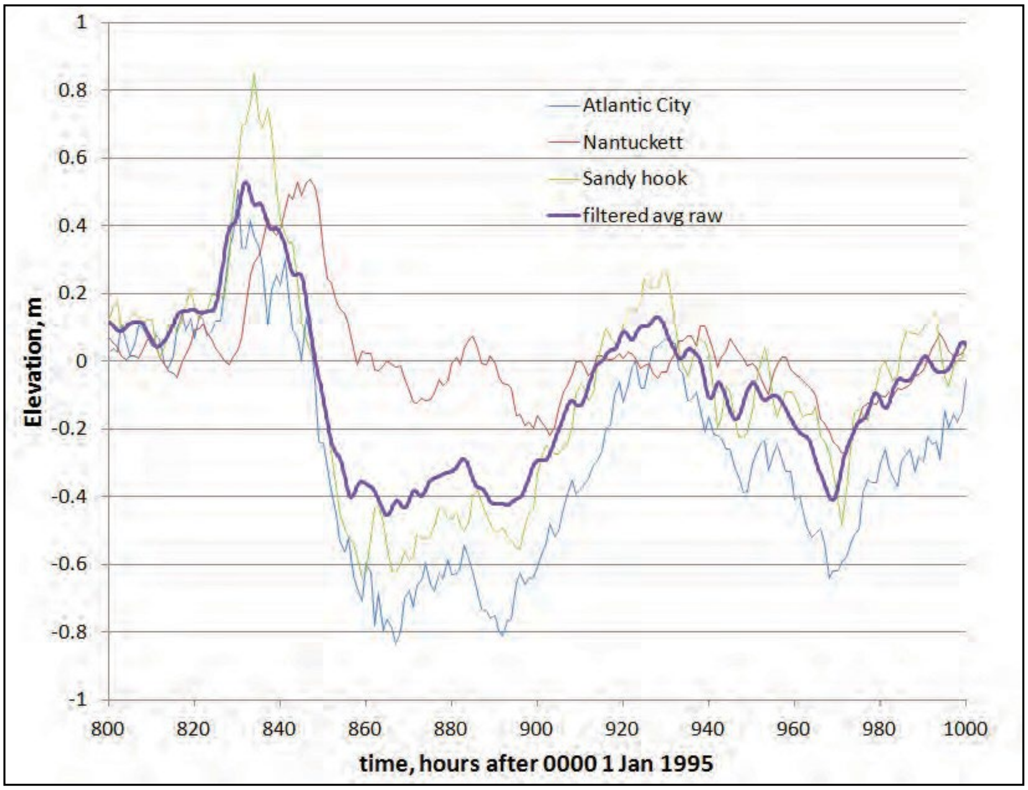


Figure 59. Details of the 1995 tidal time series for January.



The comparison of the meteorological residual tidal signals at Atlantic City, Sandy Hook, and Nantucket are presented in Figure 60. The Sandy Hook meteorological signal compares very well with the average of the Atlantic City and Nantucket residuals. The Atlantic City and Nantucket residuals were filtered using a low pass filter to filter out the high frequency noise with periods less than 3 hours. These filtered residuals were linearly interpolated along the offshore boundary and added to the reconstituted harmonic signal to create the offshore tidal signal with the appropriate meteorological component.

Figure 60. Development of the residual tidal signal for AdH model.



The results of simulating the AdH model with harmonics only is presented in Figure 61 for Sandy Hook for the month of January 1995. The results of simulating the AdH model with inclusion of the meteorological residual component are presented in Figure 62 for Sandy Hook for the entire year of 1995.

Figure 61. Result of using the combined ADCIRC and NOAA harmonics. The NOAA predicted tides at Sandy Hook are compared with the AdH model driven with harmonics only.

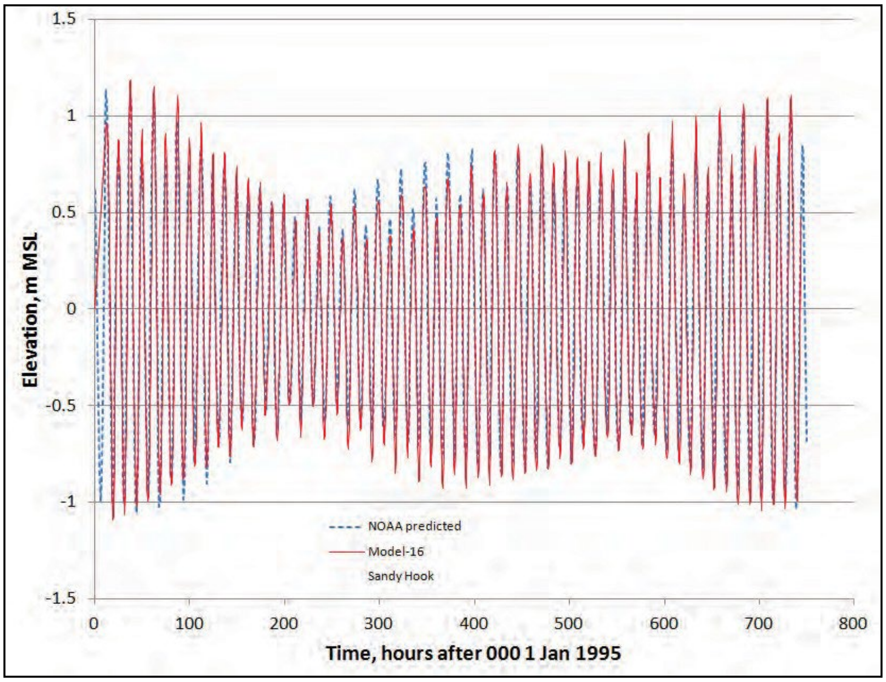
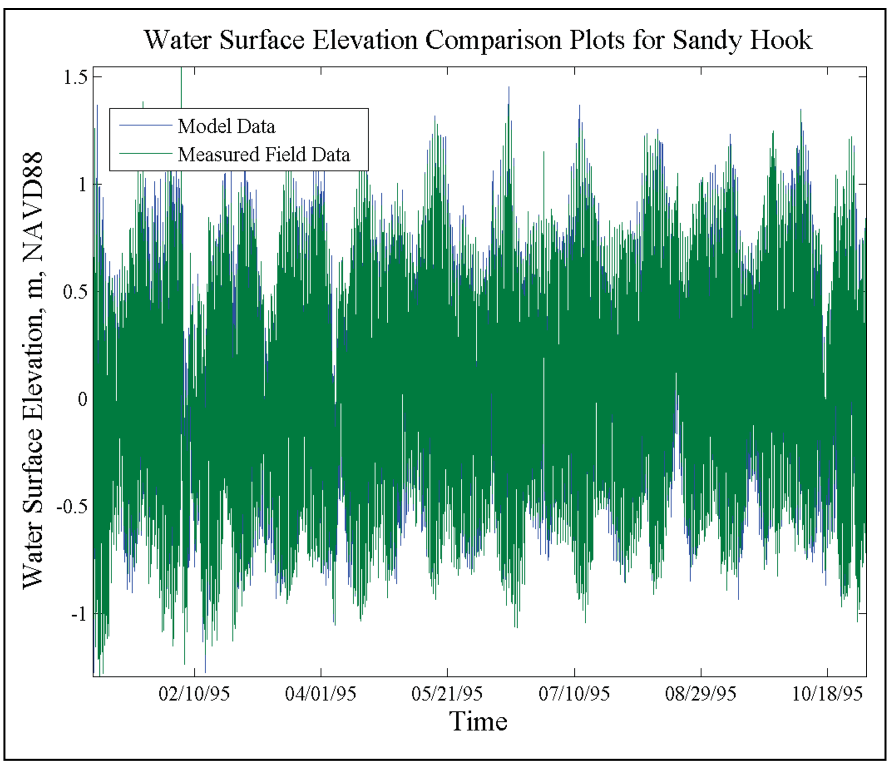


Figure 62. Comparison of modeled versus observed tidal signal at Sandy Hook when driving the model with tidal harmonics and meteorological residuals.



Summary of tidal boundary condition approach

The steps that were used to develop the tidal boundary condition for the three-dimensional AdH model are the following:

1. For normal tidal conditions (no ocean storm influence)
    a. Use the nine ADCIRC harmonic constituents as a spatially varying amplitude and phase along the AdH boundary.
    b. Use the 28 remaining NOAA harmonics (9–37) specified as a uniform amplitude and phase along the AdH model boundary.
    c. Apply (add to harmonics) the appropriate residual signal along the AdH boundary as a linearly interpolated time series along the AdH boundary to incorporate meteorological forcings.
2. For oceanic storm conditions
    a. Extract from ADCIRC storm simulations completed as part of the NACCS that includes the astronomical tides time series of tide at each finite element face along the AdH boundary.

The storm conditions tidal boundary (number 2, above) was combined with the results for the normal tidal conditions (number 1, above) to obtain a single time series at each tidal boundary location that included both the normal tidal conditions with meteorological residuals and ADCIRC generated storm surge boundary during storm events.

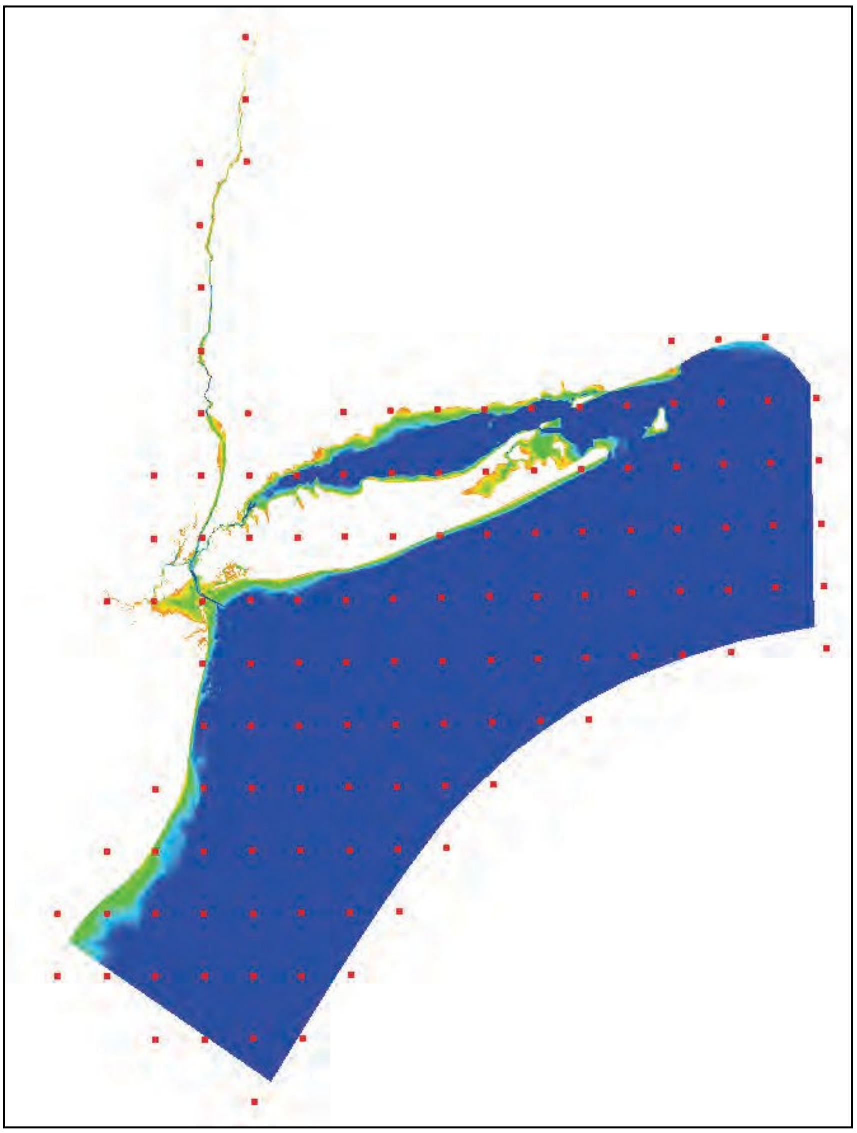
Salinity specification at the tidal boundary

The salinity specification at the tidal boundary was set to 33 ppt for the entire model simulation time period and was held constant along the entire tidal boundary. This specification was utilized for all five simulated years. The salinity at the offshore boundary was approximately 33 ppt with negligible temporal variation as observed in HydroQual, Inc (2008). Chen and He (2010) modeled New York Bight shelf dynamics and showed that 33 ppt was representative.

Wind and pressure specification

The wind and pressure fields generated as part of the WIS (http://wis.usace.army.mil/) were utilized for this modeling effort. The WIS research effort consists of hindcasting wave characteristics for much of the Atlantic and Pacific Oceans. As part of this hindcasting effort, wind and pressure fields are generated to use as input to the wave model. These wind/pressure datasets consist of wind/pressure fields with discrete locations that are consistent between years and are available as far back as the early 1980s. This dataset provides a consistent wind/pressure forcing method that is consistent for all of the time periods simulated and removes difficulty in obtaining consistent forcing conditions for various time periods. The WIS study includes wind/pressure values over the majority of the Atlantic Ocean. Since this study was limited to the NYNJH area, the WIS values were reduced to only the locations impacting the numerical model domain. Figure 63 shows the WIS wind/pressure data locations over the numerical model domain.

Figure 63. Locations of WIS wind/pressure values in relation to the AdH model domain.



Wave model offshore boundary spectra

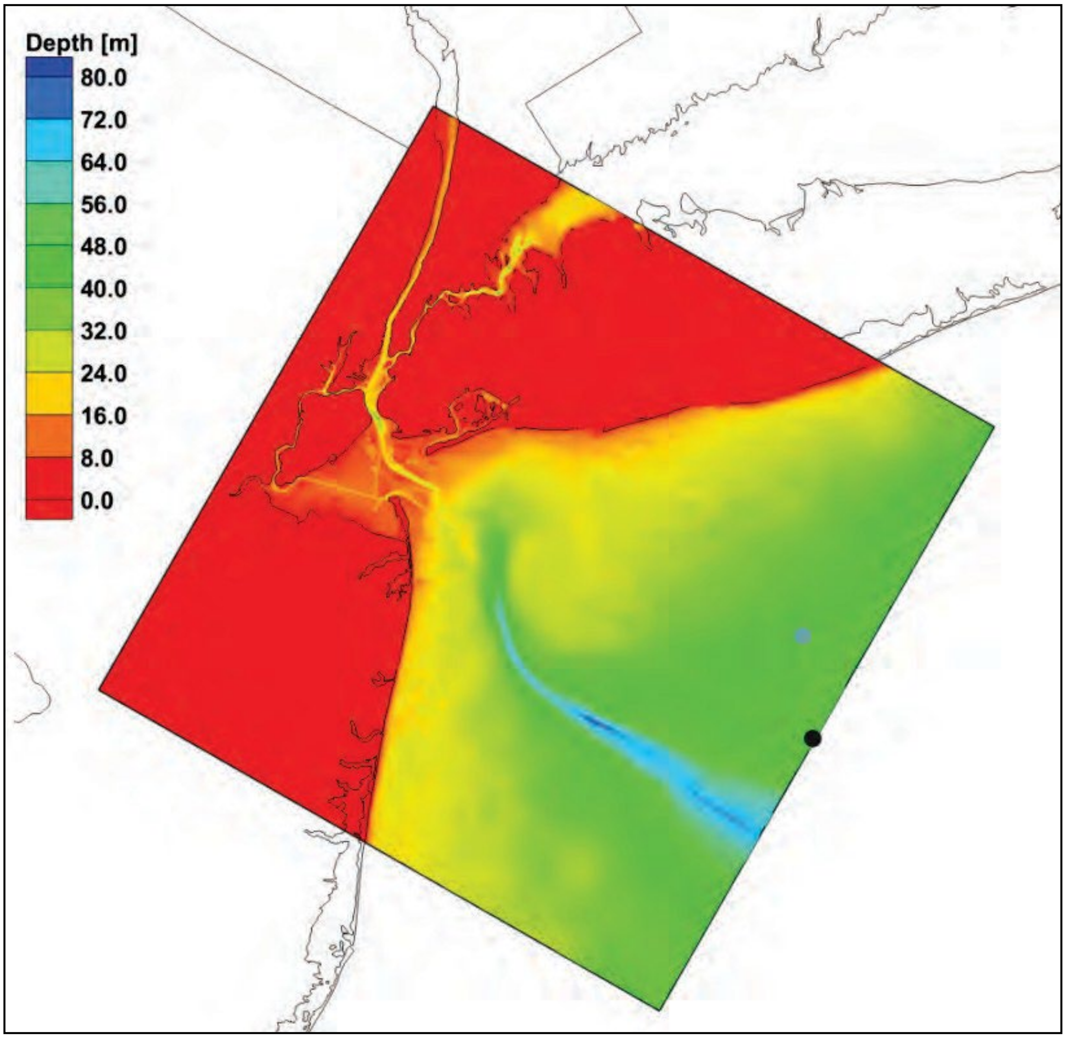
The years modeled were 1985, 1995, 1996, 2011, and 2012. These years are associated with the following historical storm events: Hurricane Gloria (1985), the Blizzard of 1996 (Nor'easter), Hurricane Irene (2011), and Hurricane Sandy (2012). The 2D spectra mined from National Data Buoy Center (NDBC) 44025 served to force STWAVE. When historical observations were not available, hindcast model data from WIS served as a supplement. The location of NDBC 44025 is 40.251°N and 73.164°W and is shown in Figure 64. Although slightly shoreward of the offshore boundary, NDBC 44025 is found in a water depth similar to that of the offshore STWAVE boundary and is the closest buoy with historical data. To force STWAVE, the location of NDBC 44025 was moved to State Plane coordinates (265431.44, 140129.39) to lie along the offshore boundary.

The number and value of the discrete frequency bands were the following:

$$ff(nn+1) = 1.1 * ff(nn) \text{ where n = 1, 29} \tag{6}$$

and the starting and ending bands were 0.035 Hz (T = 28.6 s) and 0.505 Hz (T = 1.98 s), respectively. The angular resolution was 5 deg, beginning at 0 deg and increasing to 355 deg. A one-dimensional transformation was performed along the lateral boundaries, and a constant spectrum was applied along the offshore boundary. Offshore forcing was applied every 3 hours, beginning 1 January 01:00 of the modeled year.

Figure 64. Location of NDBC 44025. The gray point is the actual buoy location whereas the black point is the assigned location for the STWAVE model.



Simulated sediment classes

The sediment transport model for the NYNJH estuary needs to address a wide range of sediment classes, from littoral sands in the bar channel to fine sediments within the inner pier slips of Newark Bay. The approach taken balanced the wide range of size classes within the model domain with the computational requirements of simulating a large number of size classes, based on the specific sizes of significance to the navigation channel maintenance. Consequently, sediment sizes equal to and coarser than pebbles were excluded from analysis. The model was developed using five noncohesive sand classes and five cohesive sediment classes. These 10 size classes are defined in Table 5, based on the Wentworth size classification. The mineral specific gravity for all 10 sediment classes was set to 2.65.

Table 5. Sediment classes used in sedimentation model.

Wentworth Sediment Size Class	Type	Particle size (µm)	Specific Gravity
Clay	Cohesive	1.38	2.65
Very Fine Silt	Cohesive	5.5	2.65
Fine Silt	Cohesive	11.0	2.65
Medium Silt	Cohesive	22.1	2.65
Coarse Silt	Cohesive	44.2	2.65
Very Fine Sand	Noncohesive	88.0	2.65
Fine Sand	Noncohesive	177.0	2.65
Medium Sand	Noncohesive	354.0	2.65
Coarse Sand	Noncohesive	707.0	2.65
Very Coarse Sand	Noncohesive	1414.0	2.65

The cohesive classes are *clay*, *very fine silt*, *fine silt*, *medium silt,* and *coarse silt*. The cohesive properties for these five classes are shown in Table 6. The settling velocity for the cohesive sediments was calculated based on Stokes Law (Equation 7) and is required to be specified.

$$W_s = \sqrt{\left(\frac{4g}{3C_D}\frac{\Delta\rho}{\rho}\right) d_p} \tag{7}$$

where

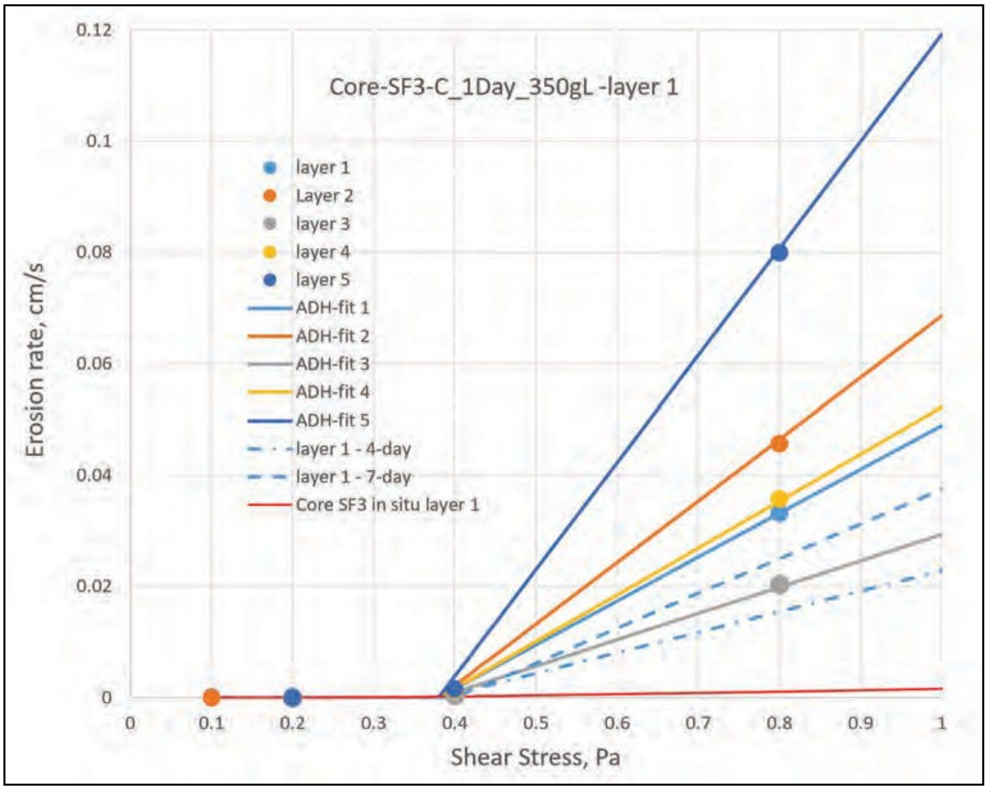
W_S = settling velocity
g = acceleration of gravity
C_D = drag coefficient
$\Delta\rho = \rho_s - \rho_f$ = density difference between sediment and fluid
ρ_s = density of sediment particles
ρ_f = density of the fluid
d_p = diameter of the sediment particle.

Table 6. Cohesive sediment class properties.

Wentworth Sediment Size Class	Particle Size (μm)	Settling Velocity (mm/sec)	Critical Shear Stress for Erosion (Pa)	Erosion Rate Constant (mm/sec)	Critical Shear Stress for Deposition (Pa)	Bulk Density (kg/m^3)
Clay	1.38	0.007	0.38	0.7	0.02	1425
Very Fine Silt	5.5	0.027	0.38	0.7	0.02	1425
Fine Silt	11.0	0.110	0.38	0.7	0.02	1425
Medium Silt	22.1	0.440	0.38	0.7	0.04	1425
Coarse Silt	44.2	1.760	0.38	0.7	0.075	1425

The critical shear stress for erosion was specified based in part on the analysis of SEDFlume cores (Figure 65) collected within Newark Bay (Sea Engineering 2008 and 2013). The values are consistent with previous investigators and experimental work (Partheniades 1962; Mehta 1973; Teeter 2001a; Teeter 2001b; Letter 2009). The critical shear stresses for erosion are set uniformly across the cohesive grain sizes because erosion rates are based on bulk samples. Critical shear stresses for deposition are based on experimental data (Krone 1962; Mehta 1973). The three finest classes are set to the same value because the current AdH model does not include a flocculation model that allows for the finer particles to combine into larger effective sizes and deposit at higher shear stresses. The bulk density was assigned based on an average of the sediment cores (Sea Engineering 2013).

Figure 65. SEDFLUME results for core sample in Newark Bay.



Noncohesive size classes used are *very fine sand*, *fine sand*, *medium sand*, *coarse sand*, and *very coarse sand*. The properties of the noncohesive sand classes are presented in Table 7. The grain porosity was set at 0.3 for all sand classes. The settling velocities in Table 7 are approximate for free settling in clear water (Graf 1971). The settling velocity for noncohesive sediment is computed internally within the numerical model taking the local fluid density into account.

Table 7. Noncohesive sediment class properties.

Wentworth Sediment Size Class	Particle Size (µm)	Settling Velocity (m/sec)*	Grain Porosity
Very Fine Sand	88.0	0.006	0.3
Fine Sand	177.0	0.02	0.3
Medium Sand	354.0	0.05	0.3
Coarse Sand	707.0	0.1	0.3
Very Coarse Sand	1414.0	0.2	0.3

* Computed internally within model, not specified.

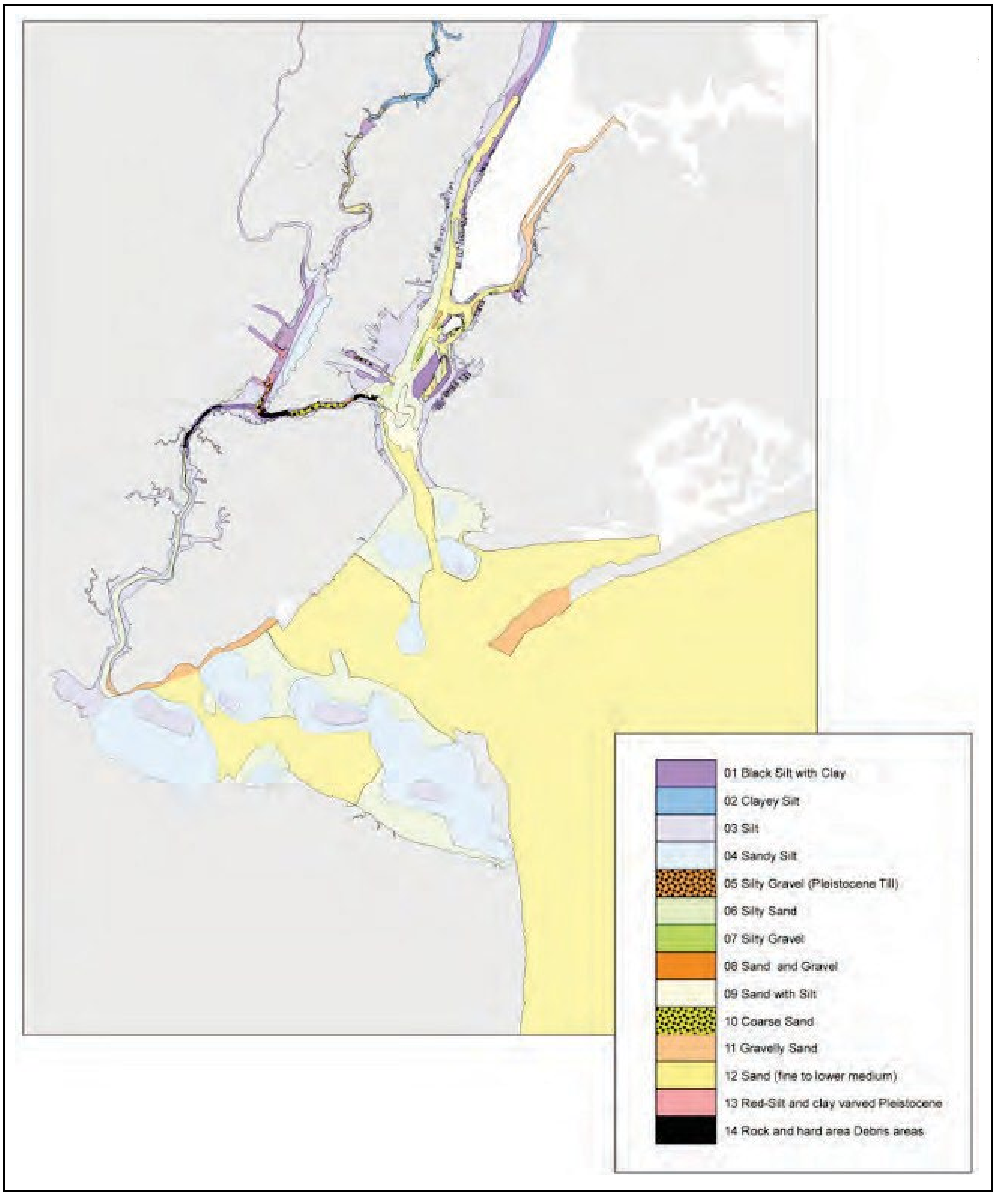
Sediment bed initialization

The development of the sediment transport model requires the specification of the characteristics of the sediment in the bottom surface of the estuary, the vertical structure of the subsurface layers within the bed, and the sediment size class concentration distribution in tributary inflows.

The sediment distribution within the bed of the model specifies the sediments available for entrainment into the water column during erosion events. Armoring of finer sediments by larger fractions is included in the model. The domain required for sediment property specification is the entire domain of the model. The inflowing size distribution within the tributary inflows will control the characteristics of much of the deposition that occurs within the estuary.

The sediment bed characteristics at the bottom of the water column over the model domain were estimated from several data sources. The primary study area was evaluated as a separate task for this study by a contractor to the US Army Corps of Engineers, New York District (e4sciences). The summary of the sediment classification performed by e4sciences for the New York Harbor and vicinity is shown in Figure 66.

Figure 66. Sediment classifications developed by e4sciences and spatial variability within the harbor.



Sediments in Ambrose Channel through the Narrows are dominated by fine to medium sand. Sediments in Upper Bay are primarily fine sand and silt. Kill van Kull has coarse sand and hard pan that required blasting to deepen. Newark Bay and Arthur Kill are dominated by fine sediments.

The sediment categories delineated by e4sciences represent a general description of sediment grain size distributions, which is comprised of sediments from a variety of size classes, some of which are represented explicitly within the model. These characterizations are presented in

Table 8. A specific sediment characterization class defined by e4sciences was developed as a composite of a group of bottom surficial samples. Consequently, the percent of sediment size classes (e.g., silt) is reported within Table 8 as a percentage range.

Table 8. Preliminary particle size of New York Harbor sediments (e4sciences 2018).

Class No.	Sediment Type		Clay	Silt	Fine Sand to Lower Medium Sand	Upper Medium Sand	Coarse Sand	Fine Gravel	Coarse Gravel
1	Black Silt with Clay	wet and soft	~30%	60%					
2	Clayey Silt	soft/loose	~38%	50 to60%	<10%	<10%		<10%	<10%
3	Silt	soft/loose	<10%	>85%	<10%	<10%		<10%	<10%
4	Sandy Silt	loose	<10%	55-85	45-15%	<10%		<10%	<10%
5	Silty Gravel (Pleistocene Till)	dense	5-15%	10 to 30%	<10%	<10%	<10%	60 to 90%	<10%
6	Silty Sand	loose	5-10%	10 to 30%	60 to 90%	<10%	<10%	<10%	<10%
7	Silty Gravel	dense	5-10%	10 to 30%	<10%	<10%	<10%	60 to 90%	<10%
8	Sand and Gravel	dense	<10%	<10%	<10%	<10%	80 to 50%	20-50%	<10%
9	Sand with Silt	loose	<10%	10 to 20%	70-90%	<10%		<10%	<10%
10	Coarse Sand	loose	<10%	<10%	<10%	<10%	80 to 90%	5 to 20%	
11	Gravelly Sand	dense	<10%	<10%	30%	50%		5 to 20%	5 to 20%
12	Sand (fine to lower medium)	loose	<10%	<10%	80-90%	<10%		<10%	<10%
13	Red-Silt and clay varved Pleistocene	compact/ cohesive	30-40	30-40	<10%	<5%		<5%	<1%
14	Rock and hard debris areas								

To use the sediment categories from e4sciences, these needed to be converted into distinct grain size distributions that sum to 100%. By taking the lower and upper percentage reported for each size class in Table 8, percent finer cumulative curves as lower and upper bounds were developed. These curves for clayey silt are presented in Figure 67 as an example. The cumulative percentage through coarse gravel (assumed

76 mm) was bounded between 88% and 134% (Figure 67). Forcing that cumulative percentage to 100% places the corrected curve 26% from the lower bound to the upper bound for that size class. This adjustment was applied for each size class reported as shown in Figure 67 as the curve weighted to sum to 100%. This procedure was applied to all of the sediment categories defined by e4sciences to yield the grain size distribution curves shown in Figure 68.

Figure 67. Example of the methodology used to approximate particle size distribution classifications provided by e4sciences (class number 2, clayey silt).

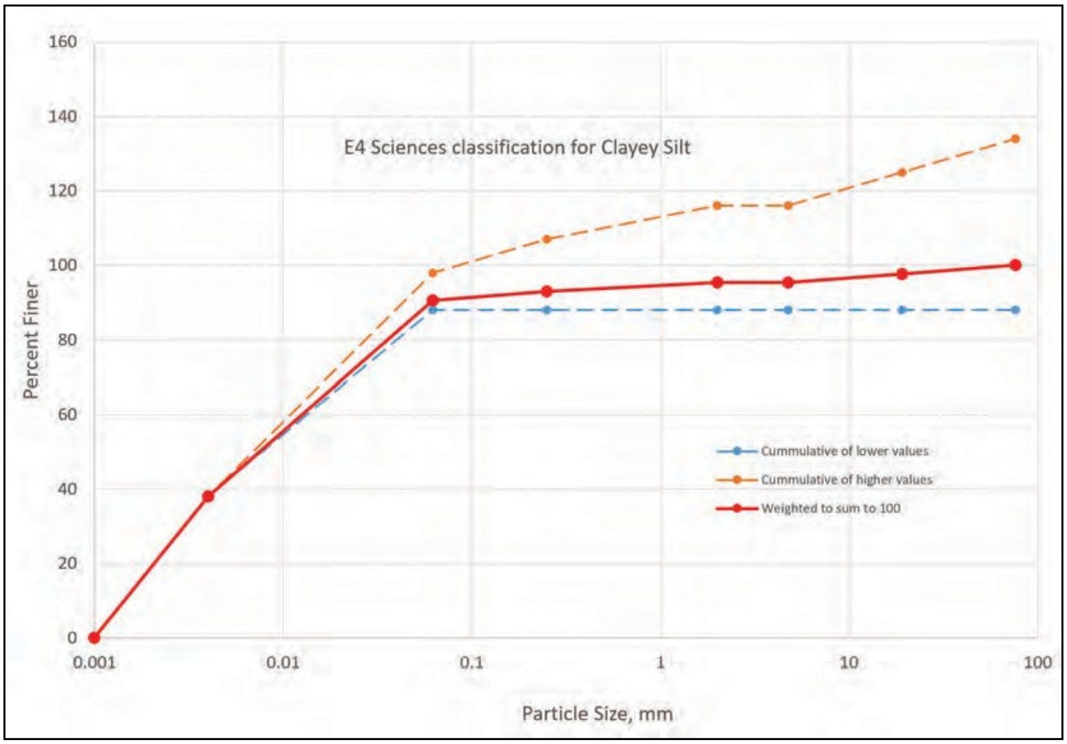
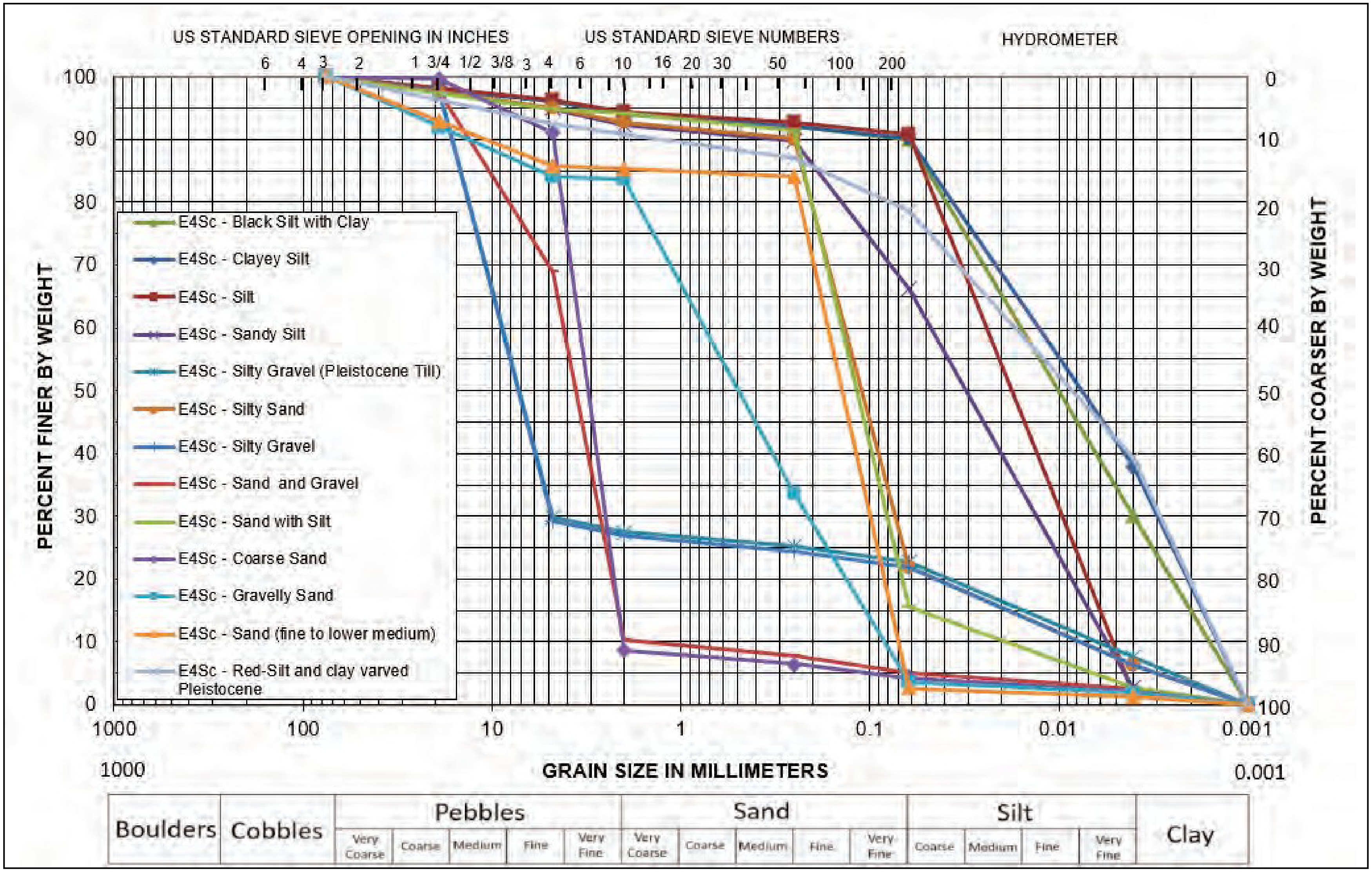
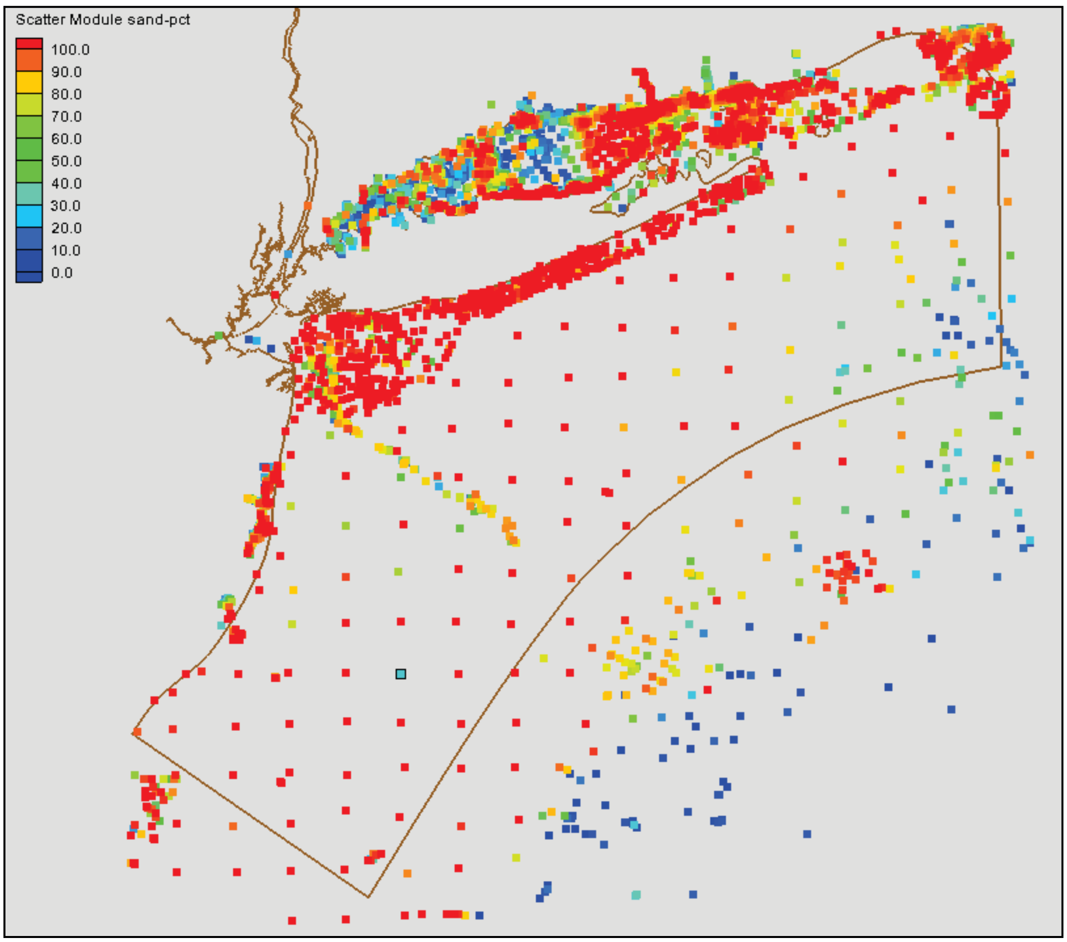


Figure 68. Particle size distribution approximations for all classifications developed by e4sciences.



The numerical model domain includes large areas outside of the coverage analyzed by e4sciences (Figure 66). Additional sediment bottom surficial samples were available from the USGS, Woods Hole, MA. Two separate databases were used: the Long Island Sound Sediment Database (LISSDB) and the East Coast Sediment Texture Database (ECSTDB). These two databases were combined, and the locations of samples are presented relative to the numerical model domain in Figure 69. The location markers are colored based on the percent sand of the samples, from blue for 0% to red for 100%.

Figure 69. Location of sediment characterization sampling from the combined LISSDB and ECSTDB sediment databases. The percent sand is color coded for each station.



The sediment classification types within the LISSDB and ECSTDB were different than those developed by e4sciences. For consistency in the specification over the full domain of the model, the classifications from e4sciences were compared with the classifications from the LIS and ECSTDB and refinements were made for each category of grain size distribution for use within the numerical model. These refinements are illustrated in Figure 70 through Figure 82 for the sediment categories 1 through 13, respectively. A summary of defined sediment classification distributions used in the AdH numerical model is presented in Figure 83 for all of the 13 sediment characterizations.

Figure 70. Refinement of sediment class 1 for consistency between e4sciences and LISSDB/ECSTDB.

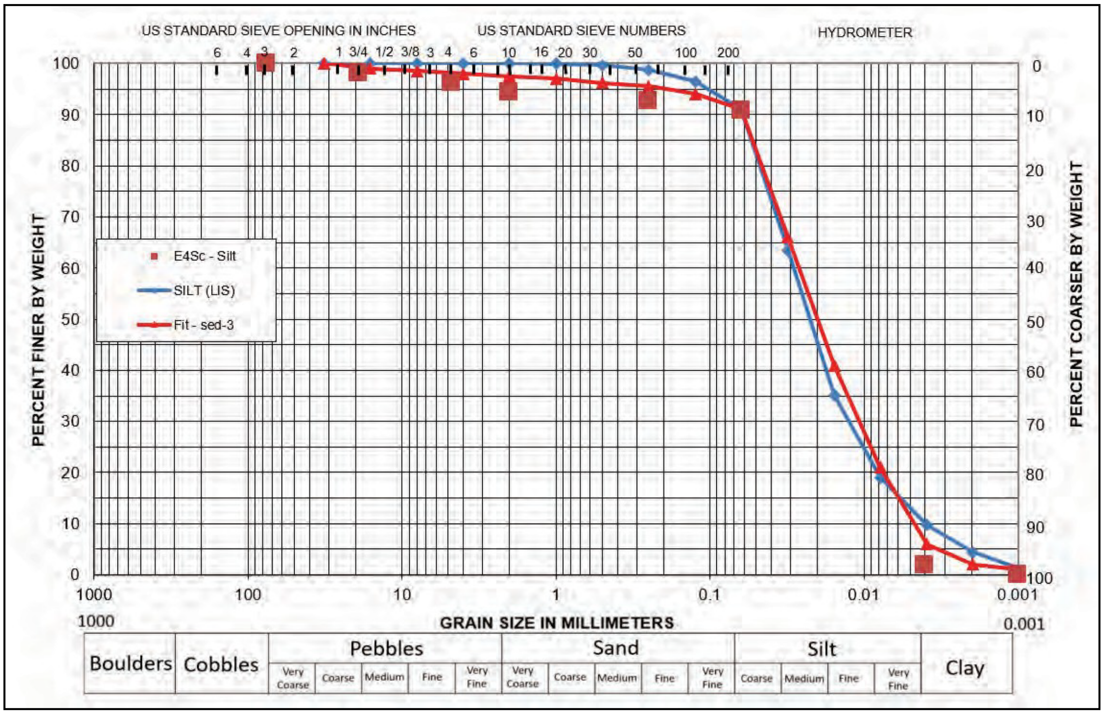


Figure 71. Refinement of sediment class 2 for consistency between e4sciences and LIS/ECST databases.

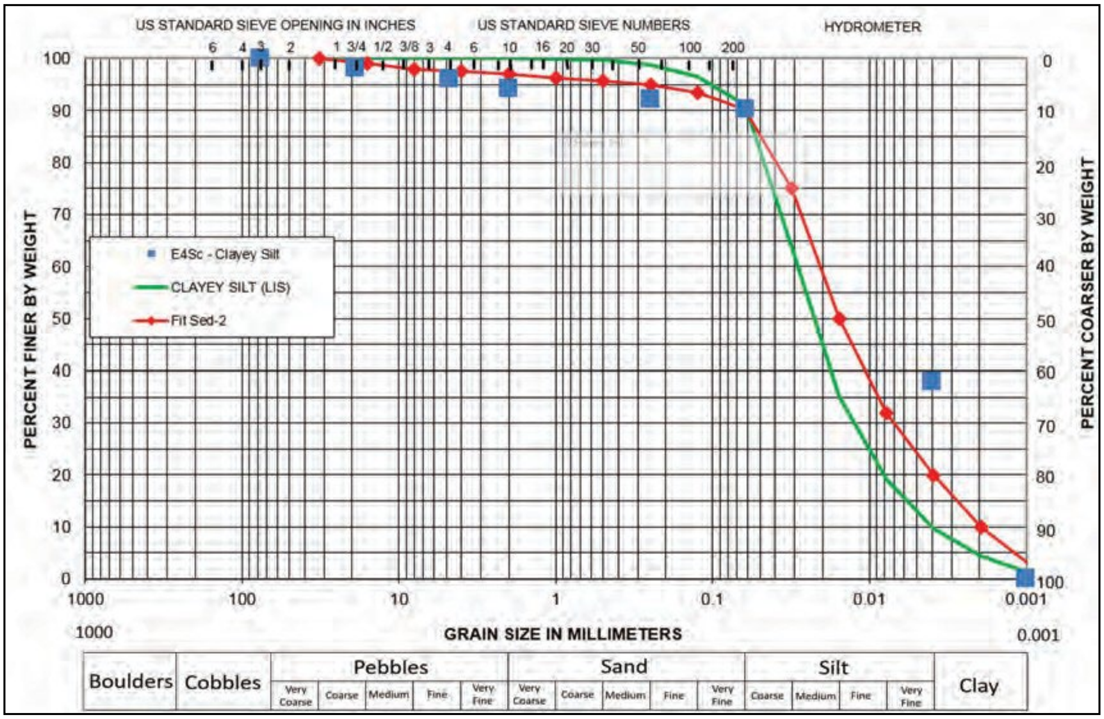


Figure 72. Refinement of sediment class 3 for consistency between e4sciences and LIS/ECST databases.

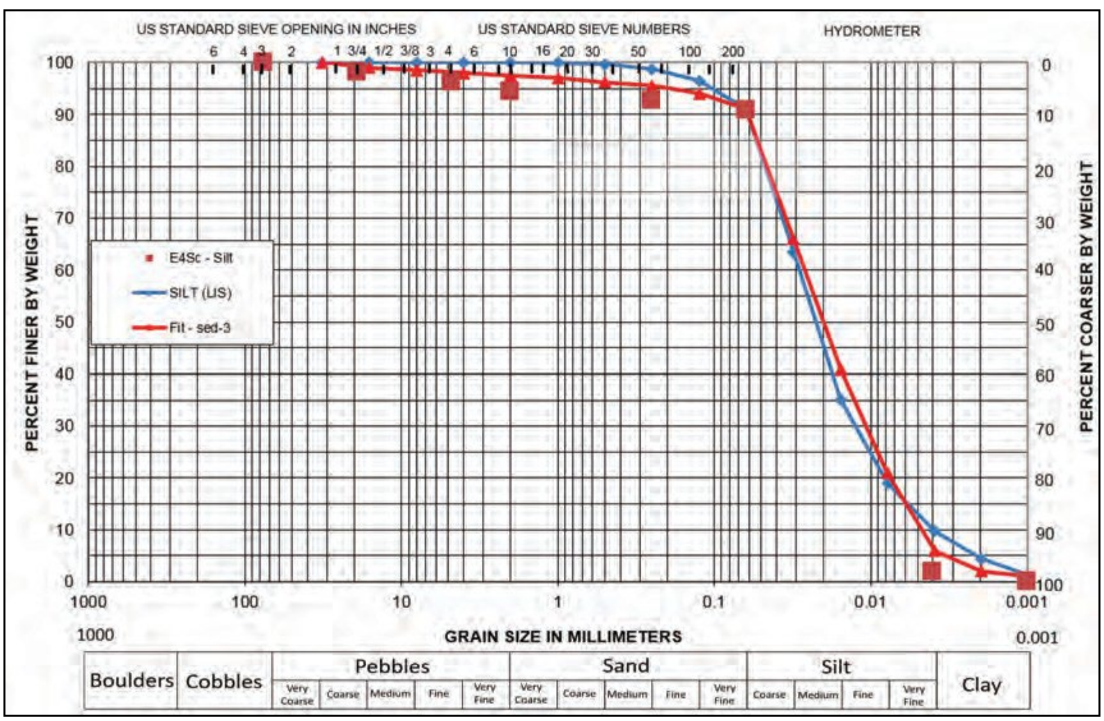


Figure 73. Refinement of sediment class 4 for consistency between e4sciences and LIS/ECST databases.

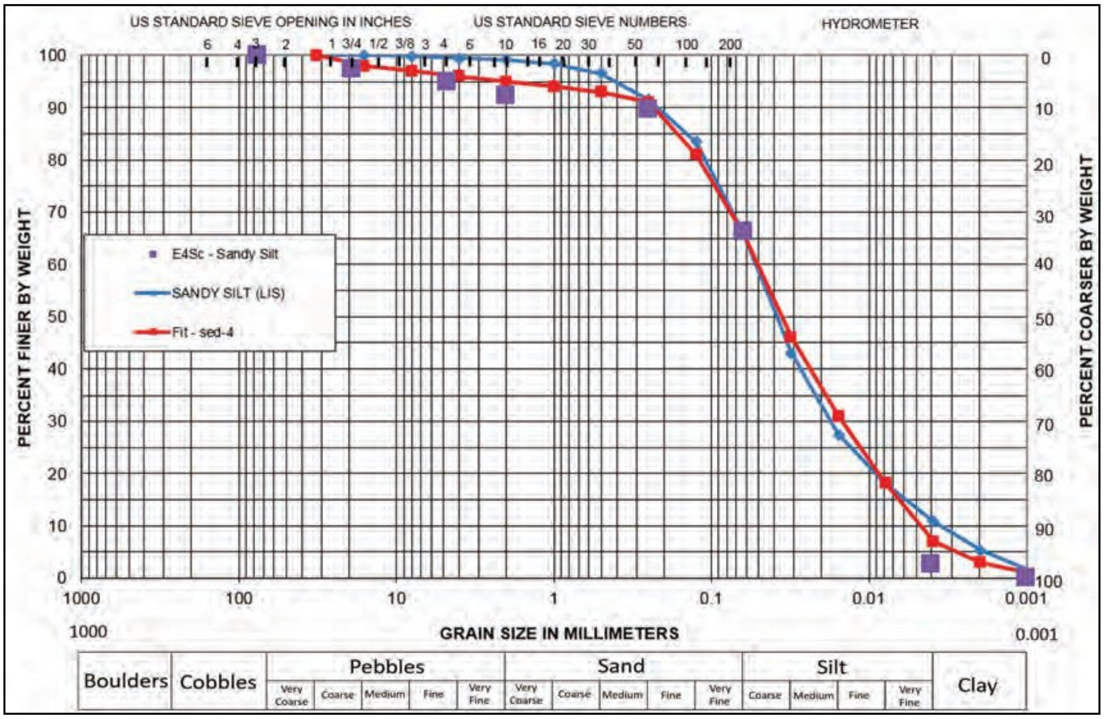


Figure 74. Refinement of sediment class 5 for consistency between e4sciences and LIS/ECST databases.

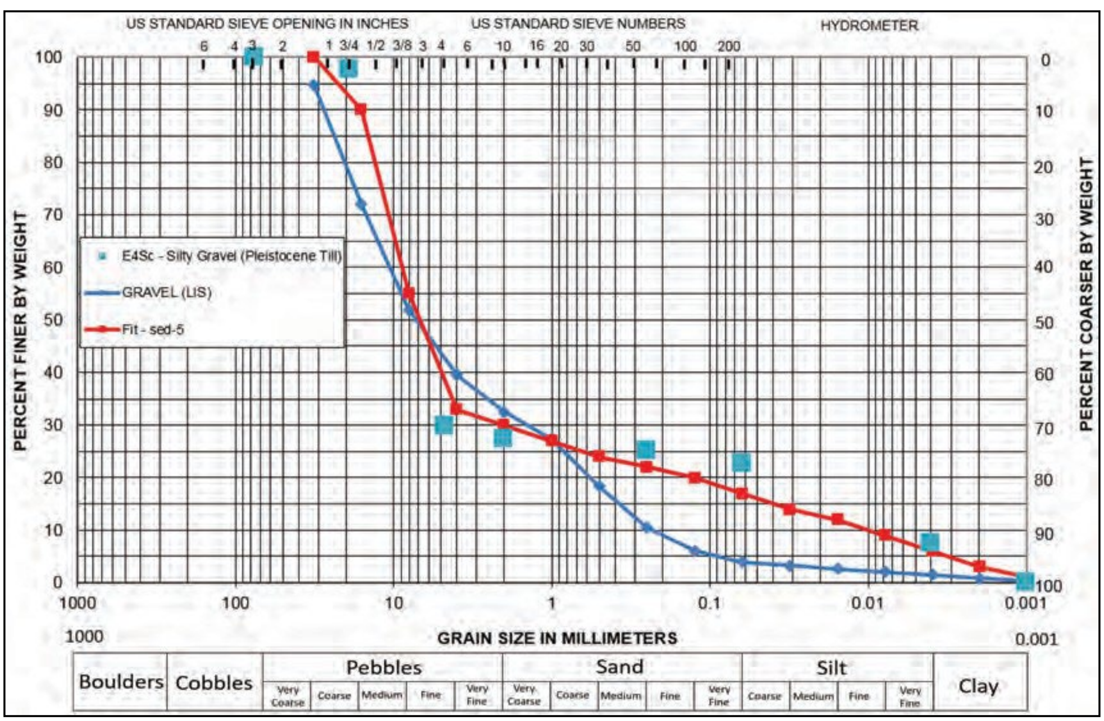


Figure 75. Refinement of sediment class 6 for consistency between e4sciences and LIS/ECST databases.

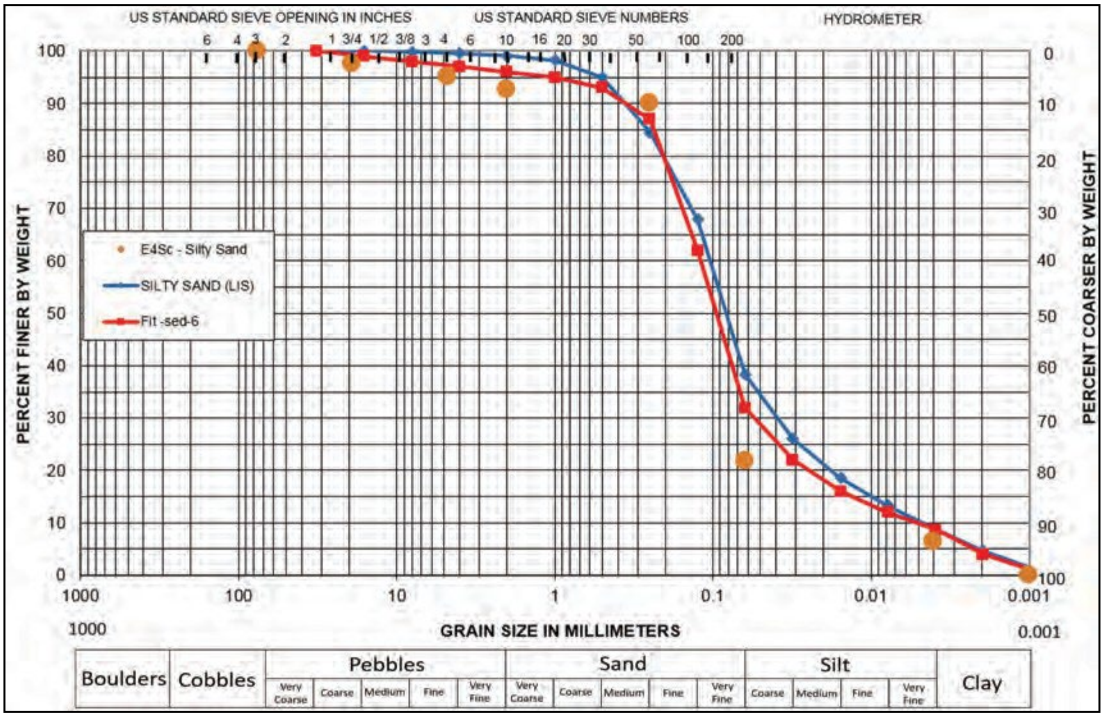


Figure 76. Refinement of sediment class 7 for consistency between e4sciences and LIS/ECST databases.

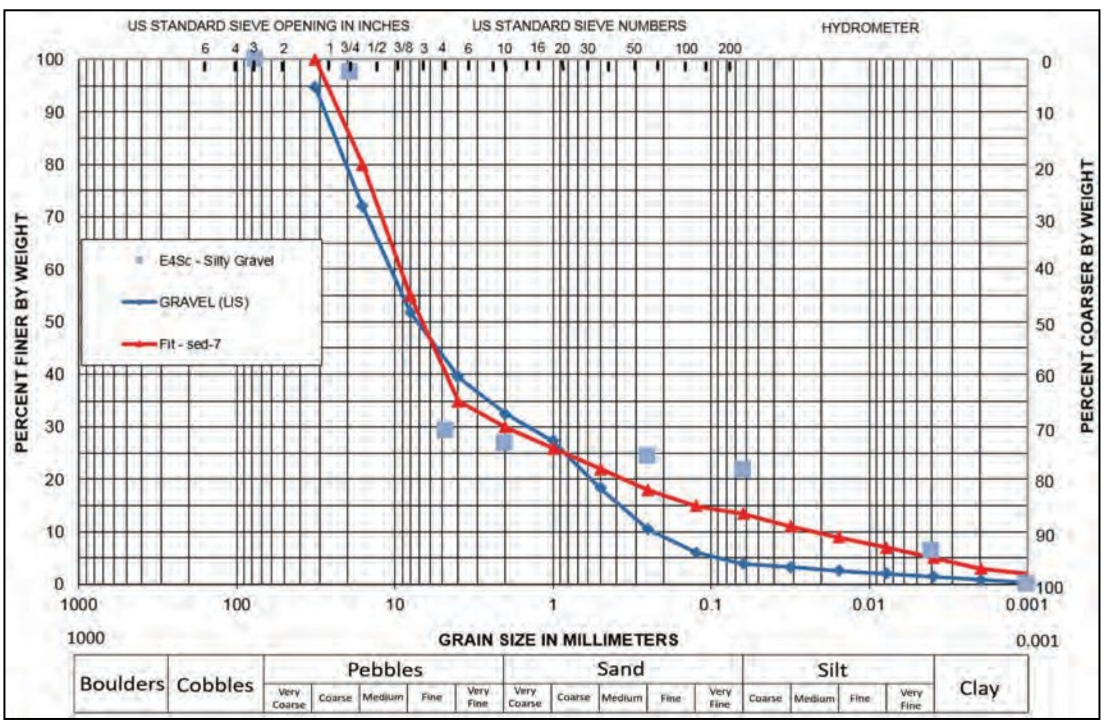


Figure 77. Refinement of sediment class 8 for consistency between e4sciences and LIS/ECST databases.

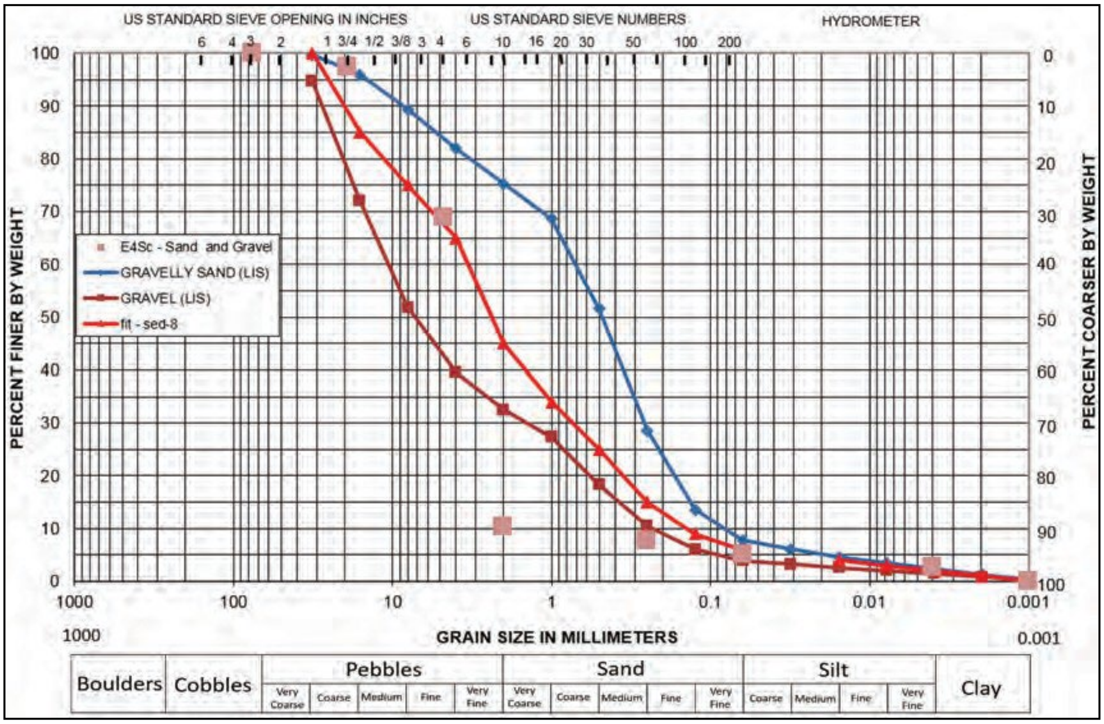


Figure 78. Refinement of sediment class 9 for consistency between e4sciences and LIS/ECST databases.

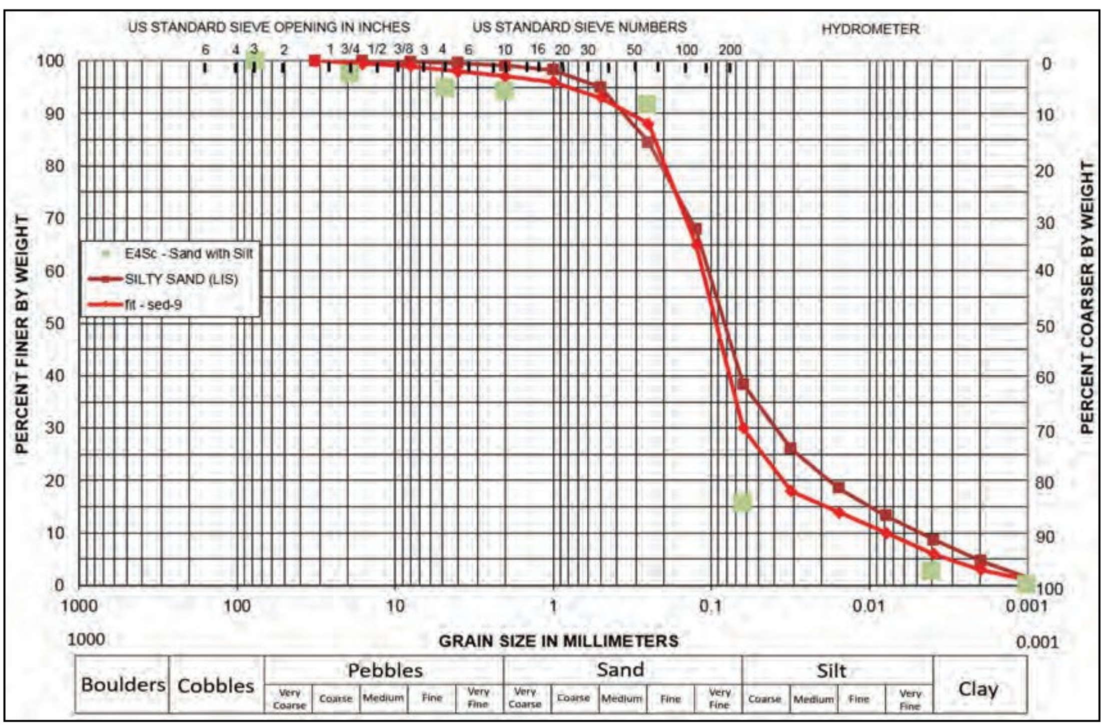


Figure 79. Refinement of sediment class 10 for consistency between e4sciences and LIS/ECST databases.

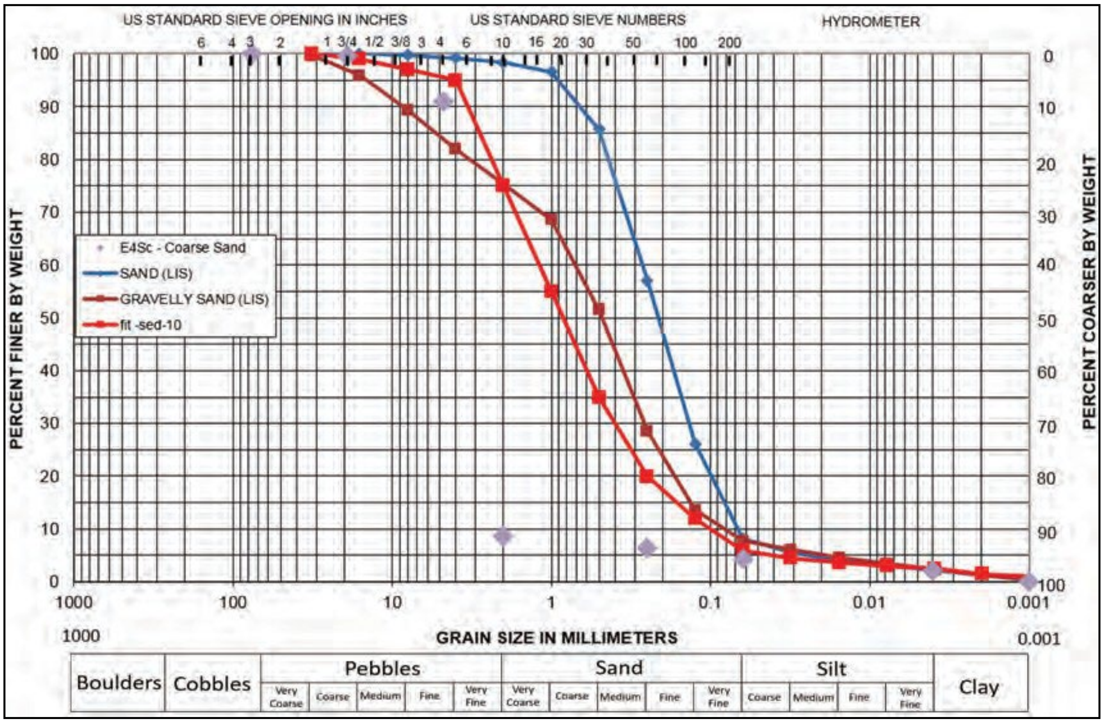


Figure 80. Refinement of sediment class 11 for consistency between e4sciences and LIS/ECST databases.

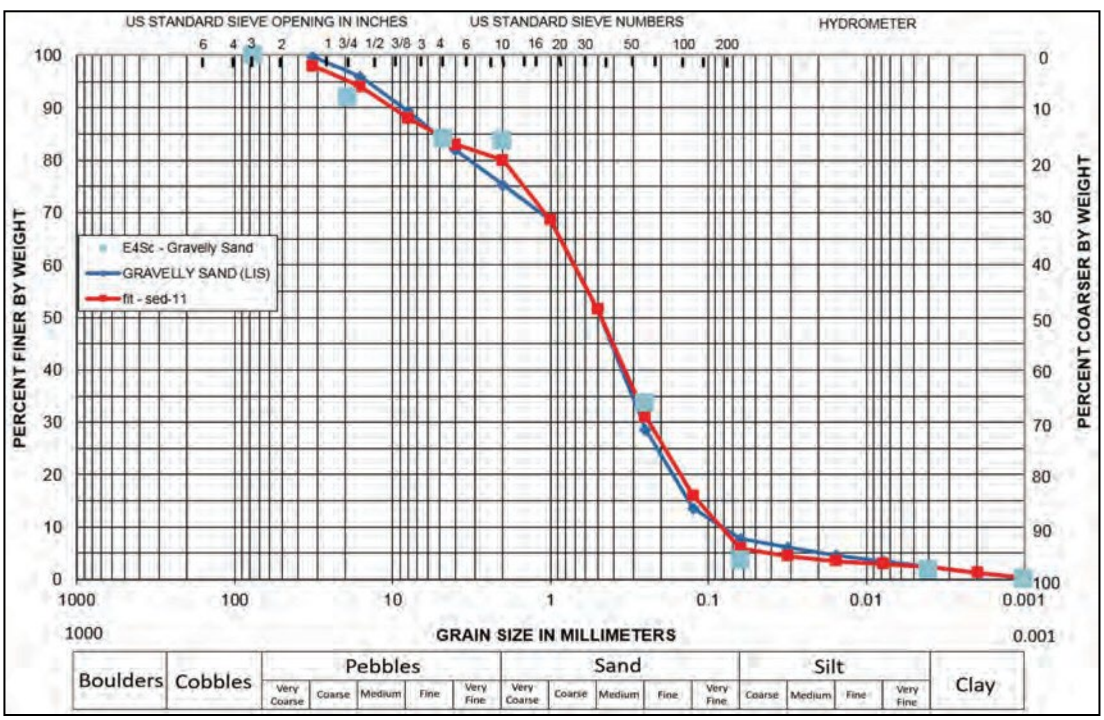


Figure 81. Refinement of sediment class 12 for consistency between e4sciences and LIS/ECST databases.

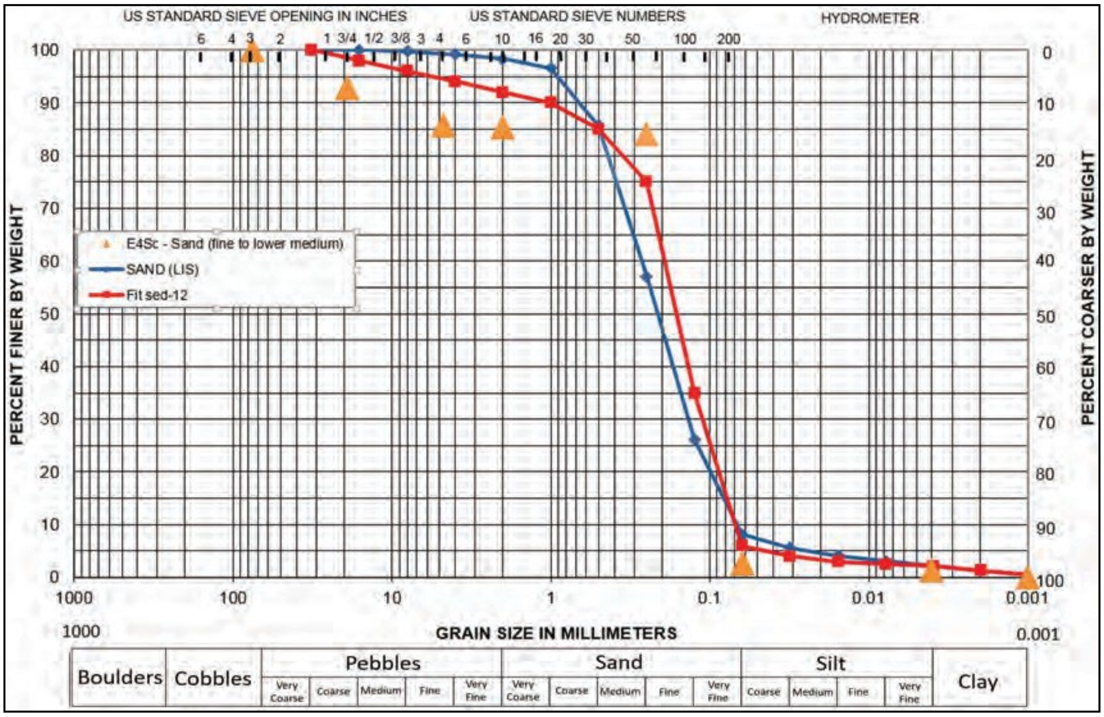


Figure 82. Refinement of sediment class 13 for consistency between e4sciences and LIS/ECST databases.

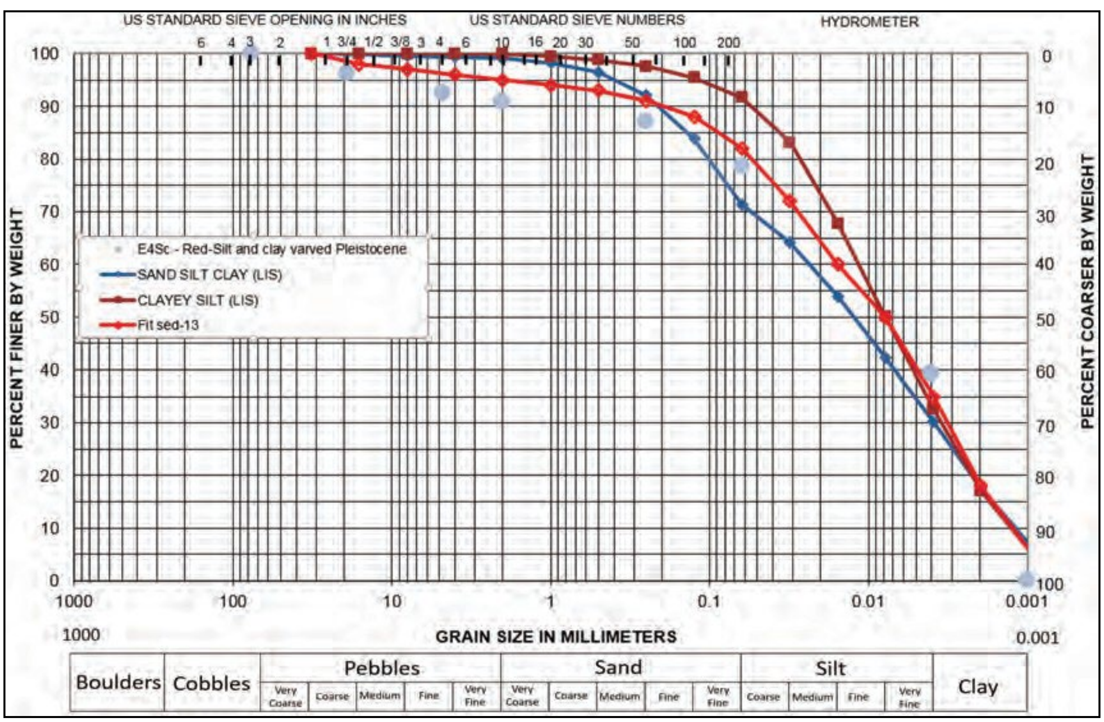
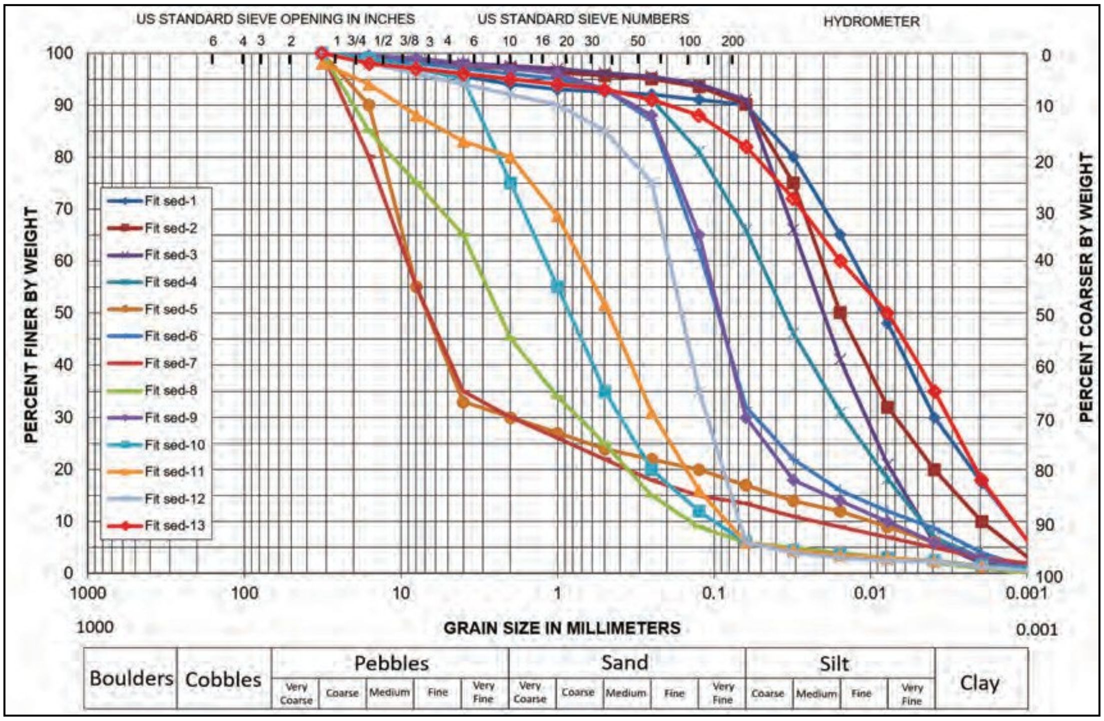


Figure 83. Summary of defined sediment classification distributions used in AdH numerical model.



The sediment characteristics within the domain of the numerical model vary dramatically. The trends of greatest interest to the model specification are the broad trends over scales associated with the dimensions of the estuary water bodies. Local heterogeneity at the scale of the numerical model mesh resolution is not within the capability of the model to resolve.

The specification of the initial bottom sediment gradations was made through the assignment of material types, which vary over the horizontal domain of the model. Fourteen material types were defined which corresponded to the fourteen characterizations developed by e4sciences and the refinements made for consistency with the LIS and ECSTDB. The material specifications within the harbor are presented in Figure 84. These are presented so that the color coding corresponds to the e4sciences delineation shown in Figure 66. The material specifications over Long Island Sound and offshore are presented in Figure 85.

Figure 84. Sediment classifications used in the AdH numerical sediment transport model within the harbor (see color bars in Figure 66 and Figure 85).

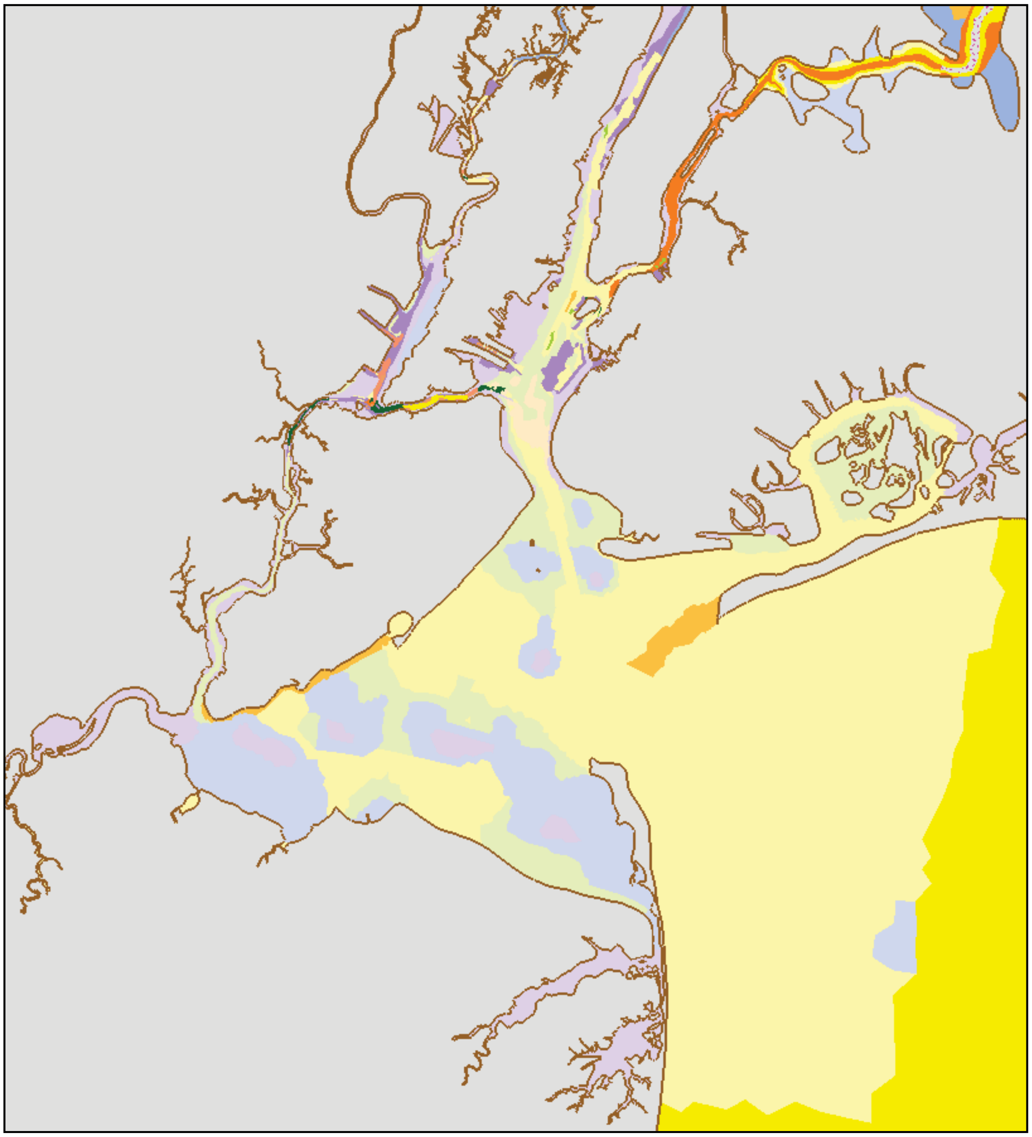
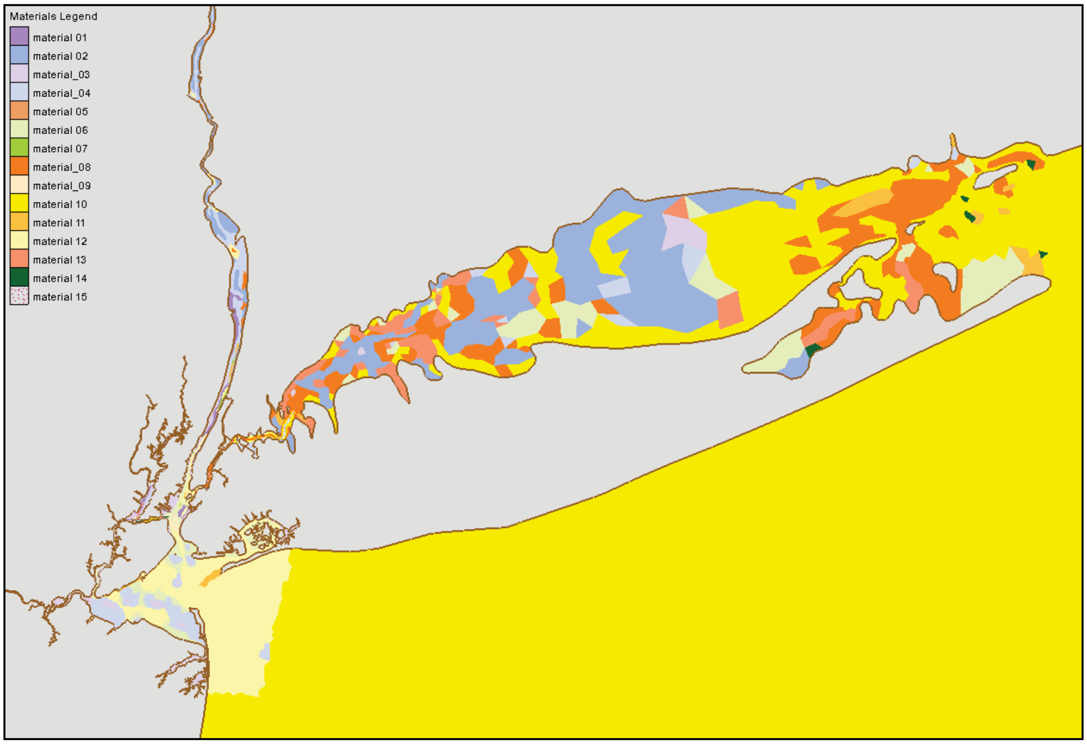


Figure 85. Sediment classifications used in the AdH numerical sediment transport model within the harbor and Long Island Sound.



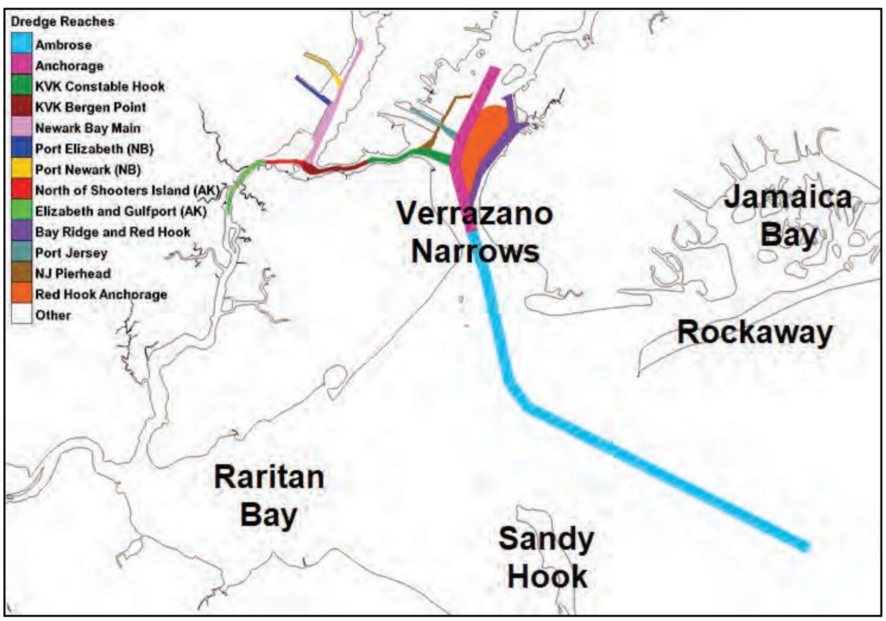
A 1-year model simulation (2012 forcings) was completed to *spin up* the bed composition without allowing the bed elevations to change. This process initializes the bed by allowing the grain size distribution to vary spatially in a manner consistent with the local bed shear stresses. This procedure was deemed necessary to minimize the impacts of discontinuous specification and localized discrepancies between the specifications and the local hydrodynamic conditions. The data used to develop the bed specification were collected over a variety of hydrodynamic conditions, and there is no way to determine *accuracy* of the initialization of the bed. This process was repeated for both the with-project and without-project configurations. This adjusted bed distribution was utilized as the initial bed (with- or without-project as appropriate) for all subsequent sediment transport model simulations in this report. Note that the five simulated years were completed independently. Therefore, the model forcings/results from 1995 have no impact on 1996, and the same is true for 2011 and 2012.

6 Dredging History

Dredging for the 45 ft project

Malcolm-Pirnie* reported a preliminary assessment on the proposed channel deepening for the harbor. In that report, a review of channel maintenance dredging was presented. They reported dredging in Ambrose Channel that occurred between the completion of the 45 ft channel in 1940 and 1982. They estimated that non-federal maintenance dredging totals approximately 24% of the total dredging requirement in the harbor. Figure 86 illustrates the locations of the commonly dredged channels discussed in this chapter.

Figure 86. Commonly dredged channels for NYNJH.



Lower New York Harbor

The spit on the northern end of Sandy Hook has been migrating northward consistently between 1857 and 1976* at an average rate of 20 m per year. The migration has been stopped by the trapping of sediment either within the Sandy Hook channel or by transport of littoral sediments offshore and inshore by the tidal currents within the channel. The

* Malcolm-Pirnie. 1983. Unpublished report. *New York Harbor Navigation Study: Preliminary Assessment of Channel Deepening on Coastal Hydraulics*. Special Study Report prepared for U.S. Army Corps of Engineers, New York District, White Plains, NY.

maintenance dredging was reported to be approximately 249,000 cy/year in 1983. The estimated maintenance dredging for the Raritan Bay reaches was 865,000 cy/year.

Upper Bay

Malcolm-Pirnie[*] reported that data were limited for estimation of the dredging requirements in Upper Bay. They reported limited shoaling in the Anchorage Channel, which tends to be kept relatively deep because of the conveyance from the Hudson River. They reported an average annual maintenance of 33,000 cy. For the period of 1966 to 1976, maintenance of Red Hook Flats was 50,000 cy/year. The Buttermilk Channel maintenance was 253,000 cy/year. The Red Hook and Bay Ridge channels required 910,000 cy/year.

Ambrose Channel

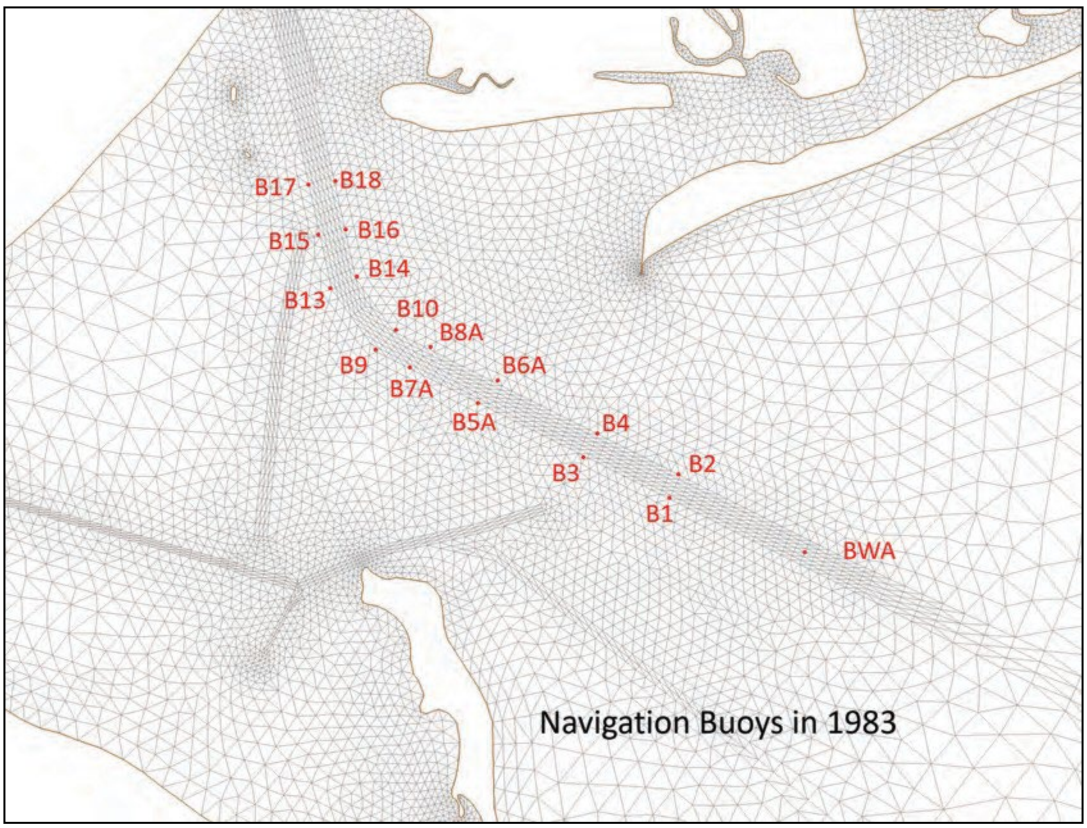
Malcolm-Pirnie* performed a more thorough analysis of the maintenance dredging within Ambrose Channel. They compared maps obtained from the US Army Corps of Engineers (USACE) with the dredged quantities removed. The resulting average annual dredging requirements by channel reach, broken down further into the south, north, and center of the channel, are presented in Table 9. The locations of the navigation buoys are shown in Figure 87 for the 45 ft project. The annual average total maintenance for the 45 ft Ambrose Channel was 272,000 cy. The bulk of that dredging was performed on the north side of the channel (157,000 cy), with the lowest accumulation in the center of the channel.

[*] Malcolm-Pirnie. 1983. Unpublished report. *New York Harbor Navigation Study: Preliminary Assessment of Channel Deepening on Coastal Hydraulics*. Special Study Report prepared for U.S. Army Corps of Engineers, New York District, White Plains, NY.

Table 9. Ambrose Channel maintenance for 45 ft channel (1940–1982) in thousands of cy/year.

Reach	Distance (mi)	South	Center	North	Total
BWA to 0.5	0.25	7.8	18	10.2	36
0.5 to B2	1.2	0.9	0	26.9	27.8
B2 to B4	2.5	8.3	0	20.7	29
B4 to B6A	3.8	17.6	0	50	67.6
B6A to B8A	5.0	8.1	0	0	8.1
B8A to B10	5.7	5.4	0	2.5	7.9
B10 to B14	6.4	7.1	0.8	23.3	31.2
B14 to B16	7.2	3.4	13.6	10.9	27.9
B16 to B18	7.9	16.9	7.3	12.2	36.4
Total		75.5	39.7	156.7	271.9

Figure 87. Navigation buoys for the 45 ft project*.



* Malcolm-Pirnie. 1983. Unpublished report. *New York Harbor Navigation Study: Preliminary Assessment of Channel Deepening on Coastal Hydraulics*. Special Study Report prepared for U.S. Army Corps of Engineers, New York District, White Plains, NY.

The distribution of the dredging for each of the reaches is presented in Figure 88 for the channel reaches between buoys. These volumes of dredging were divided by the surface areas of the reaches to convert the dredging maintenance to an average sedimentation rate for the channel. These are presented in Figure 89. These figures show average sedimentation rates up to 7 cm per year over a portion of the channel and across-channel averages of up to 5 cm per year.

Figure 88. Distribution of Ambrose Channel dredging for the 45 ft project (1940–1982).

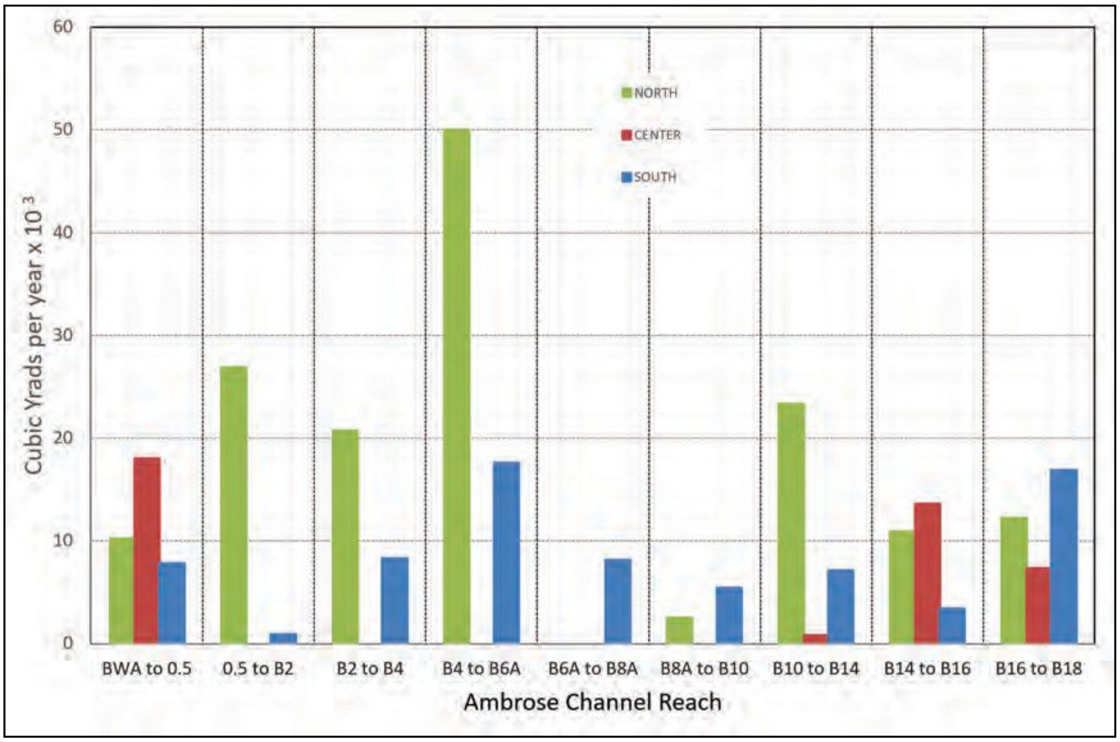
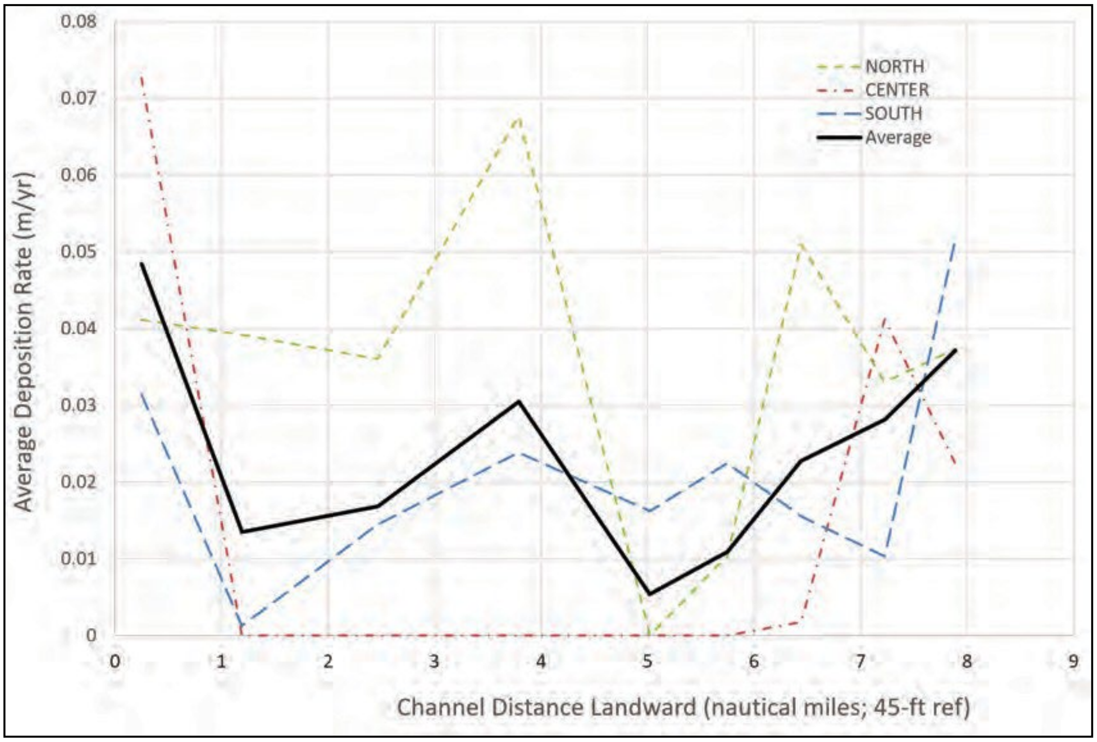


Figure 89. Average annual sedimentation rate derived from dredging volumes for 45 ft project



Malcolm-Pirnie* warned about the uncertainty in these numbers due to variability in the actual dredged depth over different reaches and the nonuniformity of dredging within specific contract limits. However, the data are generally representative of the trends in maintenance requirements. The reach between buoys B4 (B3) and B6A(B5A) is the peak of the dredging requirement, which lies on the transect between Rockaway Point and Sandy Hook. This is the area of the greatest littoral transport of sediment.

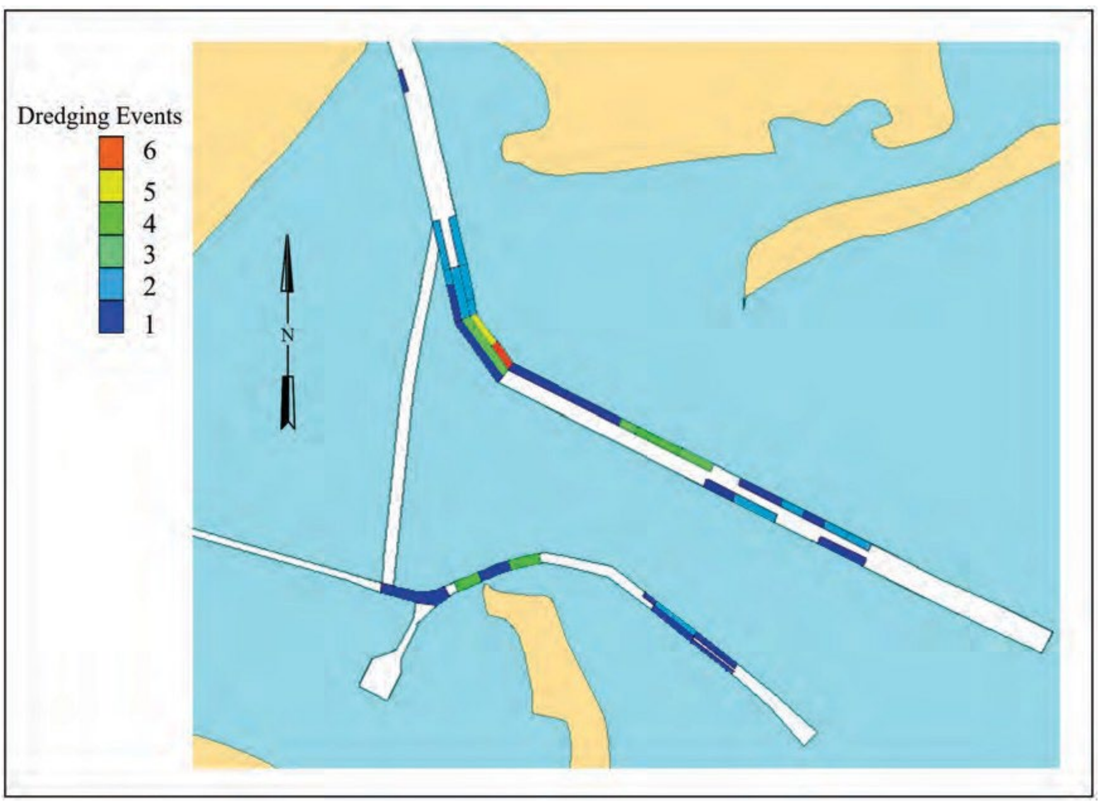
The temporal variability of the dredging requirement for the 45 ft project is illustrated by the range of reported dredging requirements for differing periods by a variety of investigators. The 1940 to 1982 average for Ambrose Channel was reported as 272,000 cy/year*. The Mitre Corporation (1979) reported that the period 1966 to 1976 required 307,000 cy/year. Malcolm-Pirnie* reported 900,000 cy/year for the period 1976 to 1980. This is a

* Malcolm-Pirnie. 1983. Unpublished report. *New York Harbor Navigation Study: Preliminary Assessment of Channel Deepening on Coastal Hydraulics*. Special Study Report prepared for U.S. Army Corps of Engineers, New York District, White Plains, NY.

range of over a factor of three for Ambrose Channel, which shows that long-term trends must cover a variety of conditions.

For evaluation of the spatial distribution of dredging requirements, ERDC investigated the dredging records of Operations Division of the U.S. Army Corps of Engineers, New York, for the period 1961 through 1984 to estimate the general trends in dredging. The coverage of the specific dredging contracts was overlaid to define a frequency of dredging, defined as the number of dredging events during the 24-year period. The results of this analysis are presented in Figure 90. The peak frequency was six events at the first inbound bend in the navigation channel. There are areas of four dredging events on the north side of Ambrose Channel at the crossing of the Rockaway-Sandy Hook transect, as well as the Sandy Hook Channel just off Sandy Hook. These results are very similar to the maintenance dredging distribution reported by Malcolm-Pirnie*.

Figure 90. Prototype dredging frequencies, 1961–1984.



Development of maintenance volumes by e4sciences

The average annual dredging volumes were evaluated and summarized by e4sciences, under contract with US Army Corps of Engineers, New York District (CENAN) (e4sciences 2018). e4sciences compiled the data from CENAN dredging records. The data provided included estimates of dredging for the following periods:

1. Pre-1999 dredging volumes and annual rates
2. 1999 – 2007 dredging volumes and annual rates
3. Post-2007 dredging volumes and annual rates.

The dredging volumes developed by e4sciences are summarized for these periods in Table 10. The pre-1999 volumes were taken from the New York and New Jersey Harbor Deepening re-evaluation report (USACE 2004). The dredging volumes for the 1999 to 2007 period were reported with a low and a high range of annual dredging volumes based on the uncertainty in the dredging records for the duration of time between dredging activities.

The post-2007 dredging volumes are shown as those volumes reported as purely maintenance dredging in the fourth and fifth columns of Table 10. However, a portion of the dredging reported as new work included material that was unacceptable for open water disposal at the Historic Area Remediation Site (HARS) dump site. That material required special upland disposal. Those volumes could be assumed to be the result of recent deposition and therefore a component of the maintenance volumes. The two final columns include those volumes in the post-2007 volume estimates for both the low and high ranges of the dredging estimates.

The variability in the annual rate of dredging estimates over the differing periods and channel depths suggest that natural variability due to different river flows and meteorological conditions is more significant than the navigation channel depth. This observation is the primary motivation for the current numerical model study, which can isolate the navigation channel depth impacts by simulating the exact same conditions for both pre- and post-deepening channel conditions.

Table 10. Dredging volume distributions by channel reach in cy (e4sciences 2015).

Channel	pre-1999	1999–2007		post 2007		post 2007+ non-HARS	
		Low range	**High range**	**Low range**	**High range**	**Low range**	**High range**
Ambrose	400,000			57,175	133,408	134,209	313,153
Anchorage				12,565	29,317	186,623	435,454
Kill van Kull Constable Hook	28,000	0	0	11,710	27,324	11,710	27,324
Kill van Kull Bergen Point	4,000	14,591	10,228	11,710	27,324	11,710	27,324
Newark Bay (NB) Main	211,000	92,137	65,812			160,528	374,566
NB Port Elizabeth	121,700	64,358	48,269	18,441	43,029	63,545	148,271
NB Port Newark	226,200			14,780	34,487	14,780	34,487
AK north of Shooters Island	115,000	99,725	62,328	4,888	11,404	4,888	11,404
AK Elizabeth and Gulfport	7,000	96,205	60,128	20,641	48,163	20,641	48,163
Bay Ridge and Red Hook	520,000						
Port Jersey	58,000	160,220	112,089	11,368	26,525	106,299	248,031
Claremont	25,000						
NJ Pierhead	40,000						
Red Hook Anchorage	145,000						
Gravesend Anchorage	28,000						
Stapleton Anchorage	0						

7 Description of Project

The purpose of this study is to determine an approximate impact to the NYNJH system due to the channel deepening with particular emphasis on the impact to dredge volumes. To accomplish this goal, an appropriate without-project mesh configuration was determined and then altered to incorporate the project deepening. As previously discussed, the without-project bathymetry was created by taking the bathymetry dataset compiled by e4sciences and removing any components of the project already constructed in 2004. The with-project mesh configuration was then developed by modifying the without-project configuration to create a new mesh where the only differences were associated with the project. The deepening project increased the authorized depth from 45 ft (13.72 m mean lower low water [MLLW]) to 50 ft (15.24 m MLLW) with the Ambrose Channel further deepened to 53 ft (16.16 m MLLW). These channel elevations were decreased by 0.78 m) to correct from MLLW to MSL datum (based on Sandy Hook) in the numerical model mesh. The with-project bathymetry dataset is shown in Figure 91, and the without-project bathymetry dataset is shown in Figure 92.

Areas in the channel deeper than the new authorized depth were left unchanged and are equivalent in both mesh configurations. The Verrazano Narrows is an example of this. Prior to the channel deepening project, the depth in the Verrazano Narrows was approximately 90 ft, and therefore no channel deepening was required in this location.

Figure 91. Without-project bathymetry.

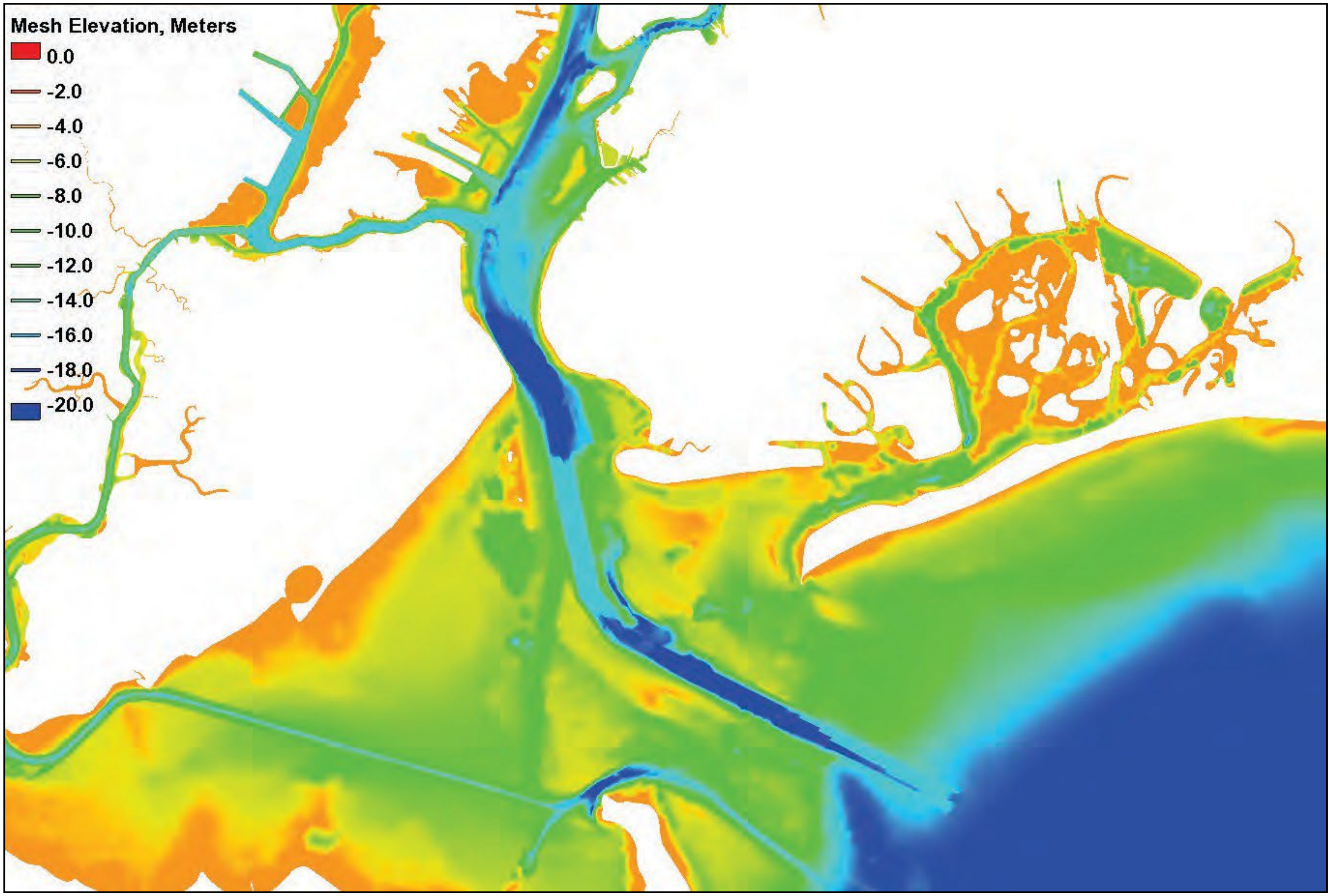
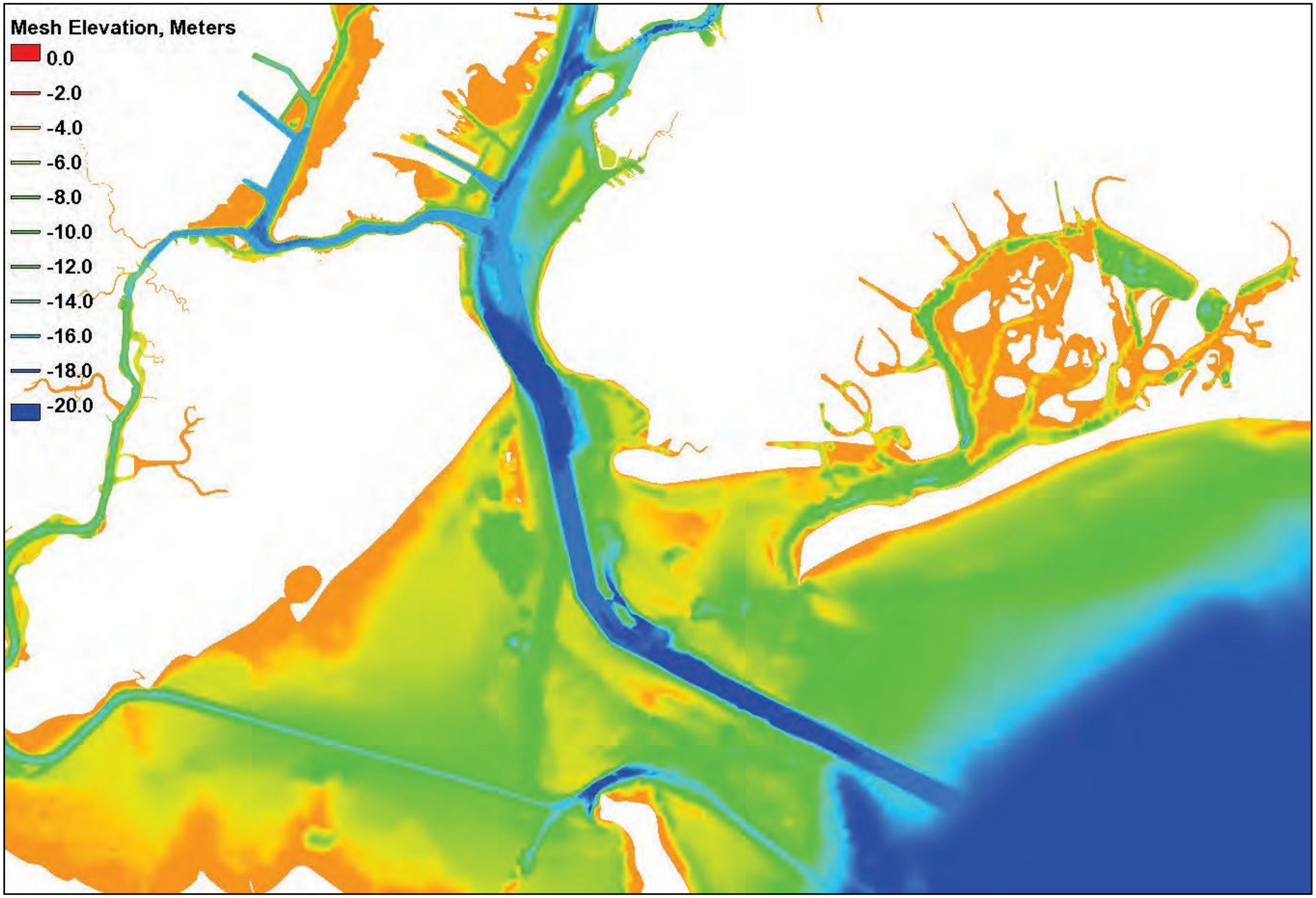


Figure 92. With-project (channel deepening) bathymetry.



8 Model Validation

The model validation was a multistep process that continuously expanded the complexity of the model. A 3D hydrodynamic and salinity and sediment transport model has numerous components that individually could negatively impact the model results. This step-by-step approach allowed for the isolation of particular components to prevent unknowingly propagating a hydrodynamic error through the process all the way to the sediment transport results. The steps followed in the model validation were as follows:

1. 2D model validation to NOAA (2005) tidal harmonics and phases
2. 3D model validation of hydrodynamics to observed NOAA water level data
3. 3D salinity transport validation to observed salinity measurements
4. 3D sediment transport validation to historical dredging volumes.

The final simulations were 3D simulations with hydrodynamics, salinity and sediment transport that also include the impact of local wind generated waves using the CSTORM-MS system to link the AdH hydrodynamic, salinity and sediment transport model to the STWAVE model. This chapter details the validation process and comparisons to the observed data.

Before performing sedimentation simulations, the salinity model was validated to the salinity distribution within the estuary. The primary calibration parameters for the salinity validation are the turbulent mixing coefficients (Harleman 1966). These mixing coefficients within the salinity transport equation are the same coefficients used in the sediment transport governing equations (advection/diffusion equation). The only difference in the basic equations is that the sediment transport equation includes a settling velocity for the particles and a source/sink term at the bottom for deposition/erosion. Other terms in the equations are the same between the salinity and sediment transport. Of course, the initial conditions are different, and there are 10 separate sediment transport equations, one for each sediment size class.

After salinity validation, the model incorporated sediment transport by adding specific sediment size classes and the associated sediment properties for each size class. The sediment properties included the settling velocities of the sediment when in suspension and boundary conditions, which include the sediment size distribution within the bed sediment layers and the sediment suspended concentrations by size class within the river inflows (previously discussed in Chapter 4).

This study is essentially a hindcast project whereby the validation of the numerical model consisted of comparing observations to both the with- and without-project model results. Some observations were prior to the construction of the project, some were during construction, and some were post construction. The model-to-field comparisons in this chapter were compared to the most appropriate mesh configuration based on the time the data were collected. As such, this project, as opposed to most projects, includes model to field comparisons for the with-project model results.

Model simulations

The model simulations consisted of simulating five calendar years (1985, 1995, 1996, 2011, and 2012) with both the without-project conditions and the with-project conditions and analyzing the model results to quantify the variation between the two sets of simulations. The primary point of focus was on the dredge volumes but additional analysis was also completed to investigate the overall impact of the channel deepening project.

Sources of model uncertainty and consequences

Uncertainty can, in general, be classified as either natural uncertainty or epistemic uncertainty (Merz and Thieken 2005). Natural uncertainty arises from the stochastic nature of the forcing conditions that lead to the processes being studied. Epistemic uncertainty arises from a variety of sources, including measurement error, a limited period of record, modeling limitations, and other factors related to imperfect knowledge or measurement of the processes of interest. Epistemic uncertainty can be reduced by careful design of the analysis while the natural uncertainty cannot be reduced.

In numerical modeling, the high-fidelity results (both temporally and spatially) can sometimes mislead the user into assuming an unrealistic level of accuracy in the model results. For complex models such as the one utilized in this study, there are numerous forcing conditions and model input parameters that are uncertain, each of which impact the model results. For the hydrodynamic model results, the bathymetry, tidal boundary, river inflows, wind and pressure fields, and frictional specification are just a few of the parameters specified in the model that possess uncertainty. While it is extremely difficult to determine an exact level of uncertainty in the model results, some indication of the accuracy of the model can be inferred from the accuracy of the model in replicating the observed data. It is also beneficial to analyze the variation in the model results across a wide range of forcing conditions and through the completion of sensitivity simulations to investigate the impact of certain parameters. By simulating 5 years with a wide range of forcing conditions, an uncertainty due to the boundary conditions can be inferred from the model results. The absolute dredge volume results can vary significantly with these differing boundary conditions, but the with-project versus without-project comparisons will be more consistent as the impact of some of these variations between years will be negated by comparing the model results in this manner.

For the salinity transport, the uncertainty is primarily attributed to any inaccuracies in the hydrodynamics, the initial salinity field specified in the model, offshore salinity boundary specification and the mixing values utilized for model stability. The initial salinity field can sometimes impact the salinity results for long periods of time depending on the residence time for the particular estuary. That is why it is important to choose a reasonable beginning salinity field. For this study, 2D salinity transport baroclinic simulations were performed to obtain a realistic spatially varying salinity field. Then this 2D (constant over depth) salinity field was simulated in the 3D model for 1 month leading up to the year being simulated. Therefore, the last month of the preceding year was utilized as an initialization time period for the hydrodynamics and salinity for each yearly simulation. This initialization was performed separately for the with- and without-project conditions.

As expected the sediment transport results have the largest degree of uncertainty as the previously discussed sources of uncertainty for the hydrodynamic and salinity transport results are propagated to the sediment transport results. There is also significant uncertainty in the specification of the sediment parameters themselves. A model can never be more accurate than the data used to develop said model and with sediment transport modeling the observed input data commonly includes a wide range of uncertainty. An example of this would be the data utilized in Table 8; the observed data have a range of approximately 20% in some locations and/or sediment classes, and as such, expecting the numerical model to be more accurate than these observed values is unlikely.

Considering the previously discussed model uncertainties, some could ask “what is the use of such a model rife with uncertainties?”, but the model is useful for gaining insight into the behavior of the system. When considering the model results across the wide range of forcing conditions in this study, consistent results across simulations reinforce the confidence in those results. There is also a tiered expectation level in terms of model accuracy. The absolute value provided by the model is expected to have the largest degree of uncertainty, with base-versus-plan differences expected to be an order of magnitude more accurate, and overall trends are expected to be the most accurate (increasing in location A and decreasing in location B). In essence, the value of the numerical model is to minimize as much as possible epistemic uncertainty by simulating both with- and without-project conditions under the same forcing conditions.

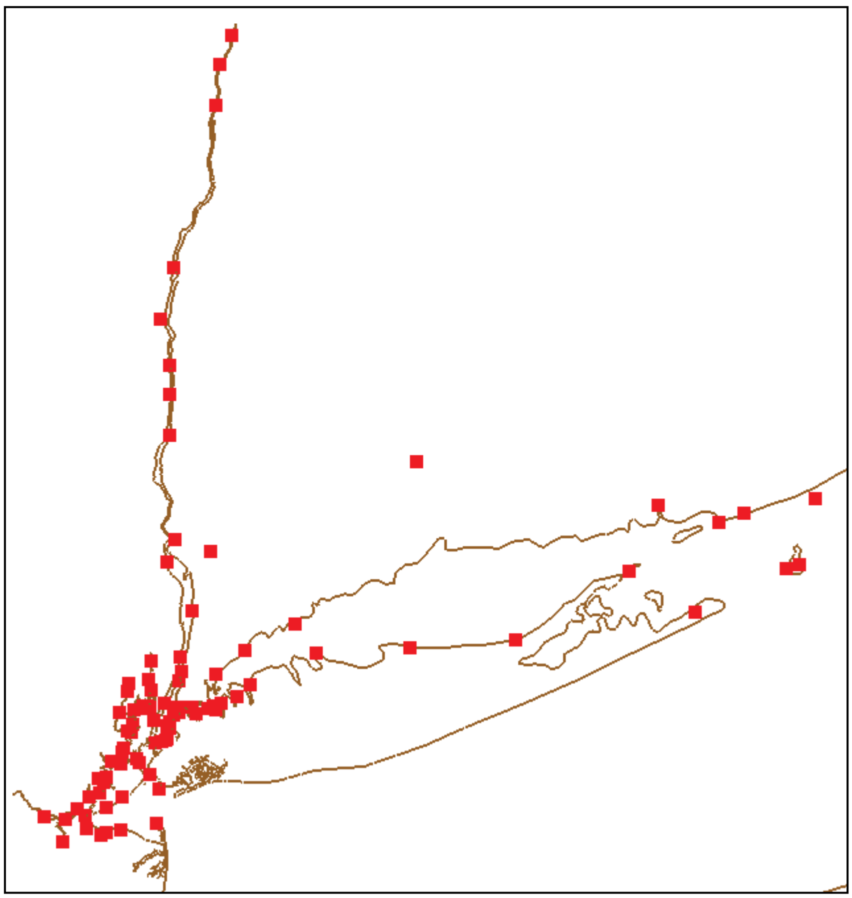
This section of the report serves as an introduction to the topic of uncertainty in the model results but additional discussion is provided in subsequent sections whereby the variation in the model results across years and mesh configurations is utilized to infer some expected level of accuracy in the model results.

Two-dimensional (2D) tidal harmonic comparisons

The first step in the AdH model validation was to simulate the harmonic tidal signal within the 2D depth-averaged module of AdH. This approach was performed as a preliminary model adjustment to get general agreement of basic harmonic tidal propagation within the harbor. There is a large database of historic tidal data throughout the harbor that supports the NOAA-predicted tidal analyses. This preliminary step was for qualitative comparisons. The detailed quantitative verification is deferred to the full 3D model with full meteorological and hydrologic forcing. The harmonic tidal simulations included no meteorological forcing and were compared with the long-term NOAA-tabulated mean tides and average spring tides along with the tidal progression as documented in the lunar intervals, tidal phases relative to Sandy Hook time of mean high water.

The 2D model horizontal mesh (previously shown in Figure 17, Figure 18, and Figure 19) is the same resolution mesh utilized for the 3D model. The tidal harmonic boundary condition used for the harmonic validation was previously discussed in Chapter 4. The data for the calibration of the model to purely harmonic propagation are provided in Appendix B from NOAA (2005). The locations of the tide stations are shown in Figure 93.

Figure 93. Location of NOAA tide stations with general tidal characteristics defined.



The AdH model was simulated with very low flow on all rivers to represent the periods used by NOAA to develop their tidal characteristics. This strategy generally gives a greater tidal influence up the rivers than when normal flows of the Hudson River are included.

Hudson River

Tidal amplitudes and high/low water arrival times relative to Sandy Hook were compared for the Hudson River locations shown in Figure 94. Some location names are omitted from the points in Figure 94 (and future location figures) due to the abundance of points. The locations in the plot figures are all represented by points in the location figures, but some locations are not explicitly named. The orders in the location figures and amplitude/arrival time plots are also consistent. The profile of the time of high and low waters up the Hudson River relative to the time of high water at Sandy Hook is presented in Figure 95 for both the NOAA data and the model results. The profile comparison of the tide range is presented in Figure 96. The progression of the wave up the river is in phase with the predicted NOAA tides, but the tide range is lower at the farthest upstream end of the profile outside of the dredging project. This underestimation of the tide range in the upper reaches of the Hudson River should have negligible impacts on the sedimentation in the harbor.

Figure 94. Hudson River analysis locations.

Figure 95. Tidal propagation for the times of high and low waters up the Hudson River for the low-flow tidal harmonic simulation.

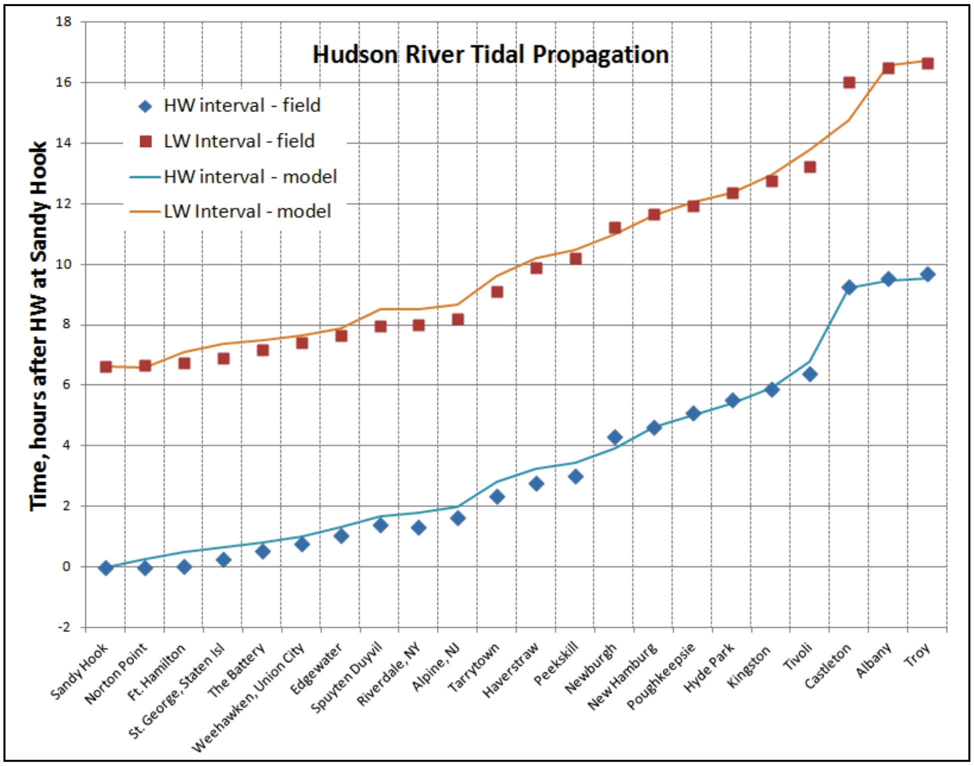
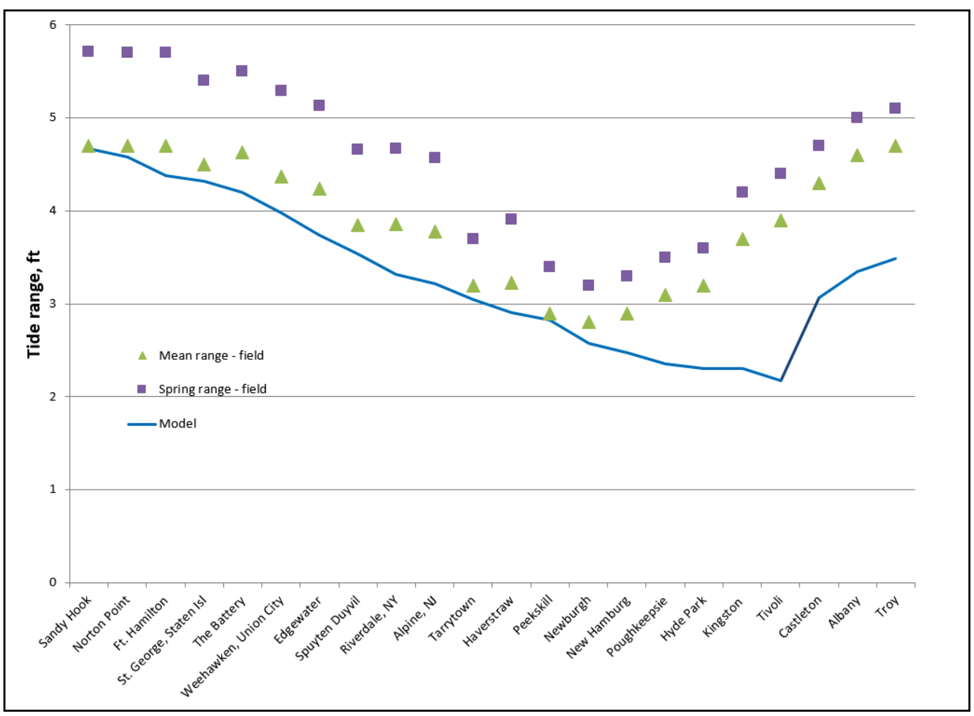


Figure 96. Tidal range propagation up the Hudson River for the low-flow tidal harmonic simulation.



East River and Long Island Sound

The profile of the time of high and low waters relative to the time of high water at Sandy Hook for a transect from Sandy Hook, through Upper Bay and then up the East River and eastward through Long Island Sound (analysis locations shown in Figure 97 and Figure 98) is presented in Figure 99. Tides propagate through Lower Bay and northward up the East River. Tides also propagate westward through Long Island Sound into the East River. The inner East River between Hell's Gate and the western end of Long Island Sound behave as a standing wave, with little phase difference. Consequently, the tide range is dramatically increased in that reach. The profile comparison of tide range through this transect is shown in Figure 100. The tidal characteristics show that the model tides arrive as much as an hour early in the eastern end of East River. Low waters are in better agreement. The high water enters Long Island Sound at the eastern end and then propagates west. The tides are in relatively good phase in the western end of East River. The tide range, which is slightly higher than a mean tide at Sandy Hook, propagates through the East River with relatively good magnitude with the exception of around Hell's Gate.

Figure 97. East River analysis locations.

Figure 98. Long Island sound analysis locations.

Figure 99. Tidal propagation for the times of high and low waters up the East River and through Long Island Sound for the low-flow tidal harmonic simulation.

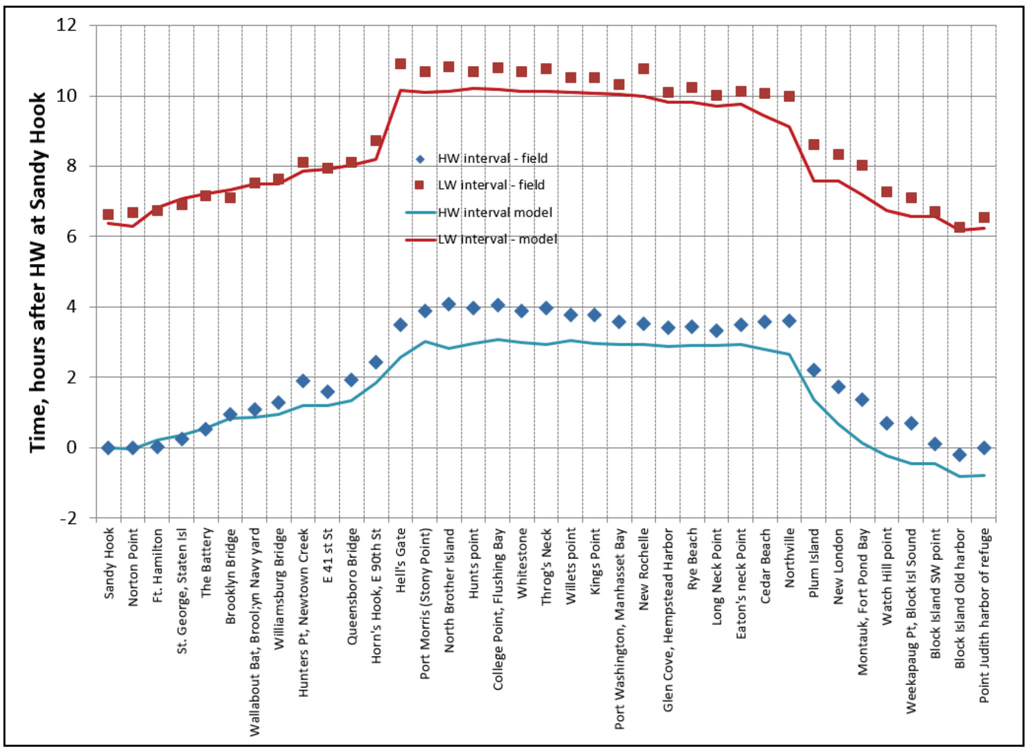
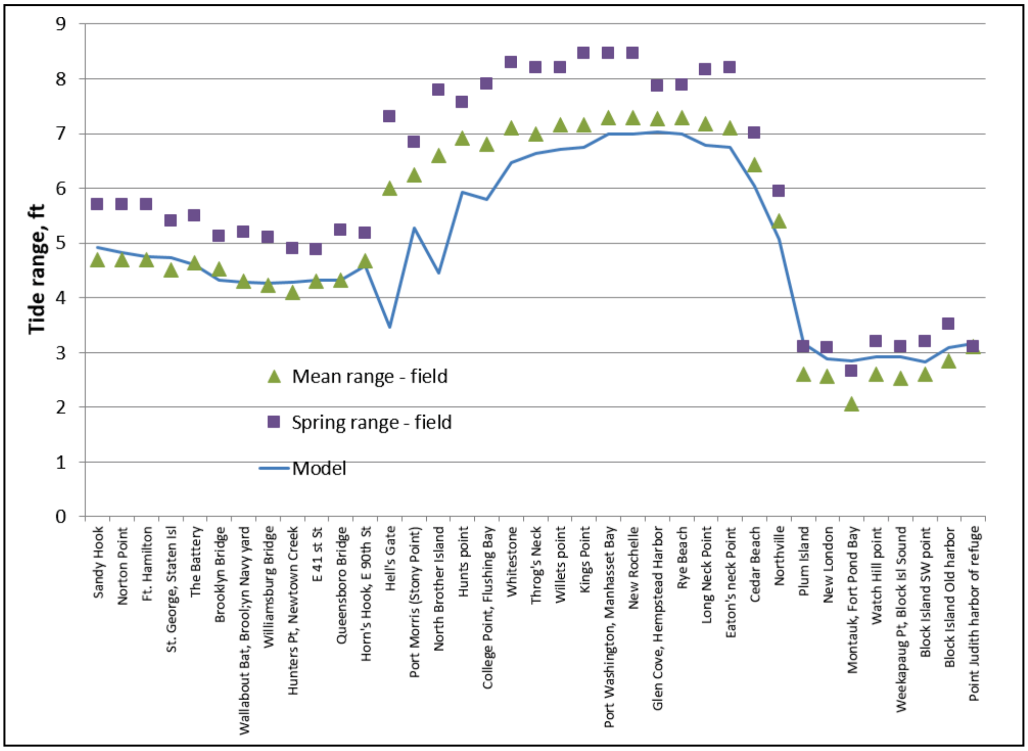


Figure 100. Tidal range propagation up the East River and through Long Island Sound for the low-flow tidal harmonic simulation.



Staten Island

The profile of the times of high and low waters relative to the time of high water at Sandy Hook for the loop around Staten Island (locations shown in Figure 101) is presented in Figure 102 for both the NOAA data and the model results. The profile comparison of the tide range is presented in Figure 103. The high and low water intervals around Staten Island are in very good agreement for both high and low waters. The comparison of tide range variation around Staten Island is also in good agreement.

Figure 101. Staten Island analysis locations.

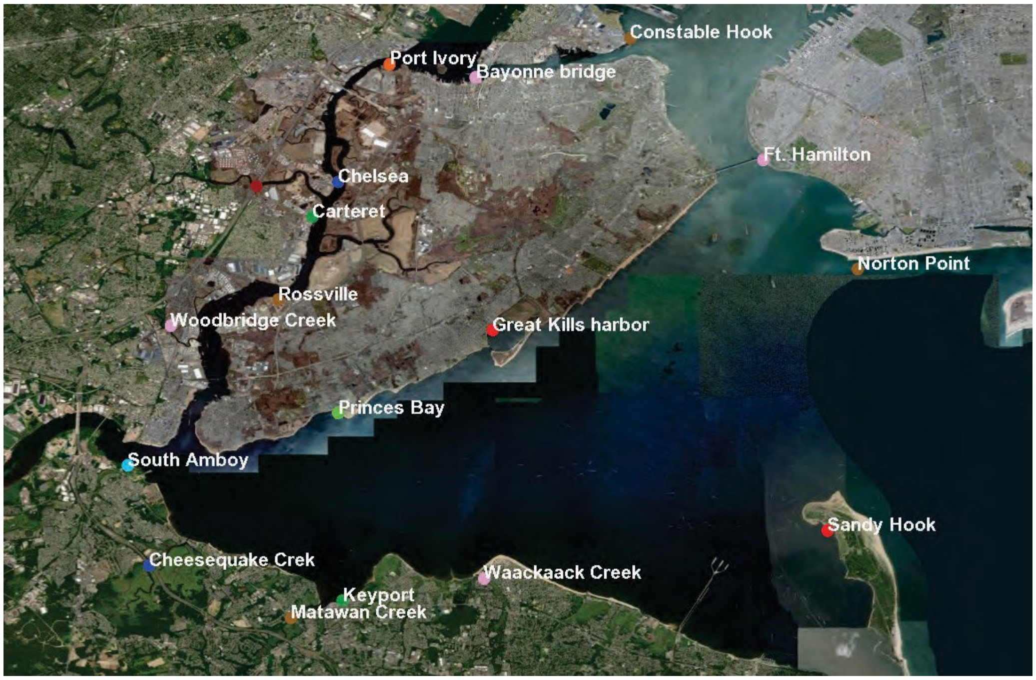


Figure 102. Tidal propagation for the times of high and low waters around Staten Island through Kill van Kull and Arthur Kill for the low-flow tidal harmonic simulation.

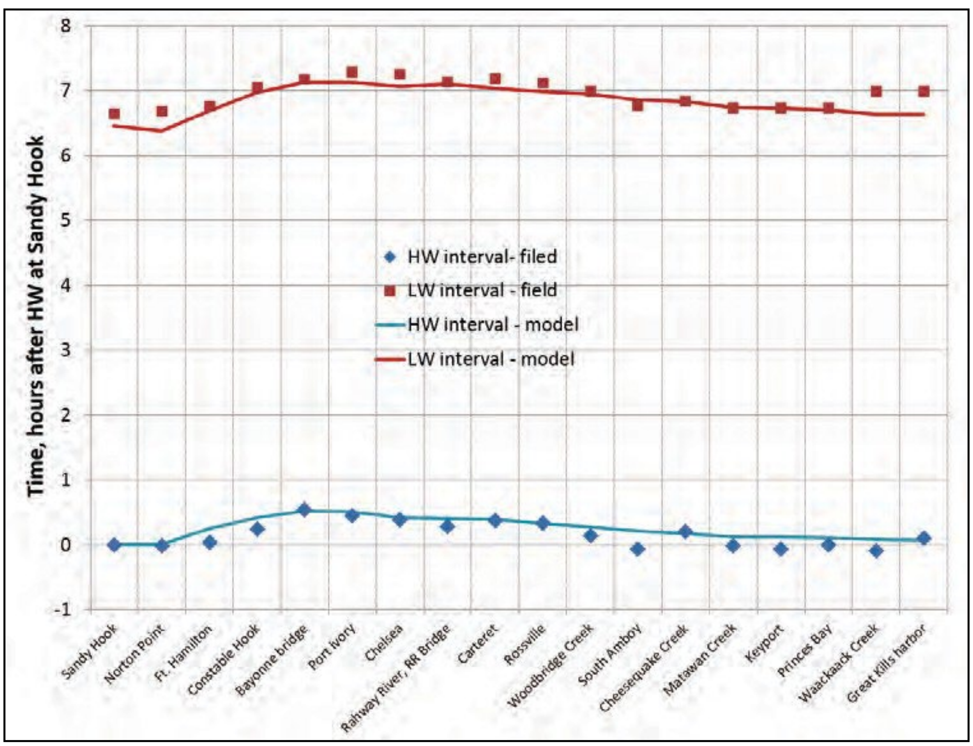
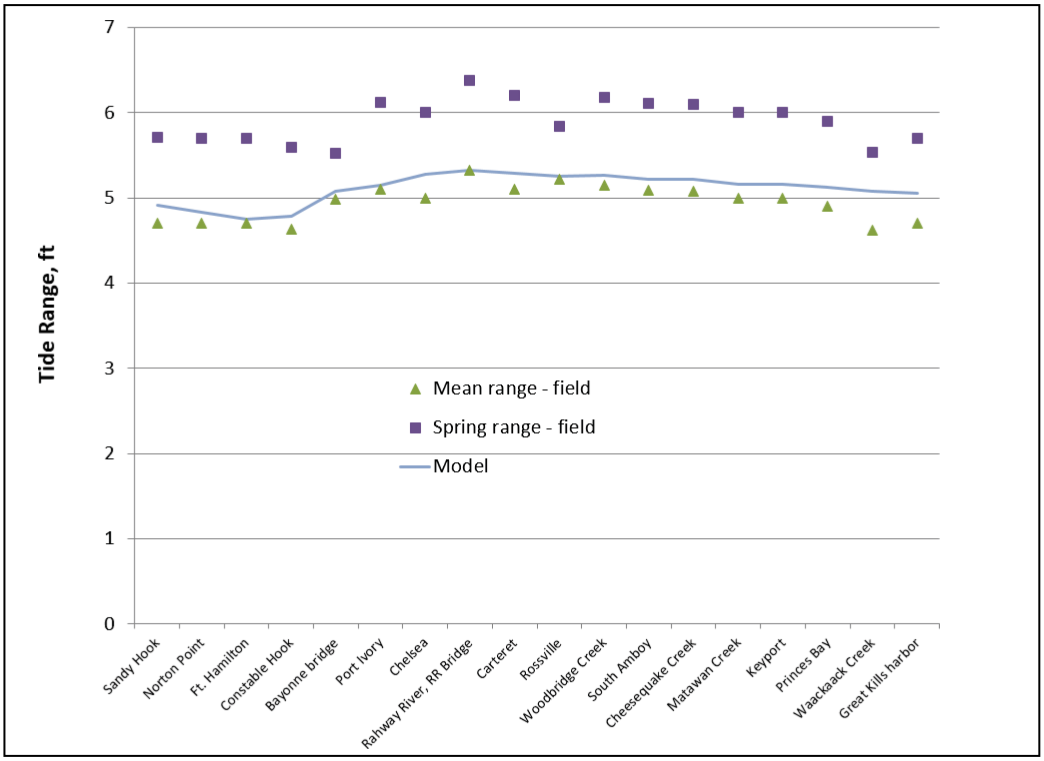


Figure 103. Tidal range propagation around Staten Island through Kill van Kull and Arthur Kill for the low-flow tidal harmonic simulation.



Hackensack River

The profile comparison of the model to the observed NOAA times of high and low waters relative to the time of high water at Sandy Hook through the harbor and up the Hackensack River (locations shown in Figure 104) is presented in Figure 105. The Hackensack River stations are above (to the right on the plot) of Kearny Point. The profile for the tide range up the Hackensack River is presented in Figure 106. The propagation of high and low waters up the Hackensack River is generally in agreement, but the times of high water are slightly early in the Hackensack River itself. Low waters are in very good agreement except for the low water at New Milford, which exhibits a drastic phase lag in the NOAA data. The tide profile comparison between the model and NOAA is good up the Hackensack, again with the exception of New Milford, which has approximately a 20% drop in range compared to Hackensack.

Figure 104. Hackensack River analysis locations.

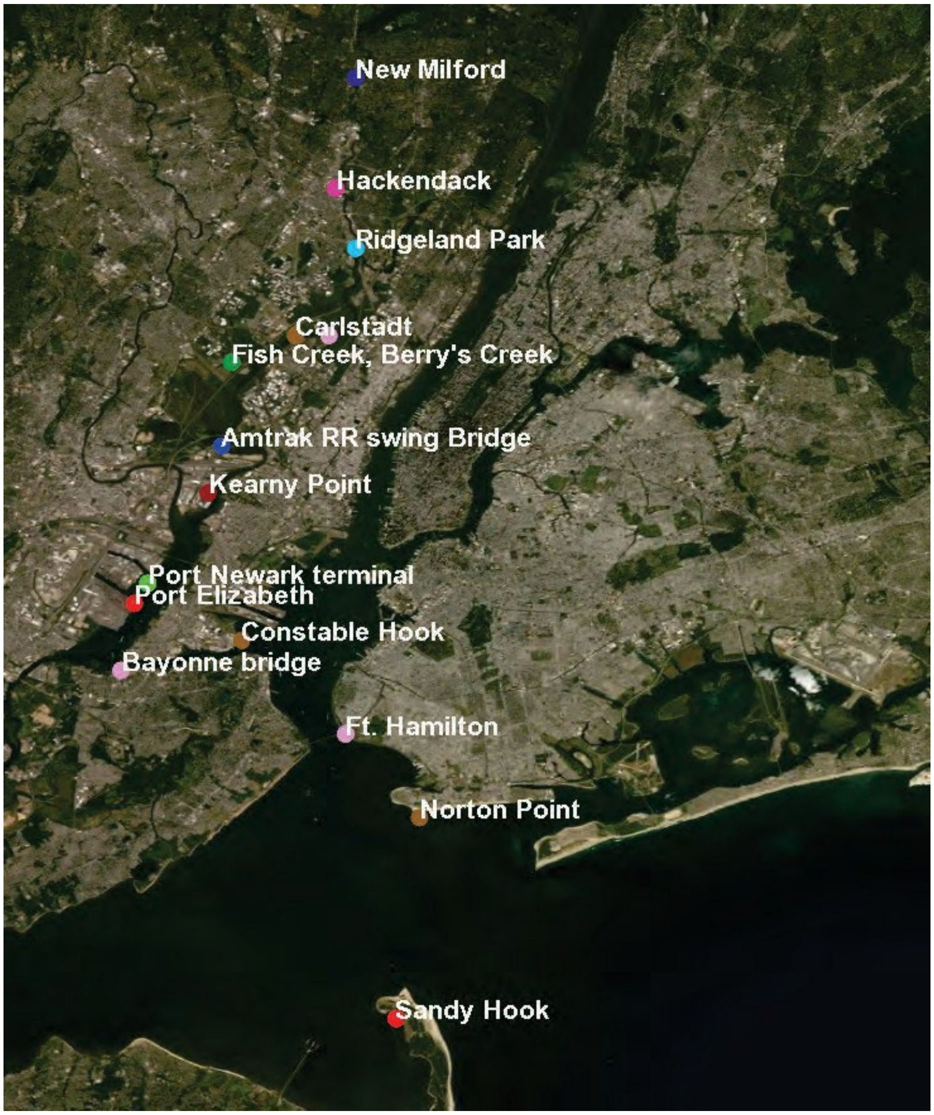


Figure 105. Tidal propagation for the times of high and low waters from Sandy Hook through Kill van Kull and up the Hackensack River for the low-flow tidal harmonic simulation.

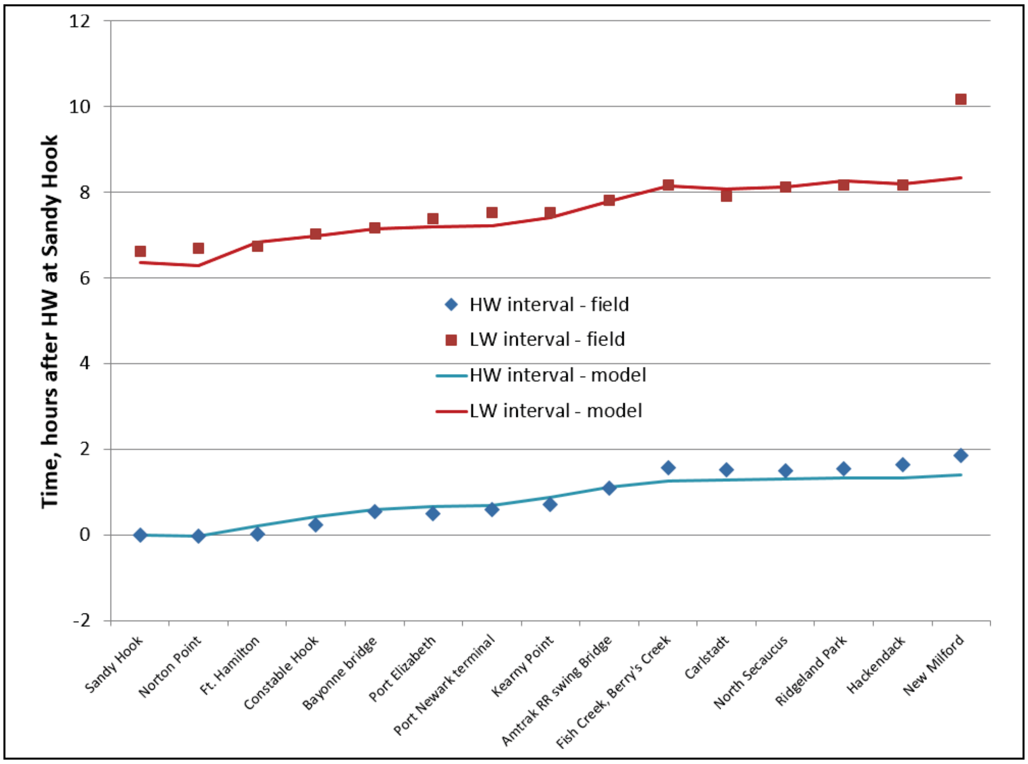
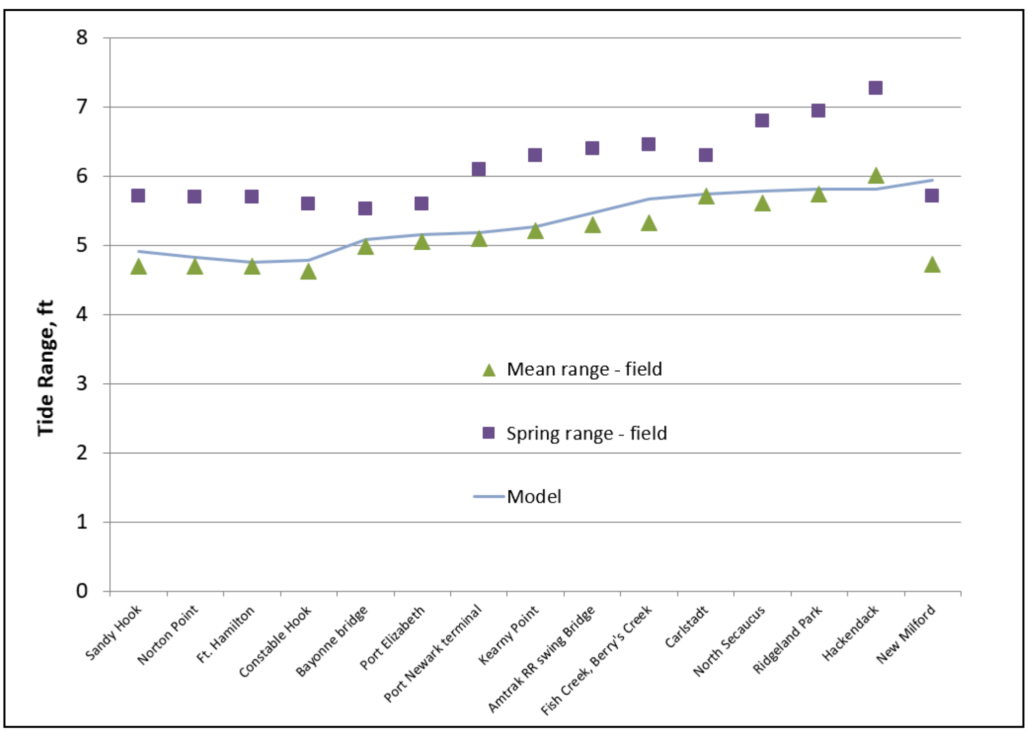


Figure 106. Tide range profile from Sandy Hook through Kill van Kull and up the Hackensack River for the low-flow tidal harmonic simulation.



Passaic River

The profile comparison of the model to the observed NOAA times of high and low waters relative to the time of high water at Sandy Hook through the harbor and up the Passaic River (locations shown in Figure 107) is presented in Figure 108. The Passaic River stations are the last three points in the profile. The profile for the tide range up the Passaic River is presented in Figure 109. The tidal propagation up the Passaic River is in good agreement both in tidal phases and in tide range.

Figure 107. Passaic River analysis locations.

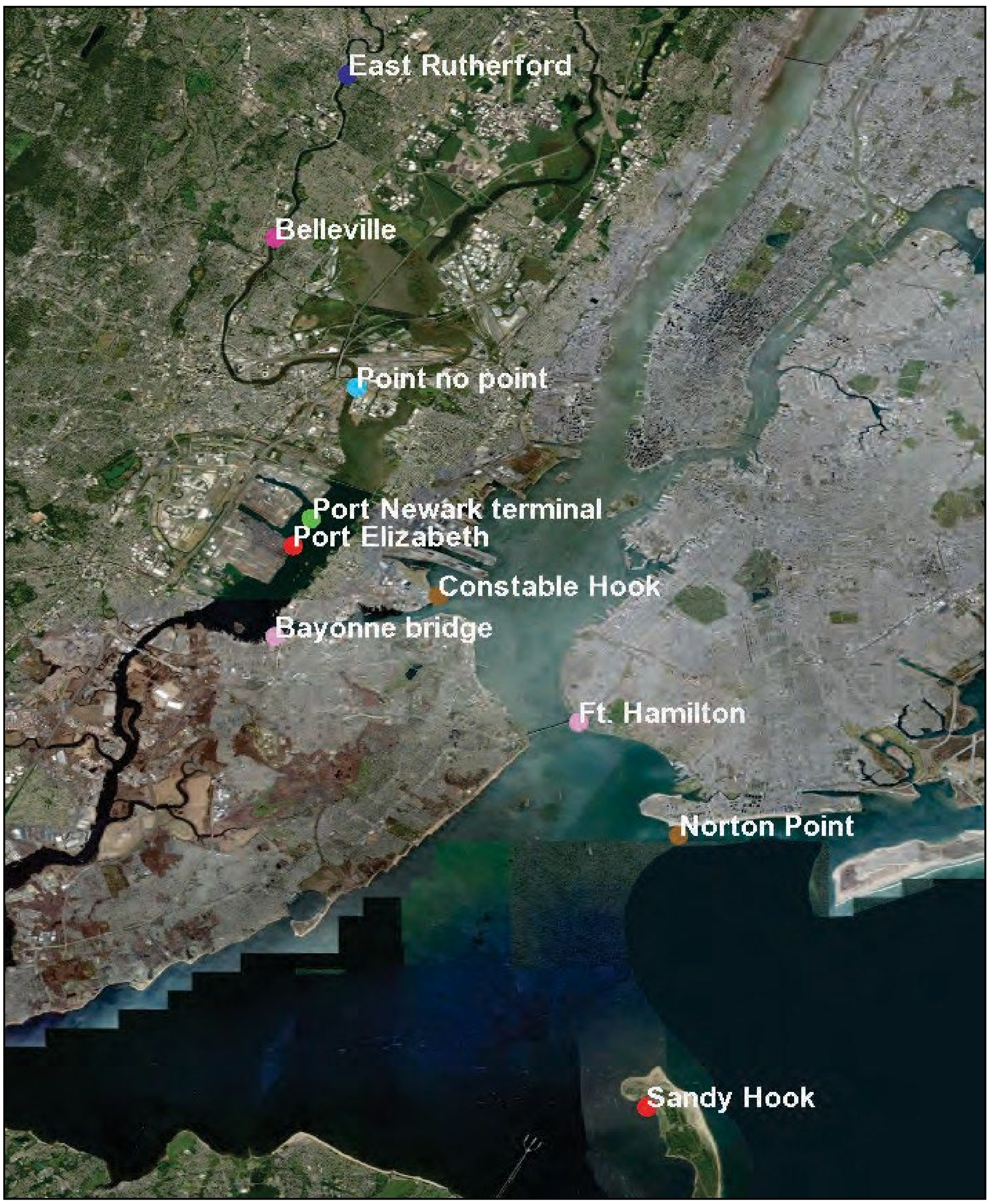


Figure 108. Tidal propagation for the times of high and low waters from Sandy Hook through Kill van Kull and up the Passaic River for the low-flow tidal harmonic simulation.

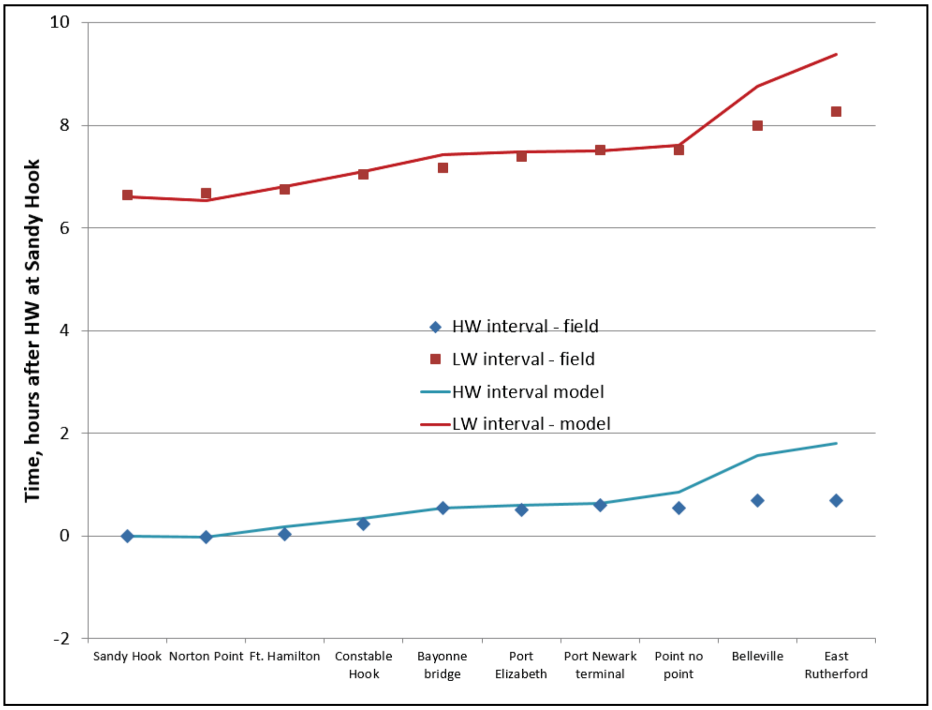
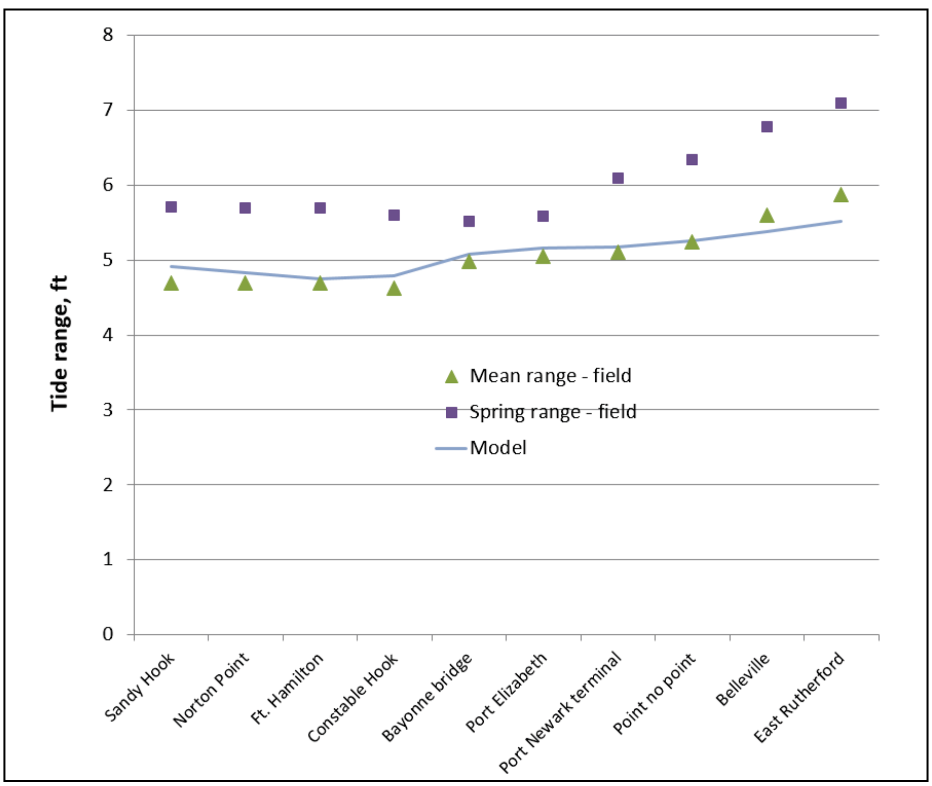


Figure 109. Tide range profile from Sandy Hook through Kill van Kull and up the Passaic River for the low-flow tidal harmonic simulation.



Raritan River

The profile comparison of the model to the observed NOAA times of high and low waters relative to the time of high water at Sandy Hook through the harbor and up the Raritan River (locations shown in Figure 110) is presented in Figure 111. The Raritan River stations are the last four points in the profile. The profile for the tide range up the Raritan River is presented in Figure 112. The tidal propagation up the Raritan River is in good agreement both in tidal phases and in tide range with the exception of the extreme upstream at New Brunswick, where the model tides slow down and drop in tide range.

Figure 110. Raritan Bay/River analysis locations.

Figure 111. Tidal propagation for the times of high and low waters from Sandy Hook through Raritan Bay and up the Raritan River for the low-flow tidal harmonic simulation.

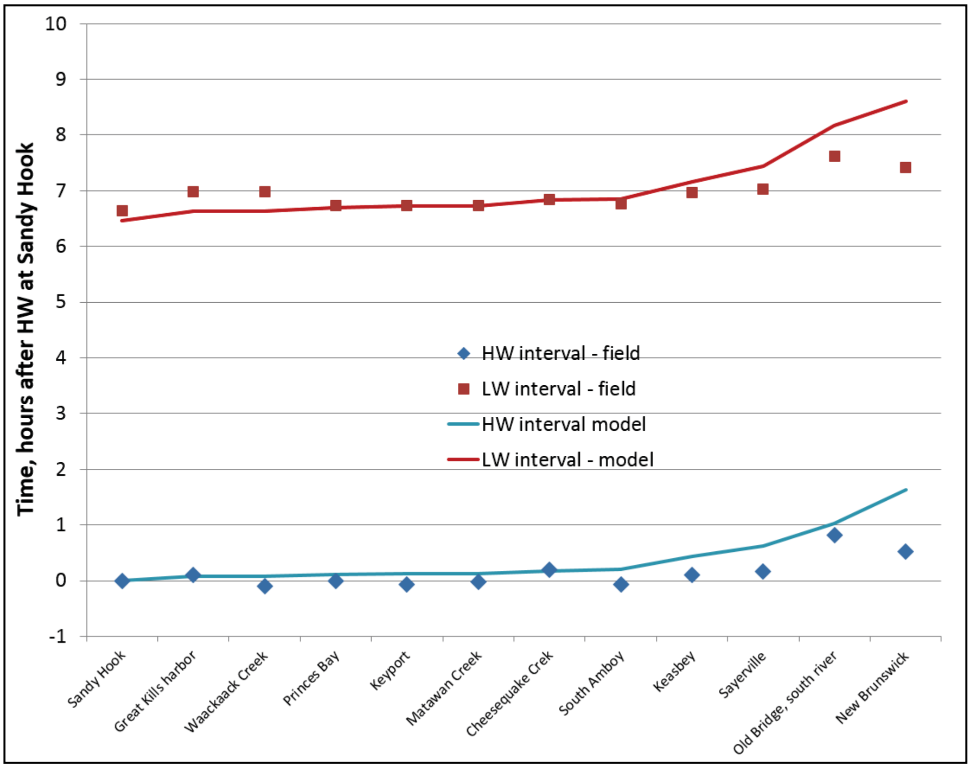
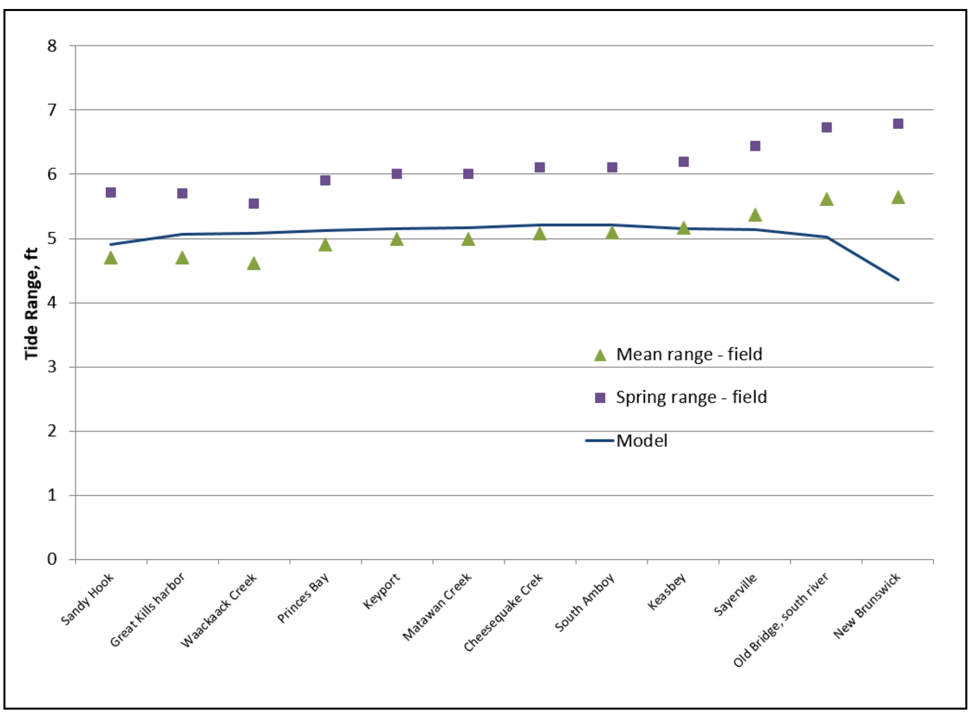


Figure 112. Tide range profile from Sandy Hook through Raritan Bay and up the Raritan River for the low-flow tidal harmonic simulation.



Conclusion for tidal harmonic verification

The general characteristics of the tidal propagation in the 2D version of AdH adequately replicate the NOAA data to warrant proceeding to the 3D model development.

Three-dimensional (3D) hydrodynamic comparisons

The 3D hydrodynamic comparisons consisted primarily of comparing the NOAA-observed water levels to the model results. As opposed to the previous section with 2D harmonic comparisons, this section details comparisons to observed data impacted by winds, pressure fields, inflows, and tidal conditions. All of these forcings were previously discussed in Chapter 4 and were included in the boundary conditions for these simulations.

Quantitative comparisons

NOAA maintains several water level gauges within the model domain of this study. The gauges are shown in Figure 113. Time-series comparison plots (1 May to 1 June) and box plots for the entire 1995 year (black line is equality line) are provided in Figure 114 to Figure 123. Error metrics were computed for all five simulated years and are provided in Table 11. The error metric values reported in Table 11 are similar in magnitude to those reported in HydroQual (2008) and Blumberg et al. (1999).

Figure 113. Hydrodynamic validation locations.

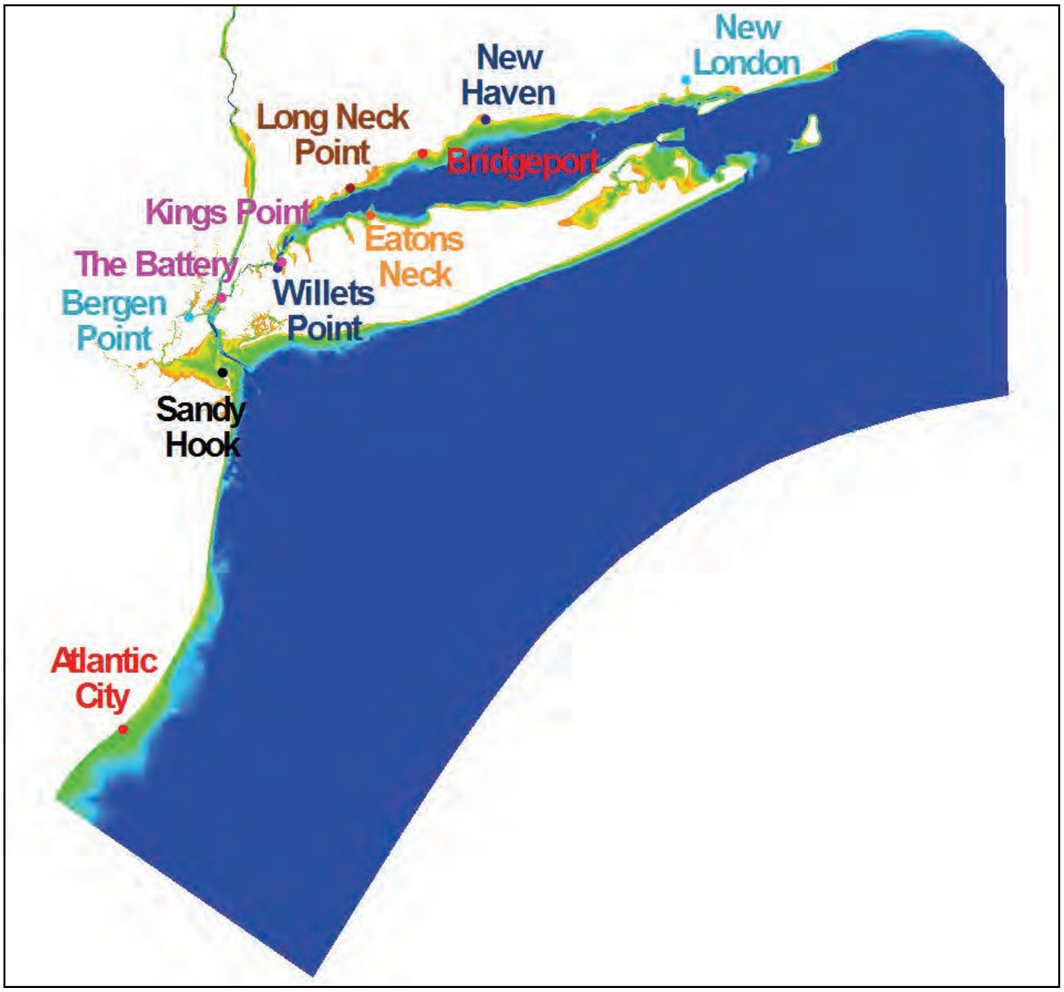
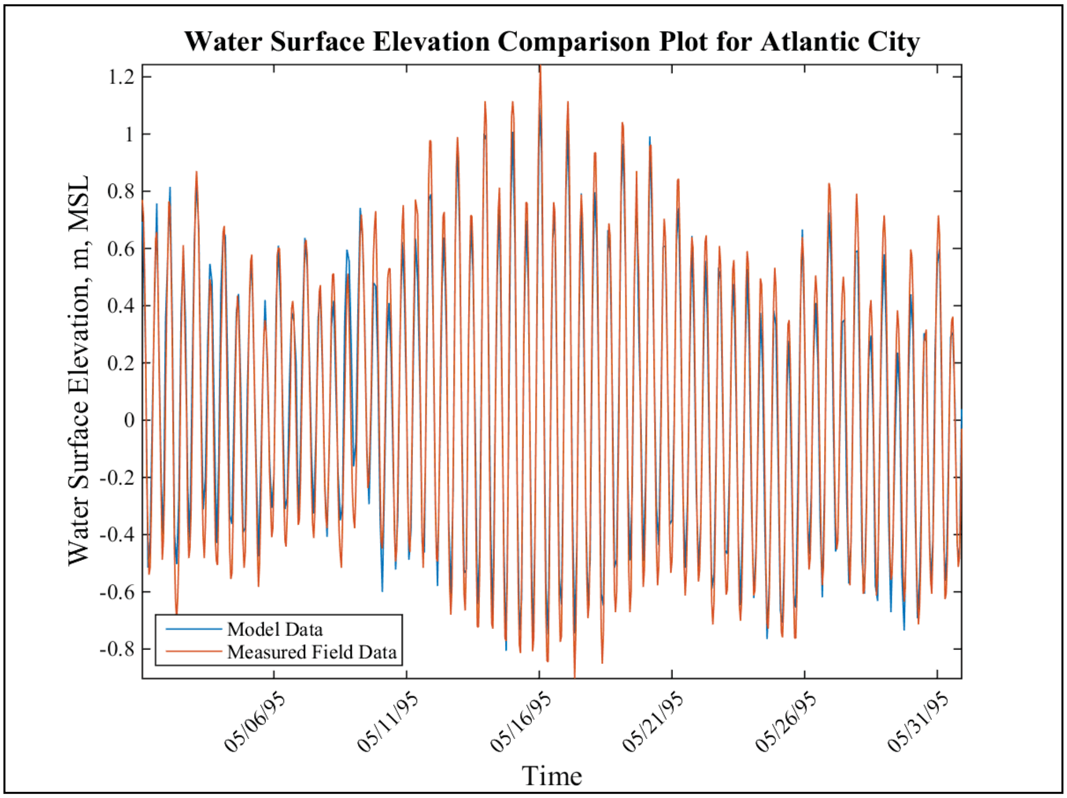


Figure 114. Water surface elevation comparison plot for Atlantic City (1995).



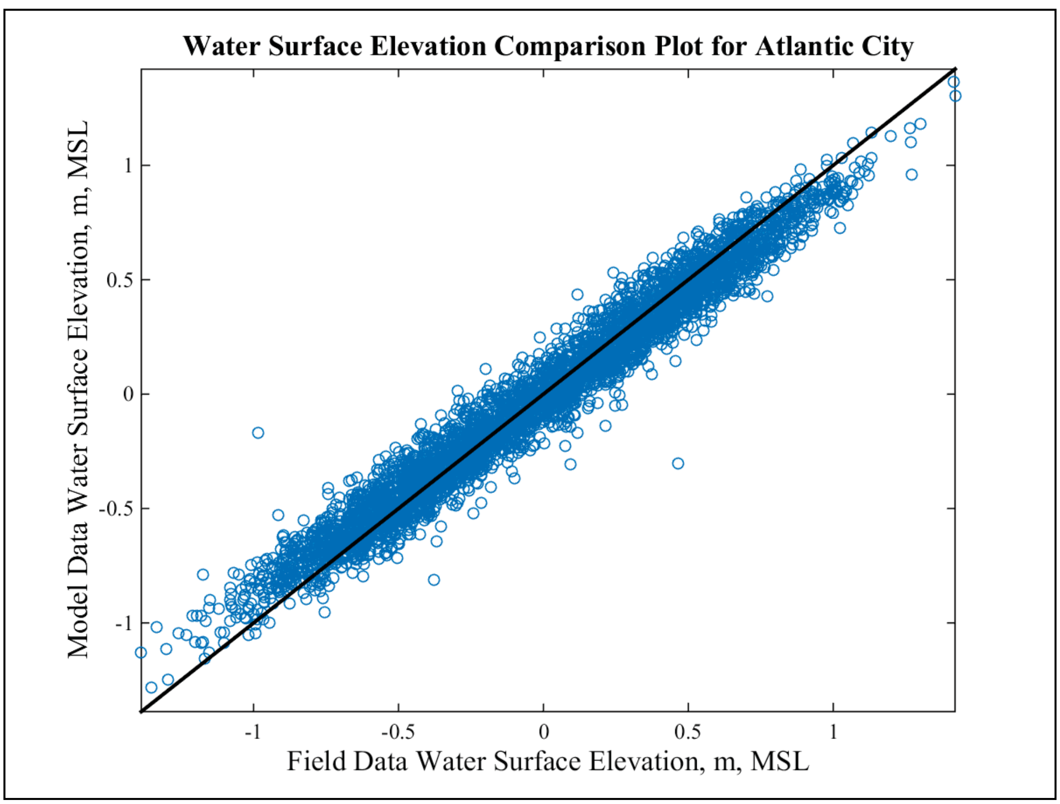
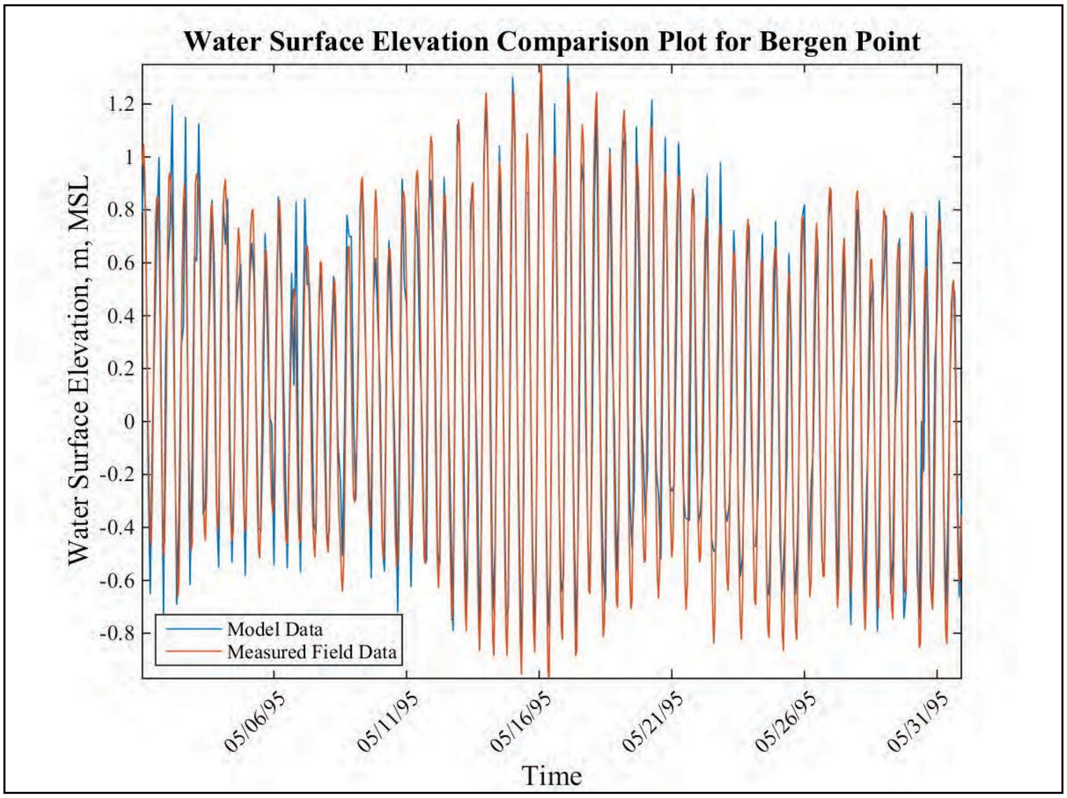


Figure 115. Water surface elevation comparison plot for Bergen Point (1995).



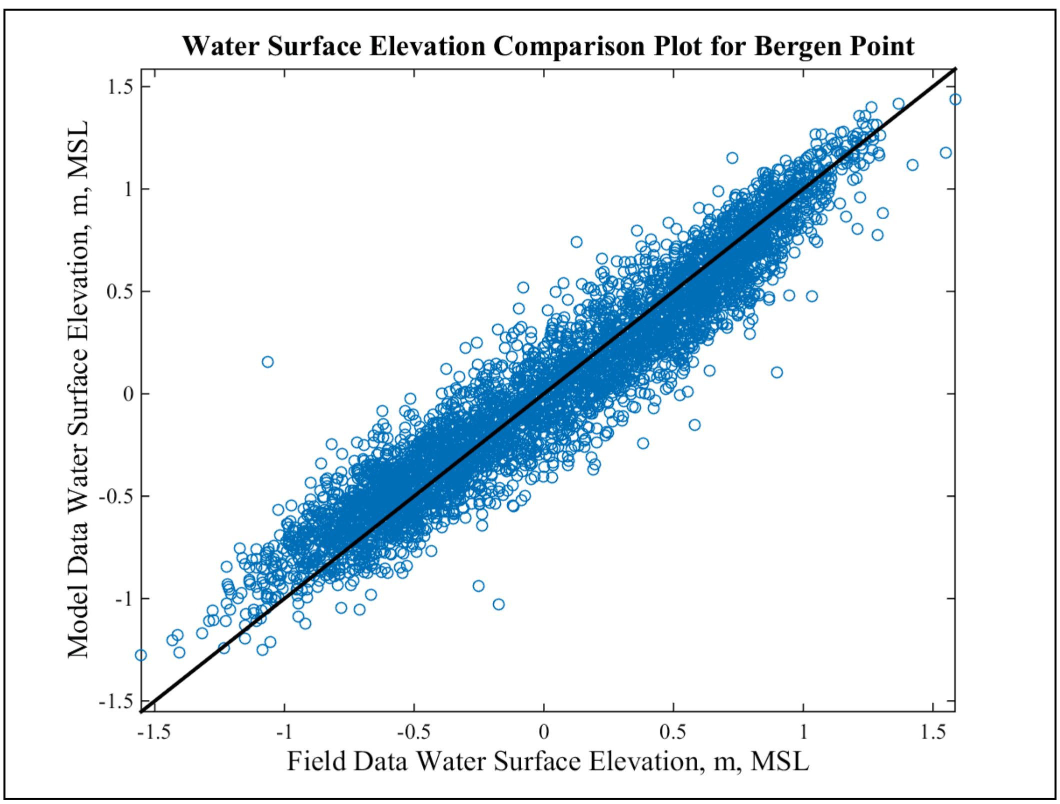
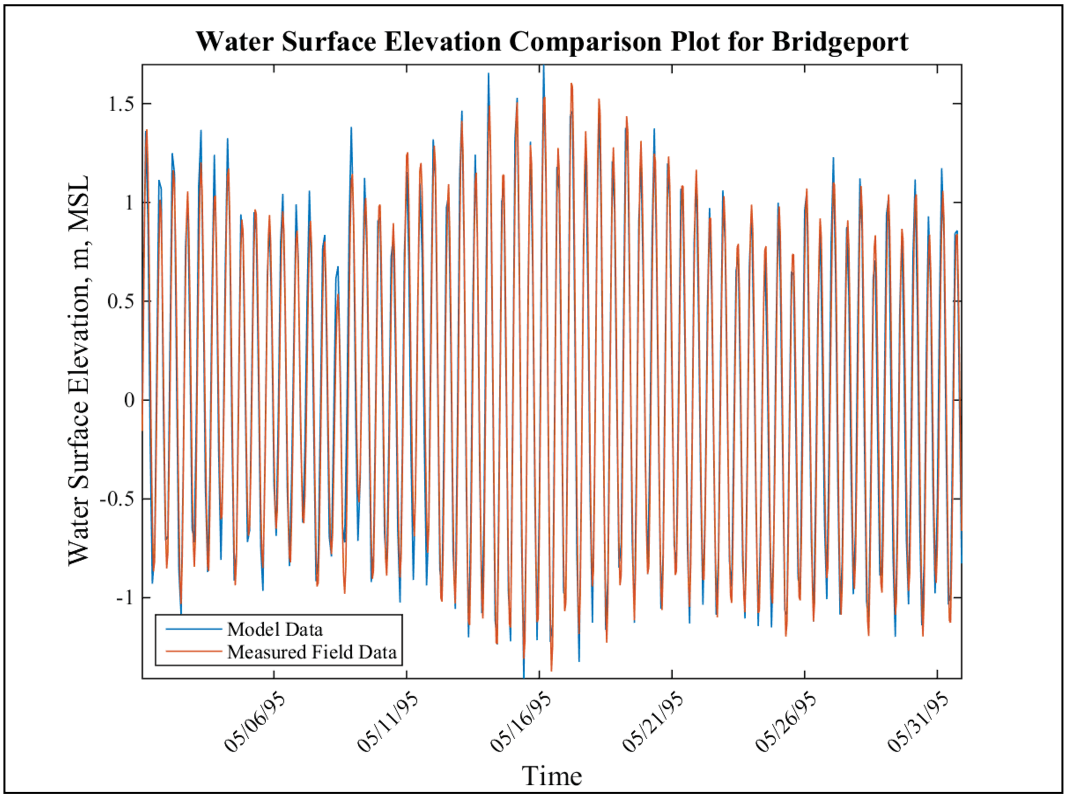


Figure 116. Water surface elevation comparison plot for Bridgeport (1995).



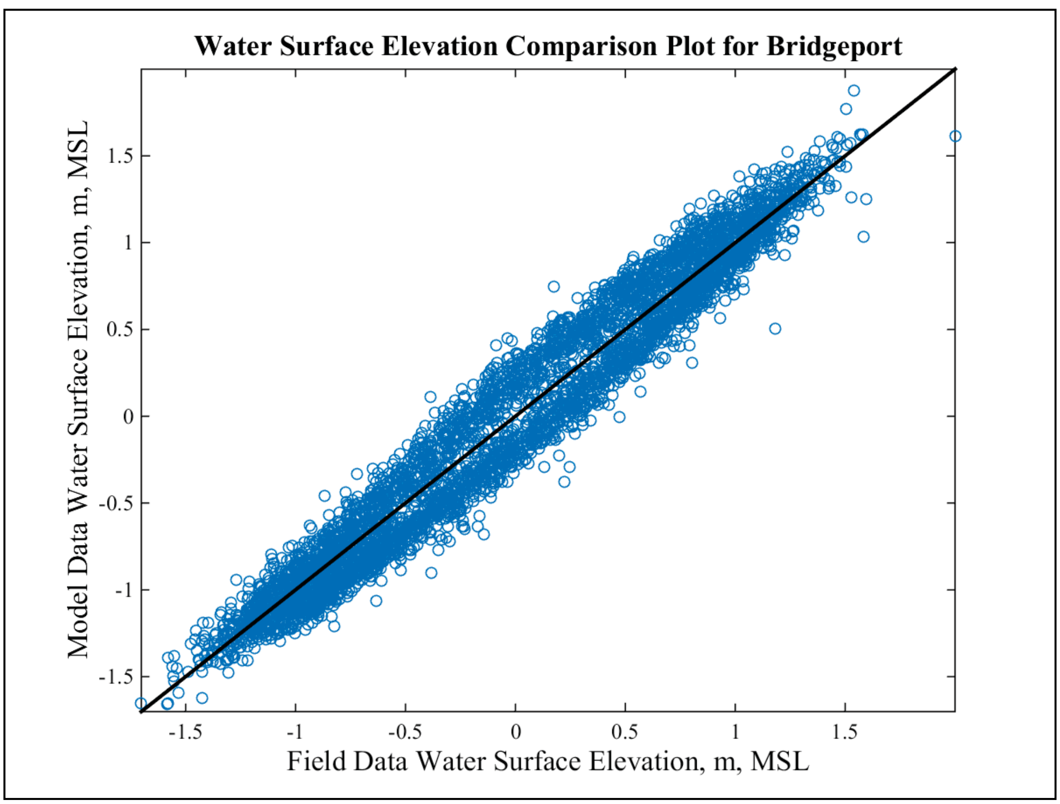
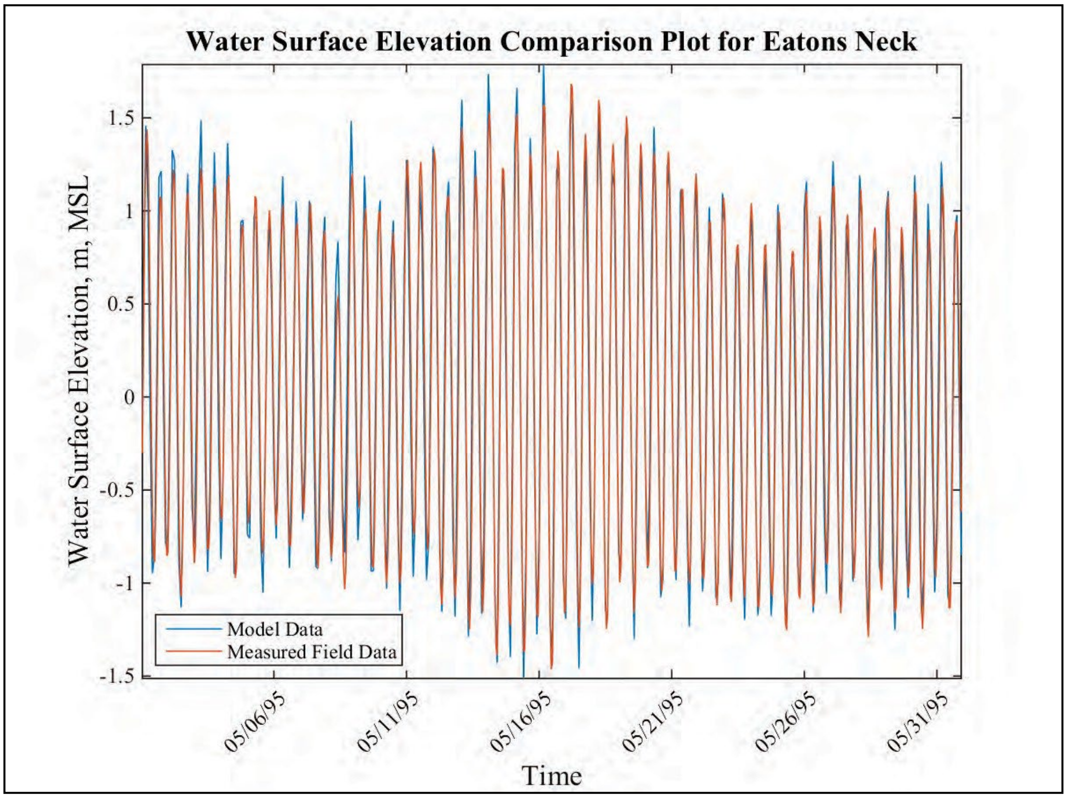


Figure 117. Water surface elevation comparison plot for Eatons Neck (1995).



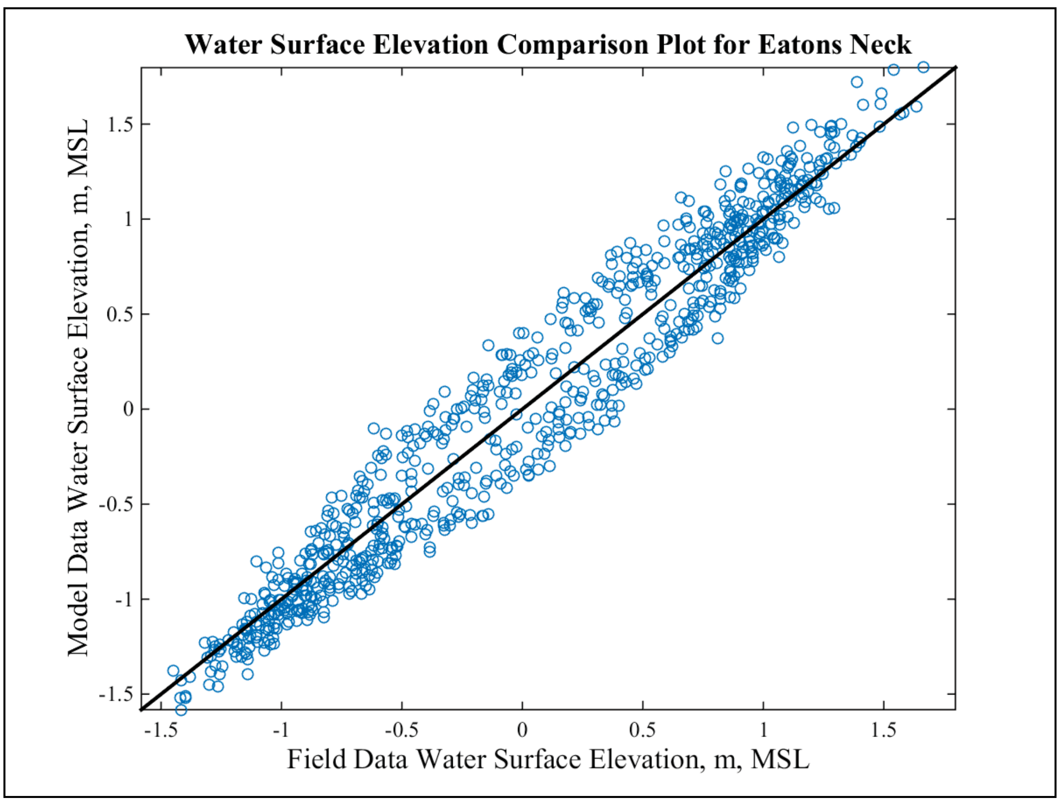
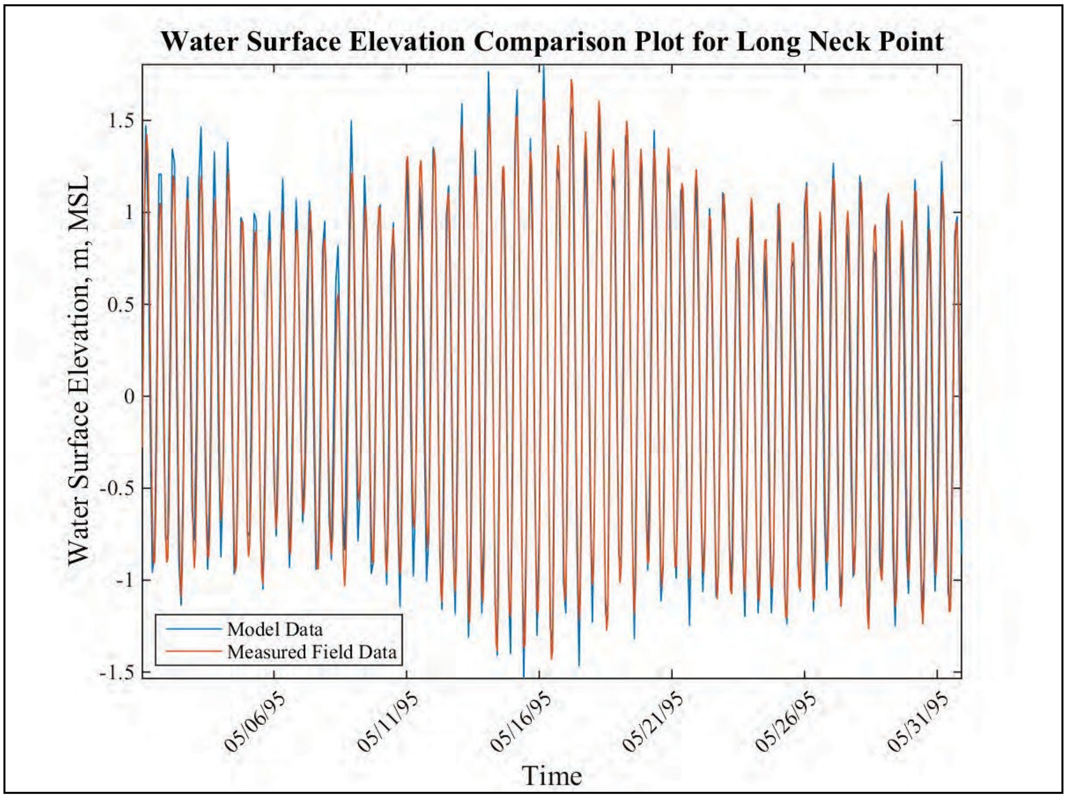


Figure 118. Water surface elevation comparison plot for Long Neck Point (1995).



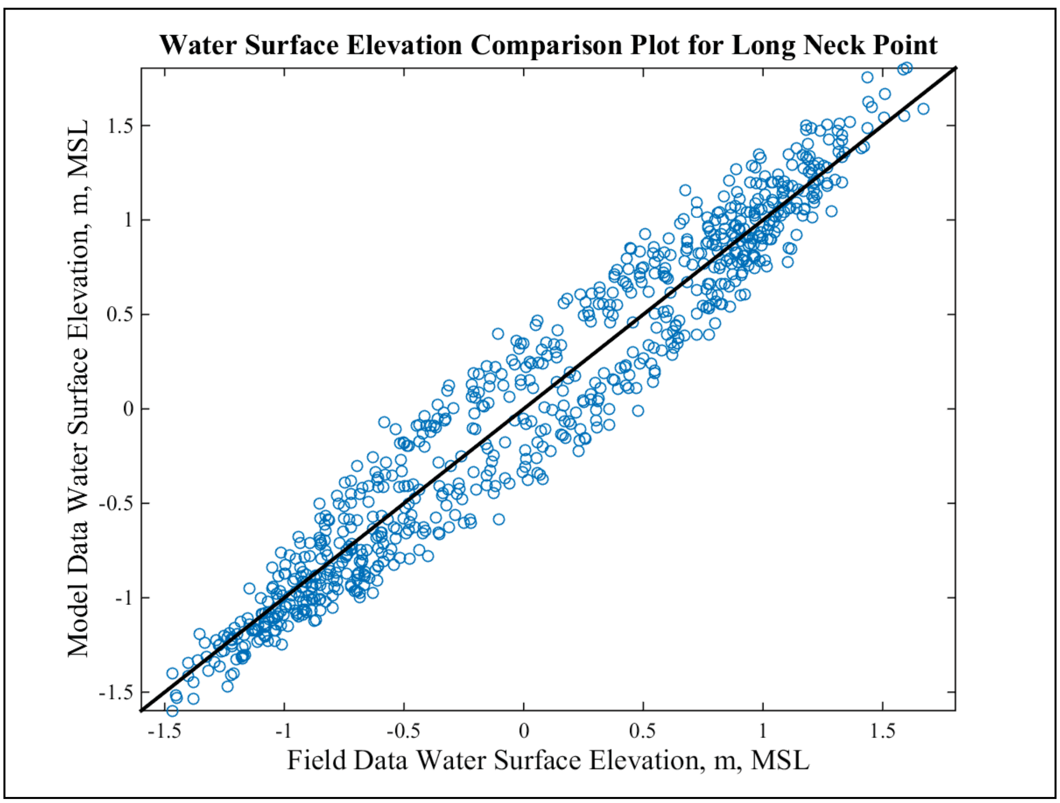
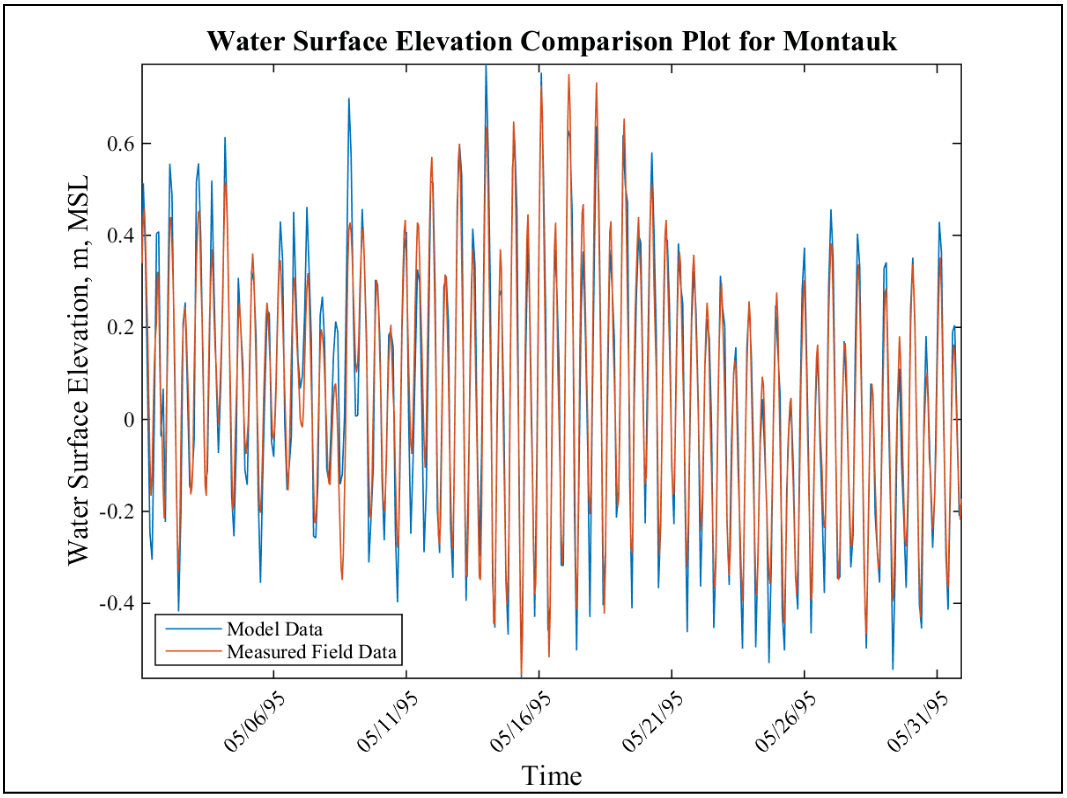


Figure 119. Water surface elevation comparison plot for Montauk (1995).



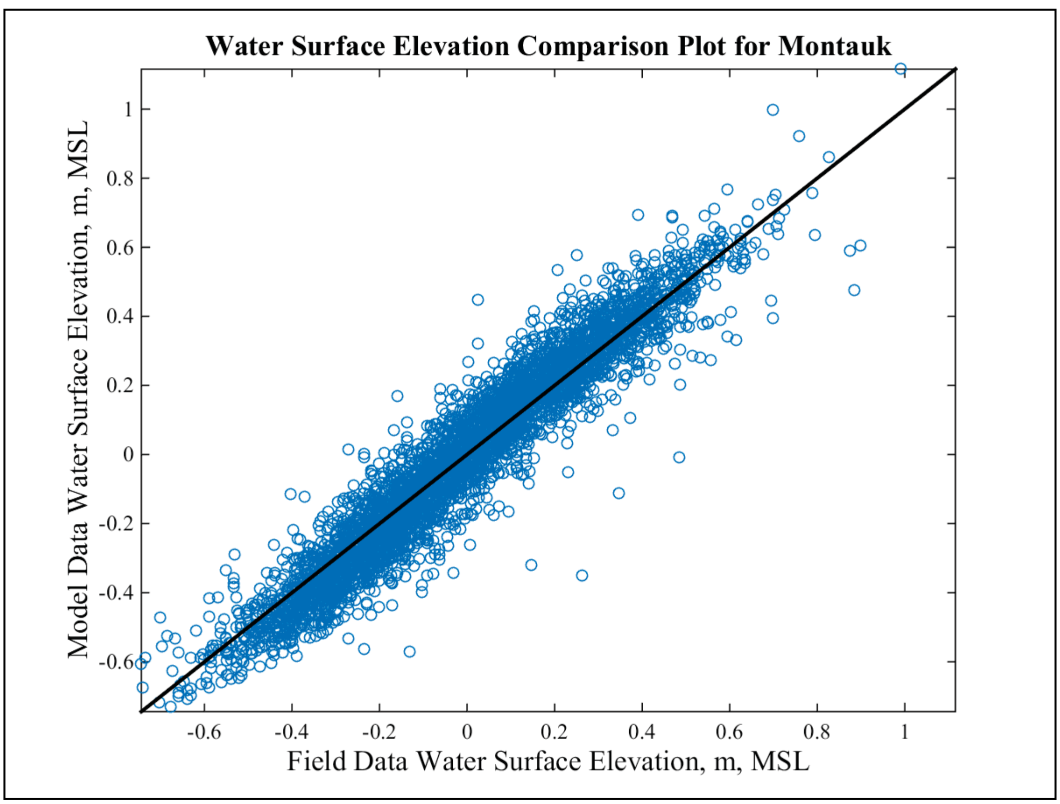
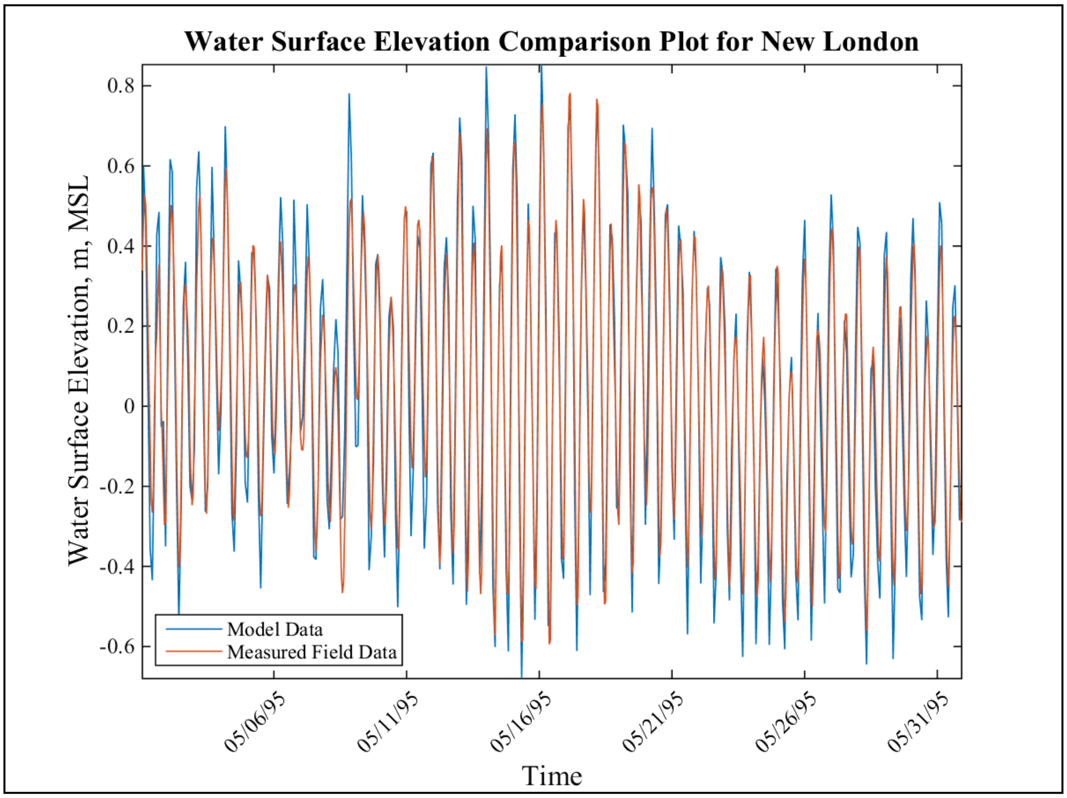


Figure 120. Water surface elevation comparison plot for New London (1995).



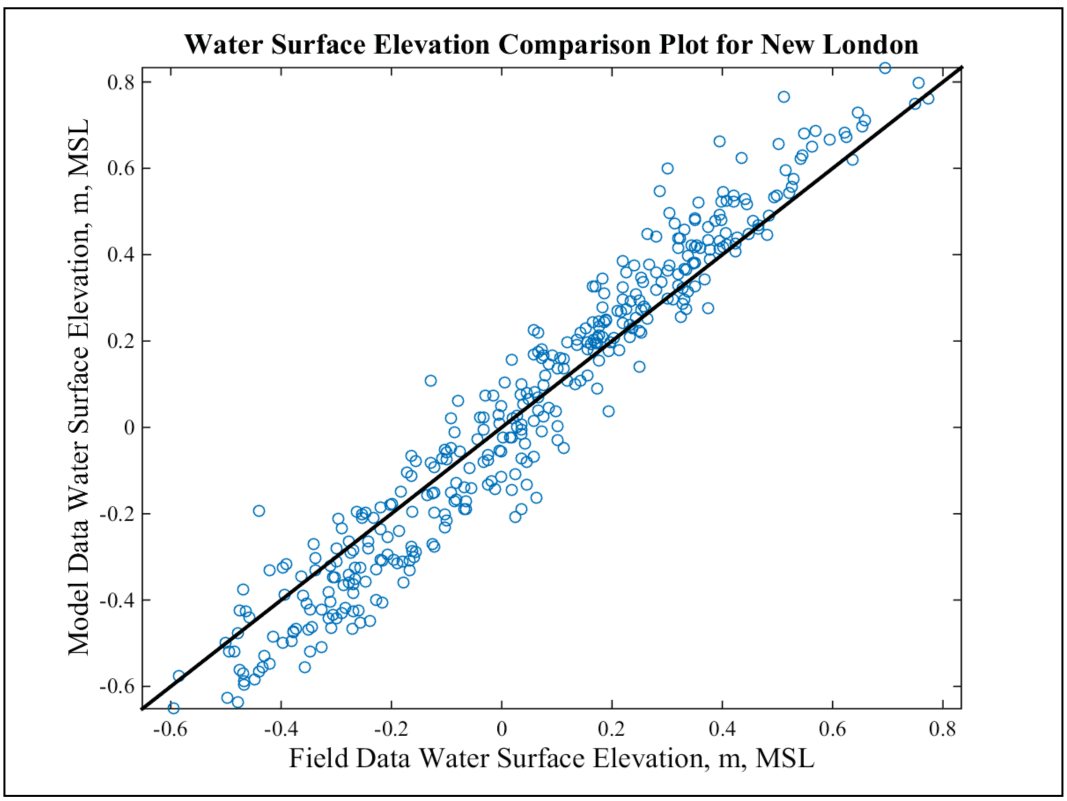
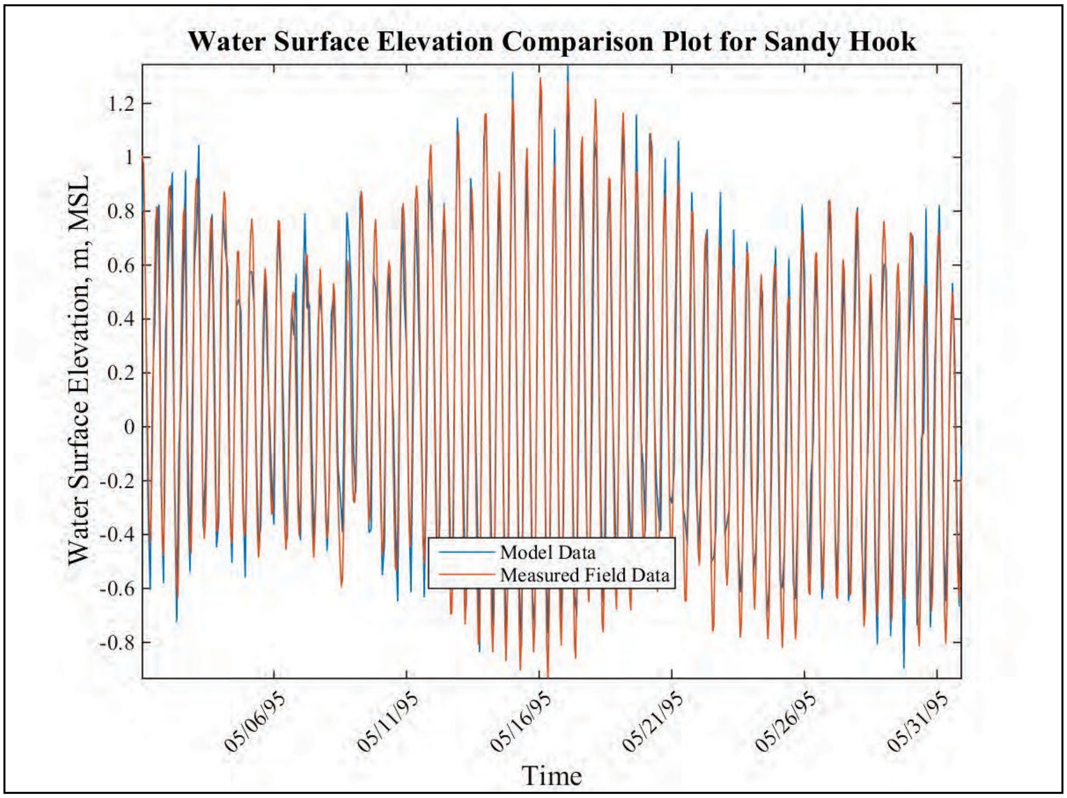


Figure 121. Water surface elevation comparison plot for Sandy Hook (1995).



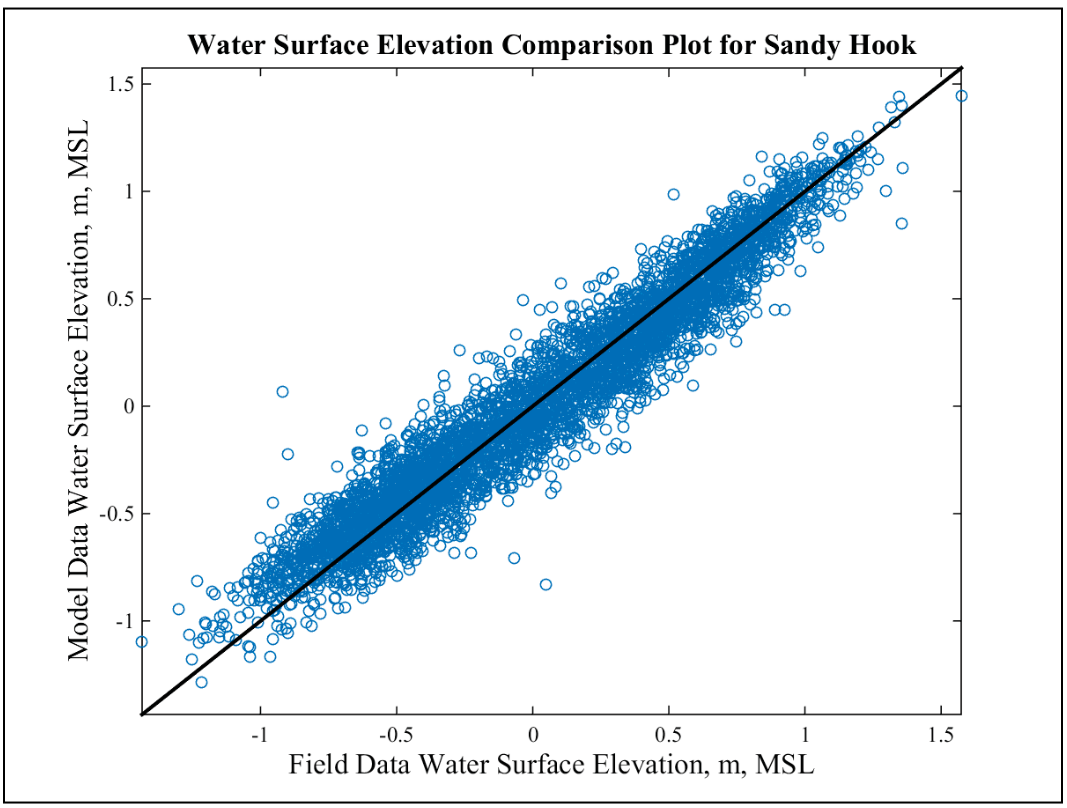
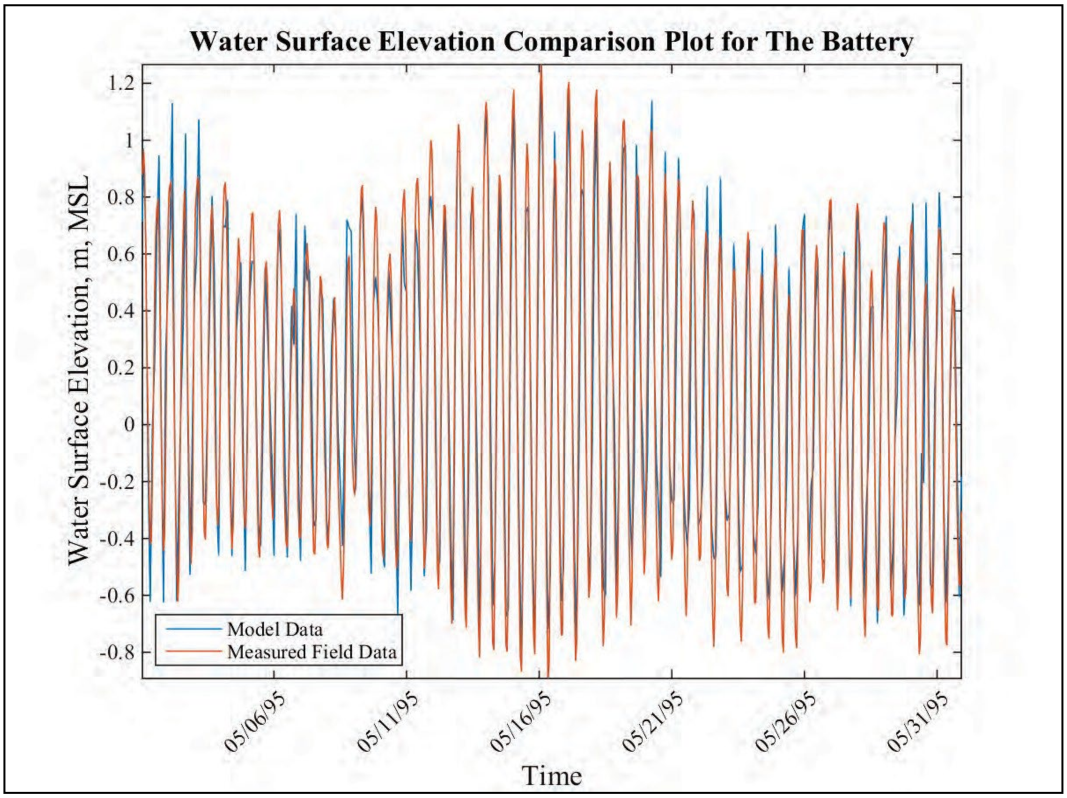


Figure 122. Water surface elevation comparison plot for The Battery (1995).



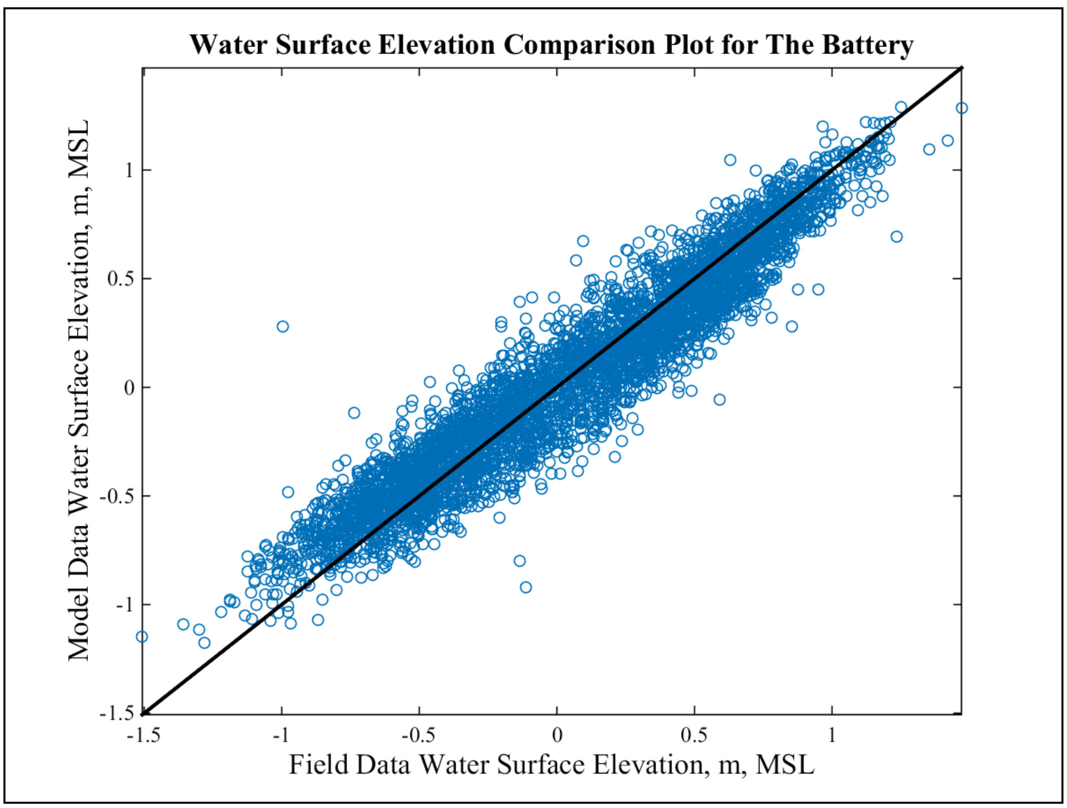
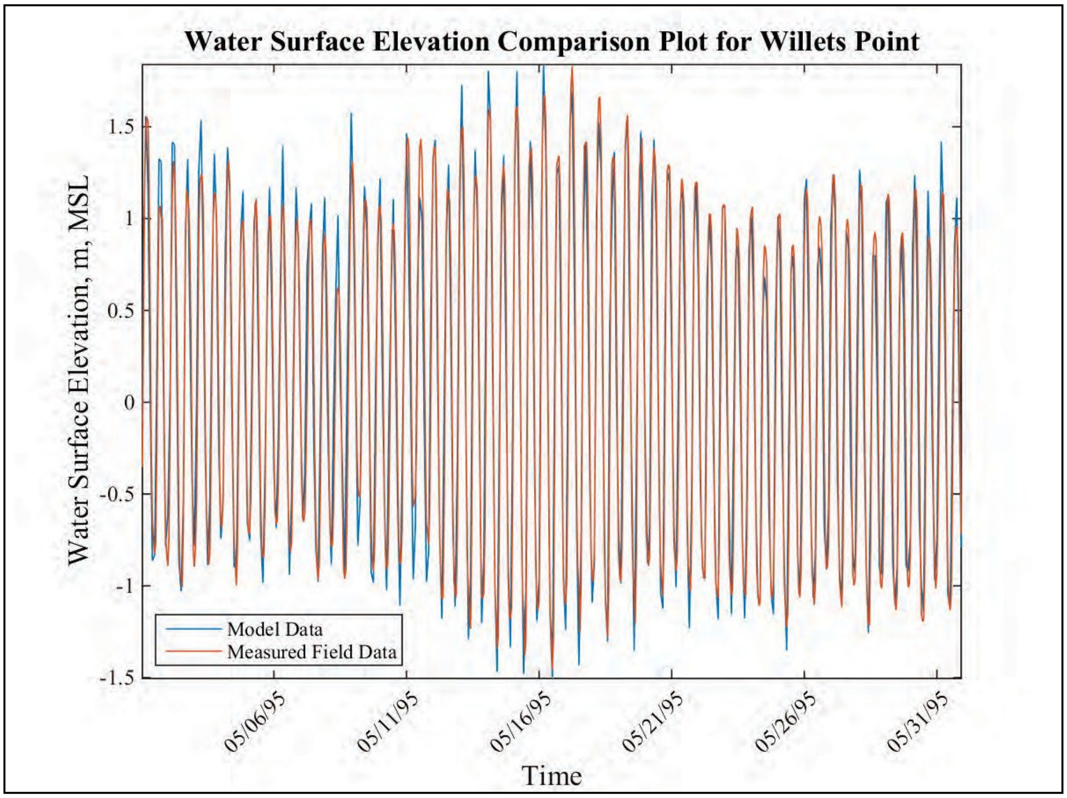


Figure 123. Water surface elevation comparison plot for Willets Point.



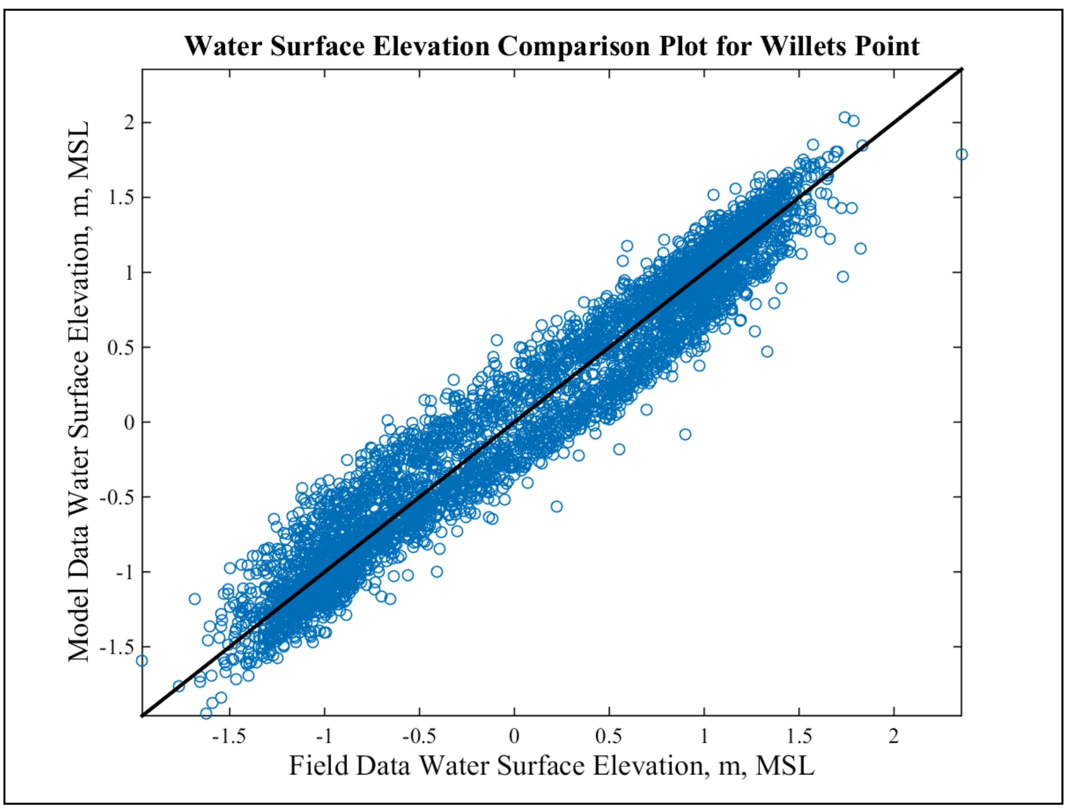


Table 11. Error metrics for water level comparisons.

Comparisons to NOAA observed water levels (1985, 1995, and 1996 were compared to the without-project and 2011 and 2012 were compared to the with-project configuration). N/A indicates data were not available for that particular year and location.															
	RMSE (m)					Correlation Coefficient					Nash-Sutcliffe Coefficient				
NOAA Gauge	1985	1995	1996	2011	2012	1985	1995	1996	2011	2012	1985	1995	1996	2011	2012
Atlantic City (Station 8534720)	0.11	0.10	0.09	0.08	0.08	0.98	0.98	0.98	0.99	0.99	0.95	0.96	0.97	0.97	0.97
Sandy Hook (Station 8531680)	0.16	0.15	0.16	0.14	0.14	0.96	0.96	0.96	0.96	0.97	0.91	0.93	0.92	0.93	0.94
Bergen Point (Station 8519483)	0.18	0.17	0.17	0.17	0.16	0.95	0.96	0.96	0.96	0.96	0.90	0.92	0.92	0.91	0.92
The Battery (Station 8518750)	0.17	0.16	0.16	0.16	0.15	0.95	0.96	0.96	0.96	0.96	0.90	0.91	0.91	0.91	0.92
Willets Point (Station 8516990)	0.22	0.22	N/A	N/A	N/A	0.97	0.97	N/A	N/A	N/A	0.93	0.94	N/A	N/A	N/A
Eatons Neck (Station 8515786)	N/A	0.20	N/A	N/A	N/A	N/A	0.97	N/A	N/A	N/A	N/A	0.94	N/A	N/A	N/A
Long Neck Point (Station 8468799)	N/A	0.20	N/A	N/A	N/A	N/A	0.97	N/A	N/A	N/A	N/A	0.94	N/A	N/A	N/A
Bridgeport (Station 8467150)	0.17	0.17	0.18	0.16	0.16	0.97	0.98	0.97	0.98	0.98	0.94	0.95	0.94	0.95	0.95
Montauk (Station 8510560)	0.08	0.08	0.09	0.08	0.08	0.95	0.96	0.96	0.96	0.96	0.90	0.90	0.90	0.90	0.91
New London (Station 8461490)	0.11	0.09	N/A	0.09	0.09	0.95	0.97	N/A	0.97	0.97	0.87	0.92	N/A	0.91	0.92
Kings Point (Station 8516945)	N/A	N/A	N/A	0.21	0.22	N/A	N/A	N/A	0.97	0.97	N/A	N/A	N/A	0.94	0.94
New Haven (Station 8465705)	N/A	N/A	N/A	0.15	0.16	N/A	N/A	N/A	0.98	0.98	N/A	N/A	N/A	0.95	0.95

The water level comparisons show a phase difference between the model results and the observations in the Long Island Sound. This is consistent with the 2D analysis discussed in the preceding section and as such was not created in the conversion of the model from two to three dimensions.

Qualitative comparisons

Qualitative comparisons of the 3D hydrodynamics consisted of comparing to velocity ranges reported in the literature in addition to net annual discharges for the Kill van Kull channel. Since either the raw data were unavailable and/or the data were for time periods not simulated, these are qualitative comparisons that should be viewed simply as a *general* agreement between observations in the field and model results. Exact comparisons should not be expected.

Velocity point comparisons

While velocity observations were not readily available to compare directly to the simulated time periods for quantitative comparisons, some velocity data are available in the literature for qualitative comparisons. Blumberg et al. (1999) reports velocity ranges for a variety of locations. Blumberg et al. (1999) does not provide the coordinate locations of these observations but does include a map of their locations. From Figure 5 in Blumberg et al. (1999), the approximate locations of the observations were determined, and the velocities in Table 12 compare the observations and the model results. Pecchioli et al. (2006) reported velocities for the Kill van Kull, Arthur Kill, and Newark Bay. Again, the exact locations are unknown, but the approximate locations are determined from Figure 2 in Pecchioli et al. (2006). The locations utilized for the model comparisons are shown in Figure 124.

Velocity point observations are impacted by several factors, and as such are difficult to replicate in a numerical model. Uncertainties in the forcing conditions, model parameters, and bathymetry can easily impact the velocities in the model to improve/worsen the comparisons. Given these uncertainties, these comparisons are only to provide an indication if the model is in general agreement with the approximate velocities reported in the literature.

Figure 124. Velocity comparison locations.

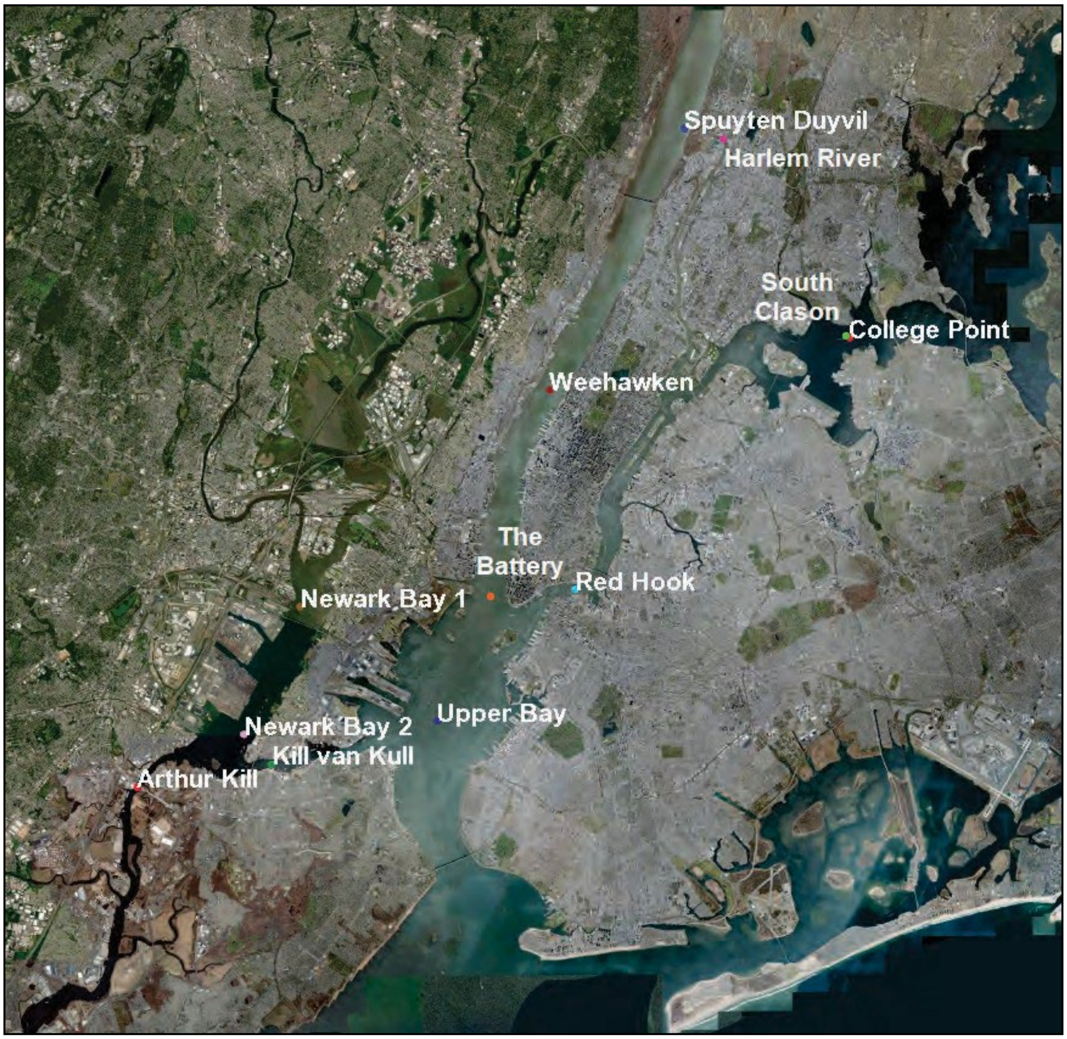


Table 12. Velocity comparisons in m/s. Parenthesis indicates with-project values.

Locations	Data Range	1985	1995	1996	2011	2012
College Point (Near Surface)[1]	1.79-1.87	1.59 (1.60)	1.63 (1.64)	1.61 (1.62)	1.66 (1.67)	1.76 (1.77)
College Point (Middepth) [1]	1.577-1.931	1.38 (1.39)	1.40 (1.41)	1.41 (1.42)	1.44 (1.45)	1.52 (1.52)
College Point (Near Bed) [1]	1.317-1.485	1.18 (1.20)	1.20 (1.19)	1.24 (1.26)	1.24 (1.24)	1.15 (1.20)
South Clason (Near Surface) [1]	1.437	1.53 (1.54)	1.53 (1.53)	1.59 (1.60)	1.62 (1.64)	1.60 (1.61)
South Clason (Middepth) [1]	1.723	1.24 (1.25)	1.25 (1.25)	1.27 (1.28)	1.28 (1.29)	1.26 (1.27)

Locations	Data Range	1985	1995	1996	2011	2012
South Clason (Near Bed) [1]	1.524	1.03 (1.07)	1.01 (1.02)	1.12 (1.10)	1.18 (1.21)	1.25 (1.15)
Red Hook (Near Surface) [1]	3.739	2.85 (2.86)	2.89 (2.90)	2.98 (2.95)	3.01 (3.02)	2.99 (3.00)
Red Hook (Middepth) [1]	3.363	2.55 (2.55)	2.57 (2.58)	2.66 (2.66)	2.72 (2.72)	2.69 (2.70)
Red Hook (Near Bed) [1]	3.035	1.89 (1.88)	1.85 (1.84)	1.97 (2.03)	1.94 (1.96)	1.85 (1.90)
Harlem River (Near Surface) [1]	2.03	1.63 (1.63)	1.50 (1.53)	1.62 (1.60)	1.59 (1.59)	1.82 (1.82)
Harlem River (Middepth) [1]	1.97	1.66 (1.67)	1.50 (1.51)	1.60 (1.60)	1.61 (1.62)	1.74 (1.74)
Harlem River (Near Bed) [1]	1.761	1.28 (1.29)	1.25 (1.26)	1.27 (1.28)	1.35 (1.36)	1.29 (1.30)
Upper Bay (Near Bed) [1]	1.169	0.77 (0.71)	0.73 (0.69)	0.76 (0.69)	0.76 (0.69)	0.77 (0.77)
The Battery (Near Bed) [1]	0.953	0.81 (0.81)	0.78 (0.77)	0.74 (0.74)	0.81 (0.80)	0.75 (0.76)
Weehawken (Near Bed) [1]	1.139	1.05 (1.06)	1.02 (1.04)	1.12 (1.12)	1.15 (1.14)	1.16 (1.16)
Spuyten Duyvil (Near Bed) [1]	1.363	0.93 (0.94)	0.93 (0.94)	0.97 (0.99)	0.91 (0.91)	0.95 (0.96)
Kill van Kull[2]	>0.70	2.15 (2.02)	2.21 (2.09)	3.08 (3.00)	1.91 (1.88)	2.03 (1.93)
Newark Bay 1[2]	<0.5	1.21 (1.26)	1.39 (1.40)	1.15 (1.18)	1.39 (1.38)	1.20 (1.20)
Newark Bay 2[2]	<0.5	1.04 (1.02)	1.09 (1.05)	1.06 (1.05)	0.95 (0.97)	1.19 (1.11)
Arthur Kill[2]	0.55-0.60	0.89 (0.91)	1.03 (1.07)	1.12 (1.18)	0.89 (0.99)	0.78 (0.78)

[1]Blumberg et al. (1999)
[2]Pecchioli et al. (2006)

Pecchioli et al. (2006) did not specify if the currents were surface, bottom, or depth averaged. The model results presented in Table 12 are surface, and as such are expected to be higher than those reported by Pecchioli et al. (2006).

While the model velocities are in general slightly below the values reported in Blumberg et al. (1999), they are not significantly lower and could easily be due to variations in the bathymetry, frictional specification, and/or boundary forcings between the observational time periods and the time periods simulated in this study. These comparisons indicate the velocities in the model are reasonable in comparison to the values reported in the literature.

Kill van Kull discharge comparisons

Blumberg et al. (1999) and Sommerfield and Chant (2010) report average flowrates through the Kill van Kull channel. These observations were over a limited amount of time (not included in the model simulated times) and utilized to report approximate yearly average flowrates. Therefore, a model yearly average flowrate for the Kill van Kull was calculated and compared to the values reported in the literature. Blumberg et al. (1999) reported a mean water flux of 95 cms and Sommerfield and Chant (2010) reported a mean water flux of 120 cms. Blumberg et al. (1999) should equate closer to the without-project conditions, and Sommerfield and Chant (2010) is between the start and finish of the with-project expansion. The model results for the simulated years are presented in Table 13. These results indicate the model may be somewhat overpredicting the net flow through the Kill van Kull by approximately 30 cms for the without-project configuration and approximately 50 cms for the with-project configuration. The model appears to be relatively accurate in predicting the percent change between the with- and without-project flowrates with the field indicating an increase of approximately 26% and the model indicating an increase of approximately 36%.

Table 13. Kill van Kull flow comparisons.

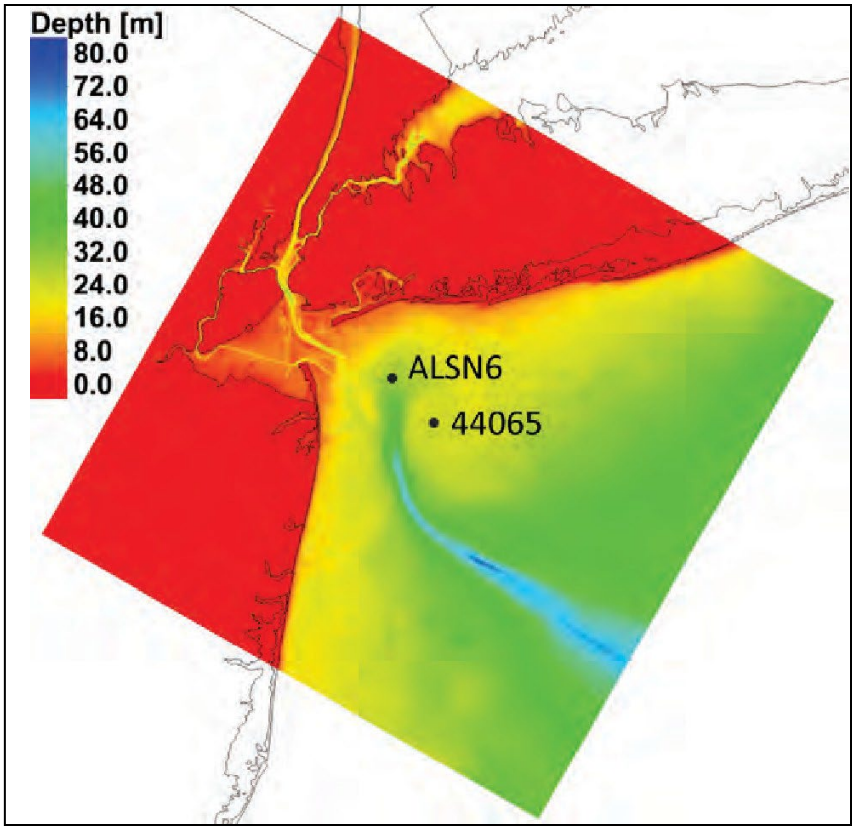
Blumberg et al. (1999) — 95 cms Sommerfield and Chant (2010) - 120 cms		
Year	Without-project average flow, cms compare to 95 cms	With-project average flow, cms compare to 120 cms
1985	122	162
1995	115	154
1996	123	170
2011	125	177
2012	129	170

Wave model validation

The accuracy of the STWAVE model results is influenced by forcing parameters (e.g., wind, water levels, and offshore spectra), representation of the geographic area (e.g., bathymetry and bottom roughness), and inherent model physics and assumptions. Comparisons between measurements and model results were undertaken to assess the STWAVE model performance in replicating the nearshore wave climate of the study area.

Only two nearshore buoys were found within the STWAVE domain, ALSN6 at the Ambrose Light Tower in New York and NDBC 44065 at the approach to New York Harbor. ALSN6 is located at 40.45°N, 73.80°W, and NDBC 44065 is located at 40.369°N and 73.703°W. The locations of these buoys are shown in Figure 125. Measurements are available at ALSN6 for 1995 and 1996 and at NDBC 44065 for 2011 and 2012.

Figure 125. Location of ALSN6 and NDBC 44065.



STWAVE results were compared to measurements both graphically and statistically. Graphical products included time-paired histories and scatter plots. Statistical calculations included bias (modeled – measured), root-mean-square error (RMSE), and linear regression (slope and correlation coefficient) (Bryant et al. 2016).

Figure 126 compares time series of measured and modeled significant wave height (Hs or Hmo), peak wave period (Tp), and mean wave period from 1 January 1995 00:00 to 31 December 1995 22:00. ALSN6 did not collect data from 17 February 18:00 until 03 August 15:00. The largest waves of the year occurred on 12 November and exceeded 4 m. The average significant wave height was 1.03 m, the average peak period was 8.08 s, and the average mean period was 6.9 s for 1995. Although STWAVE underestimates larger wave heights near the beginning of February and mid-November, the evolution of the significant wave height, peak wave period, and mean wave period is estimated reasonably well throughout the year.

Figure 126. Time series of STWAVE results versus measurements at ALSN6 for 1995.

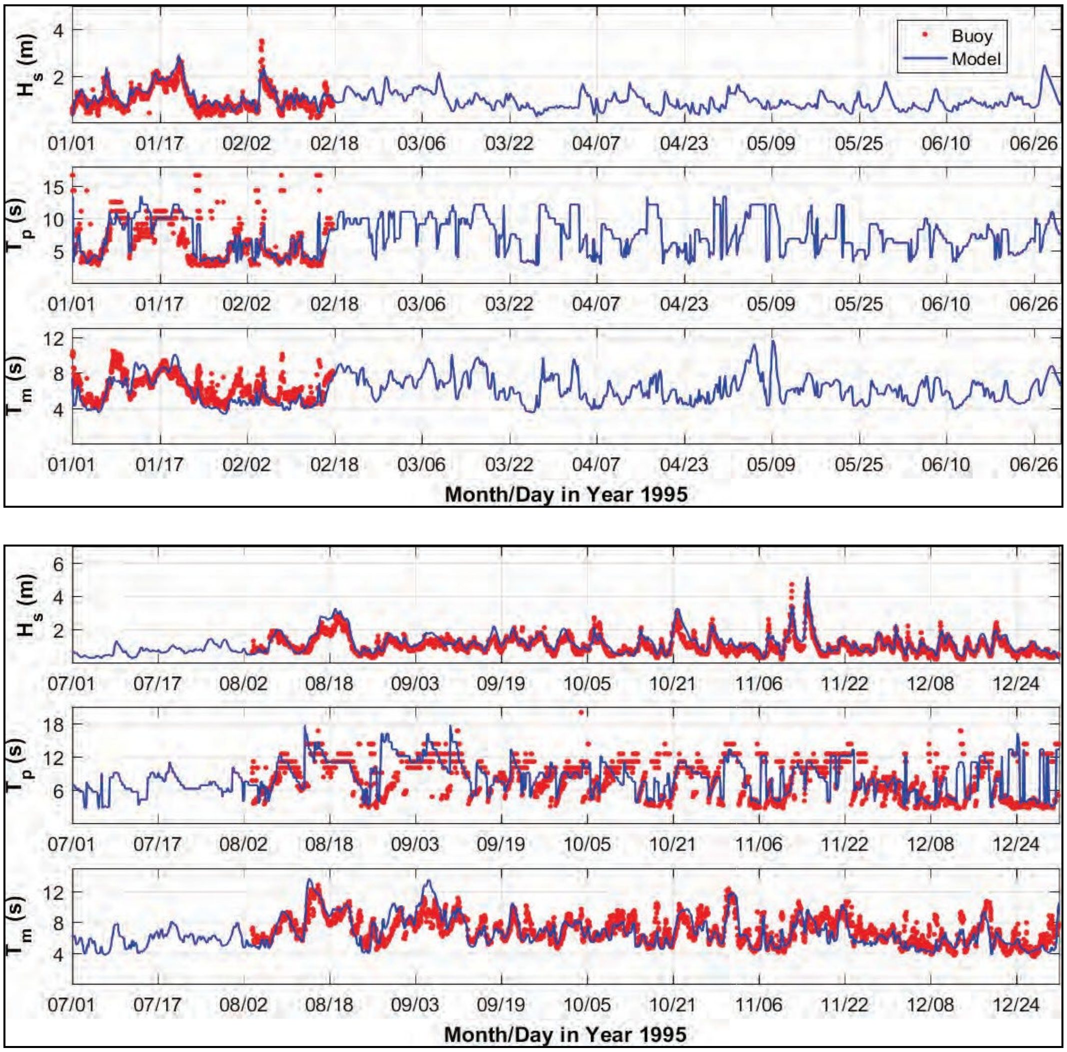


Figure 127 presents scatter plots of time-paired observed and modeled significant wave height and mean period for 1995. The blue line is a 1-to-1 line of equality plotted for visualization purposes. As observations of peak period T_p are highly variable and model results are limited to defined wave frequency bins, mean period T_m is considered a more stable parameter for comparison. The number of paired observations for 1995 was 1,291. Looking at the upper panel, there is clear binning of the wave height data. This binning is due to the resolution of the measurements being limited to one significant digit. Most of the wave height population was less than 2.5 m. STWAVE systematically overestimated wave heights at ALSN6 for 1995 as indicated by the distribution of data above the line of the best of fit and the positive bias of 0.19 m. The RMSE and Scatter Index (SI) with respect to wave height were 0.27 m and 26, respectively. A correlation of 0.89 indicates STWAVE demonstrated good association with wave height observations. Based on the regression analysis, STWAVE showed an average positive error of 16% with respect to significant wave height. Unlike significant wave height, STWAVE underestimated the mean wave period as indicated by the distribution of scatter, a negative bias of -0.28 s, and a regression slope (Sym r) of 0.97. The RMSE with respect to mean wave period was 1.4 s. STWAVE demonstrated greater association with wave height than mean wave period; the correlation for mean wave period was 0.75, lower than that for wave height.

Figure 127. Scatter plots for 1995 of significant wave height (top) and mean period (bottom).

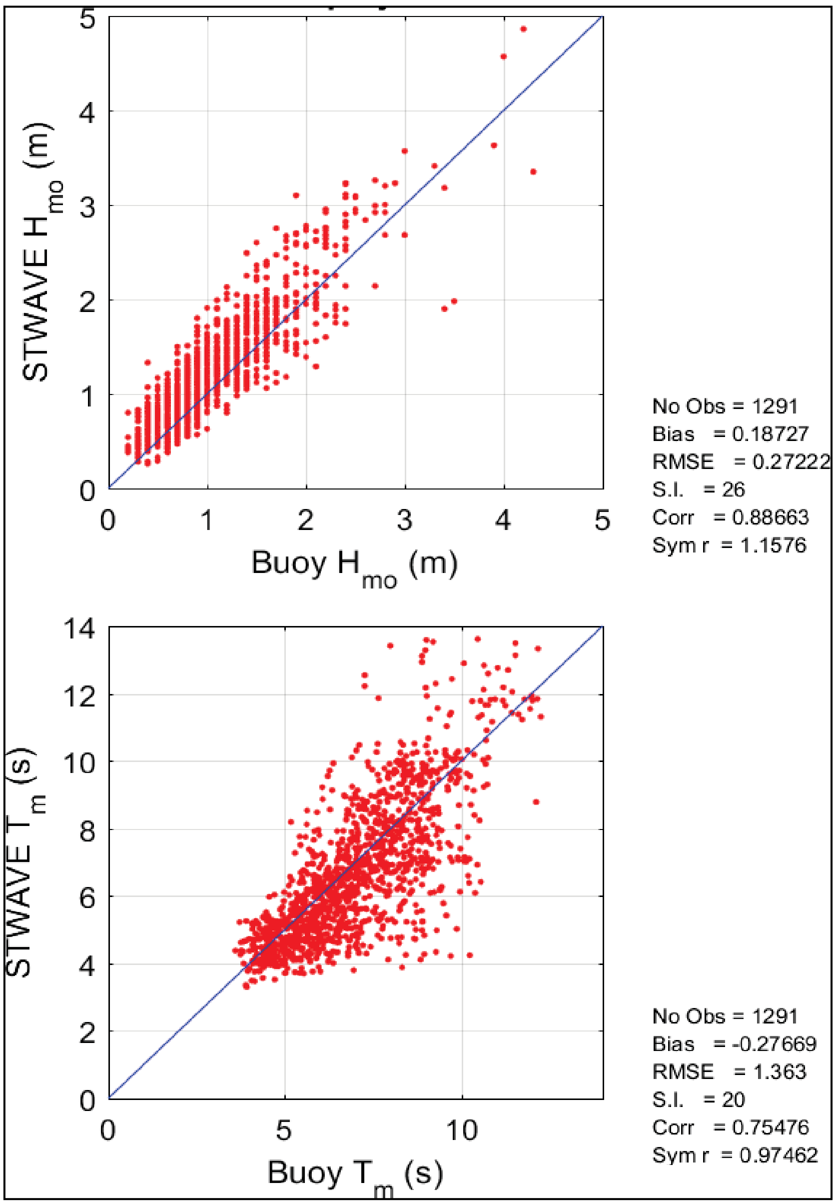


Figure 128 presents time series of measured and modeled significant wave height, peak wave period, and mean wave period from 1 January 1996 00:00 to 31 December 1996 22:00 for ALSN6. The largest wave height of approximately 5.0 m occurred on 8 January, which corresponds with the Blizzard of ’96. The average significant wave height, peak period, and mean wave period measured by ALSN6 for 1996 is 0.96 m, 8.27 s, and 7.03 s, respectively. The model results follow the evolution of the wave observations well, particularly for significant wave height and mean period.

Figure 128. Time series of STWAVE results versus measurements at ALSN6 for 1996.

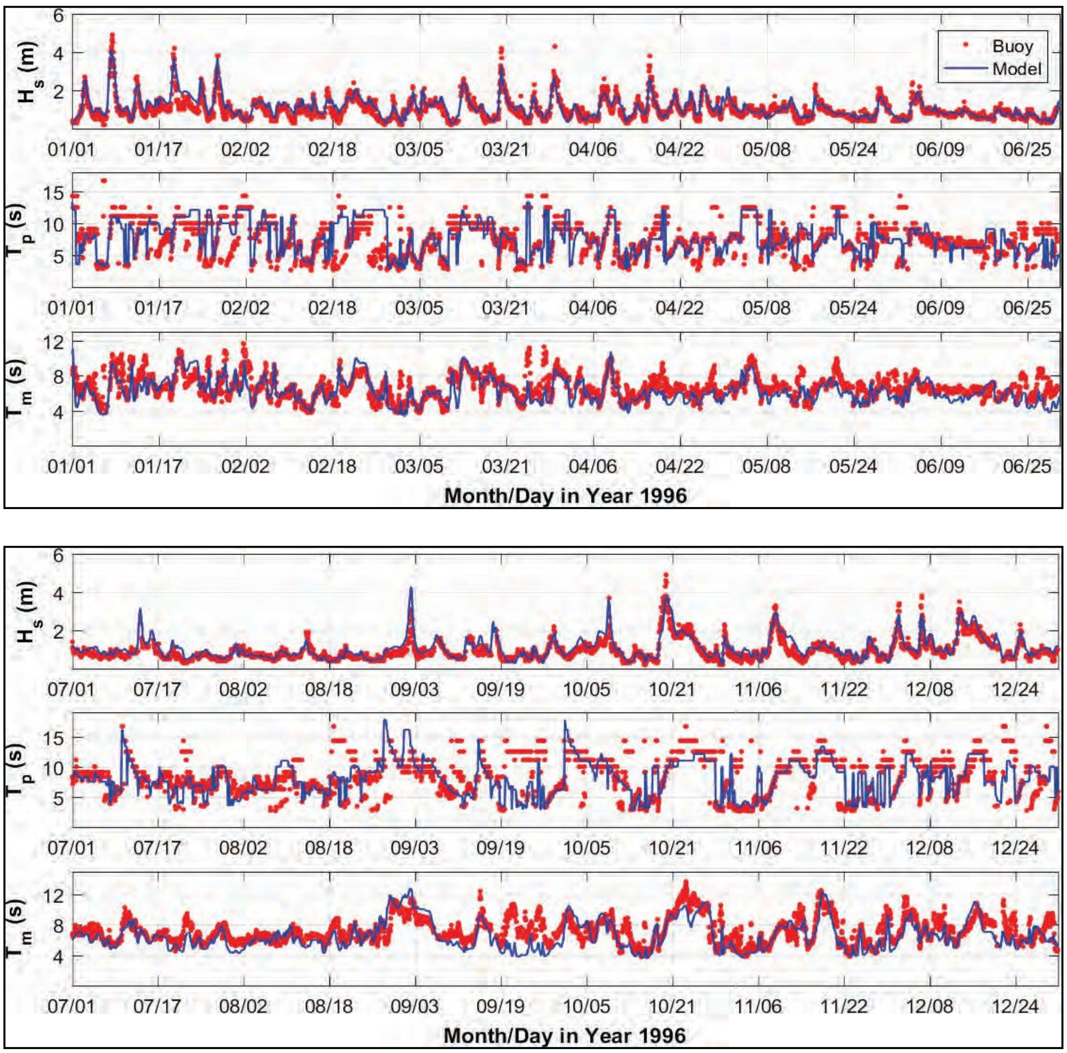


Figure 129 shows a scatter plot of time-paired measurements and models results for ALSN6 for 1996. The total number of paired observations was 2,337. The trends and statistics for 1996 are similar to those of 1995. STWAVE systematically overestimated the significant wave height (bias of 0.12 m, regression slope of 1.09) and systematically underestimated the mean wave period (bias of -0.51 s, regression slope of 0.94). The RMSE errors for significant wave height (0.25 m) and mean wave period (1.26 s) are also similar to 1995. Again, STWAVE results were better associated with respect to wave height (correlation of 0.90) compared to mean wave period (correlation of 0.71).

Figure 129. Scatter plots for 1996 of significant wave height (top) and mean period (bottom).

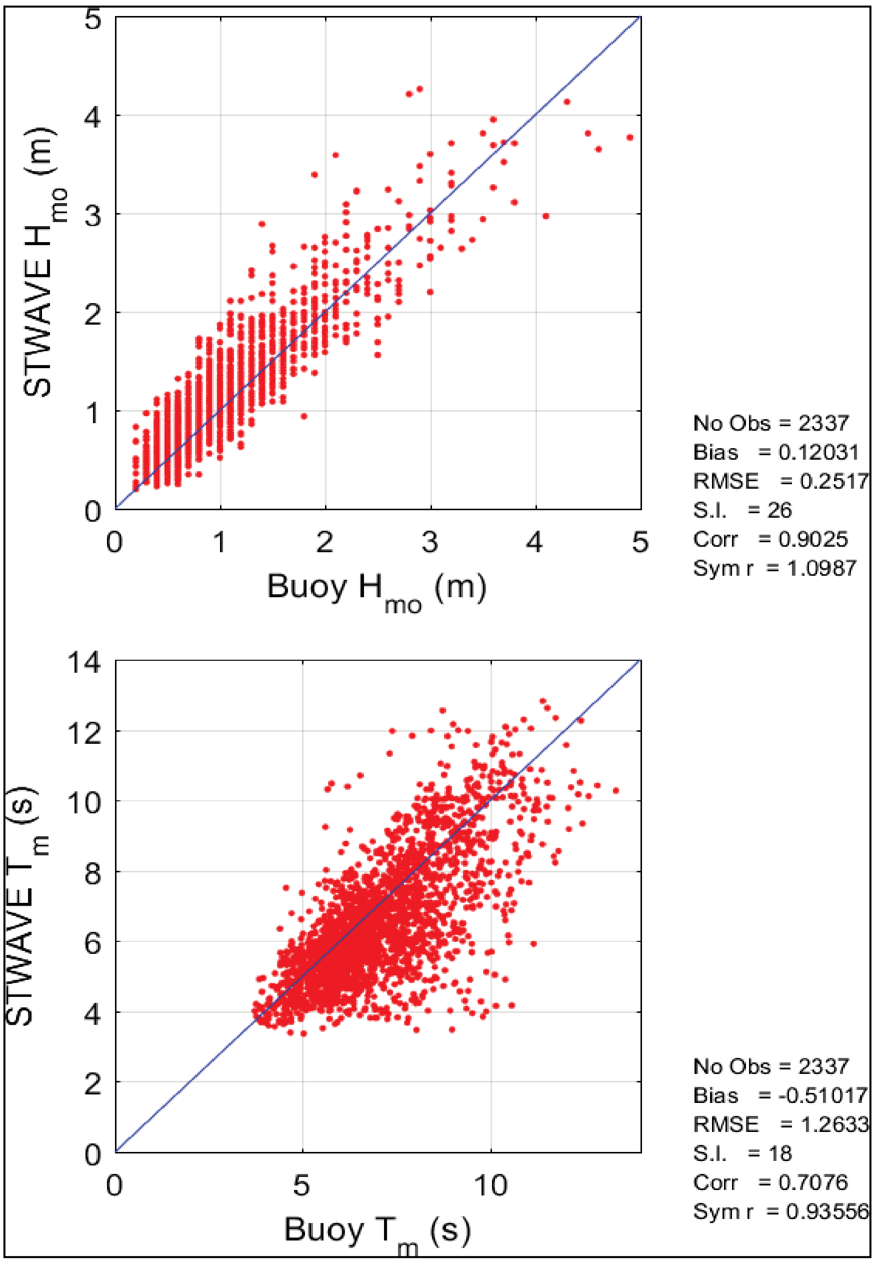


Figure 130 presents time series of measured and modeled significant wave height, peak wave period, mean wave period, and mean wave direction (θ_{wave}) from 1 January 2011 00:00 to 31 December 2011 22:00. The largest waves of the year were measured during Hurricane Irene on 28 August and exceeded 5 m. NDBC 44065 failed to collect data between 5 September and 8 October. For 2011, the average significant wave height was 1.0 m, the average peak period was 7.5 s, and the average mean wave period was 6.2 s. In general, STWAVE demonstrates good agreement with measured integral wave parameters throughout the year.

Figure 130. Time series of STWAVE results versus measurements at NDBC 44065 for 2011.

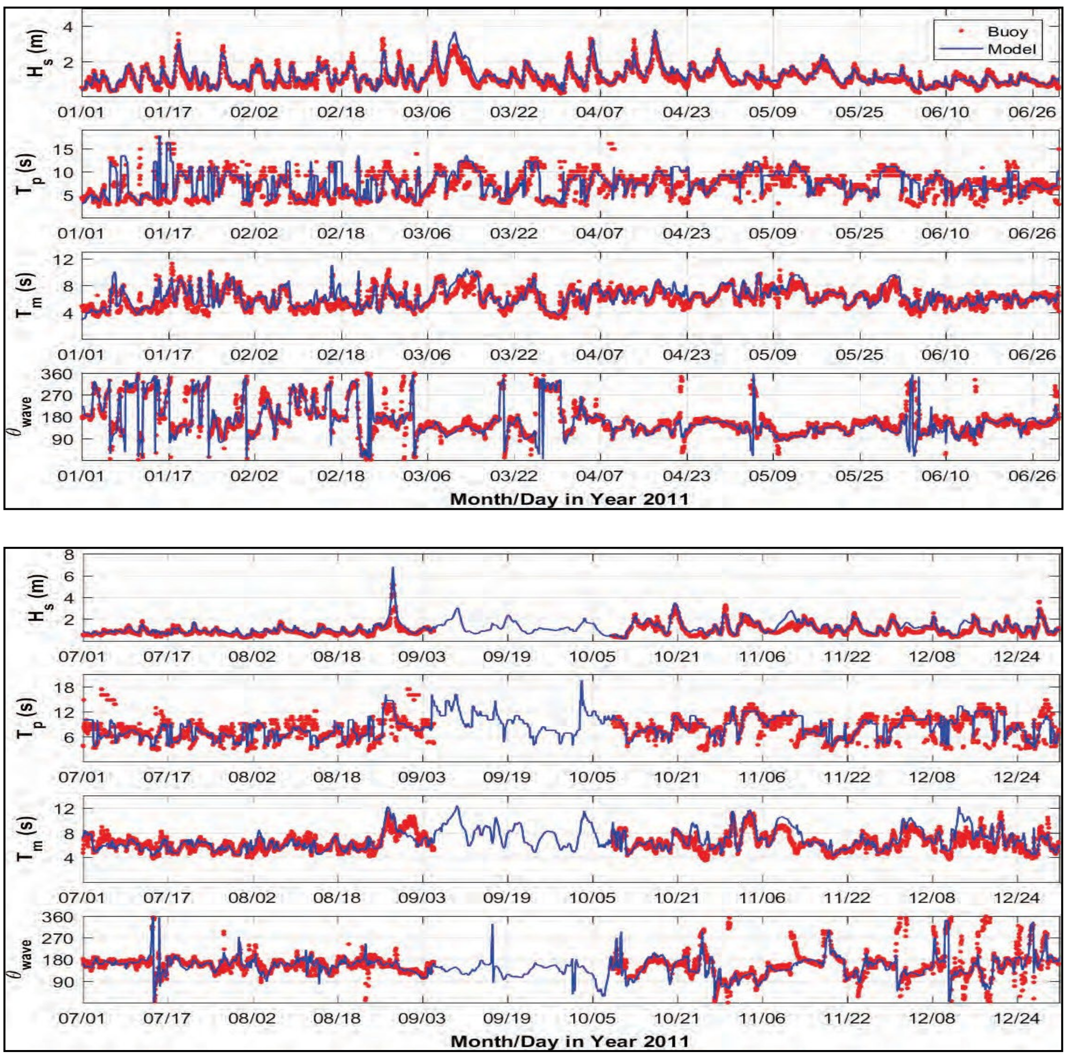


Figure 131 presents scatter plots of time-paired measured and modeled significant wave height and mean period for 2011. The total number of records compared for 2011 was 2,616. Looking at the upper panel, more scatter lies above the line of best fit than below, indicating a model trend of overestimating significant wave heights. This is supported by the slightly positive bias of 0.17 m. There is a noticeable overestimation of the largest wave heights associated with Hurricane Irene. The RMSE was 0.24 m and the SI was 24 for 2011. The correlation coefficient was about 0.90, and the symmetric slope indicated an average positive error of 14% in modeled significant wave height. Compared to significant wave height, the scatter for mean wave period is more equally distributed above and below the line of best fit. The bias and RMSE for mean period was approximately 0.25 s and 1.0 s, respectively. The correlation coefficient was 0.78, lower than that for the significant wave height, with an average positive error of 4% in modeled mean wave period with respect to measured mean wave period.

Figure 131. Scatter plots for 2011 of significant wave height (top) and mean period (bottom).

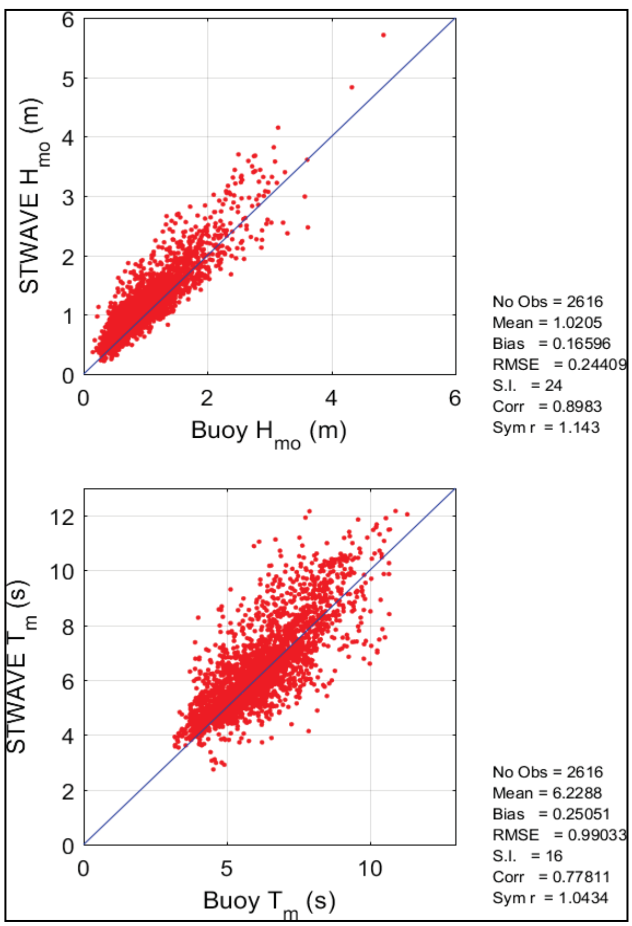
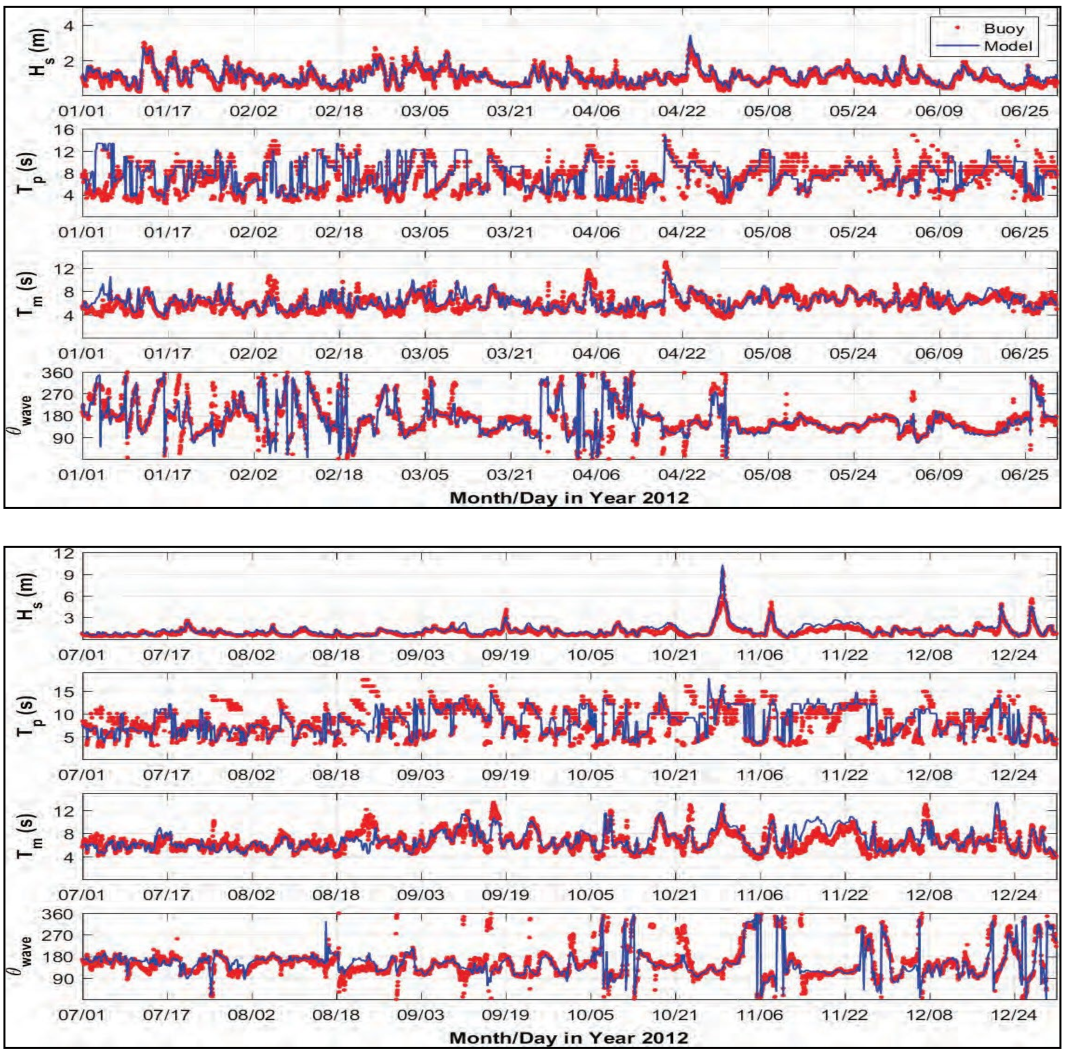


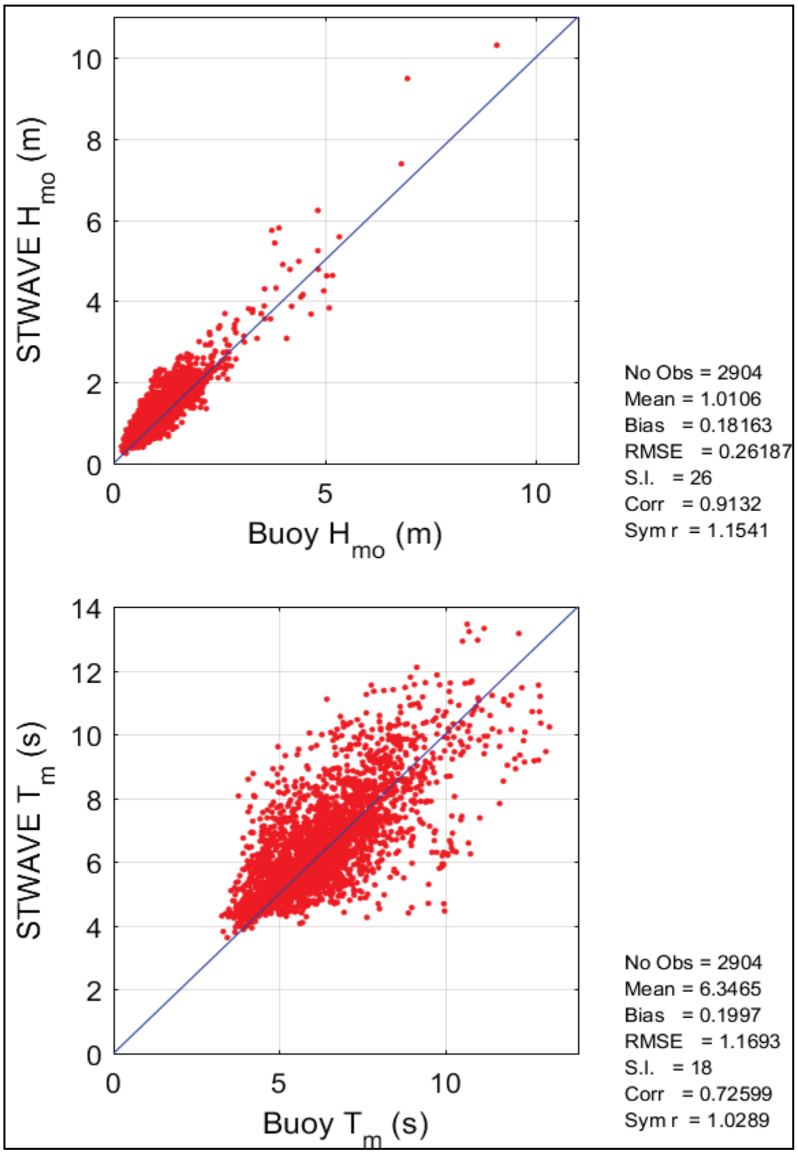
Figure 132 presents time series of modeled and measured significant wave height, peak wave period, mean wave period, and mean wave direction from 1 January 2012 00:00 to 31 December 2012 22:00. The largest waves of the year were associated with Hurricane Sandy and exceeded 9 m on 29 October. For 2012, the average significant wave height was 1.0 m, the average peak period was 7.6 s, and the average mean wave period was 6.3 s. Again, STWAVE adequately replicates the wave climate at NDBC 44065 for 2012 for the purposes of this study.

Figure 132. Time series of STWAVE results versus measurements at 44065 for 2012.



The number of time-paired records for 2012 is 2,904. Overall, results for 2012 are comparable to those of 2011 for both significant wave height and mean period. Again, STWAVE overestimated the largest waves associated with Hurricane Sandy. The bias, RMSE, and SI for the significant wave height for 2012 was slightly higher than for 2011 with values of 0.18 m, 0.26 m, and 26, respectively. The linear regression produced a correlation coefficient of 0.91 and a symmetric slope of 1.15, indicating an average positive error of 15% in modeled significant wave height. More scatter is evident for the mean wave period than for the significant wave height as seen in Figure 133. The bias and RMSE for mean wave period were 0.20 s and 1.17 s, respectively. The SI was slightly higher than in 2011 with a value of 18. The correlation coefficient was 0.73 with the symmetric slope indicating an average positive error of 3% in modeled mean wave period with respect to measured wave period.

Figure 133. Scatter plots for 2012 of significant wave height (top) and mean period (bottom).



3D salinity transport comparisons

The 3D salinity comparisons consisted primarily of comparing model results to observed surface and bottom salinity measurements from 1995. Comparisons also consisted of comparing to qualitative behavior reported in the literature.

Quantitative comparisons

In 1995, a comprehensive data collection effort was performed whereby numerous salinity measurements were collected at various times and locations in the NYNJH system. Figure 134 shows the locations where data were collected. The time-series comparisons are provided in Figure 135 to Figure 175. The lines are model data, and the stars are observations (Blue – Surface; Red – Bottom; Green – Stratification [Bottom – Surface]).

Figure 134. Salinity observation locations.

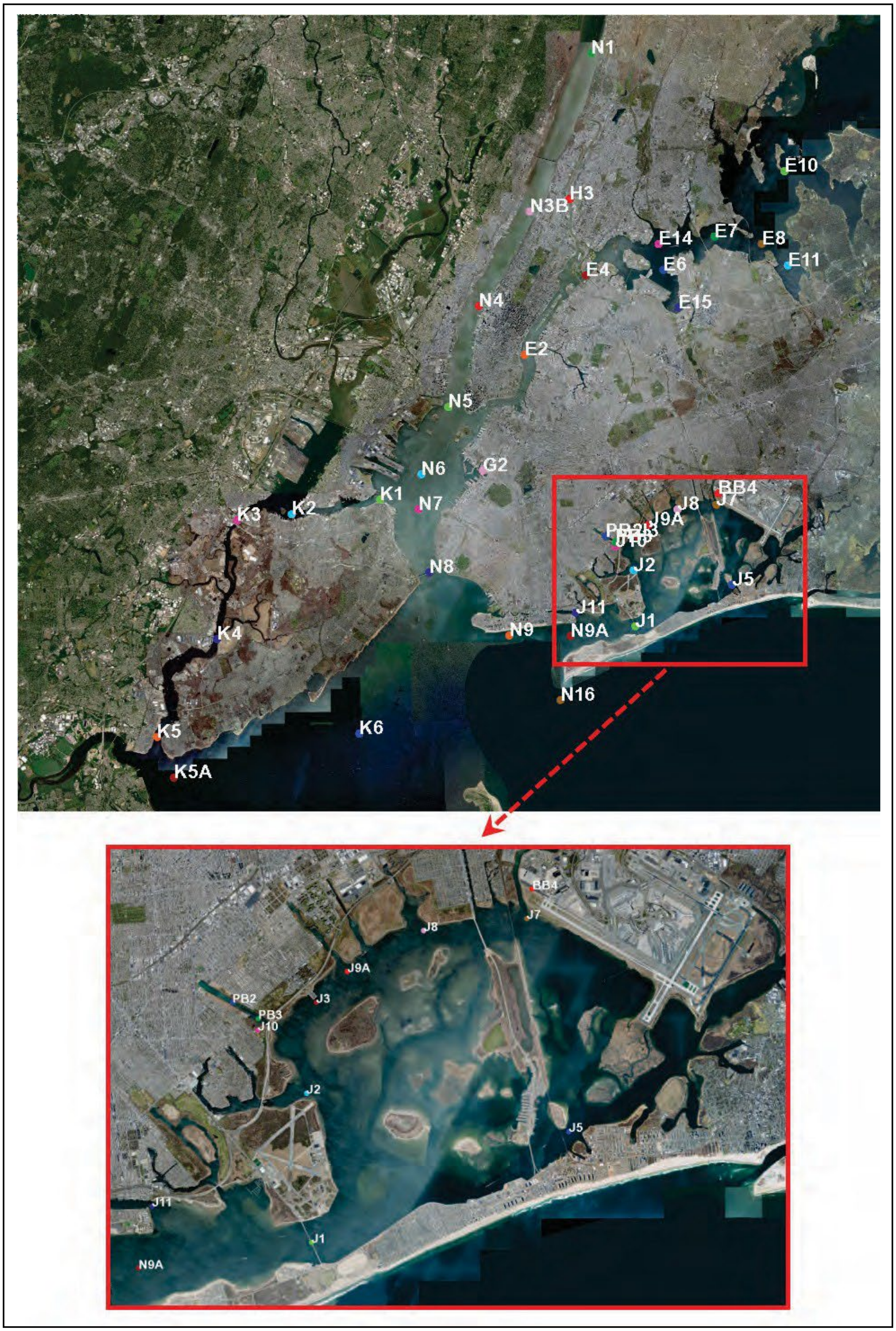


Figure 135. Salinity distribution at BB4.

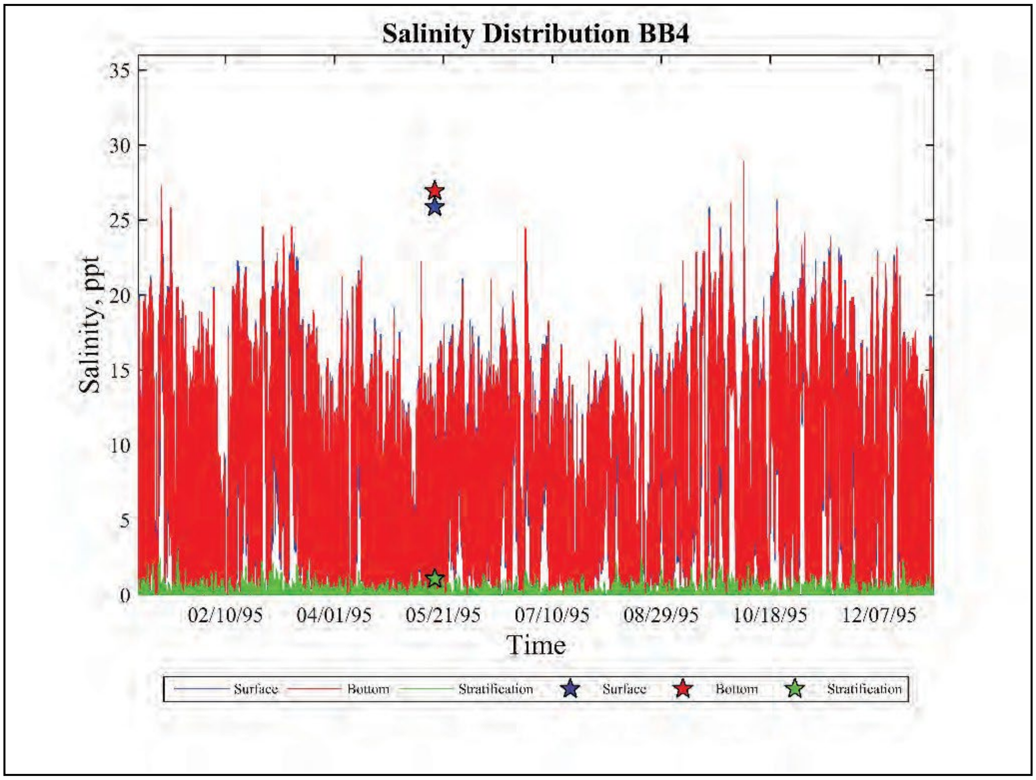


Figure 136. Salinity distribution at E2.

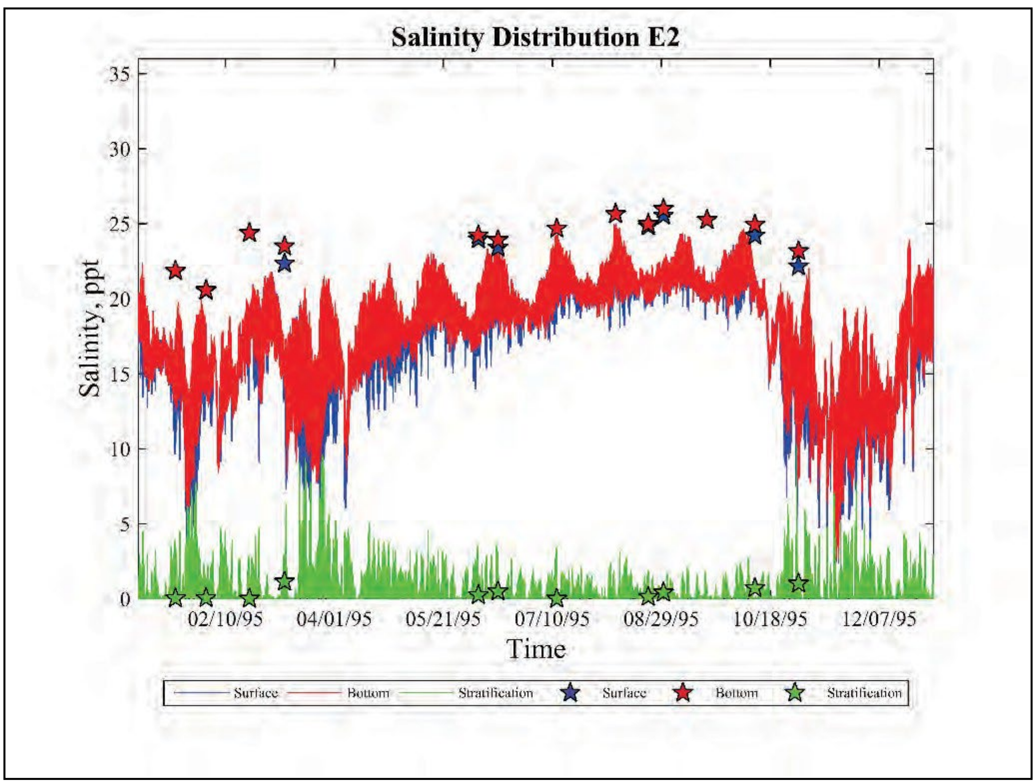


Figure 137. Salinity distribution at E4.

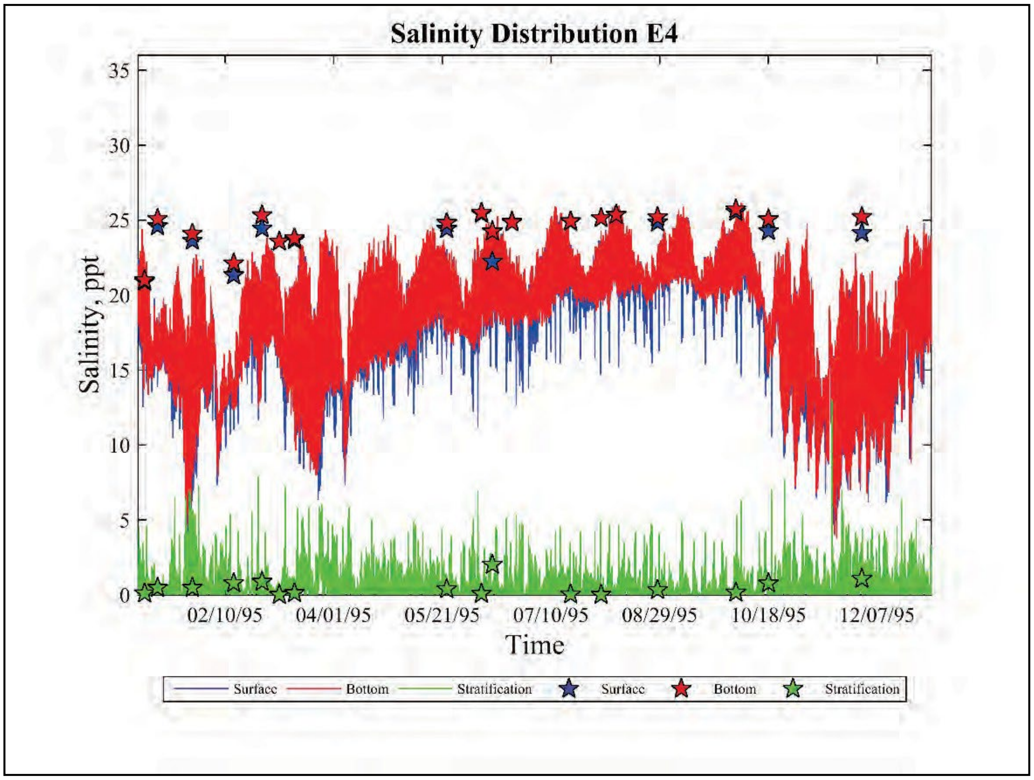


Figure 138. Salinity distribution at E6.

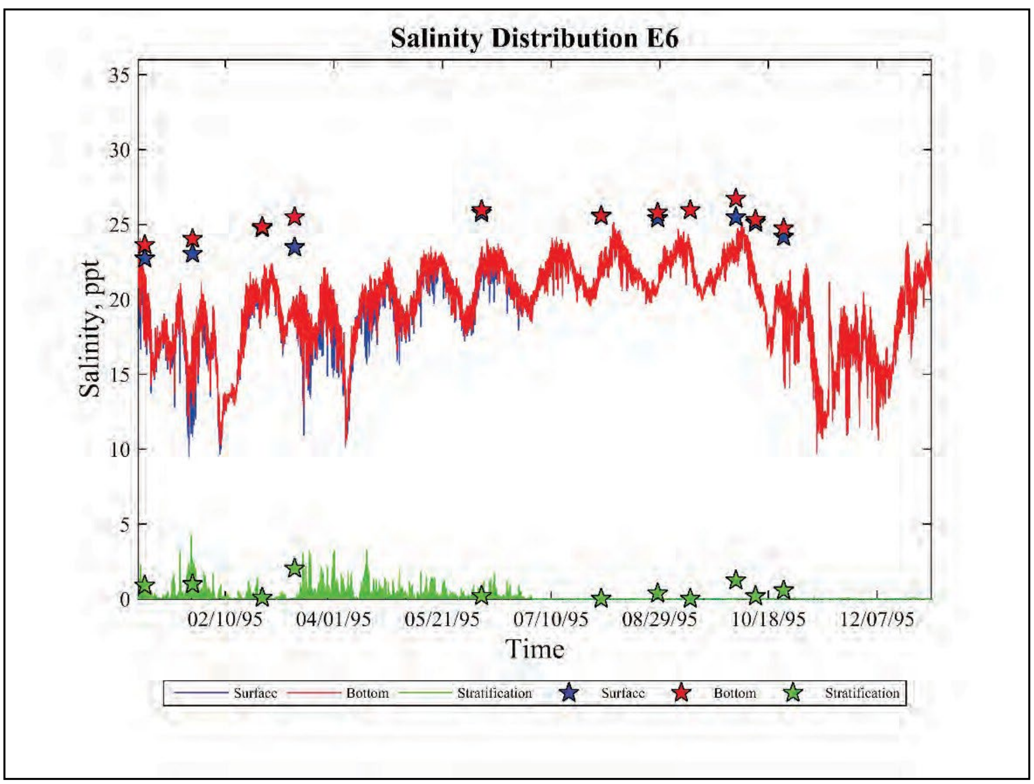


Figure 139. Salinity distribution at E7.

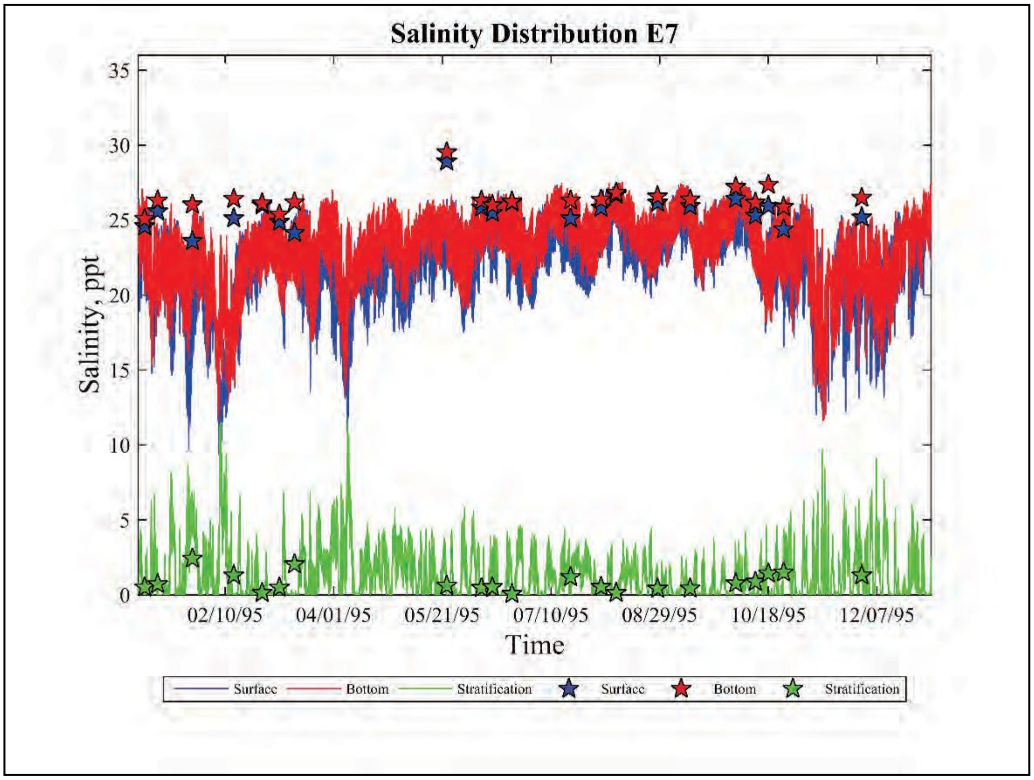


Figure 140. Salinity distribution at E8.

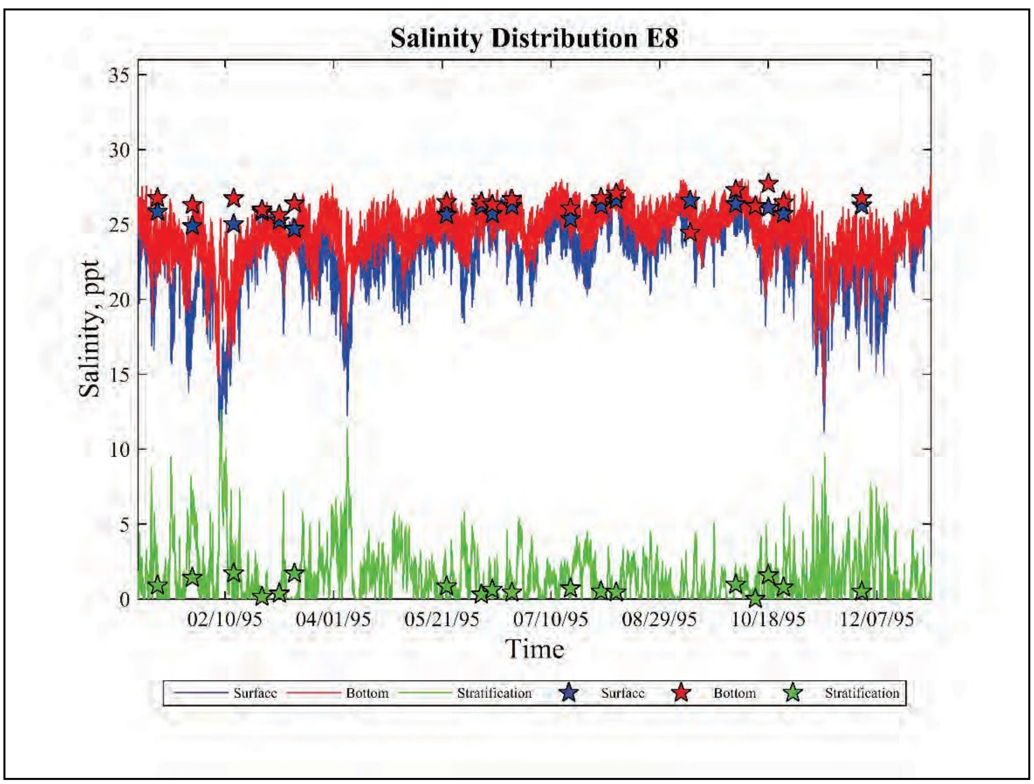


Figure 141 Salinity distribution at E10.

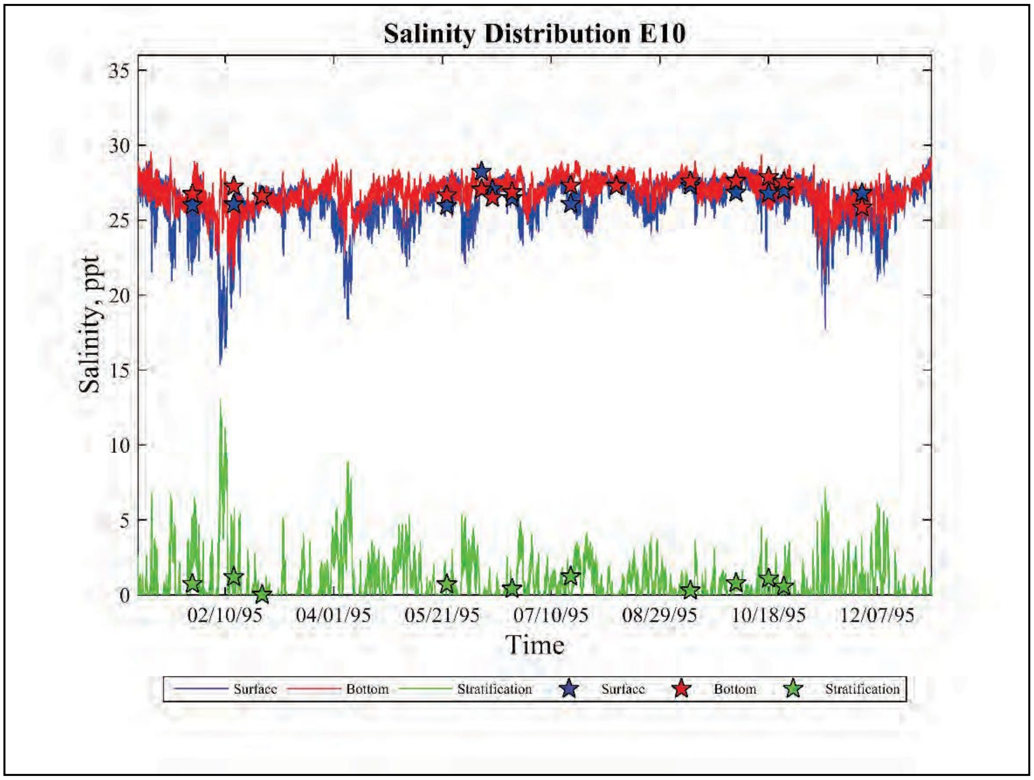


Figure 142. Salinity distribution at E11.

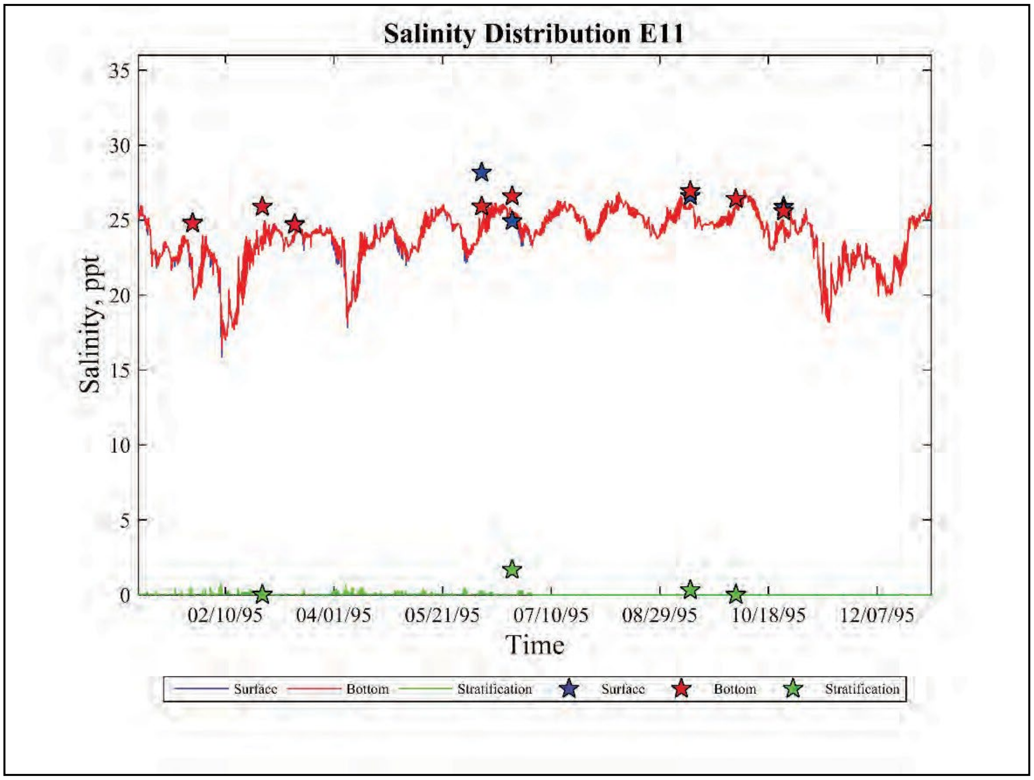


Figure 143. Salinity distribution at E14.

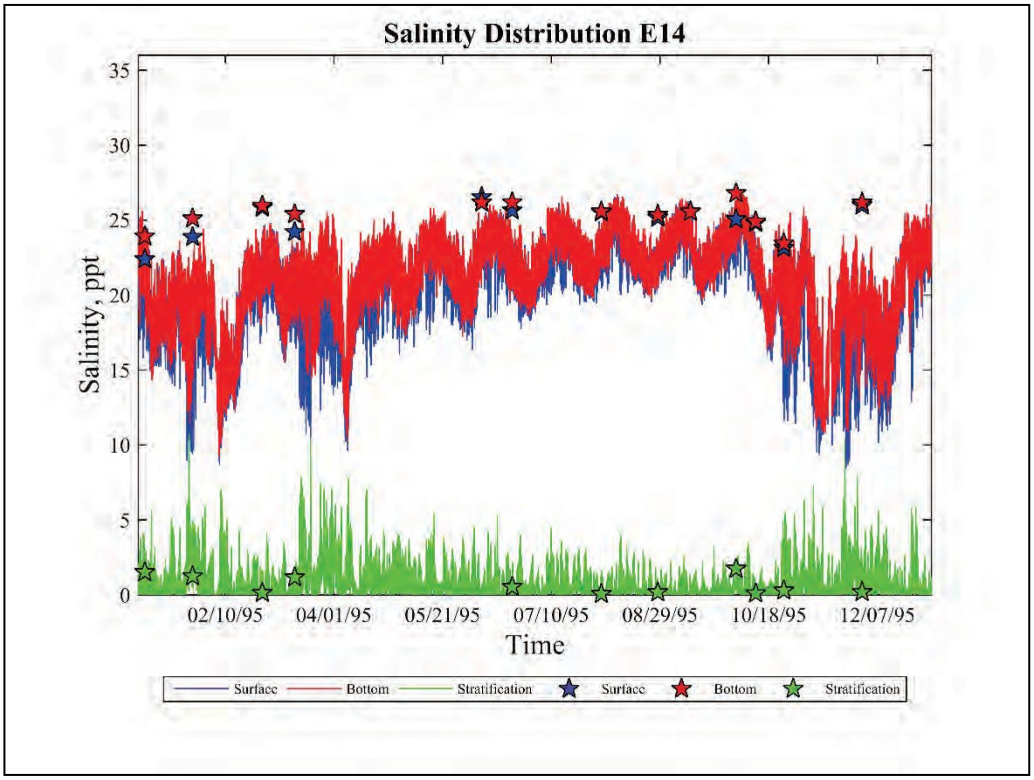


Figure 144. Salinity distribution at E15.

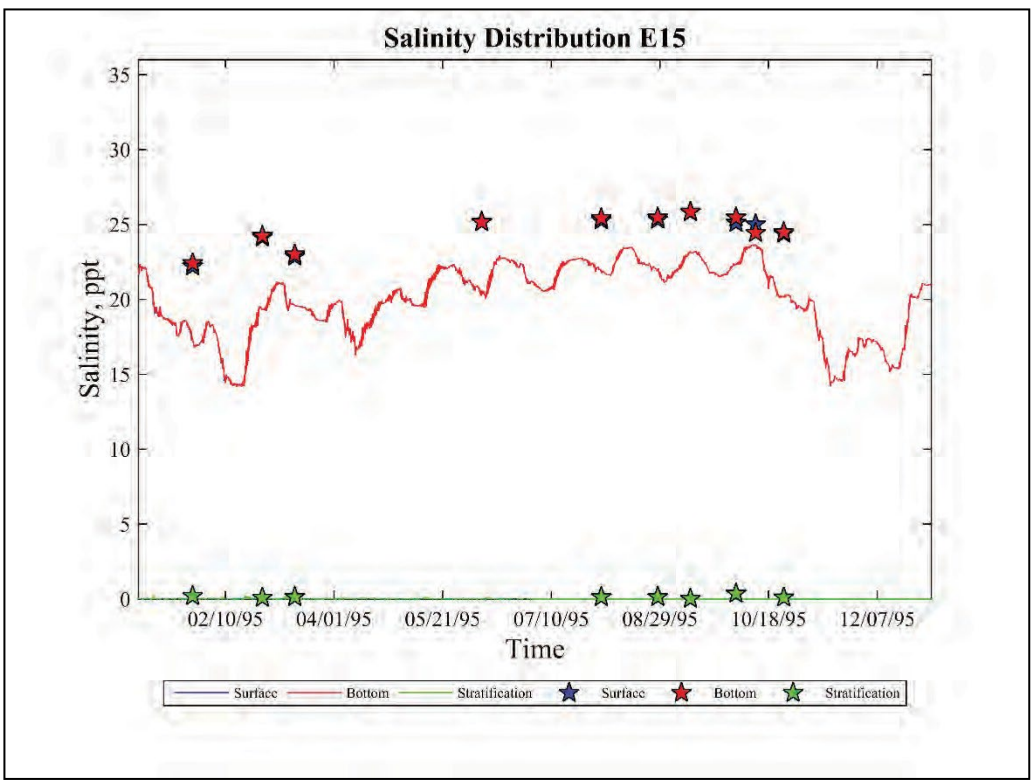


Figure 145. Salinity distribution at G2.

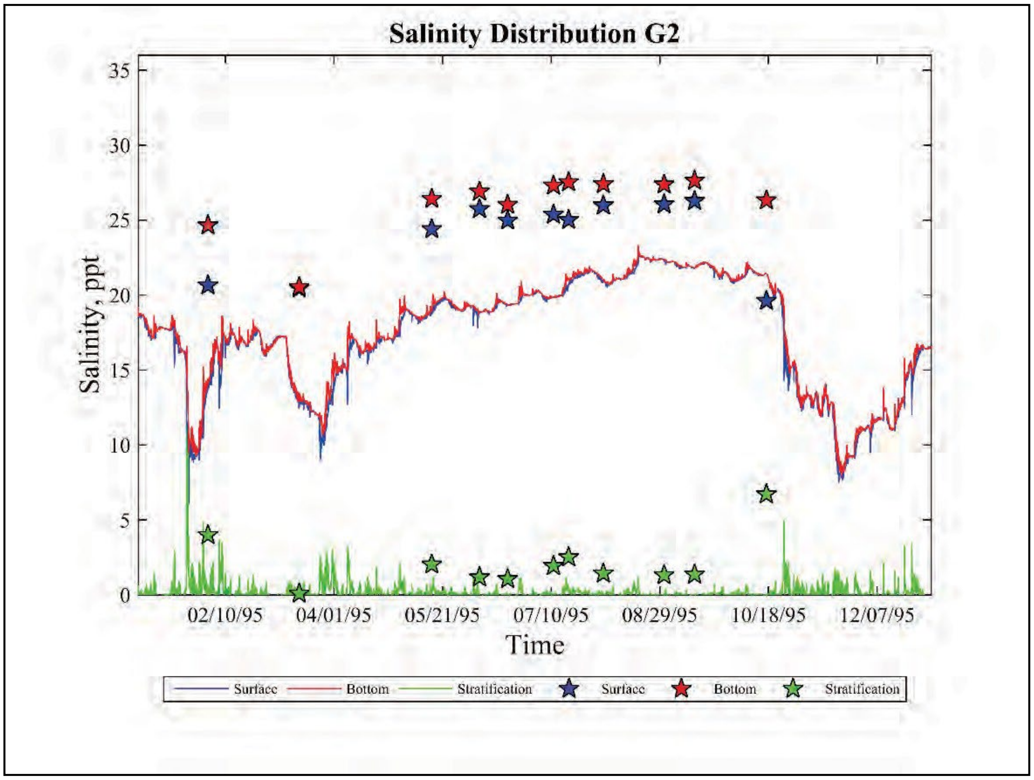


Figure 146. Salinity distribution at H3.

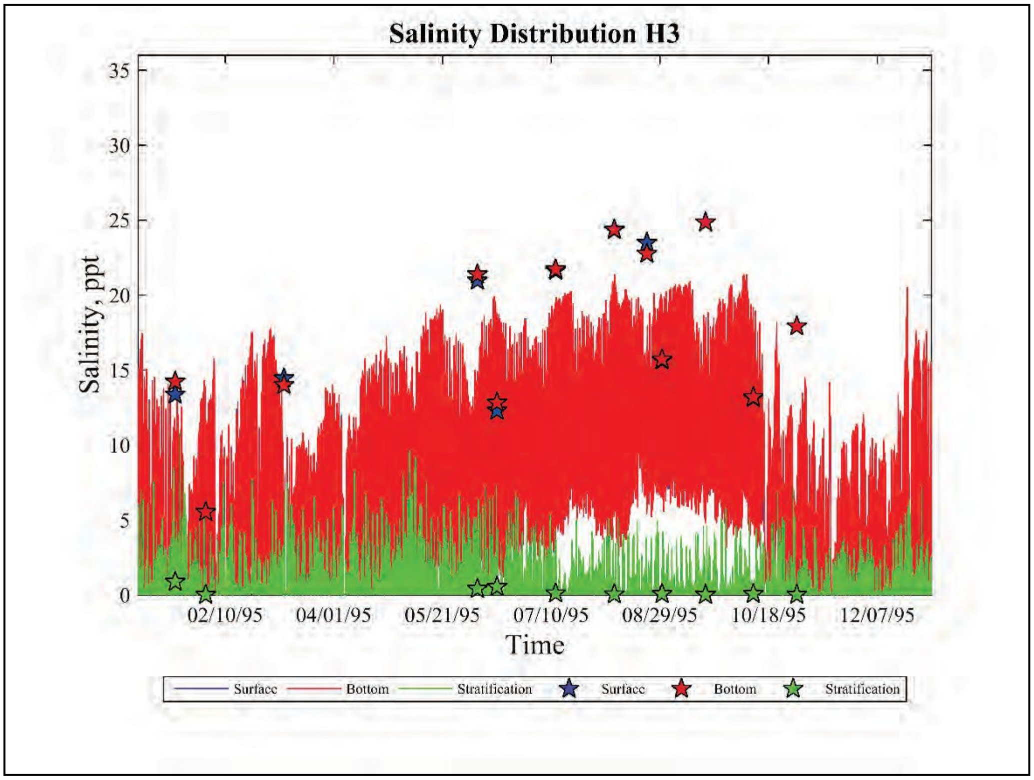


Figure 147. Salinity distribution at J1.

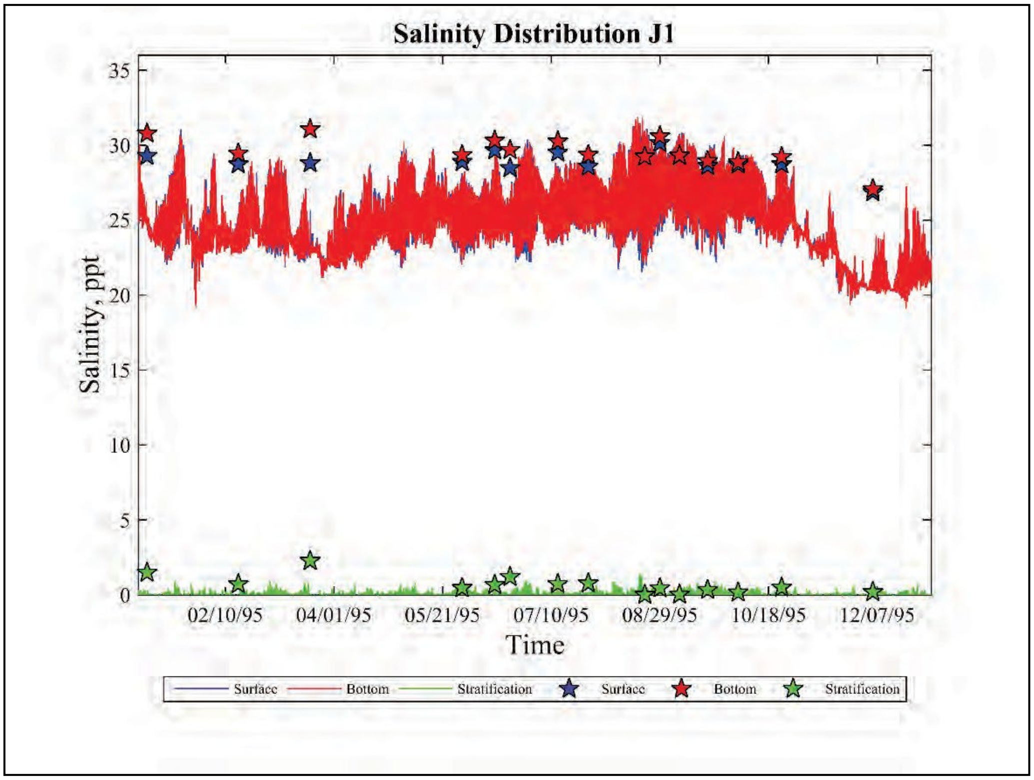


Figure 148. Salinity distribution at J2.

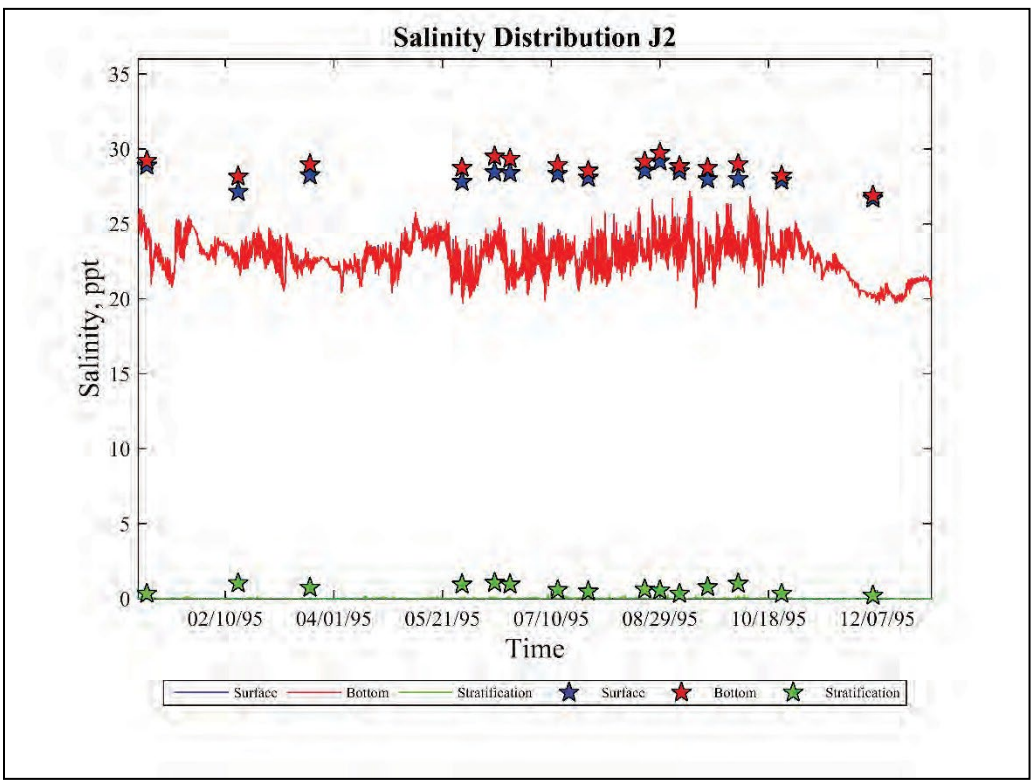


Figure 149. Salinity distribution at J3.

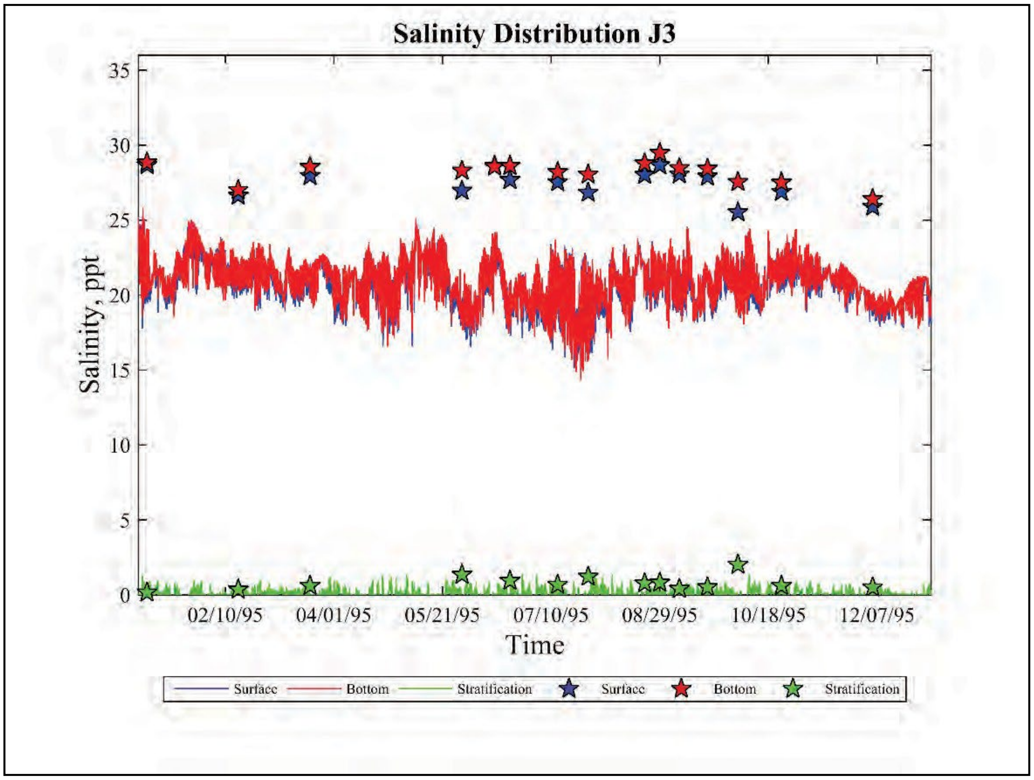


Figure 150. Salinity distribution at J5.

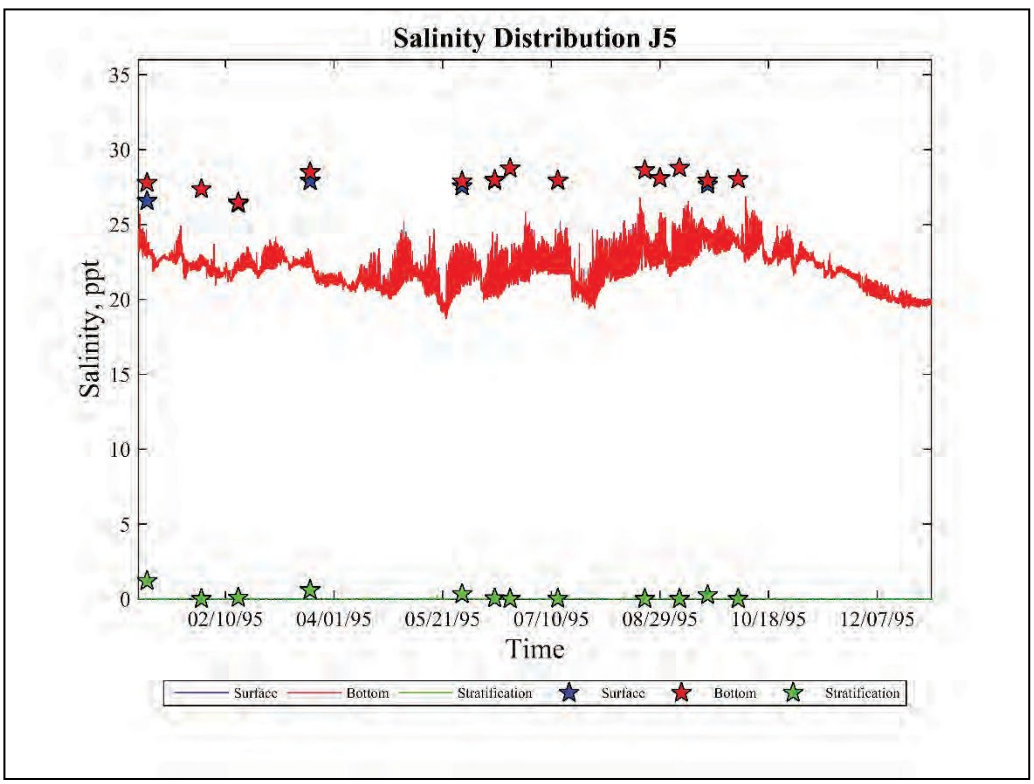


Figure 151. Salinity distribution at J5D.

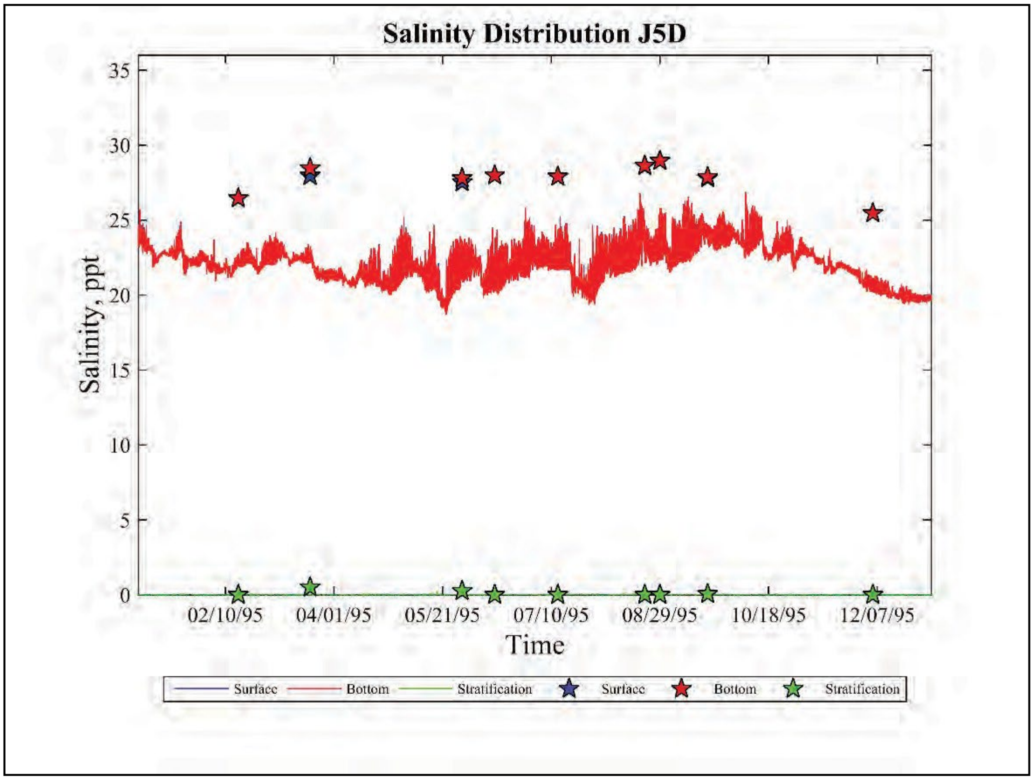


Figure 152. Salinity distribution at J7.

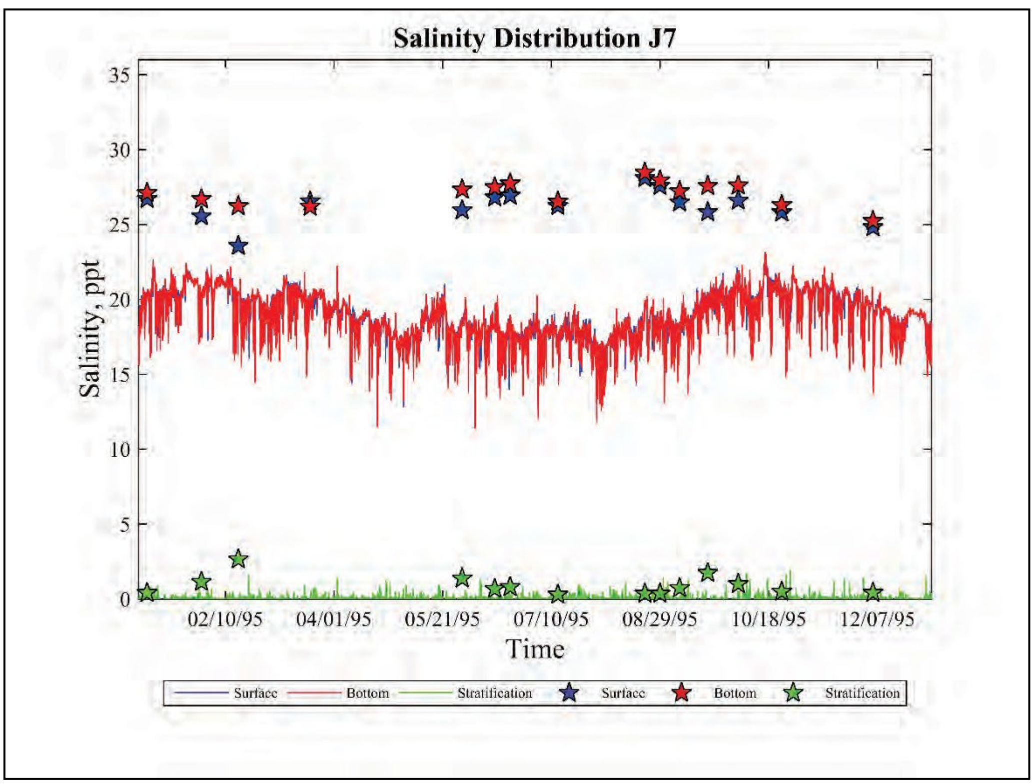


Figure 153. Salinity distribution at J8.

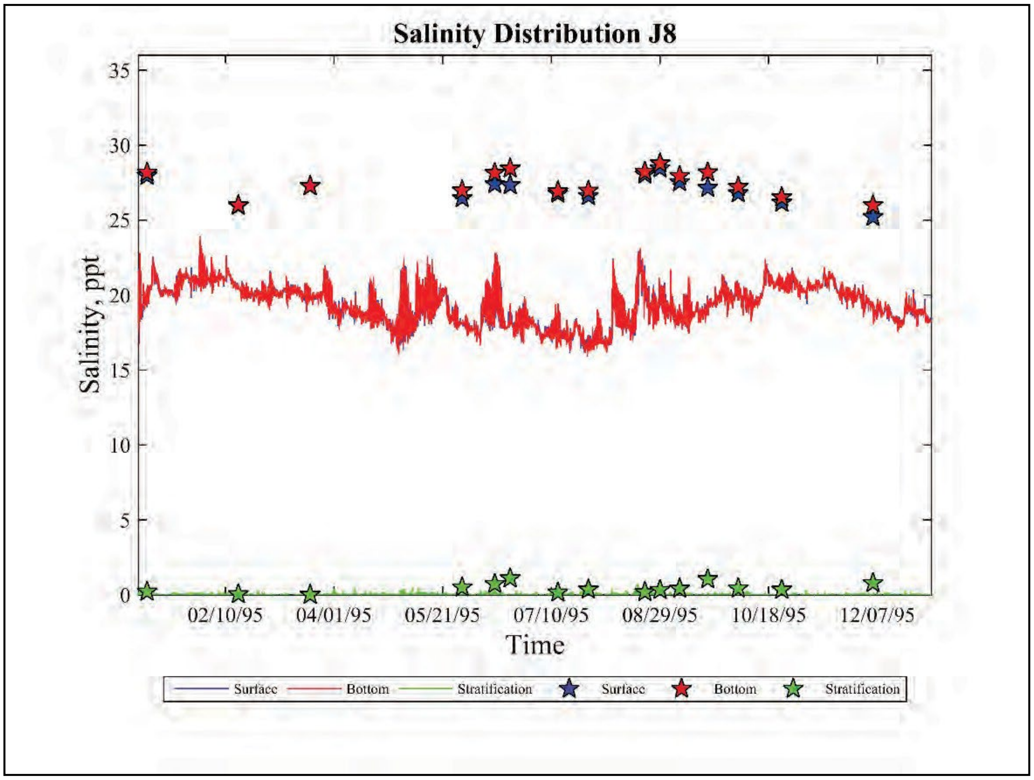


Figure 154. Salinity distribution J9A.

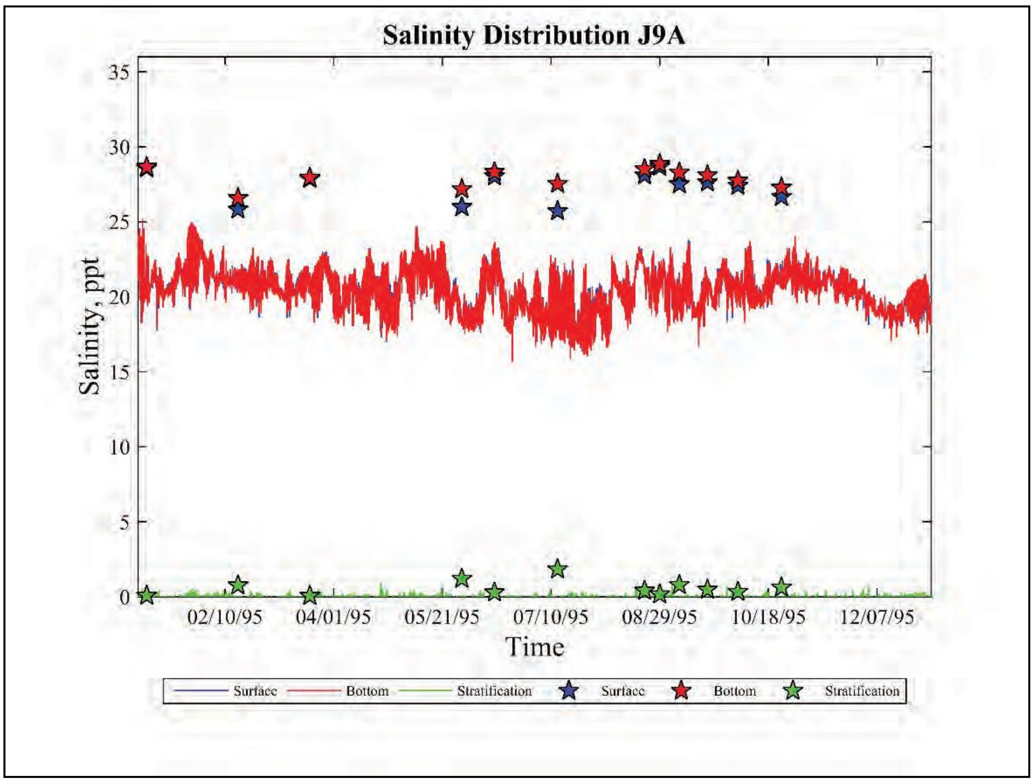


Figure 155. Salinity distribution at J10.

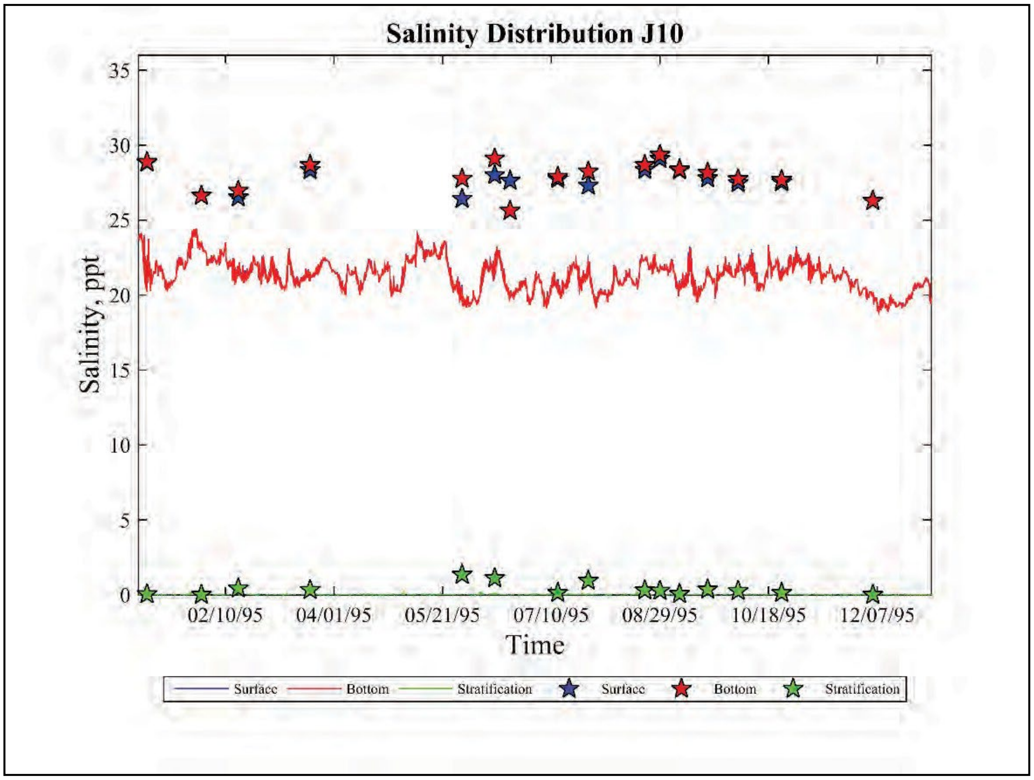


Figure 156. Salinity distribution at J11.

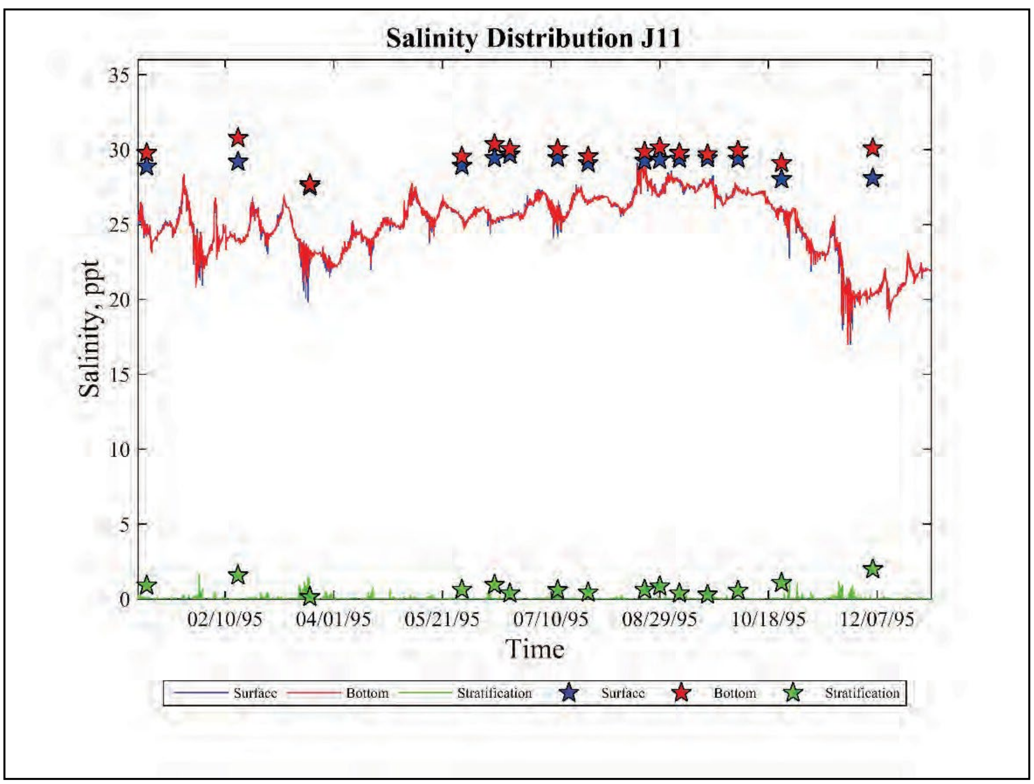


Figure 157. Salinity distribution at K1.

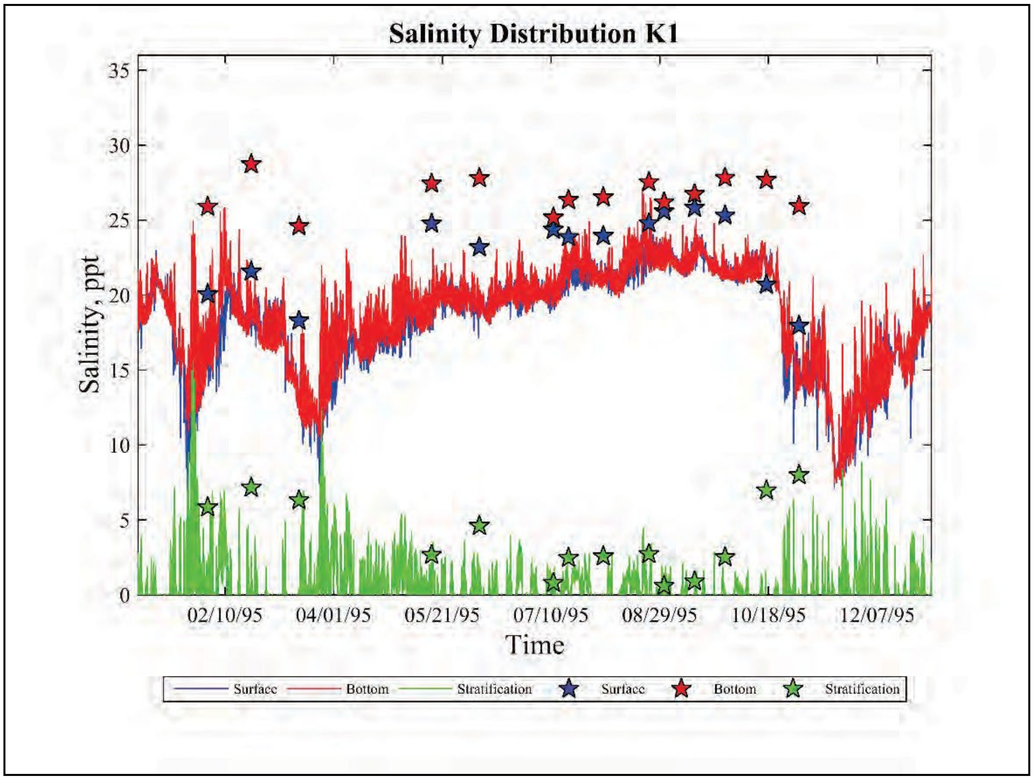


Figure 158. Salinity distribution at K2.

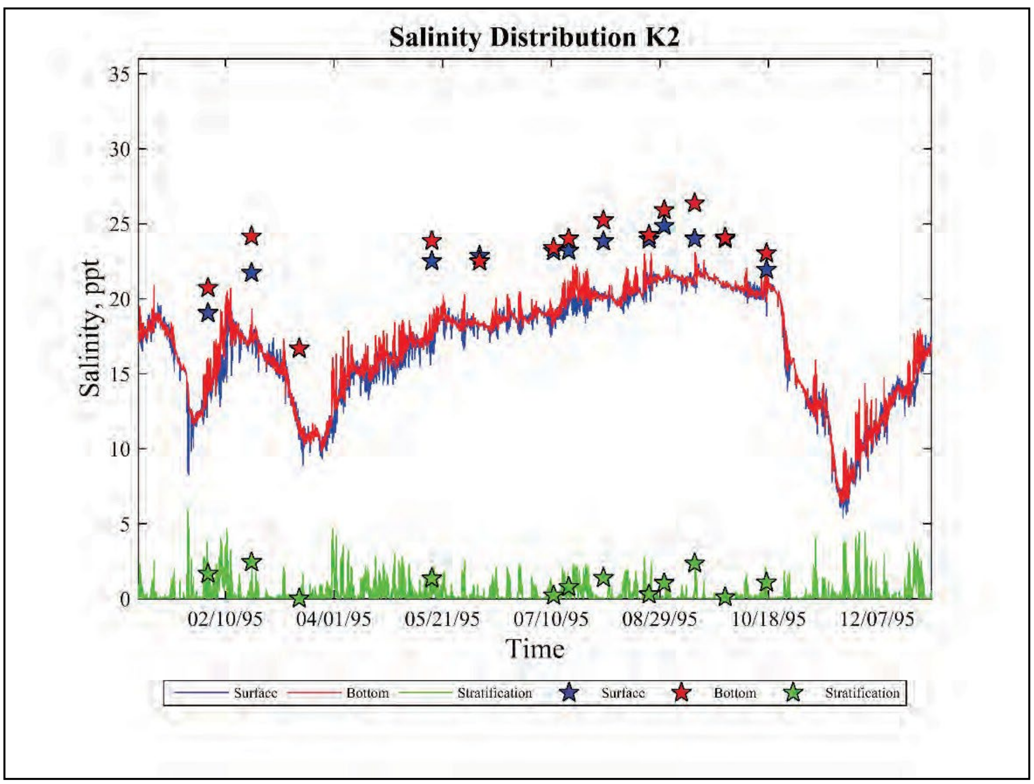


Figure 159. Salinity distribution at K3.

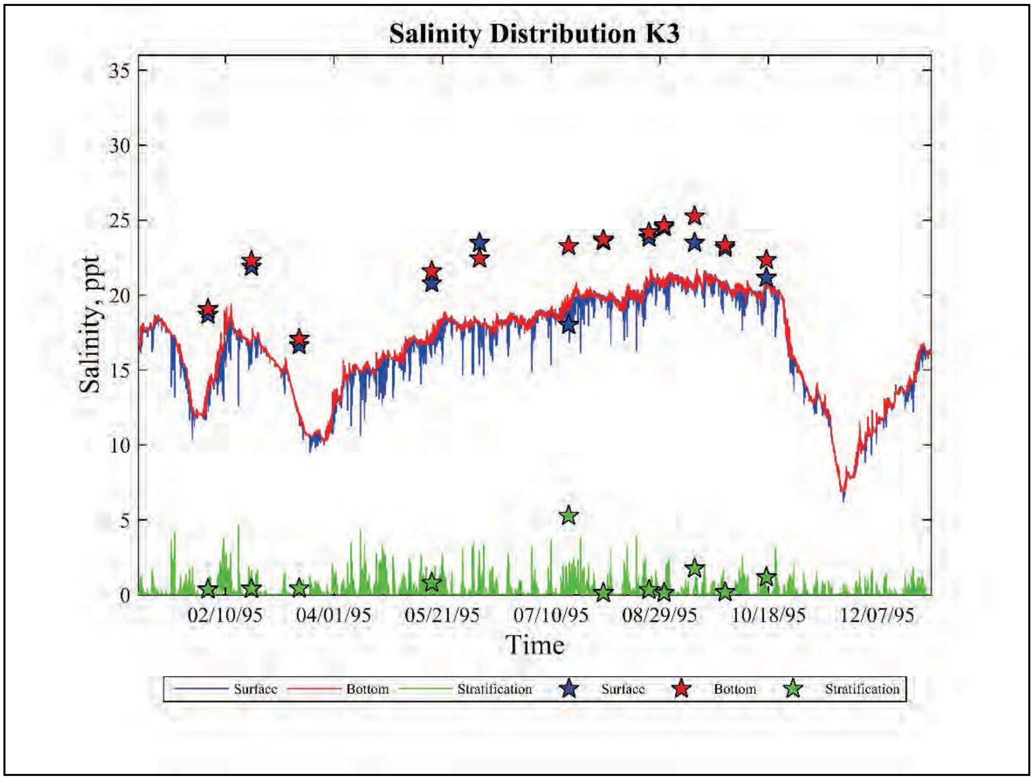


Figure 160. Salinity distribution at K4.

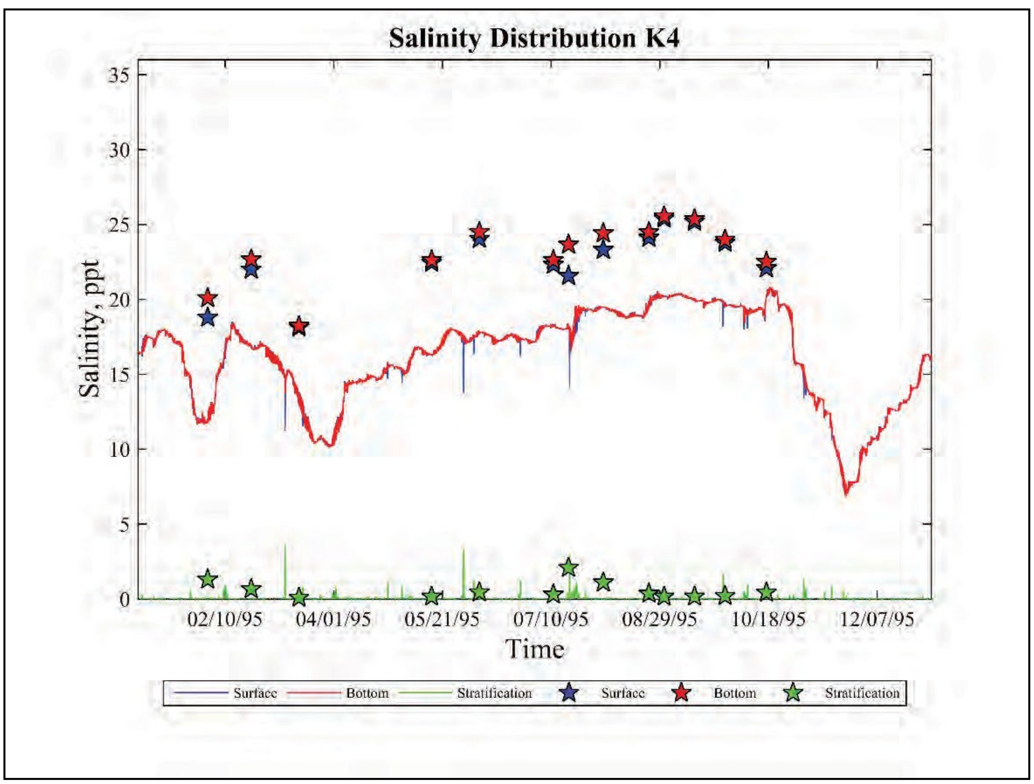


Figure 161. Salinity distribution at K5.

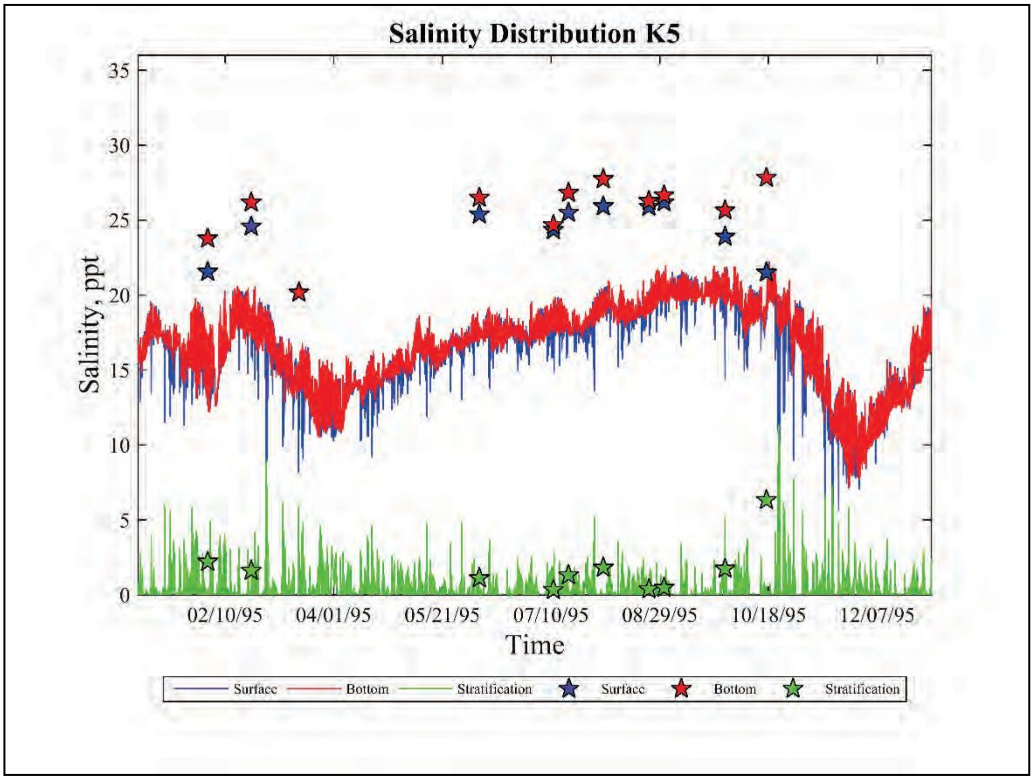


Figure 162. Salinity distribution at K5A.

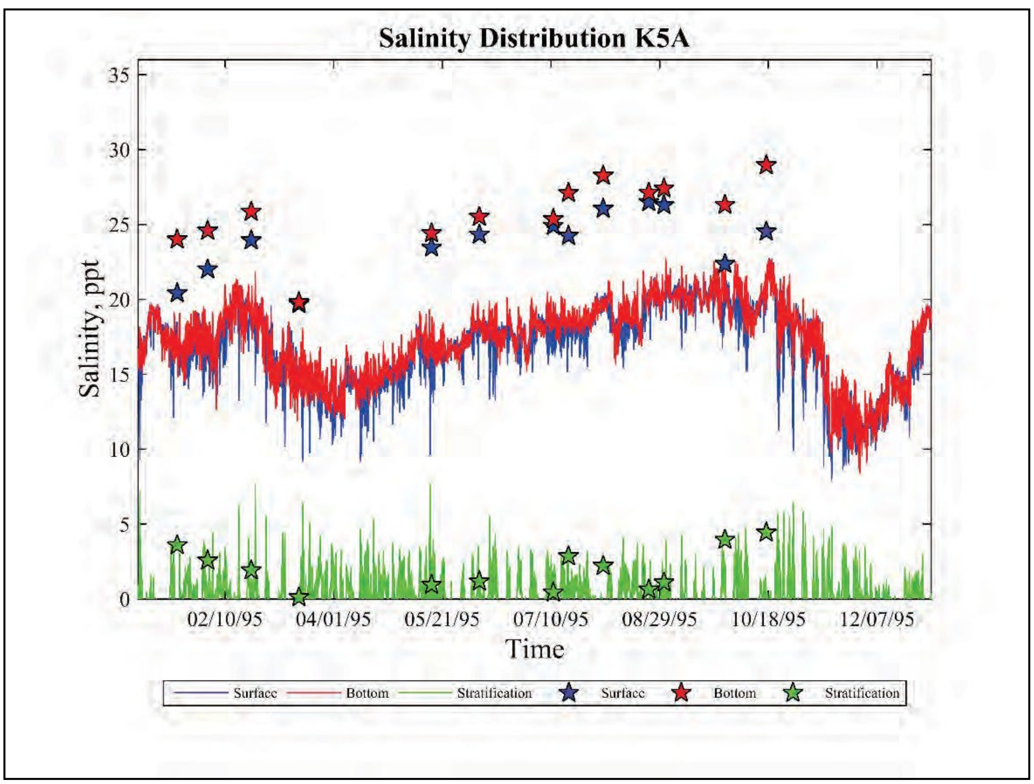


Figure 163. Salinity distribution at K6.

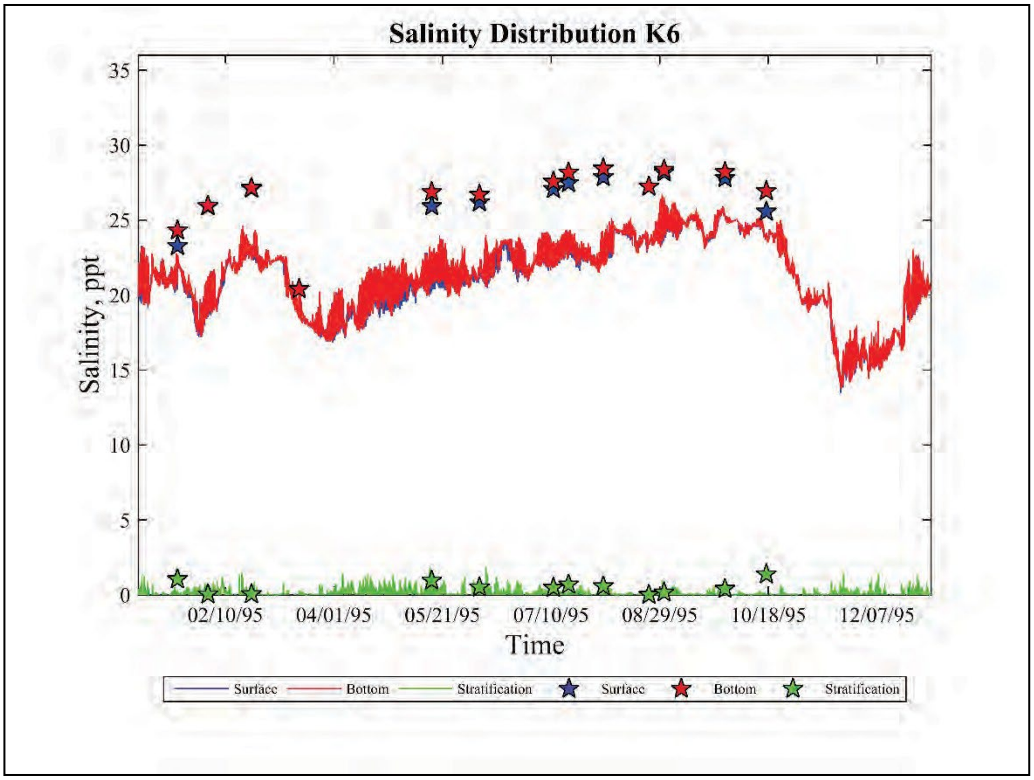


Figure 164. Salinity distribution at N1.

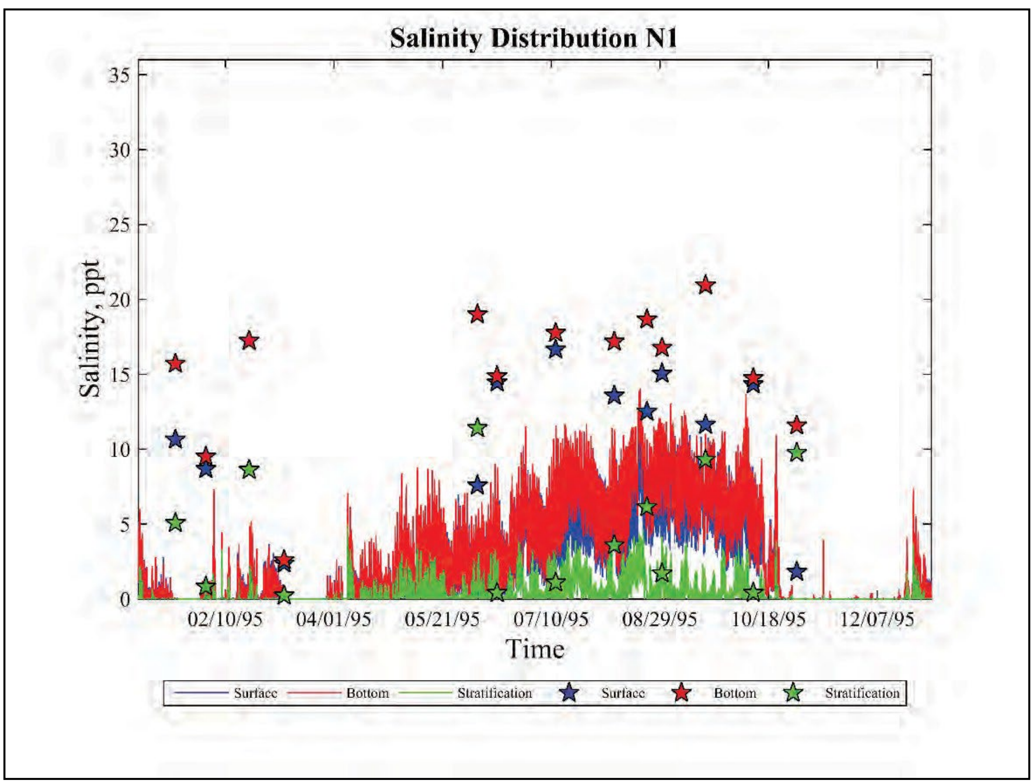


Figure 165. Salinity distribution at N3B.

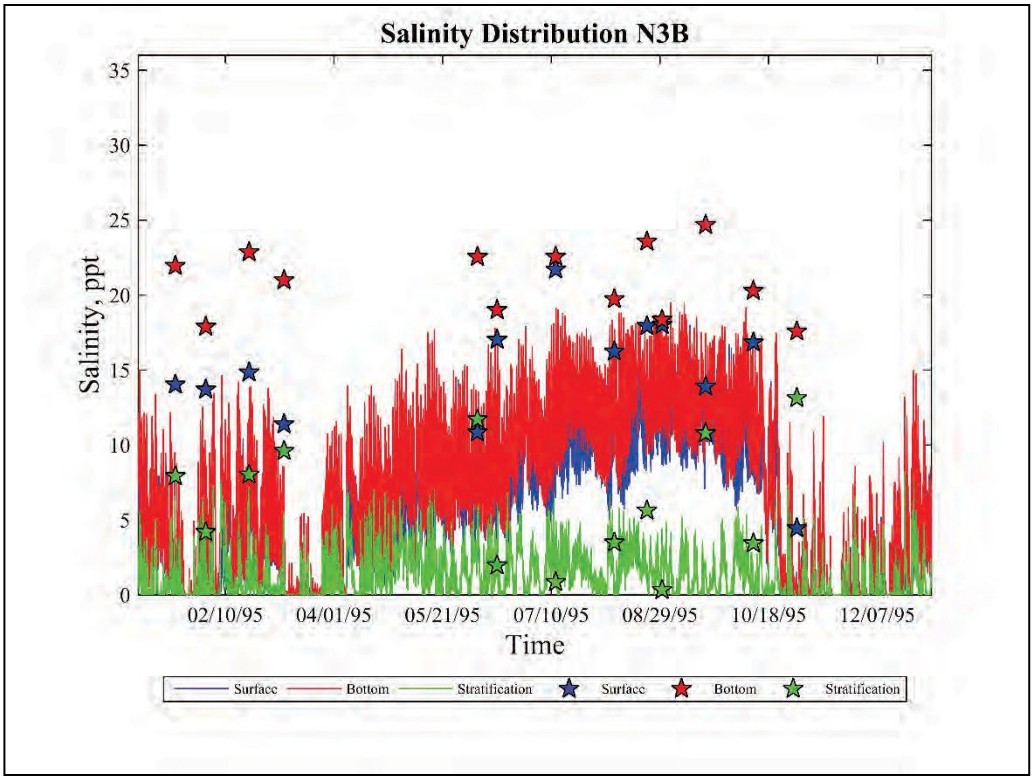


Figure 166. Salinity distribution at N4.

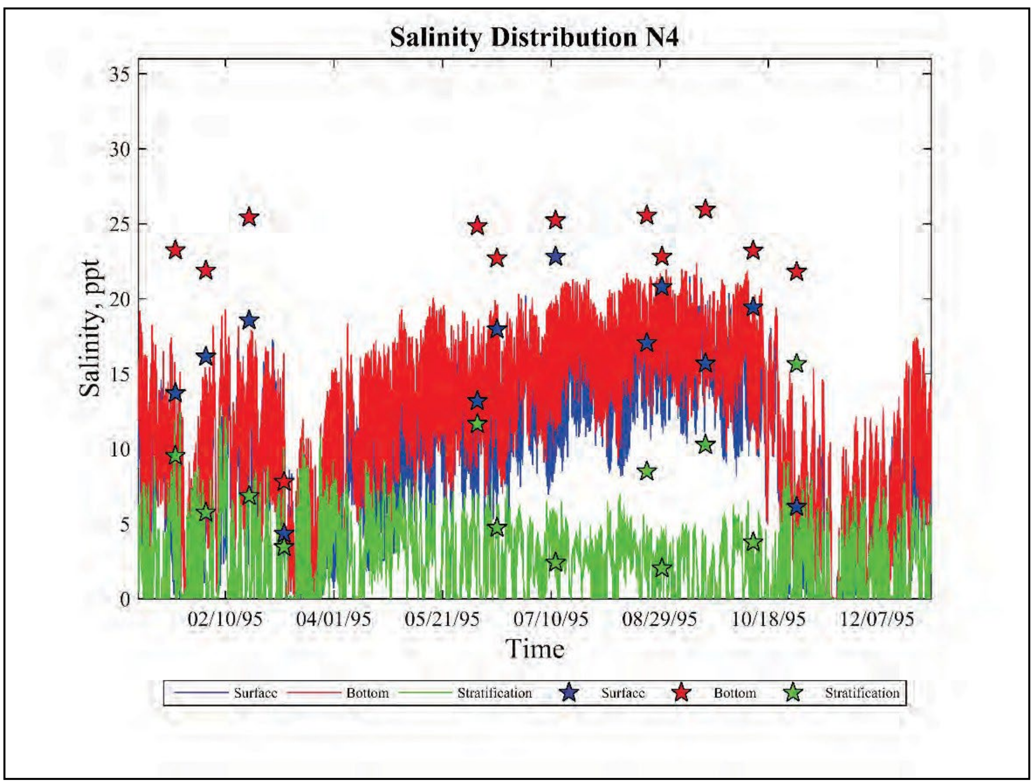


Figure 167. Salinity distribution at N5.

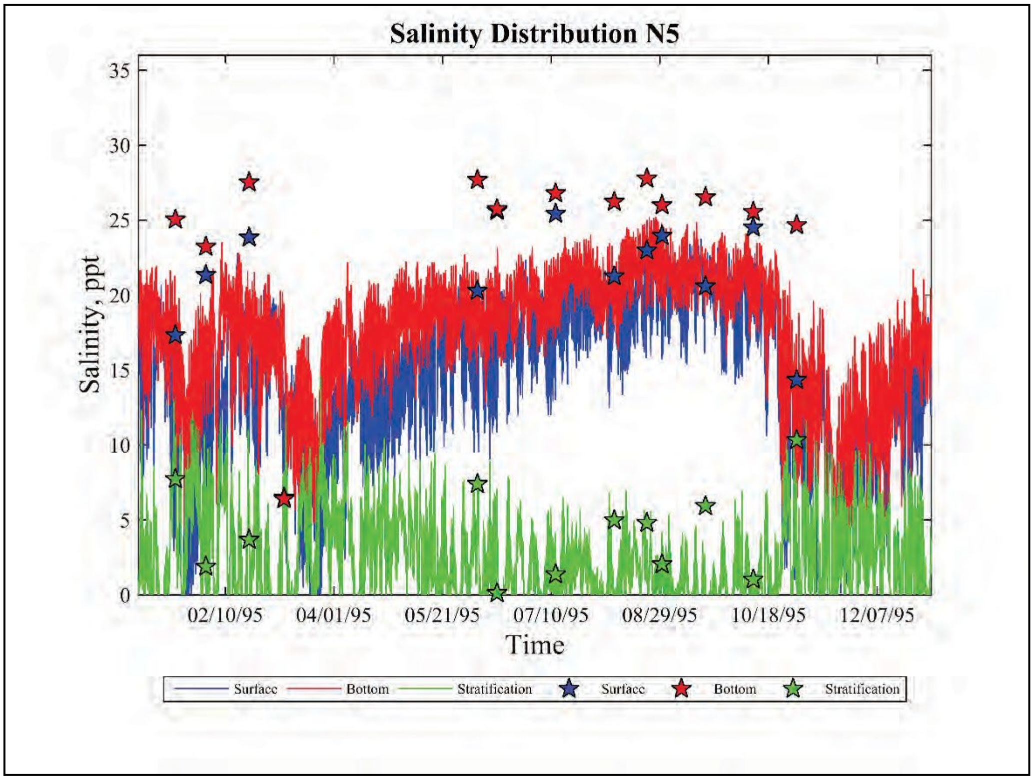


Figure 168. Salinity distribution at N6.

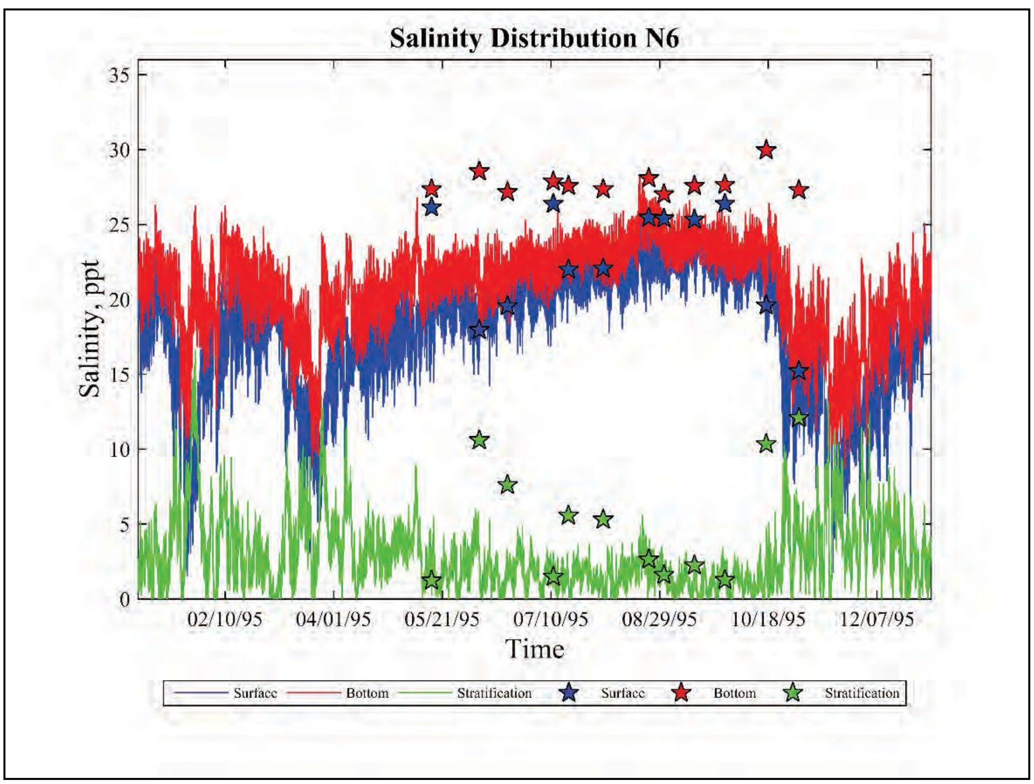


Figure 169. Salinity distribution at N7.

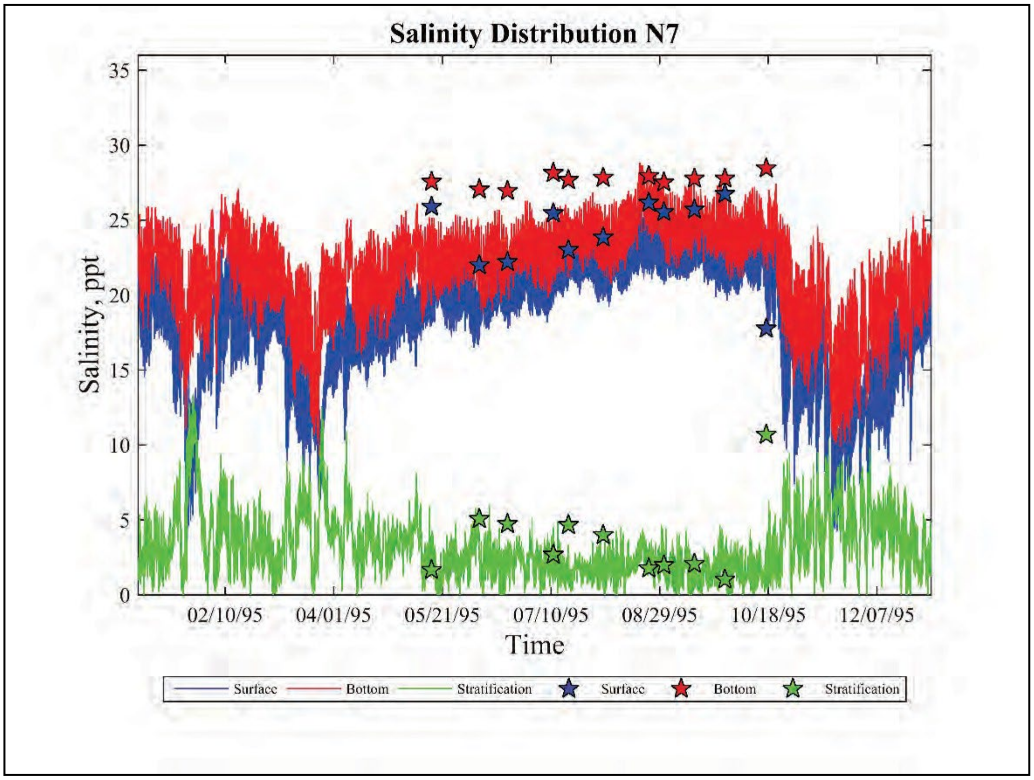


Figure 170. Salinity distribution at N8.

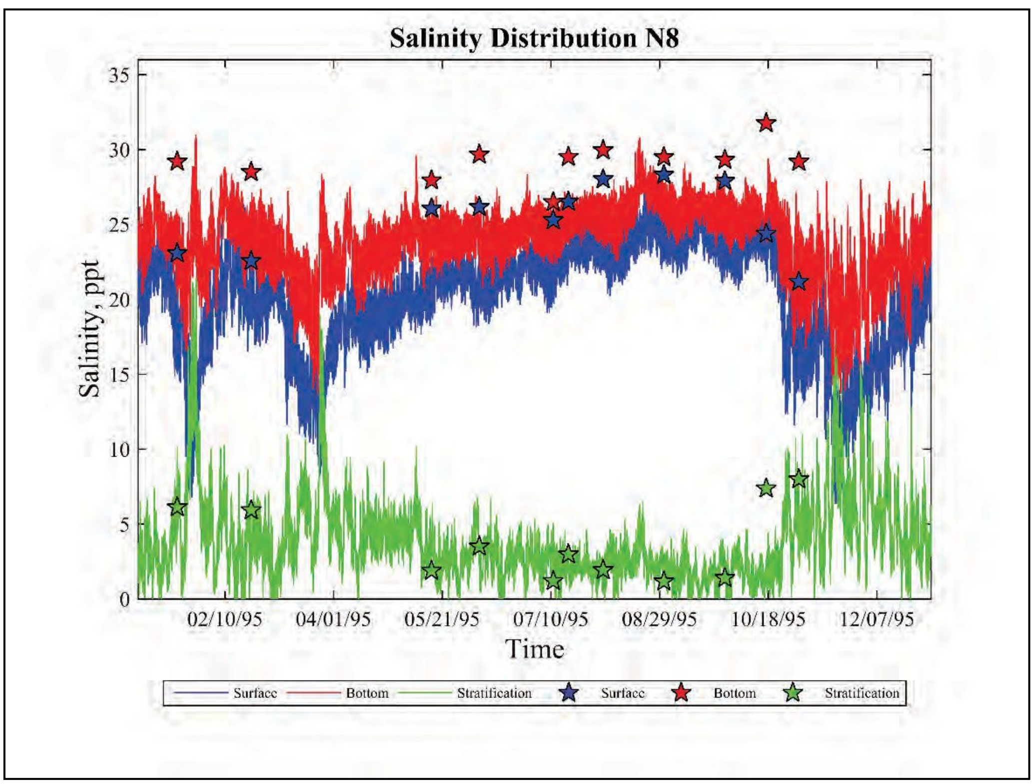


Figure 171. Salinity distribution at N9.

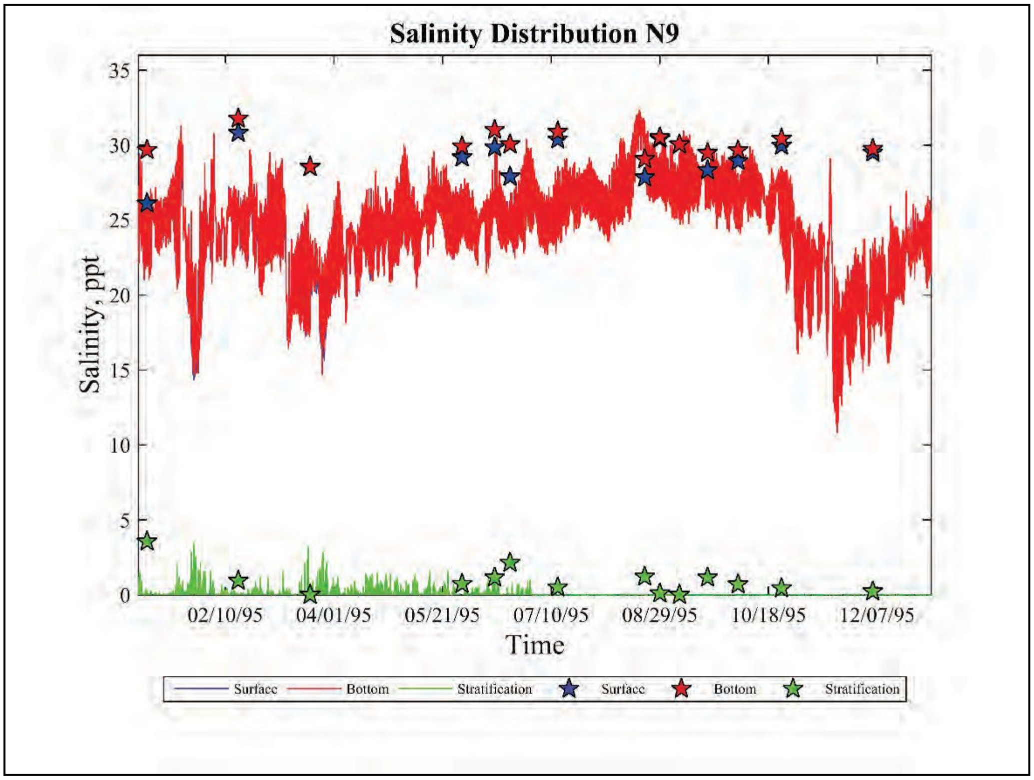


Figure 172. Salinity distribution at N9A.

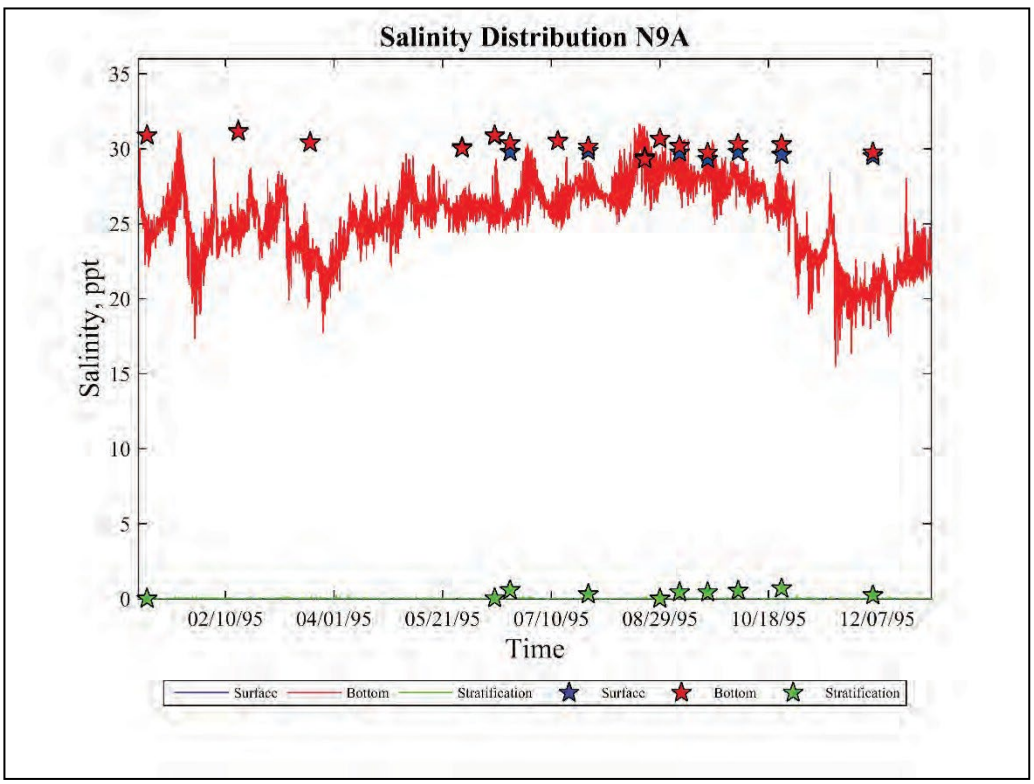


Figure 173. Salinity distribution at N16.

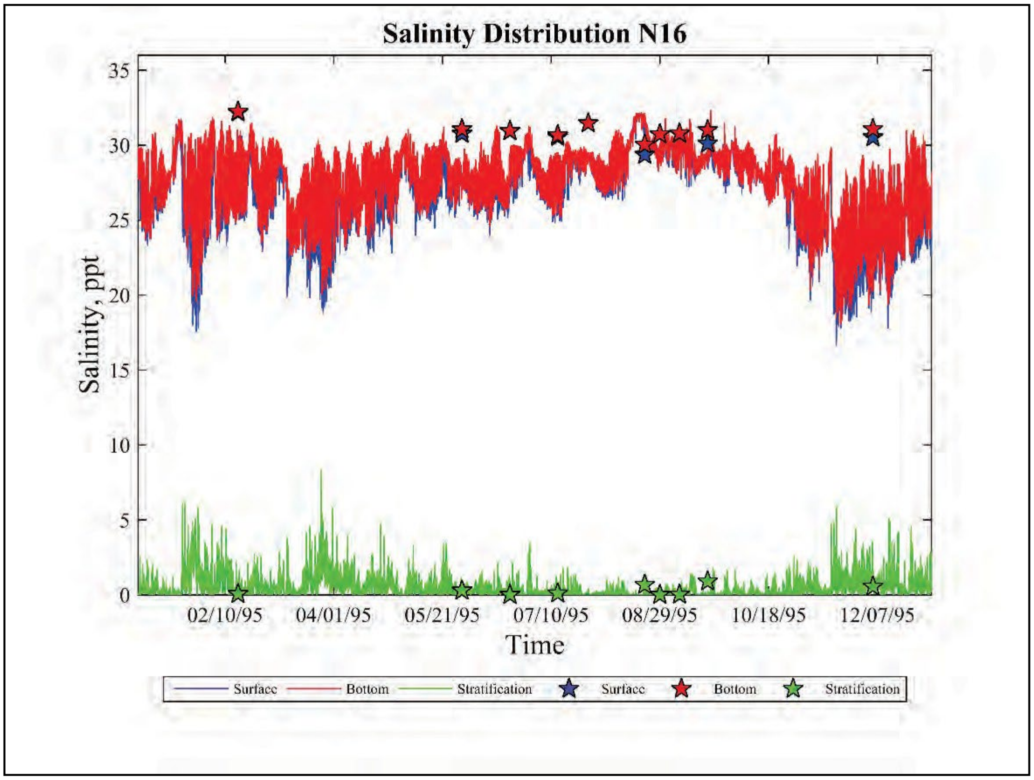


Figure 174. Salinity distribution at PB2.

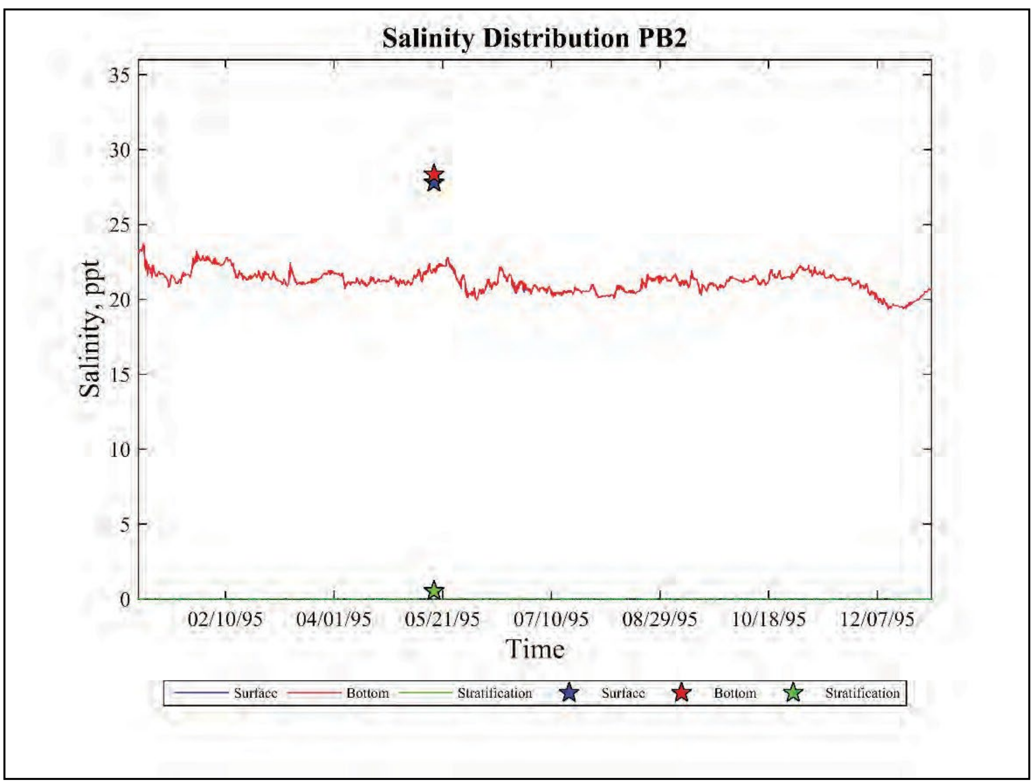
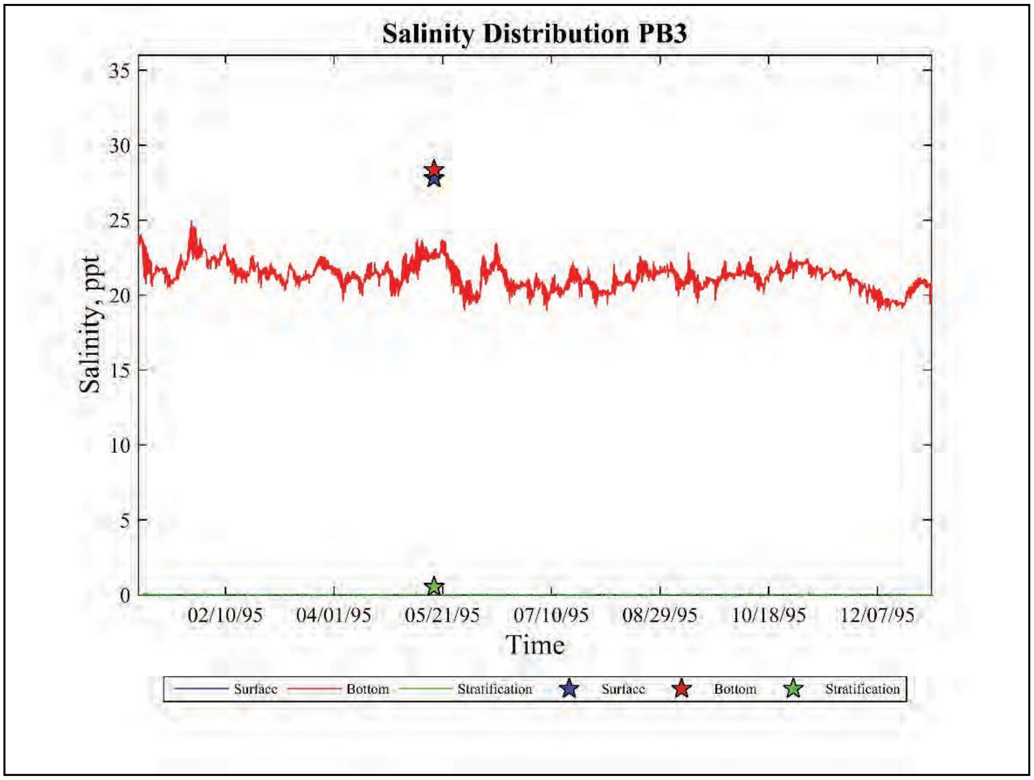


Figure 175. Salinity distribution at PB3.

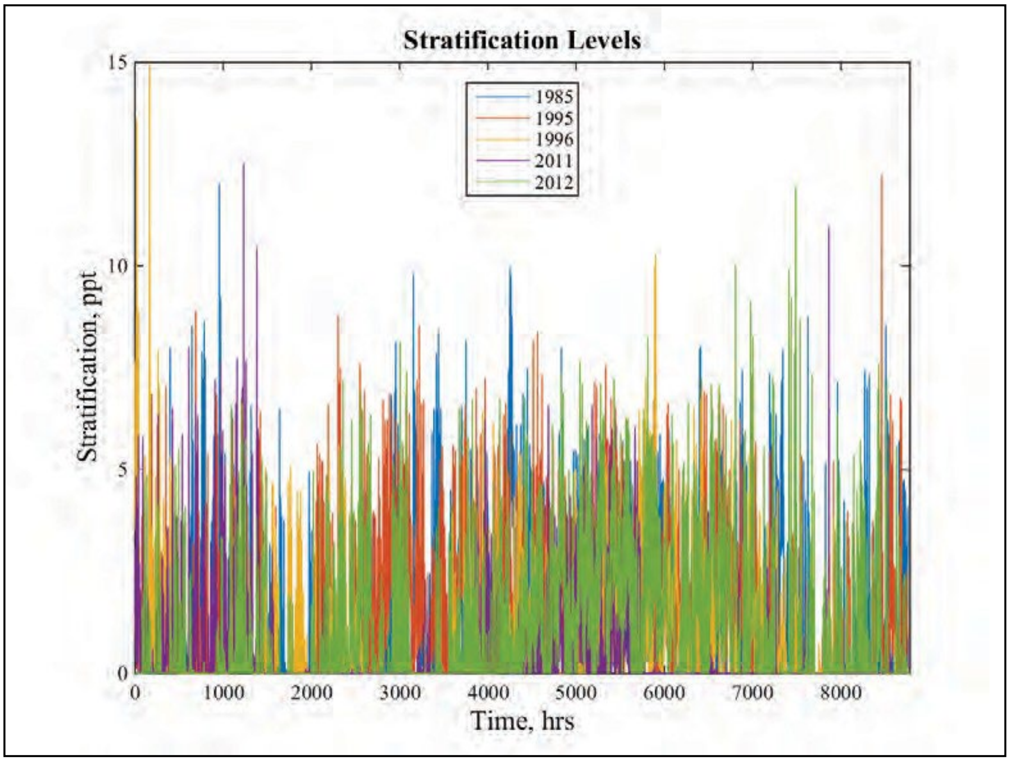


While the absolute surface and bottom salinity values are low in the model as compared to the observations, the stratification levels are adequately replicated. For the purposes of this study, the stratification levels are the primary driver of the density driven circulation that is important for the sediment transport calculations. Therefore the salinity transport results are adequate for the purposes of this study.

Qualitative comparisons

Geyer et al. (2001) reported the Estuarine Tubidity Maximum (ETM) zone is in the lower Hudson River estuary 10–25 km north of The Battery with stratification levels of 0 to 17 ppt at the ETM location. The plot in Figure 176 shows the stratification levels (bottom – surface salinity) values for the five simulated years at a distance of 18 km north of The Battery for the without-project results. While the salinity stratification never reaches 17 ppt, it does occasionally exceed 10 ppt. These stratification levels could possibly be improved with added resolution going up the Hudson River, but since this was not the purpose of this study, the added resolution and associated computational burden was not justified.

Figure 176. Stratification levels on the Hudson River.



3D sediment transport comparisons

Validation of sediment transport models is extremely challenging due to the large uncertainty in the observed results in conjunction with the limited availability of data, both temporally and spatially. It is also highly dependent on previous forcing conditions. As such, sediment transport comparisons are commonly more qualitative in nature.

Dredge volume comparisons

The primary validation metric for the sediment transport model was to ensure the model adequately reproduced the dredge volumes observed in the field. As previously discussed, the average dredge volumes for particular channel reaches were determined based on historical dredge records. Since the purpose of this study is to determine changes in dredge volumes for the with-project and without-project conditions, comparisons to these dredge volumes is a key component in determining the applicability of this model to address the goals of the study. The assumption was made that any deposition in the navigation channel in a given reach would be dredged even if said deposition did not result in channel bed elevations that exceeded the authorized depths.

The five simulated years were averaged to obtain a single *average* dredge volume for each of the reaches and compared to the historical dredge volumes as shown in Figure 177. The without-project mesh was used for the comparisons to the historical data as it was considered more representative of the conditions during these time periods than the with-project mesh. Figure 86 previously shown in Chapter 6 shows the extents of the reaches utilized in the comparisons in Figure 177.

The model computed variation in dredge volumes for the five simulated years for each of these reaches is shown in Figure 178. Year 2011 possesses extremely high dredge volumes for the Newark Bay reaches. This is due to the high Passaic River flows for that year primarily due to Hurricane Irene, which resulted in the entire system experiencing significantly higher flow rates. The Passaic River in particular experienced a flow of almost 24,000 cfs (675 cms), which was the largest flow since the early 1900s. The specification of the Passaic River bed composition allowed for significant erosion along the river due to the extreme flood event resulting in the extreme sediment supply to Newark Bay for that year. The Hudson River flow during Hurricane Irene was almost 160,000 cfs (4,500 cms), which is also one of the largest flowrates of record for the Hudson River. The accuracy of these results is somewhat suspect given the extreme conditions associated with this event (largest Passaic River discharge since the early 1900s and one of the larger Hudson River discharges) and the already discussed uncertainties in the inflowing sediment concentrations and bed characteristics.

The statistics for the annual model dredging estimates for each channel reach are presented in Figure 179 and Table 14. The minimum, maximum, average, average plus one standard deviation and average minus one standard deviation are included in the figure. The variability is defined as the standard deviation divided by the average, expressed as a percent. The variability ranges from 8% to 88% and averages 42% over all the channel reaches.

Figure 177. Dredge volume comparisons (without project versus historical rates).

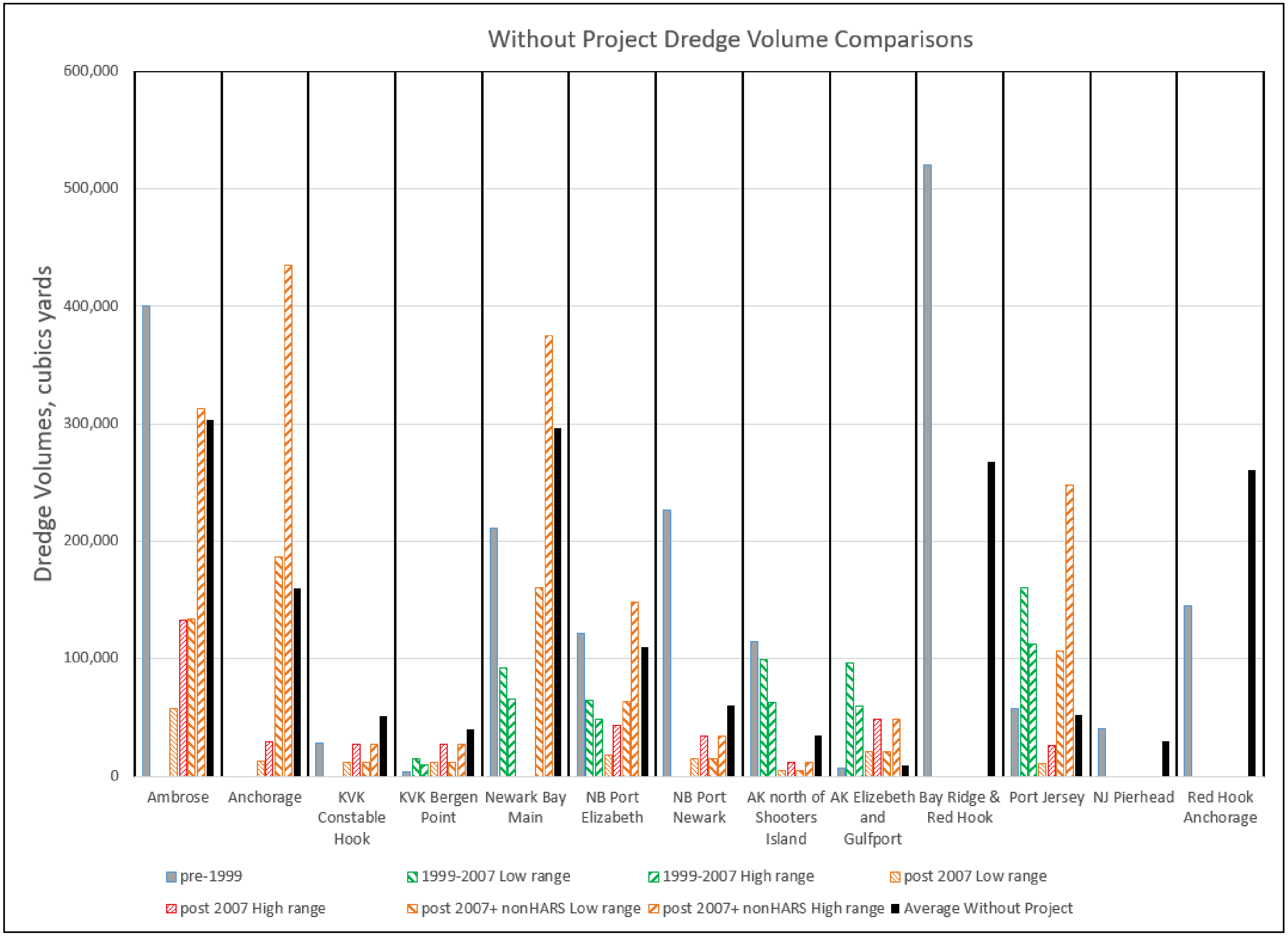


Figure 178. Variation in dredge volumes for the five simulated years (model results).

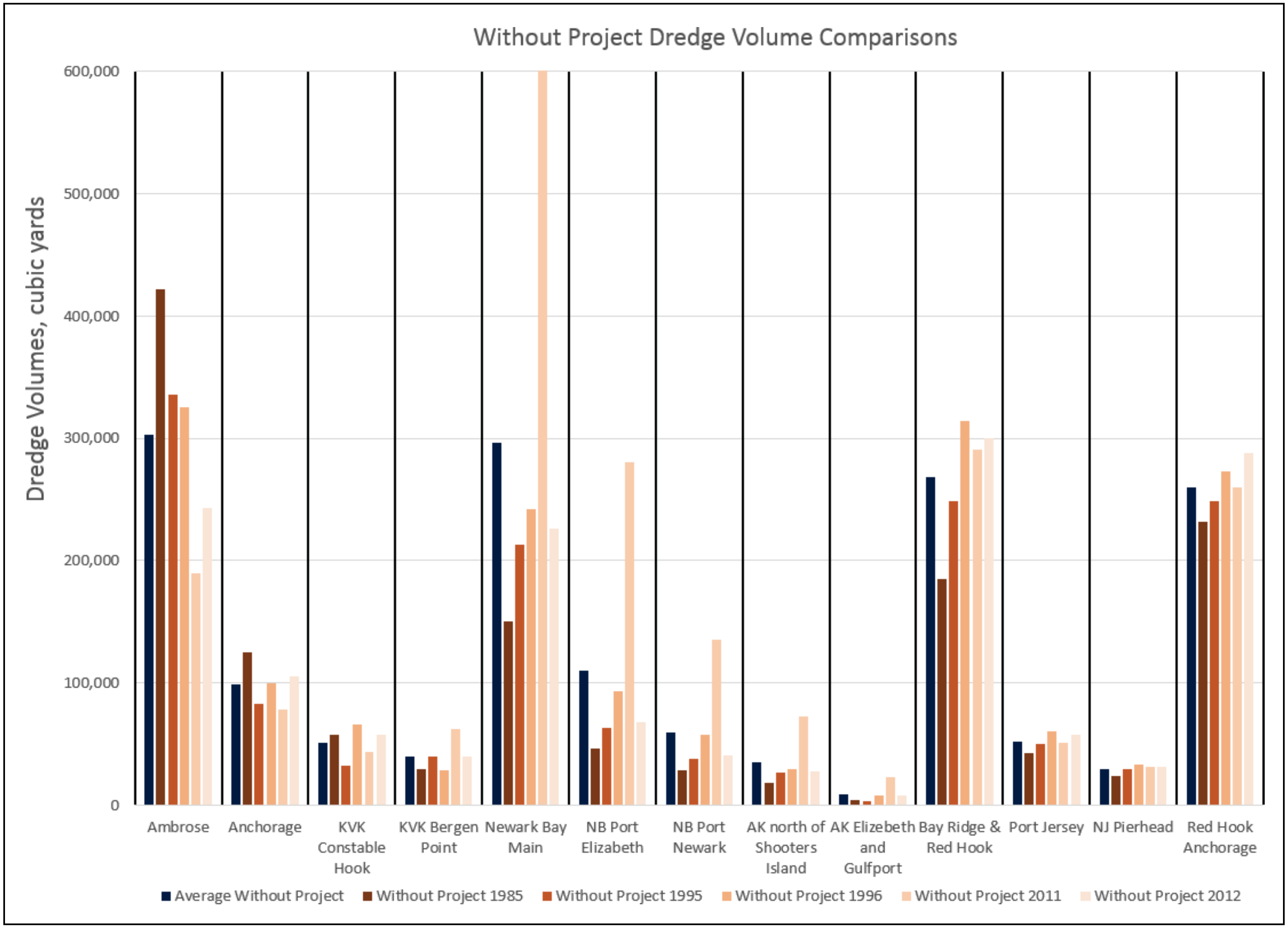


Figure 179. Statistics for the model range of dredging estimates.

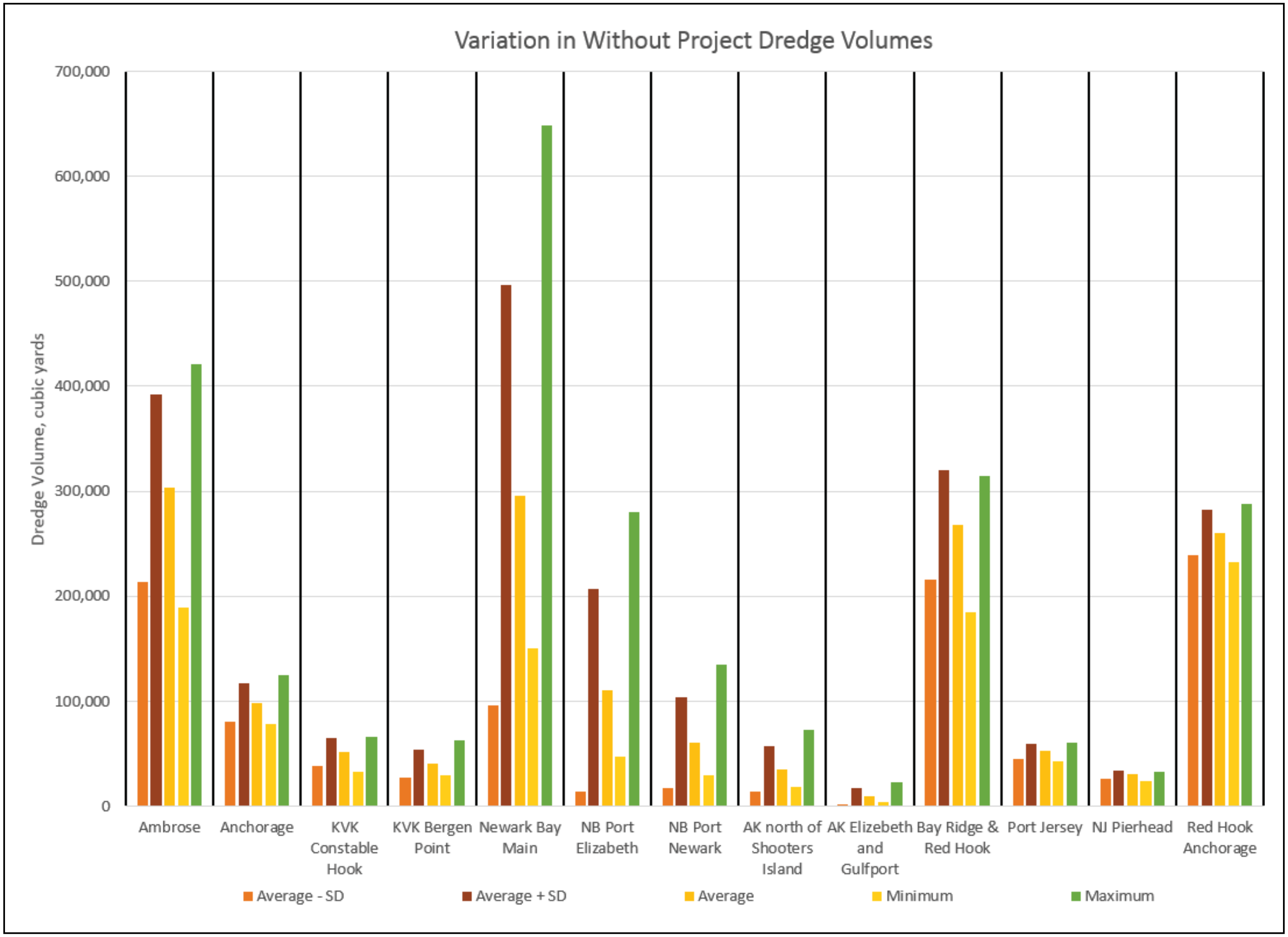


Table 14. Statistics for model estimations of annual dredging volumes in cy.

Channel	Minimum	Maximum	Average	Standard Deviation	Average - Std. Dev.	Average + Std. Dev.	Percent Variability
Ambrose	189,231	421,499	302,938	89,629	213,309	392,567	30
Anchorage	78,489	124,655	98,259	18,588	79,670	116,847	19
Kill van Kull Constable Hook	31,926	65,632	51,302	13,394	37,909	64,696	26
Kill van Kull Bergen Point	28,599	61,998	39,840	13,407	26,433	53,247	34
Newark Bay (NB) Main	150,510	648,677	296,064	200,147	95,917	496,211	68
NB Port Elizabeth	46,599	280,325	110,043	96,618	13,425	206,661	88
NB Port Newark	28,605	134,982	59,791	43,275	16,516	103,066	72
AK north of Shooters Island	18,194	72,937	35,082	21,624	13,458	56,706	62
AK Elizabeth and Gulfport	3,625	22,958	9,198	7,958	1,240	17,156	87
Bay Ridge & Red Hook	184,952	314,602	267,907	52,482	215,425	320,389	20
Port Jersey	42,073	60,549	52,147	7,124	45,024	59,271	14
NJ Pierhead	23,844	32,828	29,843	3,556	26,287	33,399	12
Red Hook Anchorage	231,985	287,755	260,258	21,558	238,700	281,816	8

Sediment core comparisons

The New York District collected some sediment cores during 2012. These are point location data and as such are less likely to provide favorable model to field comparisons due to the model being inherently less accurate at a particular spatial and temporal point. Since the sediment results at a location can be very dependent on the previous forcing conditions in the system, these observations were compared to both the 2011 and 2012 model simulations. The sediment breakdown (fines versus sands) for the entire 2011 and 2012 years are plotted versus the single core observation at the points in Figure 180 (comparisons in Figure 181 to Figure 183), Figure 184 (comparisons in Figure 185 to Figure 187), Figure 188 (comparisons in Figure 189 to Figure 191), and Figure 192 (comparisons in Figure 193 and Figure 194). Comparisons for the remaining locations are provided in Appendix C.

The figures include a breakdown of the accumulated sediment (labeled “Model Fines” and “Model Sands” along with the distribution of the superficial bed sediment composition (“Model Fines (Top)” and “Model Sands (Top)”). The superficial results would be equivalent to a surface grab comparison and are included to illustrate the variability in the surface sediment distributions. The “sediment ratio” is defined as the percentage of the size fraction for the fines and the sands.

There is a distinct difference in the model results for 2011 as opposed to 2012. This is due to 2011 being a much higher flow year than 2012. In reality, the higher-than-normal 2011 flows impacted the 2012 bed distributions, but in these model results, 2011 had no impact on the 2012 results and as such could explain why 2011 compares much better to the observations in Newark Bay. Note that extreme events can significantly alter the bed composition at a location. This is evident in the model results for Hurricane Irene in 2011 and Hurricane Sandy in 2012.

For times/locations that possess no deposited sediment, the sediment ratio is set to 50%.

Figure 180. Sediment core locations in Upper Bay.

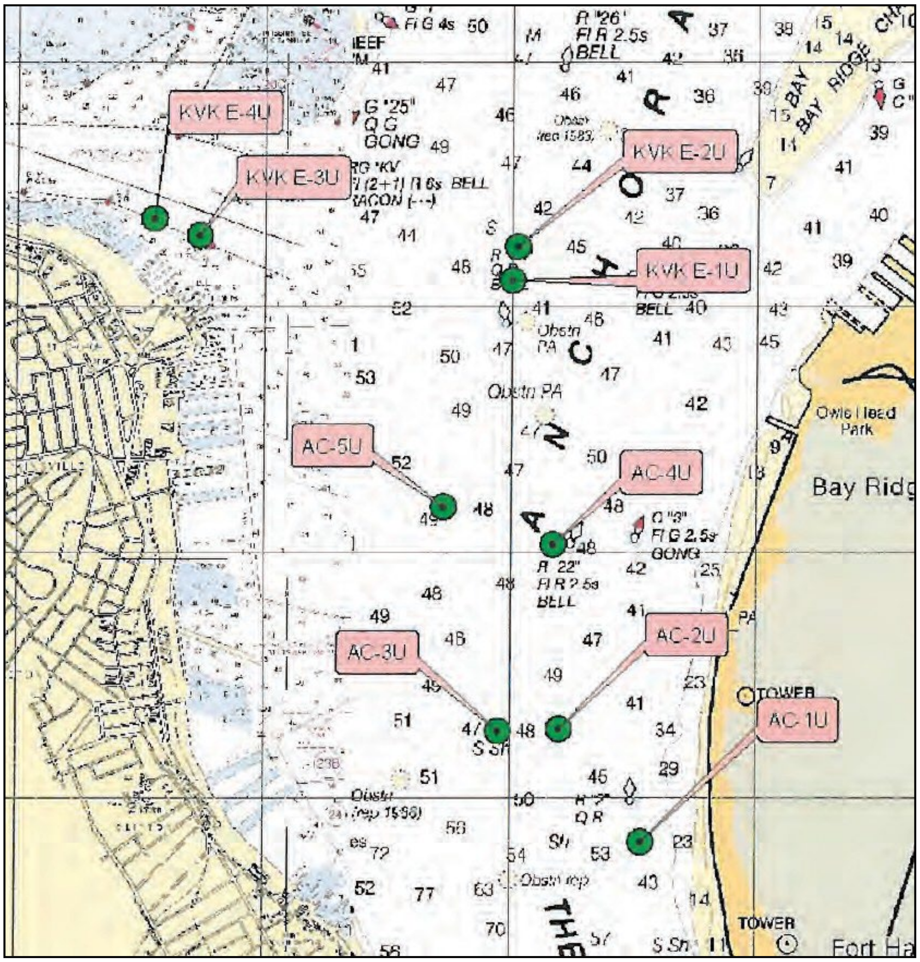
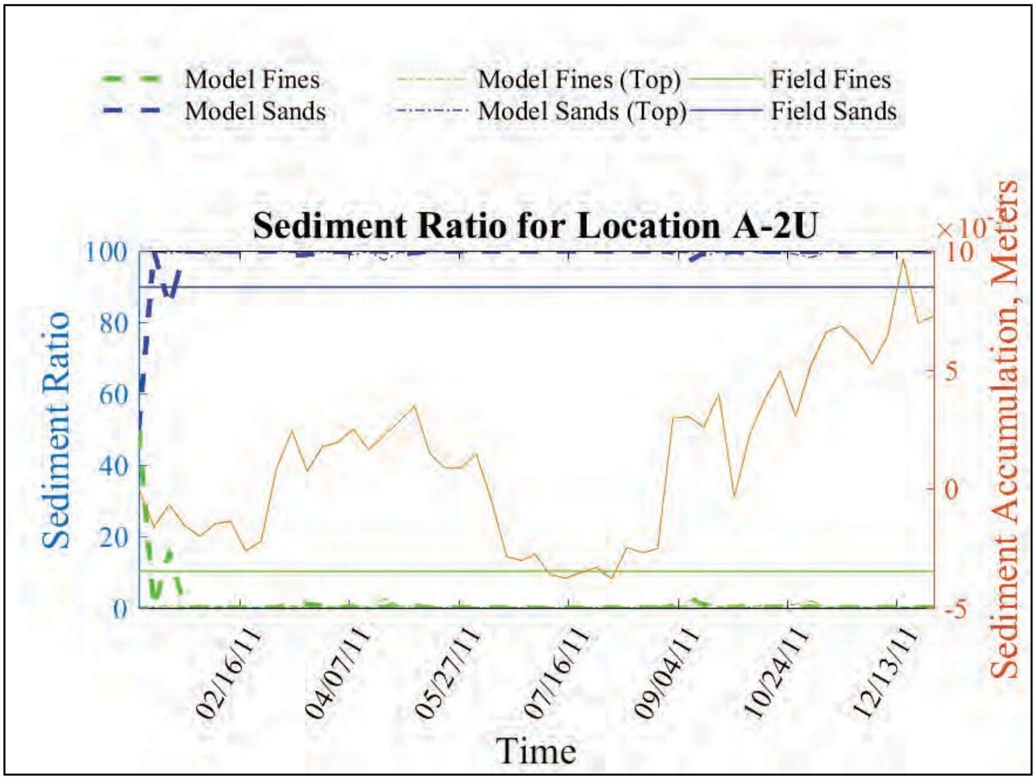


Figure 181. Sediment bed composition comparisons at Location A-2U for 2011 (top) and 2012 (bottom).



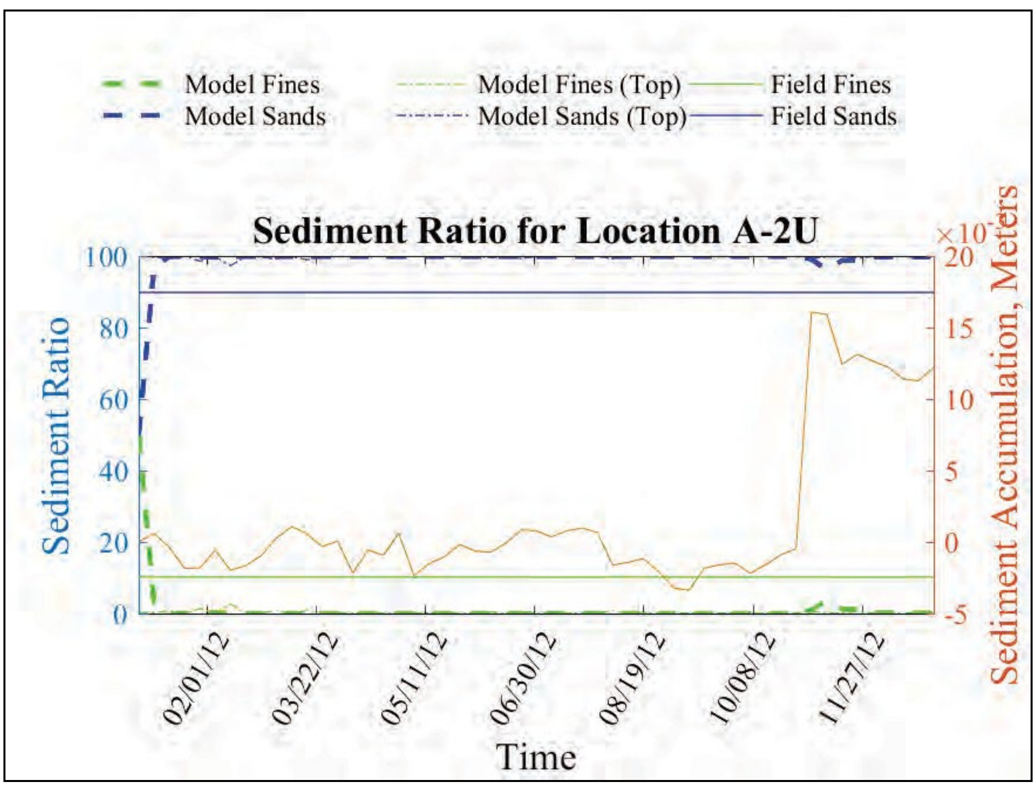


Figure 182. Sediment bed composition comparisons at Location E-1U for 2011 (top) and 2012 (bottom).

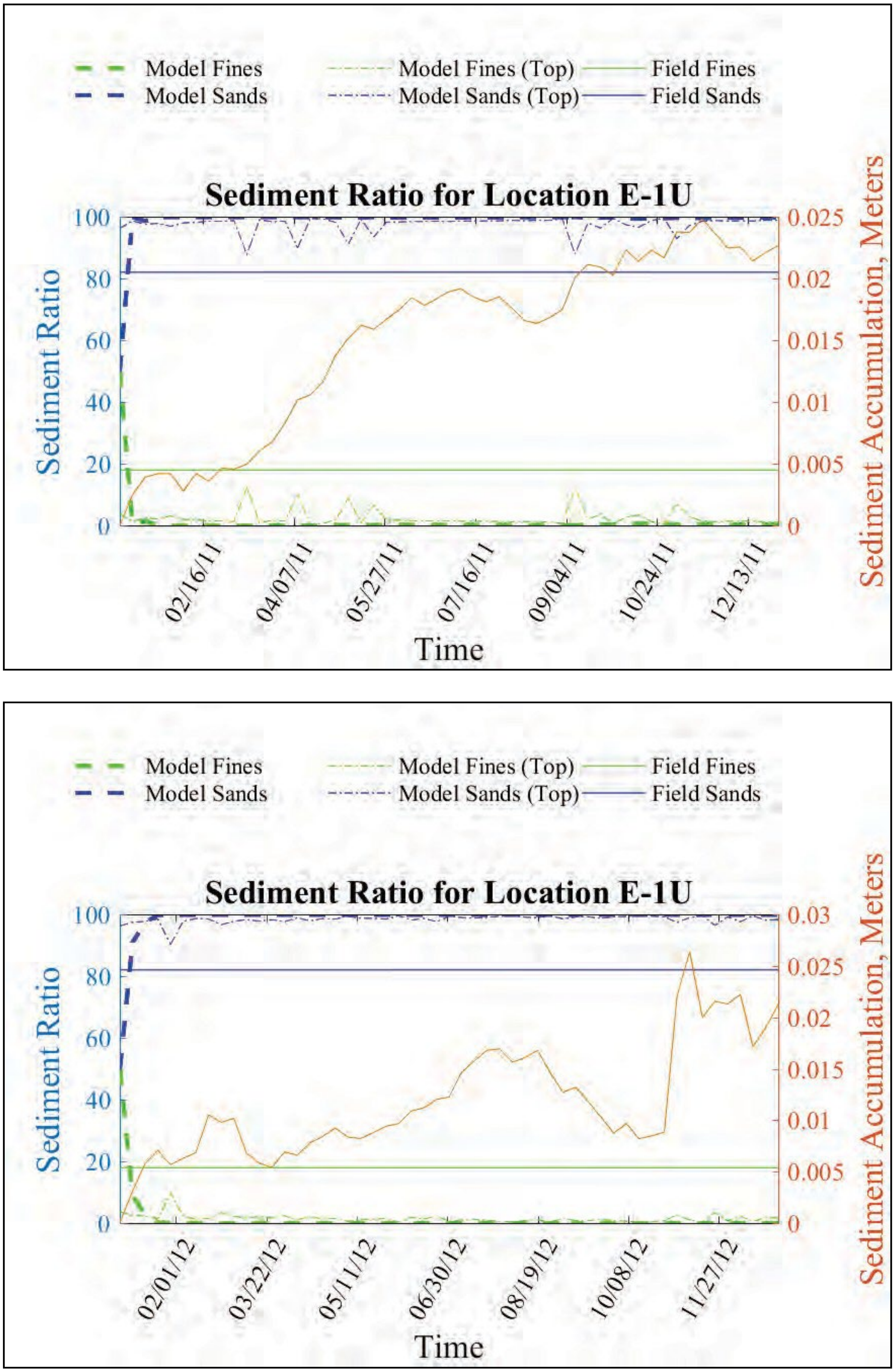
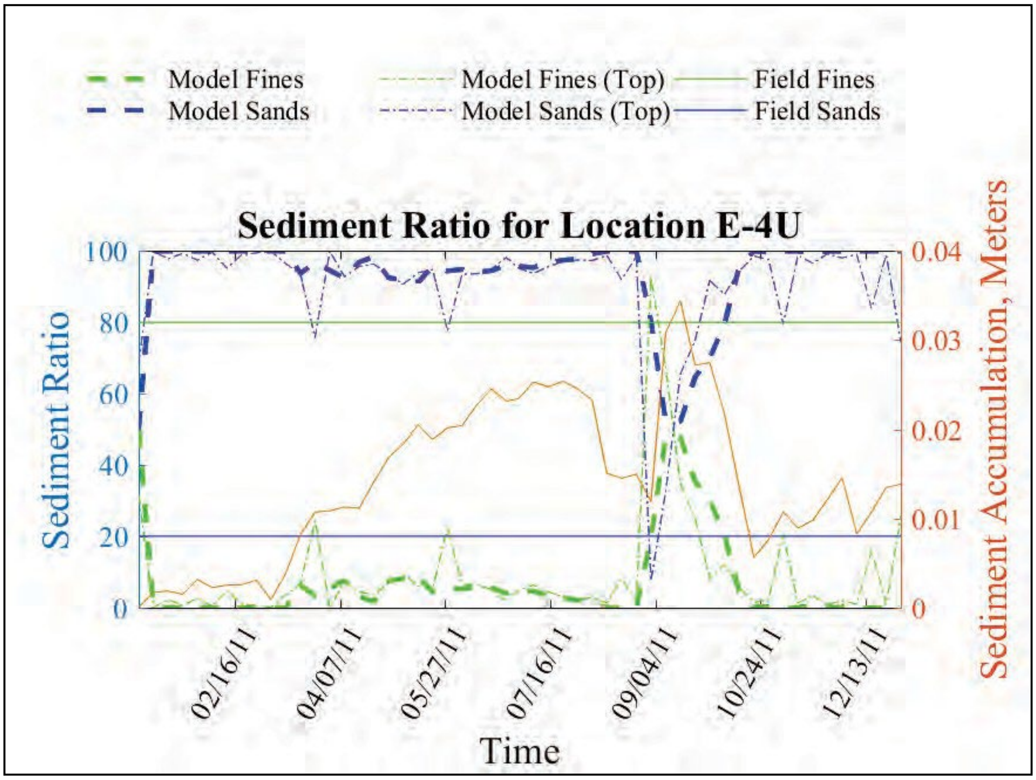


Figure 183. Sediment bed composition comparisons at Location E-4U for 2011 (top) and 2012 (bottom).



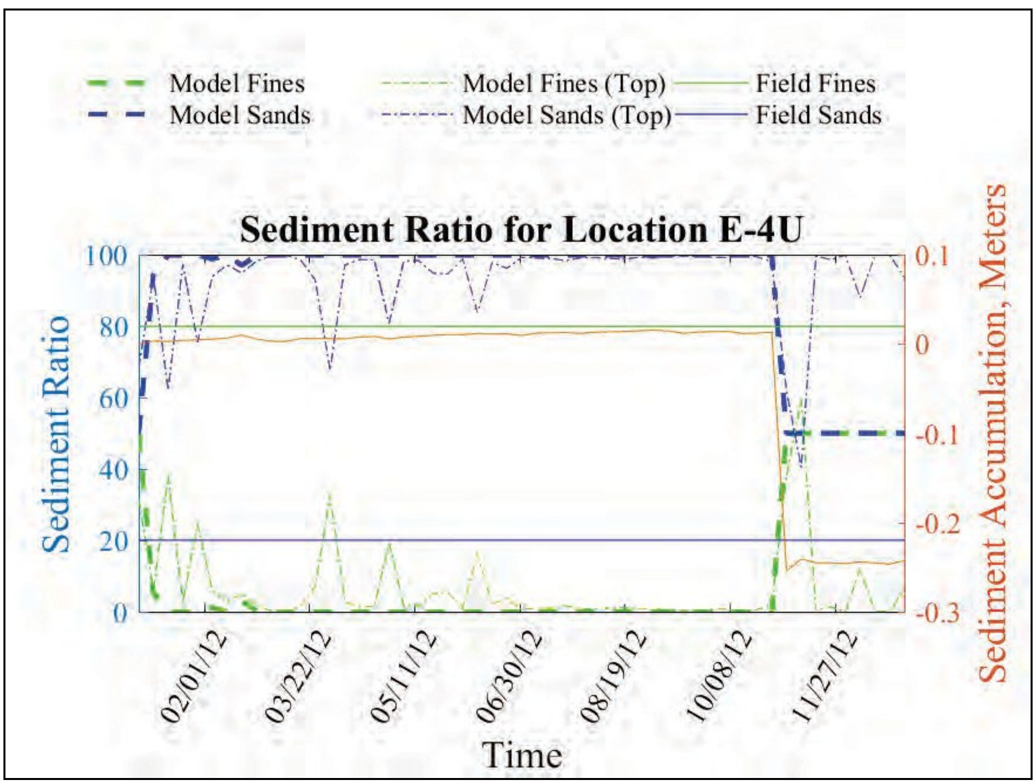


Figure 184. Sediment core locations in western Kill van Kull and southern Newark Bay.

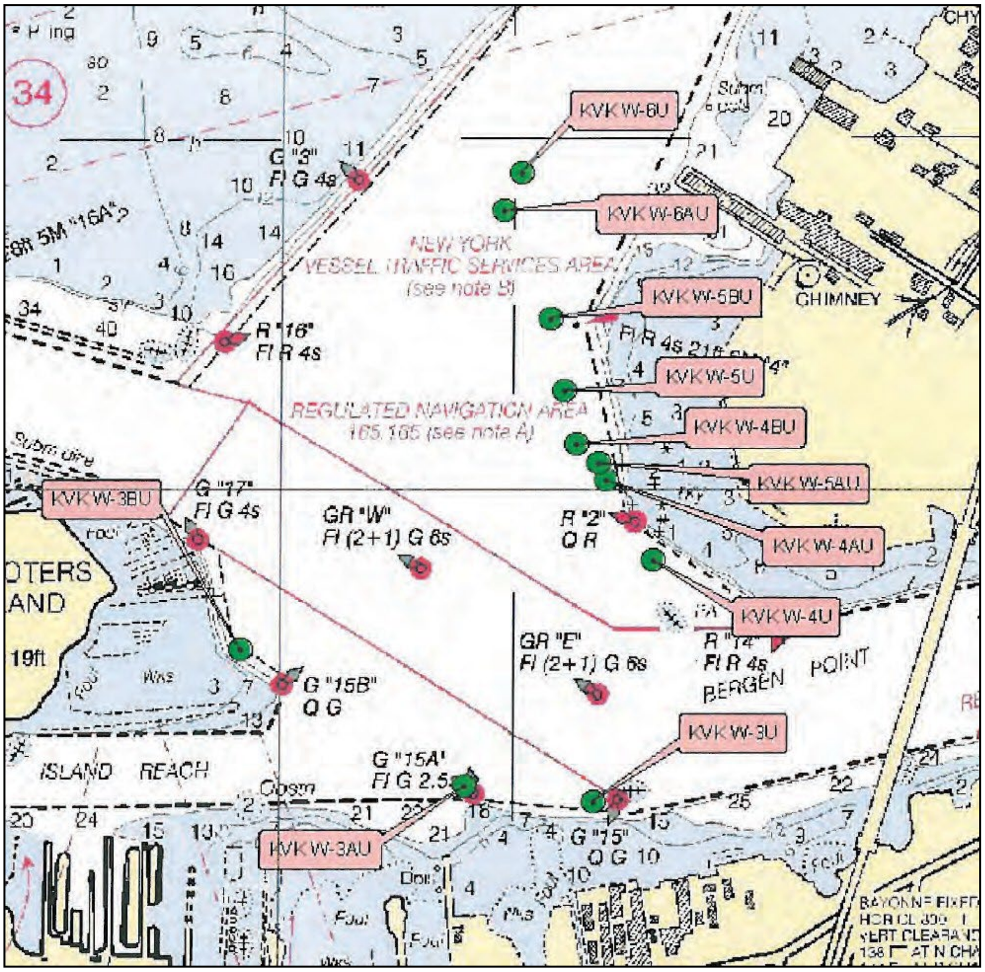
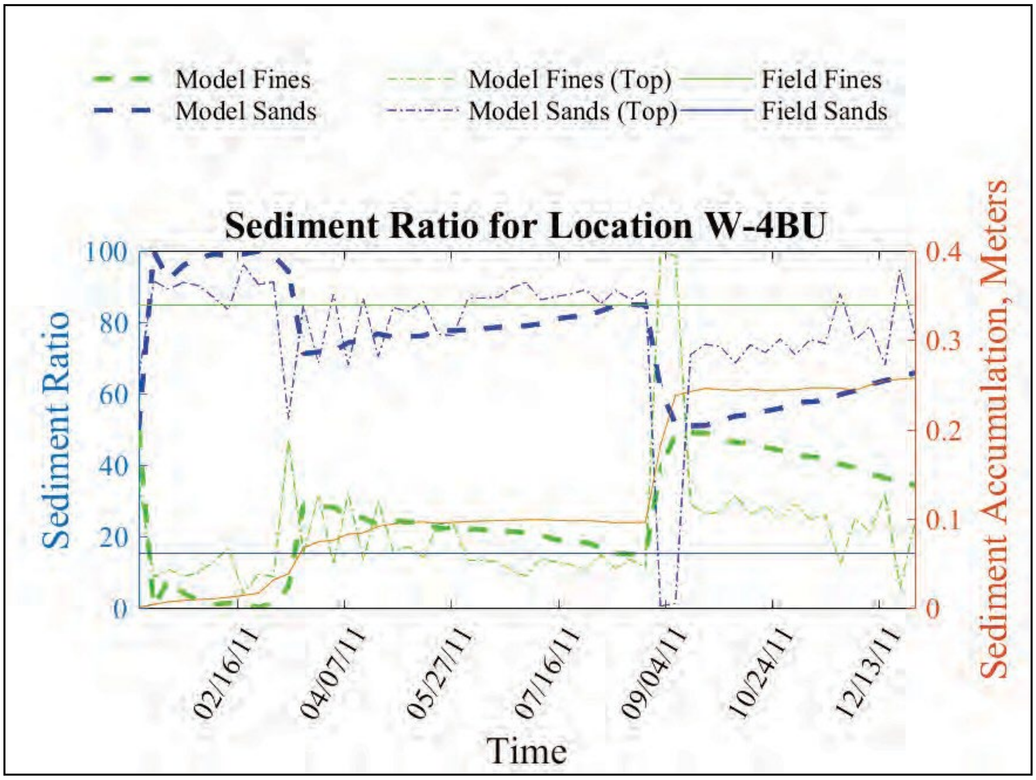


Figure 185. Sediment bed composition comparisons at Location W-4BU for 2011 (top) and 2012 (bottom).



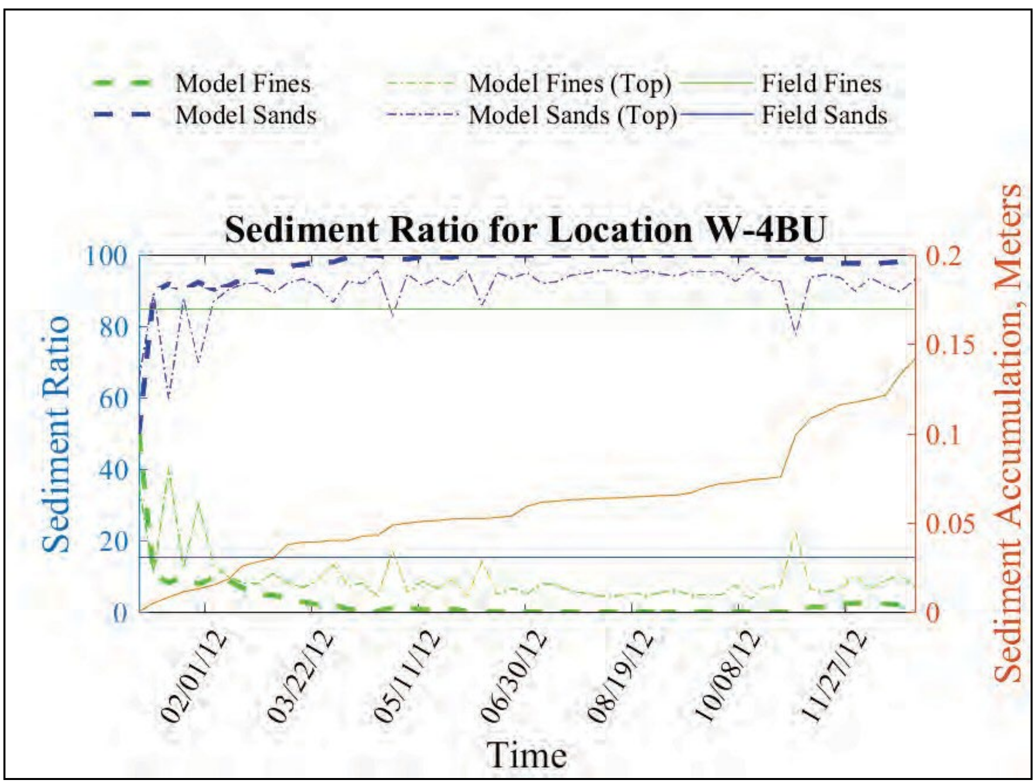
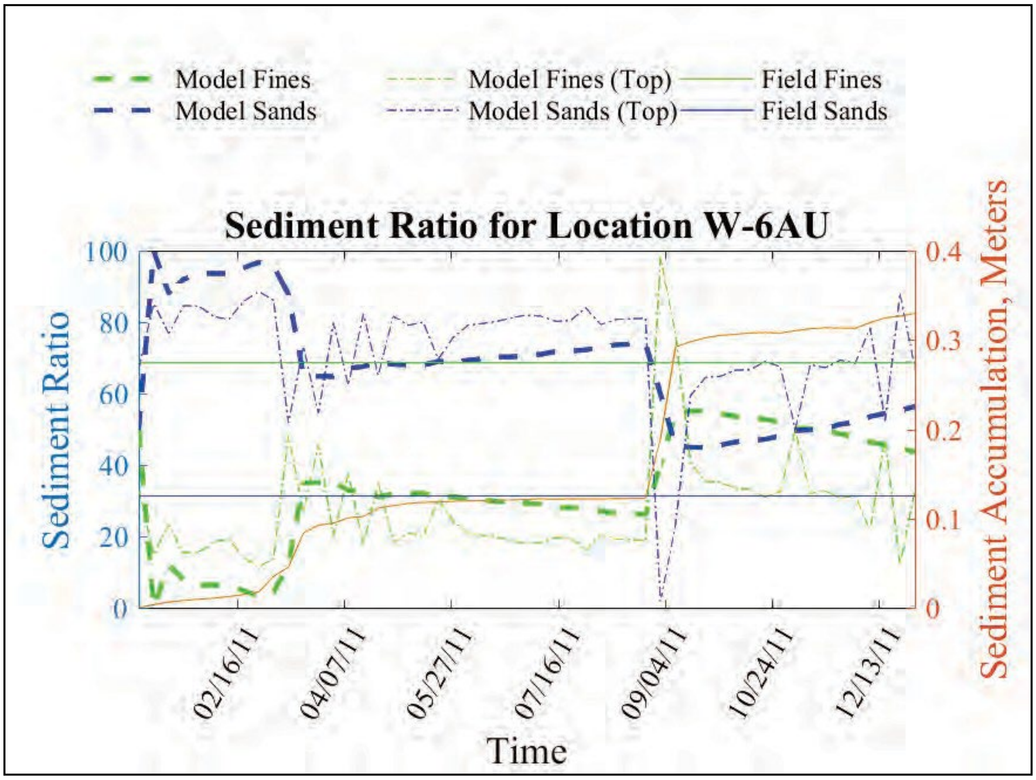


Figure 186. Sediment bed composition comparisons at Location W-6AU for 2011 (top) and 2012 (bottom).



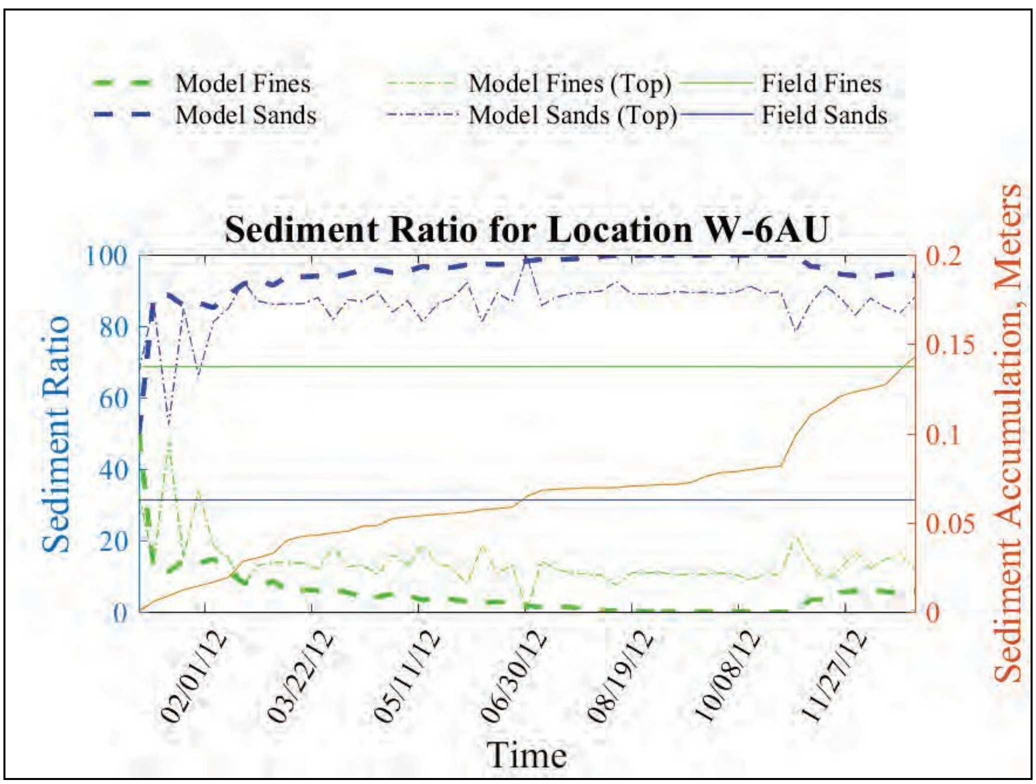
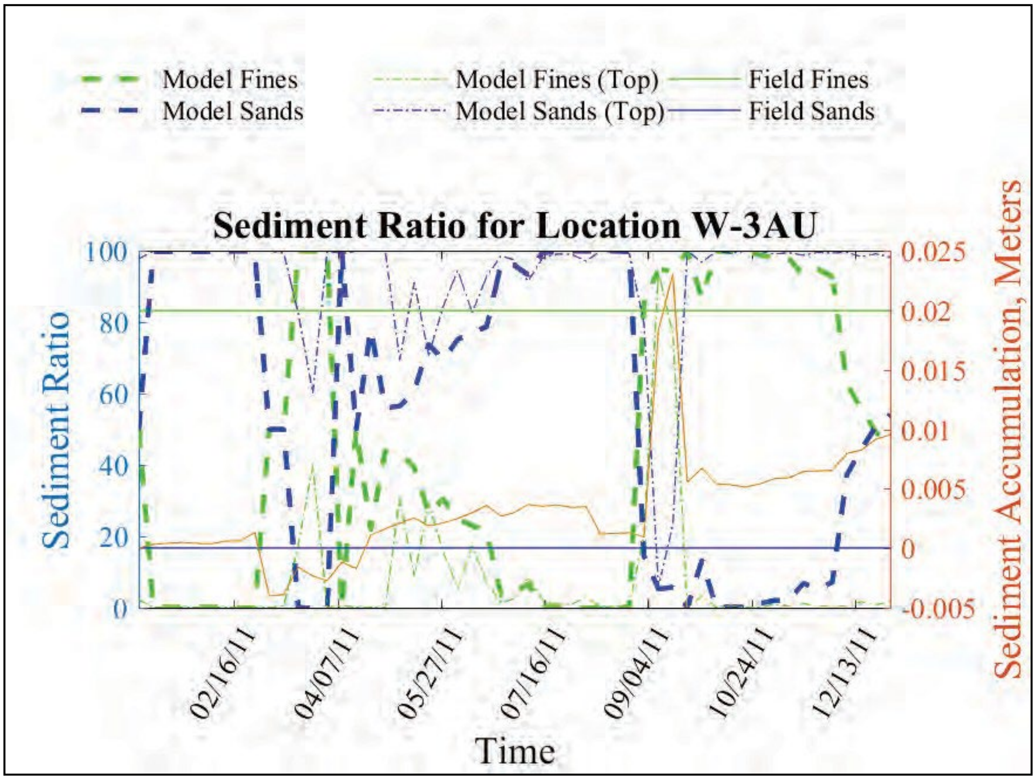


Figure 187. Sediment bed composition comparisons at Location W-3AU for 2011 (top) and 2012 (bottom).



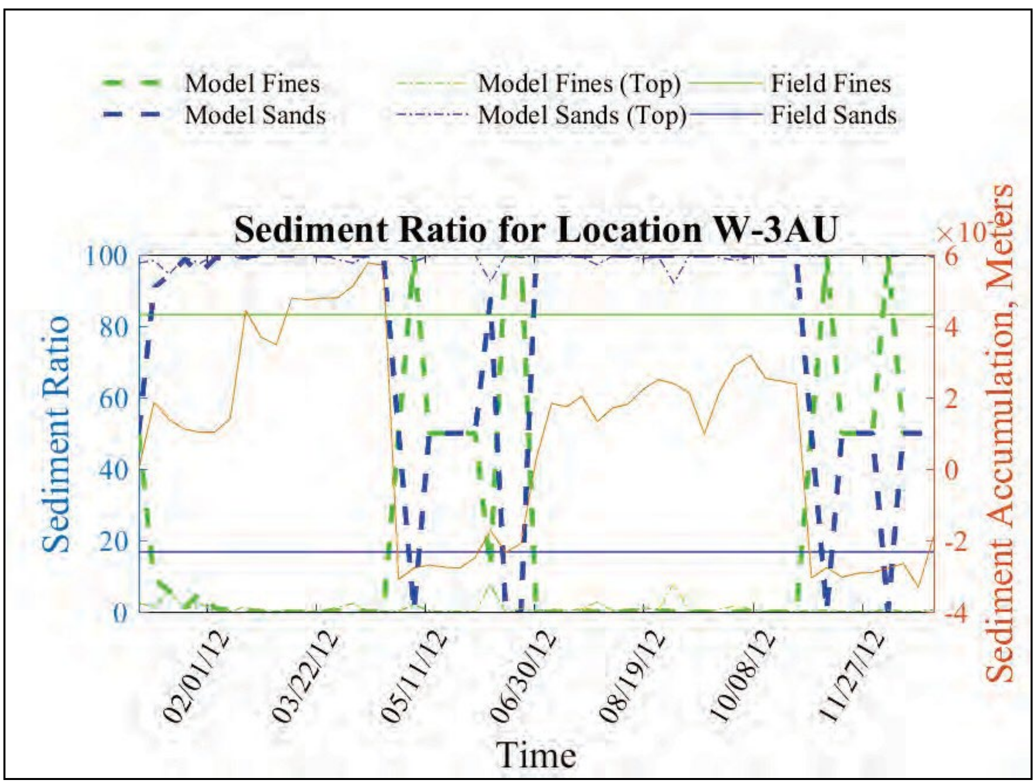


Figure 188. Sediment core locations in Newark Bay.

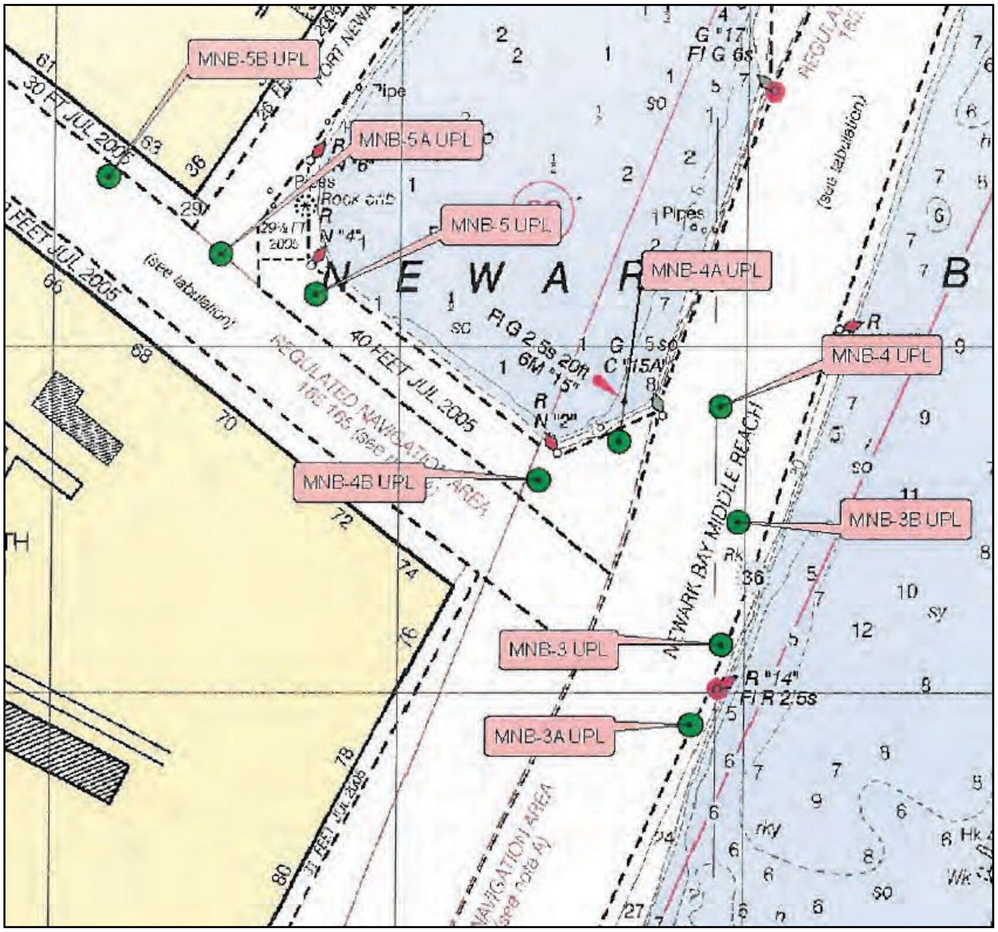
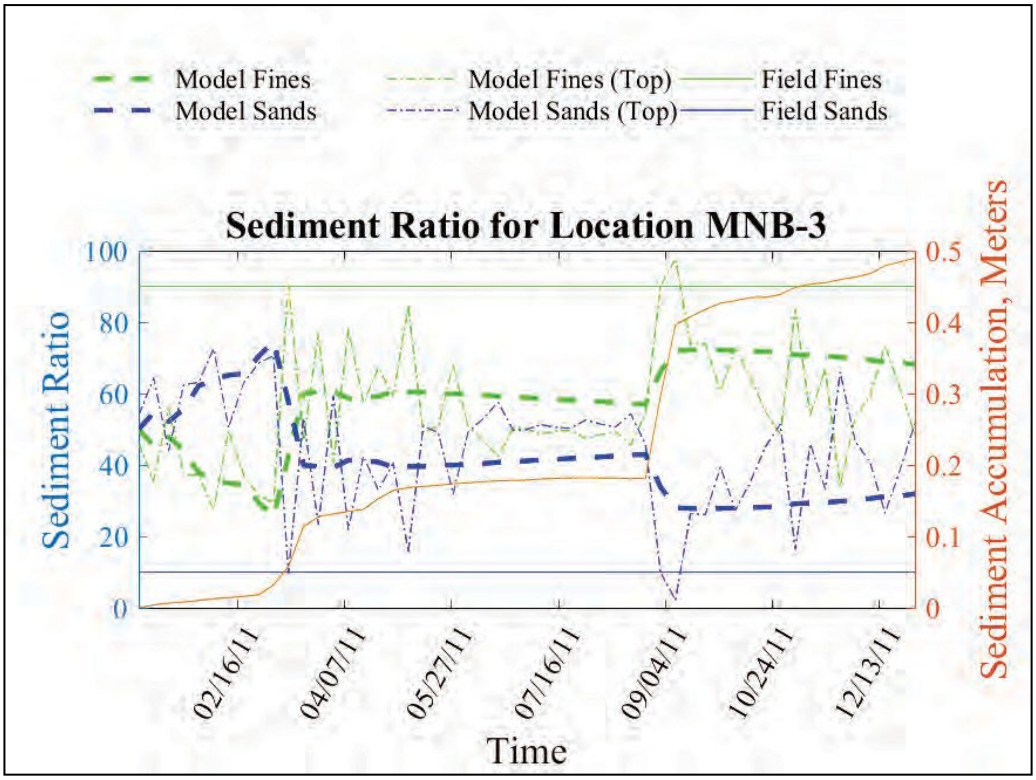


Figure 189. Sediment bed composition comparisons at Location MNB-3 for 2011 (top) and 2012 (bottom).



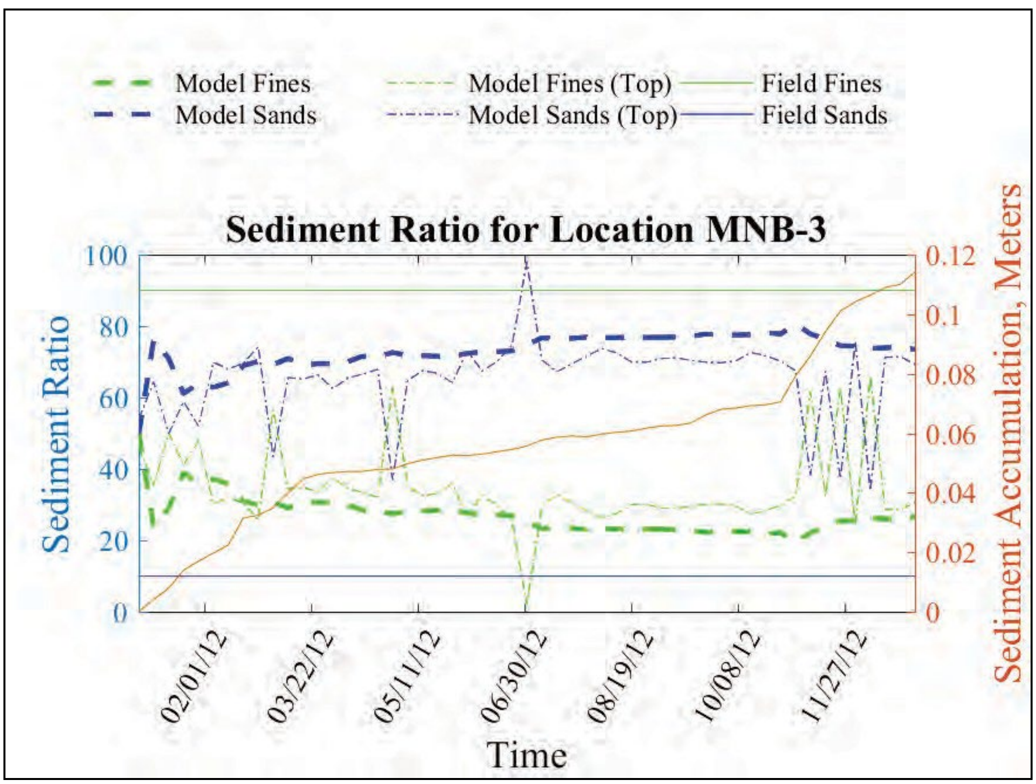
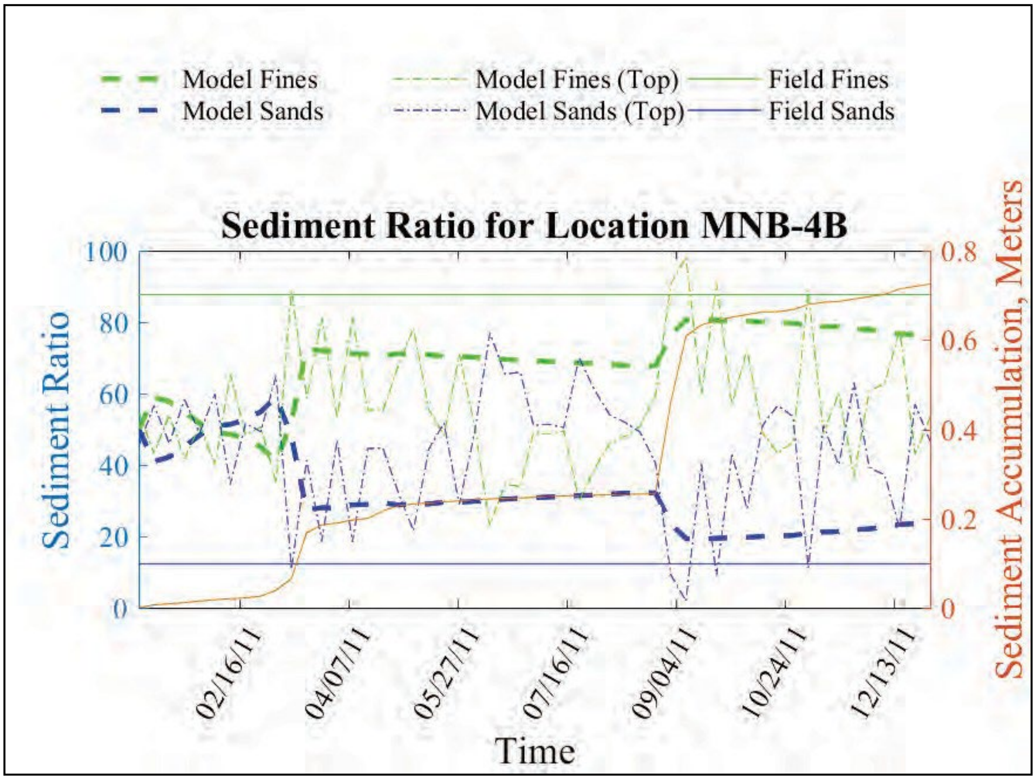


Figure 190. Sediment bed composition comparisons at Location MNB-4B for 2011 (top) and 2012 (bottom).



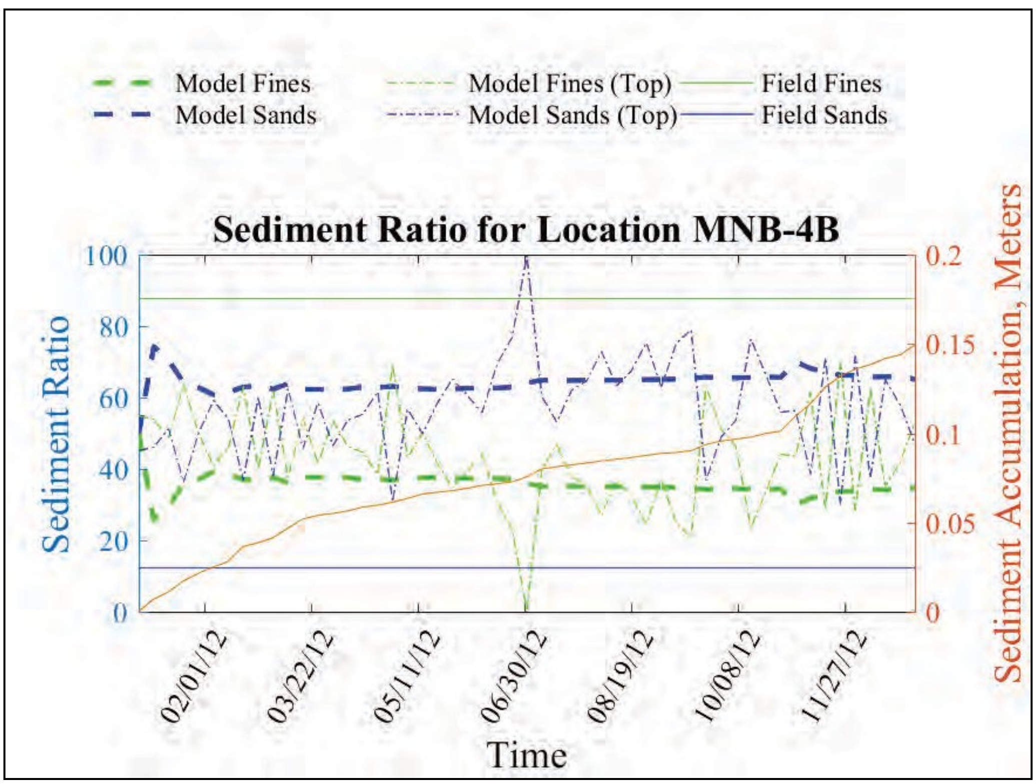
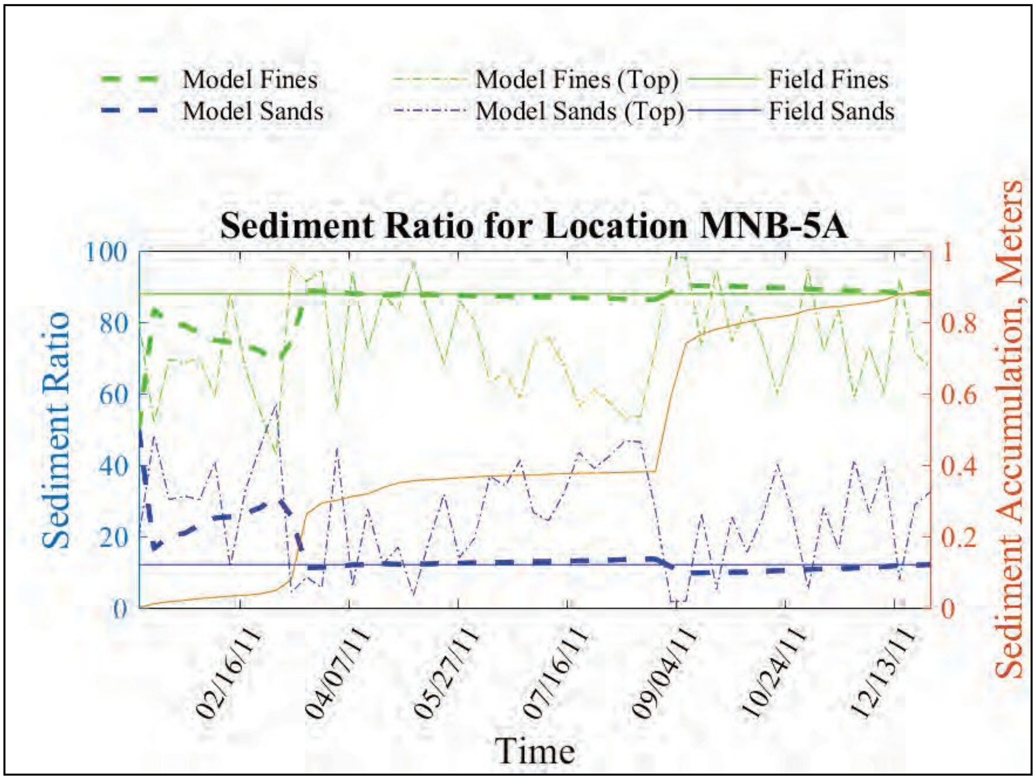


Figure 191. Sediment bed composition comparisons at Location MNB-5A for 2011 (top) and 2012 (bottom).



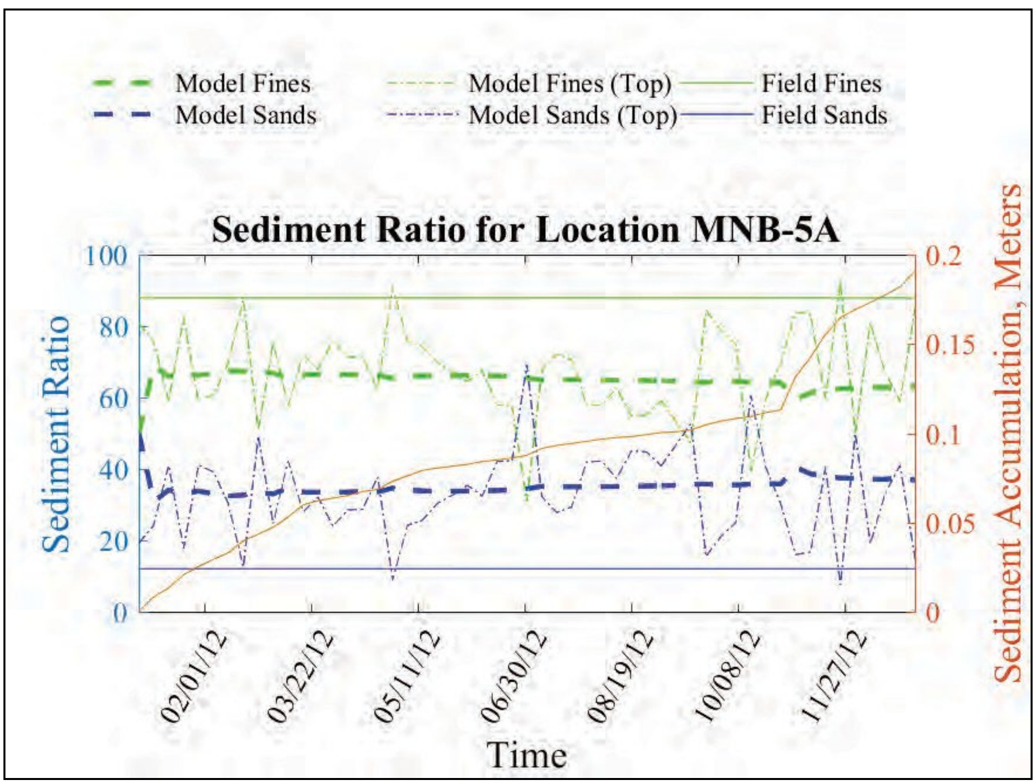


Figure 192. Sediment core locations in the Port Jersey channel.

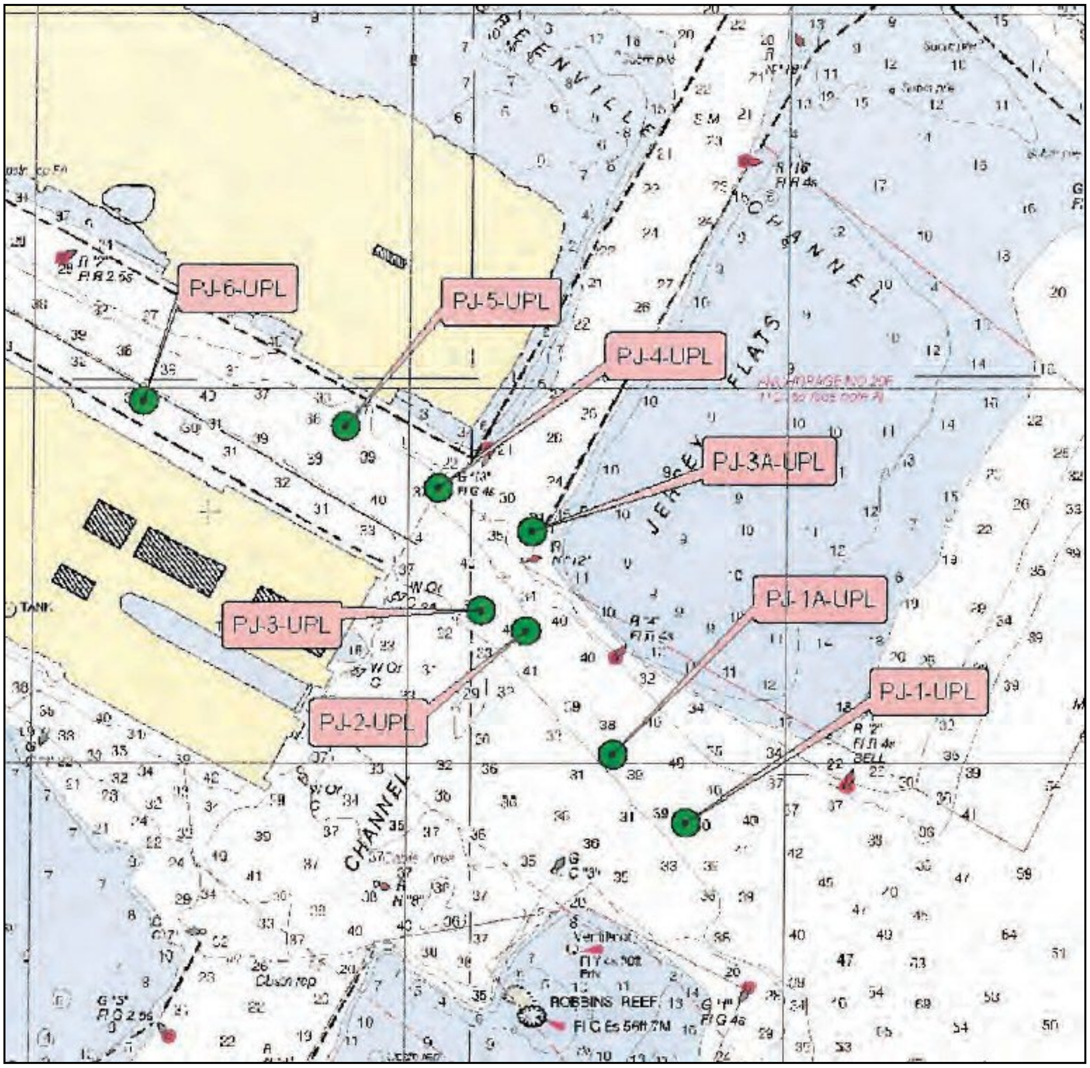
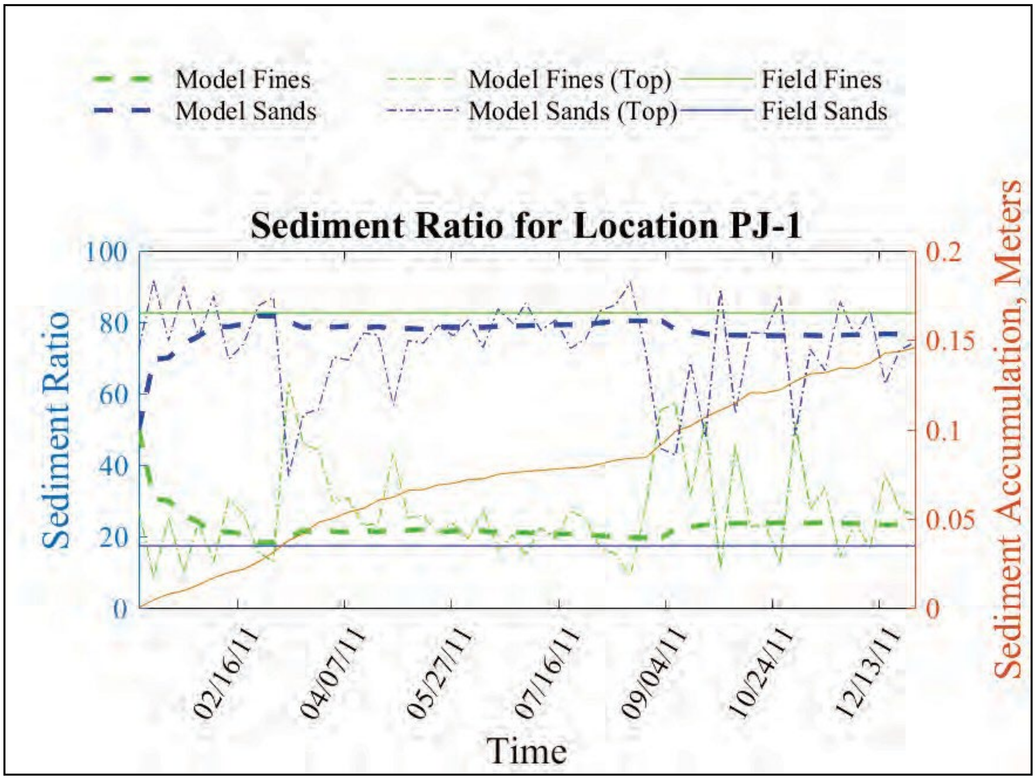


Figure 193. Sediment bed composition comparisons at Location PJ-1 for 2011 (top) and 2012 (bottom).



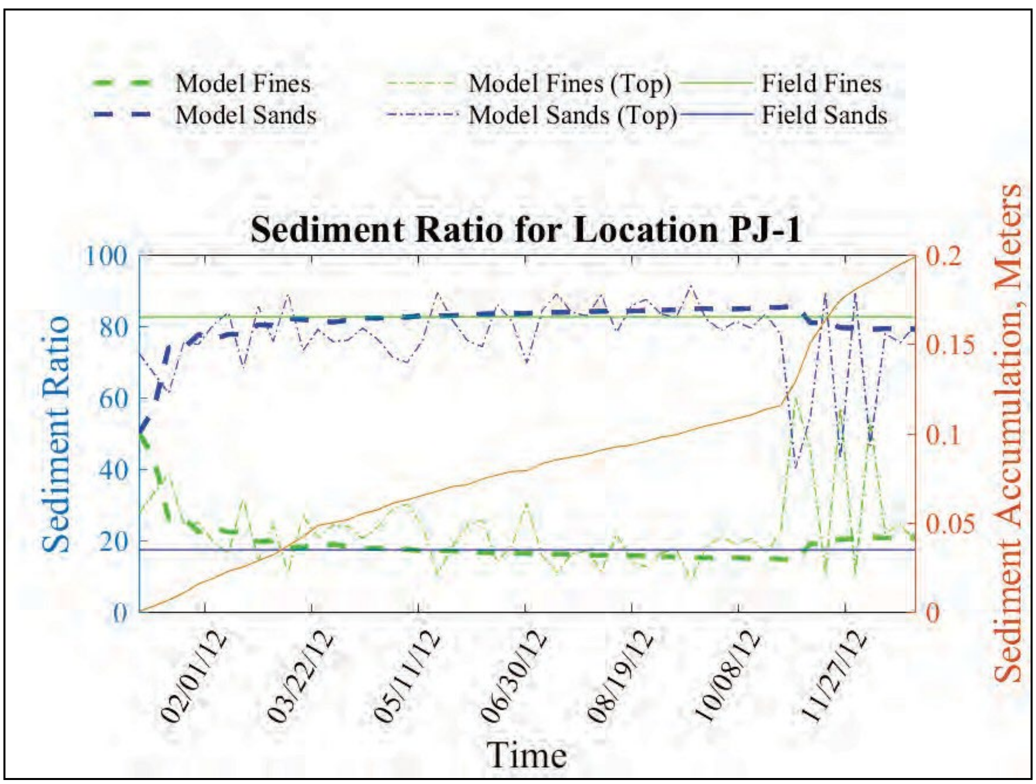
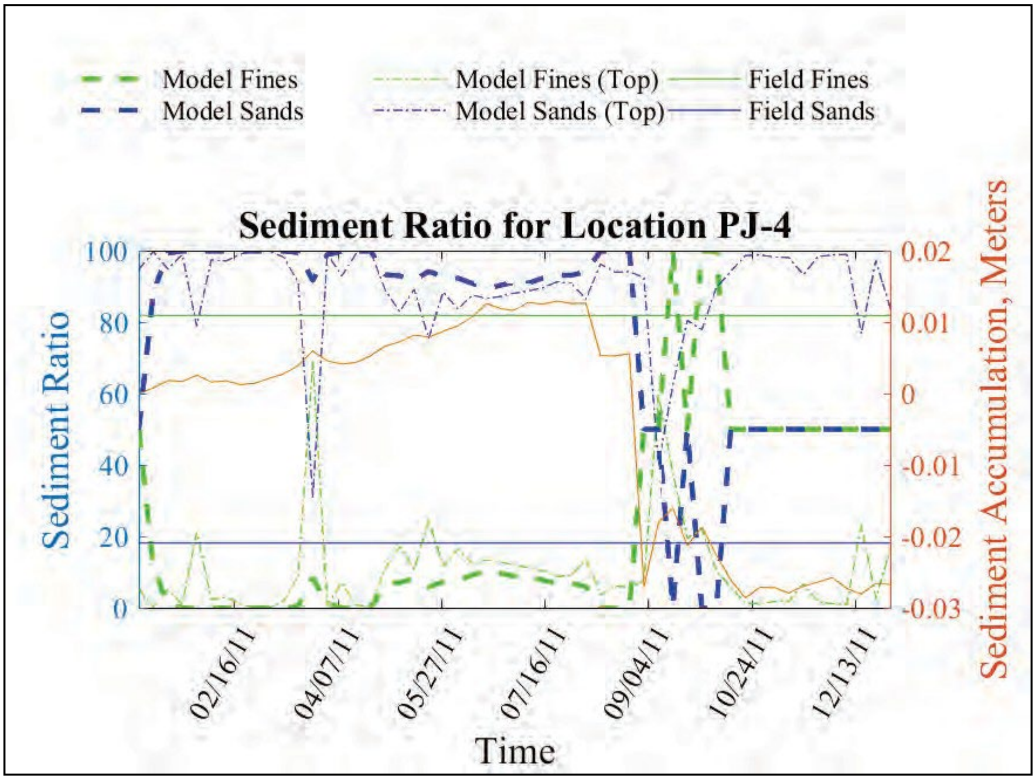
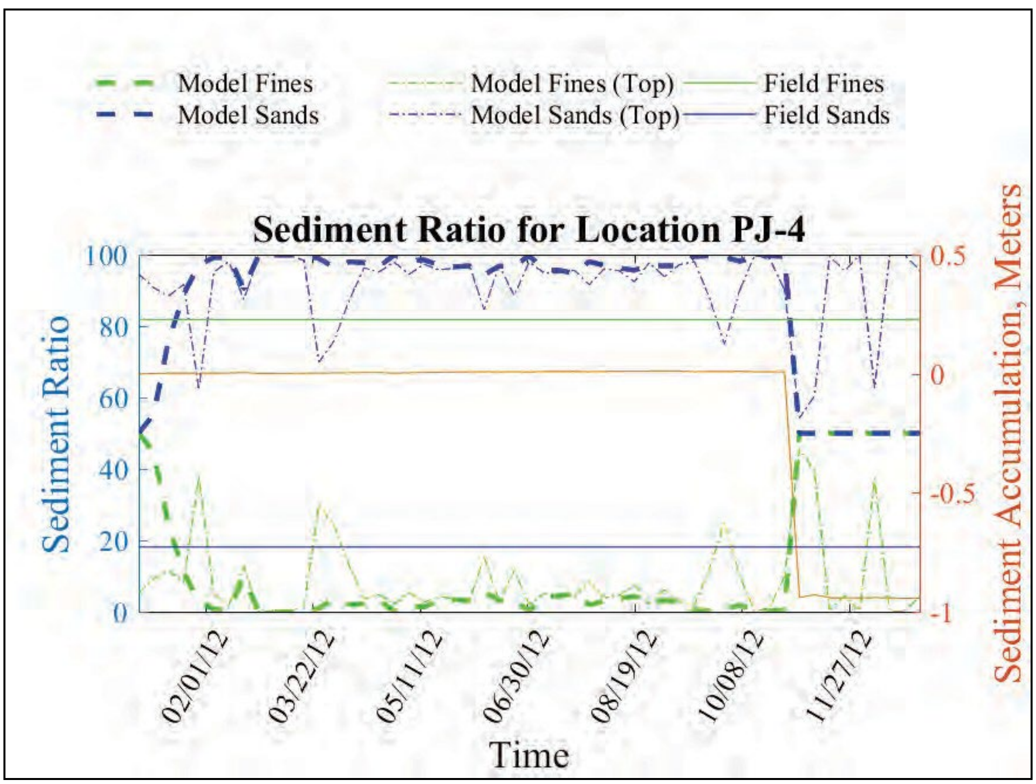


Figure 194. Sediment bed composition comparisons at Location PJ-4 for 2011 (top) and 2012 (bottom).





Qualitative sediment flux comparisons

From the literature, there are several reports of various sediment fluxes up and down the Hudson River, through the Kill van Kull, and through the Narrows. While these values are not for the periods simulated in the model, comparisons can be performed to determine if the results are consistent with the simulated results.

Hudson River sediment loads

There are various sediment transport estimates for the Hudson River. Panuzio (1965), Olsen (1979), and Wall et al. (2008) estimated ranges of Hudson River sediment loads of 0.2 to 1.0 Megatons (1 million metric tons). Woodruff et al. (2001) estimated 560,000 metric tons delivered by the Hudson River in 1998 and 120,000 metric tons in 1999. Obviously, this provides a very wide range of estimates and the model values in Table 15 indicate a similarly broad range of values over the five simulated years. The majority of the Hudson River sediment load is fine sediment, but the values reported in Table 15 include sand transport as well.

Table 15. Hudson River sediment loads for the simulated years.

Year	Without-Project Sediment Load, metric tons	With-Project Sediment Load, metric tons
1985	83,000	85,000
1995	111,000	111,000
1996	647,000	645,000
2011	932,000	927,000
2012	170,000	168,000

The literature also discusses sand moving up the Hudson River on the east side of the Hudson River while fine sediment moves down the river (Coch, 2016). Geyer and Chant (2006) have shown that this up-estuary transport (sands) extends northward at least to the George Washington Bridge. The sand load was extracted from the model results for the two locations shown in Figure 195. The bottom line represents the location of the George Washington Bridge. The sand transport values up the Hudson River are provided in Table 16. Calendar years 1996 and 2011 have a net export of sand from the Hudson River. This is not unexpected as these 2 years were above-average flow years (see Figure 37). The remaining 3 years are consistent with the reported behavior in the literature.

Figure 195. The black lines represent extracted sand transport locations. The lower black line is at the George Washington Bridge.

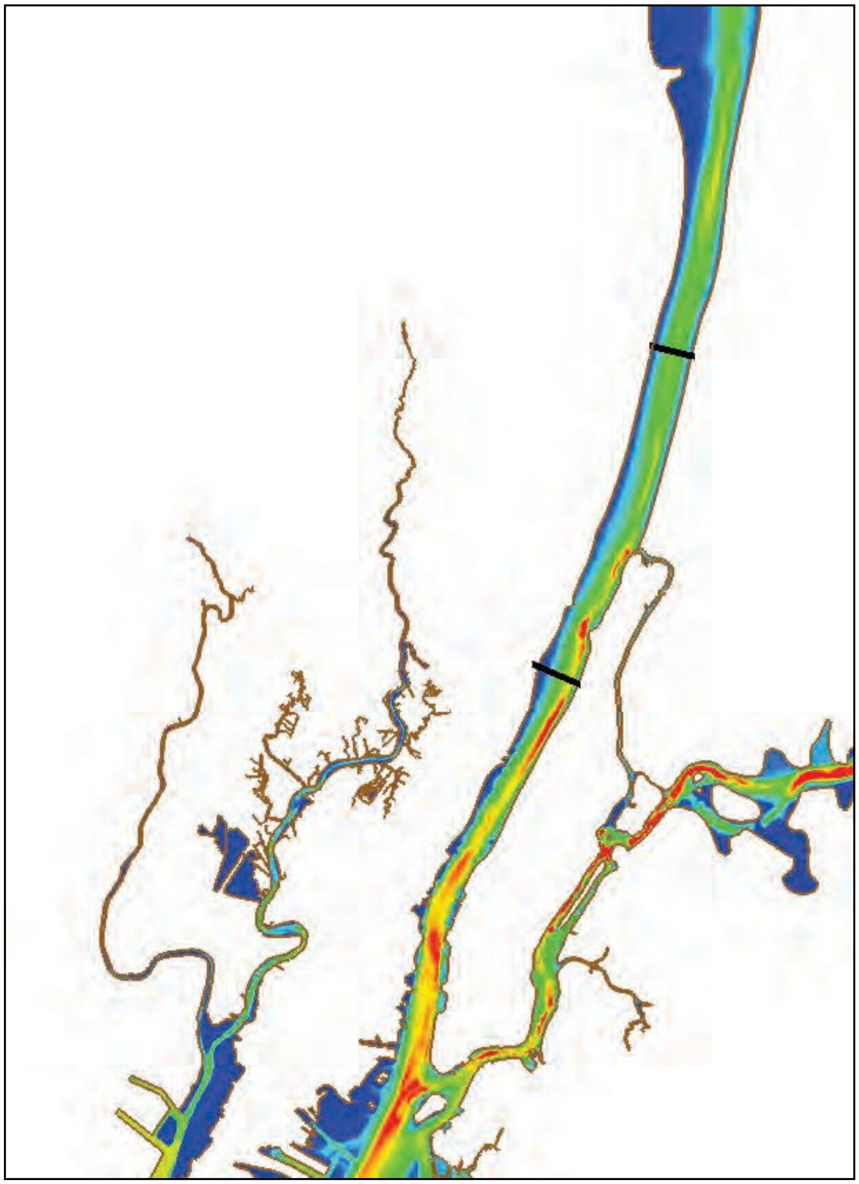


Table 16. Sand transport up the Hudson River Estuary (negative indicates downward transport).

Sand Transport in the Hudson River at the George Washington Bridge. Values in parentheses are the location farther upstream.		
Year	Without-Project Sand Load, metric tons	With-Project Sand Load, metric tons
1985	29,000(26,000)	29,000(25,000)
1995	12,000(19,000)	13,000(19,000)
1996	-2,600(1,200)	-3,100(1,900)
2011	-7,600(-3,000)	-7,900(90)
2012	21,000(15,000)	23,000(16,000)

Kill van Kull sediment loads

Several studies have been completed attempting to quantify the sediment load traveling through Kill van Kull (from Upper Bay toward Newark Bay). Pecchioli et al. (2006) estimated approximately 100,000 MT/year of suspended sediment through Kill van Kull. Chant (2006) reported transport of between 120,000 and 200,000 MT/year using data collected in 2002, and Shrestha et al. (2014) reported Kill van Kull transport of 140,000 MT/year. This indicates an acceptable range of approximately 100,000 MT/year to 200,000 MT/year, although this would vary depending on the Hudson River flow conditions. These yearly transport rates are also based on shorter-term observations providing some level of uncertainty in the reported values.

The total sediment load through Kill van Kull in the numerical model results is provided in Table 17. These results indicate 1985, 1995, and 2012 as slightly below the reported values with 1996 and 2011 in the range of the reported values. This is not unexpected as 1985, 1995, and 2012 are below average flow years for the Hudson River (Figure 37). It is also assumed the Pecchioli et al. (2006) and Chant (2006) data are more applicable for comparing to the without-project results and the Shrestha et al. (2014) would be more appropriate to compare to the with-project results as the majority of the project had been completed prior to 2014. The majority of the sediment load traveling through the Kill van Kull is fine sediment, but there is a sand component as well.

Table 17. Kill van Kull total sediment load for the simulated years.

Year	Without-Project Total Sediment Load, metric tons	With-Project Total Sediment Load, metric tons
1985	48,000	67,000
1995	60,000	78,000
1996	110,000	144,000
2011	54,000	121,000
2012	73,000	96,000

Passaic and Hackensack sediment loads

Shrestha et al. (2014) compiled a table of sediment load values for the Passaic and Hackensack Rivers from other sources in the literature that ranged from a low of 7,440 MT/year to as high as 47,456 MT/year with an average of 25,661 MT/year. The total model sediment load being delivered to Newark Bay from the Passaic and Hackensack Rivers is provided in Table 18. The 2011 results are extremely high and would appear to be somewhat unrealistic. From further analysis of the results for the 2011 calendar year, the inflow specification included approximately 175,000 MT with the remaining being sourced from the bed. This large bed sourced load indicates the model bed specification in the Passaic and Hackensack Rivers may not have been appropriate for such an extreme event but currently it is unknown if the model is greatly overestimating the sediment delivery for 2011 or if this year was actually that extreme in relation to the other four simulated years. This model definition also explains the large variation in the previously shown dredge volumes in Newark Bay for 2011 (Figure 178).

Table 18. Passaic and Hackensack River total sediment load into Newark Bay for the simulated years.

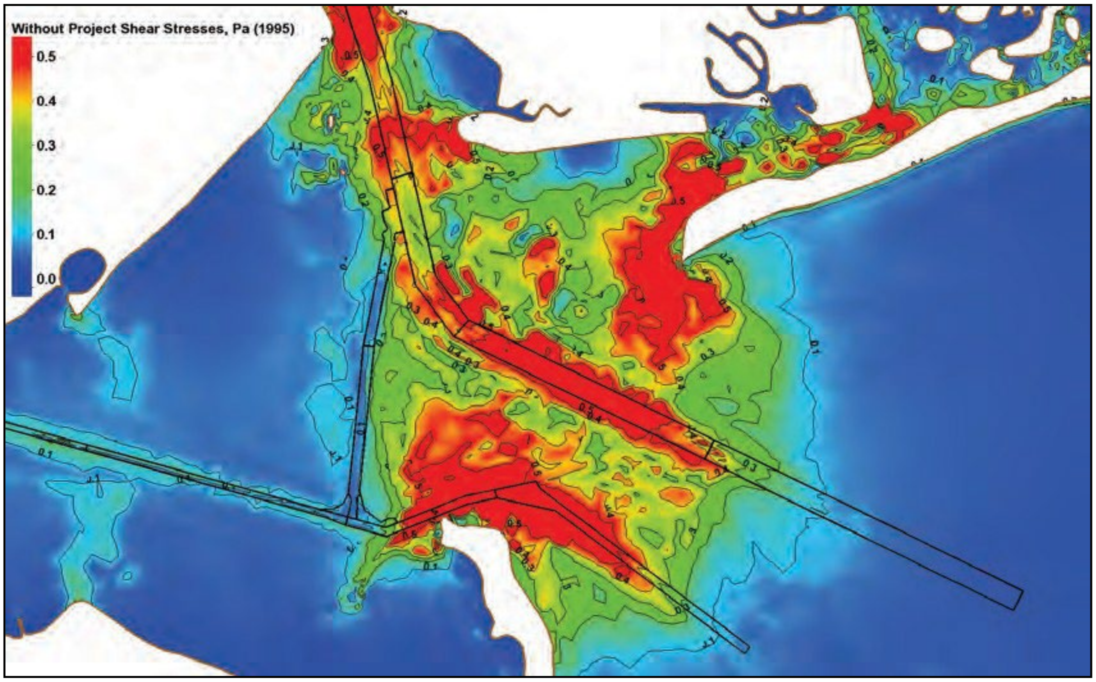
Year	Without-Project Total Sediment Load, metric tons	With-Project Total Sediment Load, metric tons
1985	31,000	31,000
1995	41,000	43,000
1996	87,000	87,000
2011	444,000	438,000
2012	33,000	33,000

9 With-Project and Without-Project Comparisons

The with-project versus without-project comparisons were broken up into areas consisting of Lower Bay (Figure 196 to Figure 203 and Table 19); Newark Bay, Kill van Kull and Upper Bay (Figure 204 to Figure 211 and Table 20); and Arthur Kill and Raritan Bay (Figure 212 to Figure 219 and Table 21). The analysis consisted primarily of comparing the yearly averages for shear stresses, salinities, sediment concentrations, bed change, and dredge volumes for the channel reaches provided by CENAN. The results provided in Chapter 9 are the average values for the 1995 calendar year. The results for the remaining years are provided in Appendix D (1985), Appendix E (1996), Appendix F (2011), and Appendix G (2012). Difference plots of the shear stresses, salinities, and sediment concentrations for all years are provided in Appendix H. The black lines in the images represent the channel reaches as supplied by CENAN. While comparisons of the absolute values across multiple years do indicate variations in the results, the patterns tend to be consistent.

Lower Bay results

Figure 196. Without-project (top) and with-project (bottom) average shear stresses, Pa (1995).



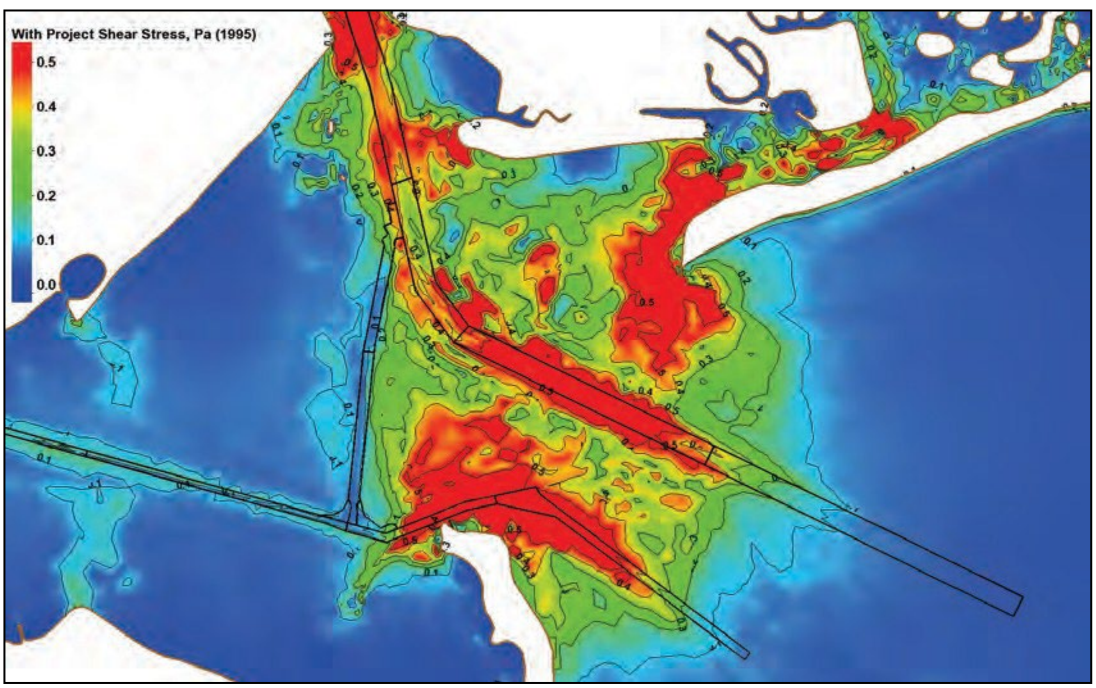
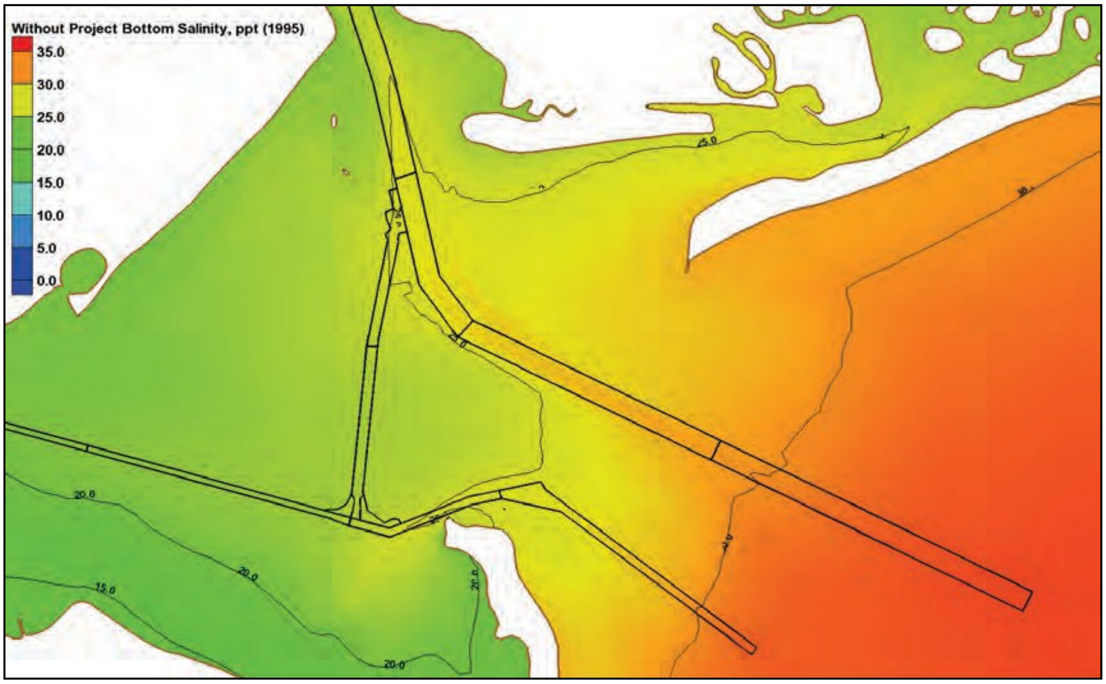


Figure 197. Without-project (top) and with-project (bottom) average bottom salinity, ppt (1995).



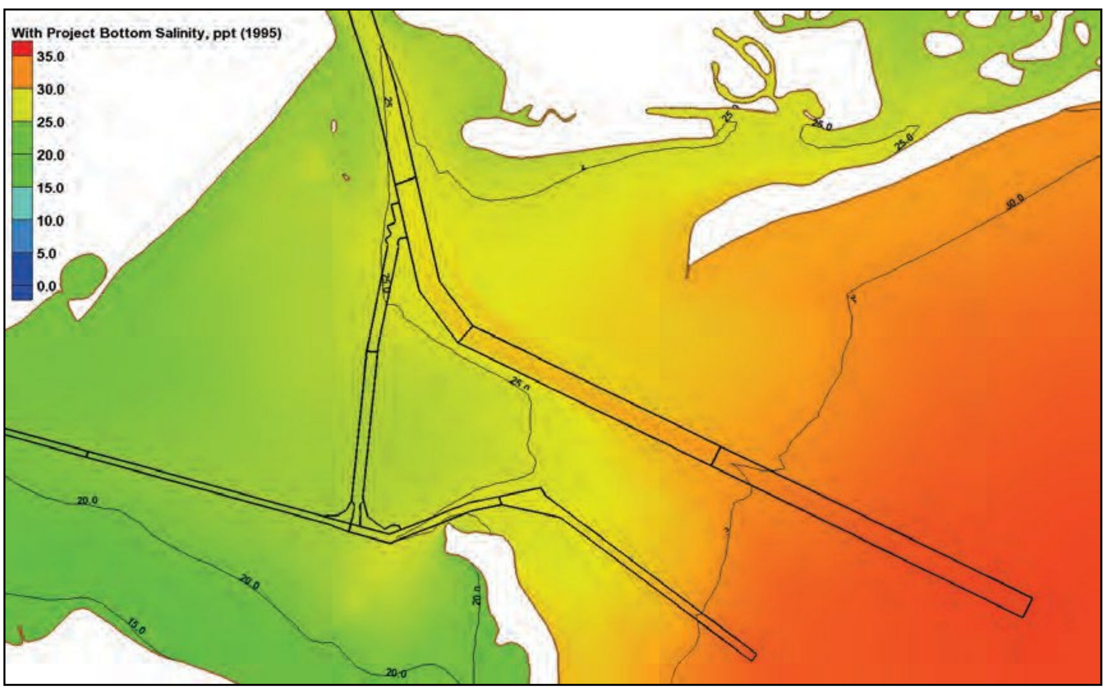
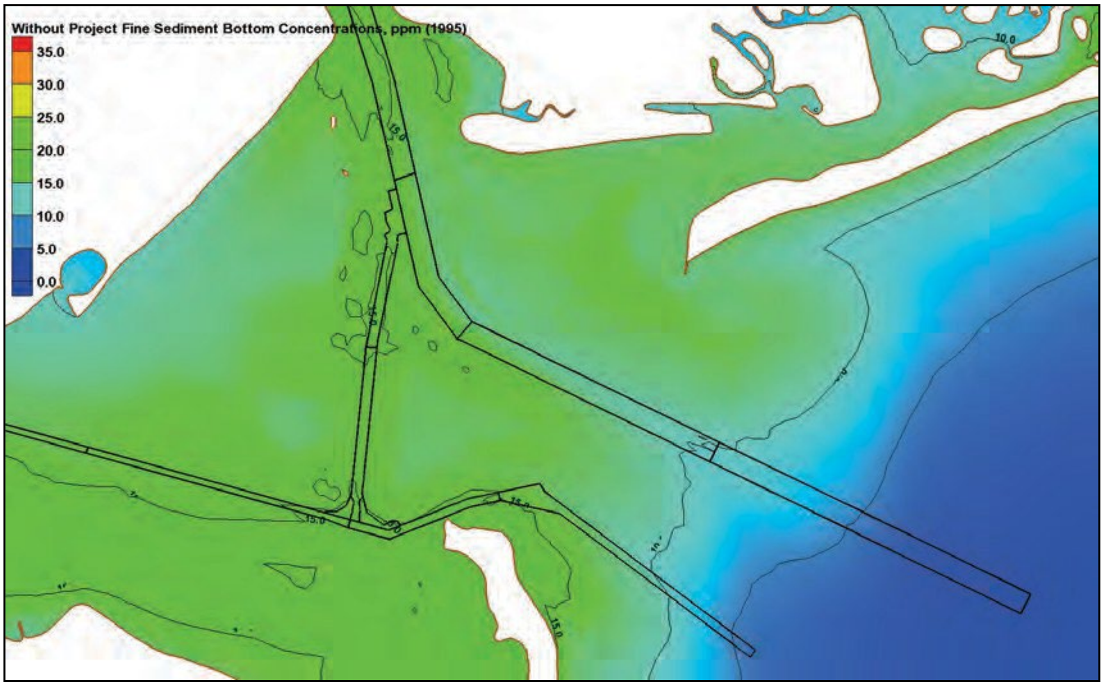


Figure 198. Without-project (top) and with-project (bottom) average fine sediment bottom concentrations, ppm (1995).



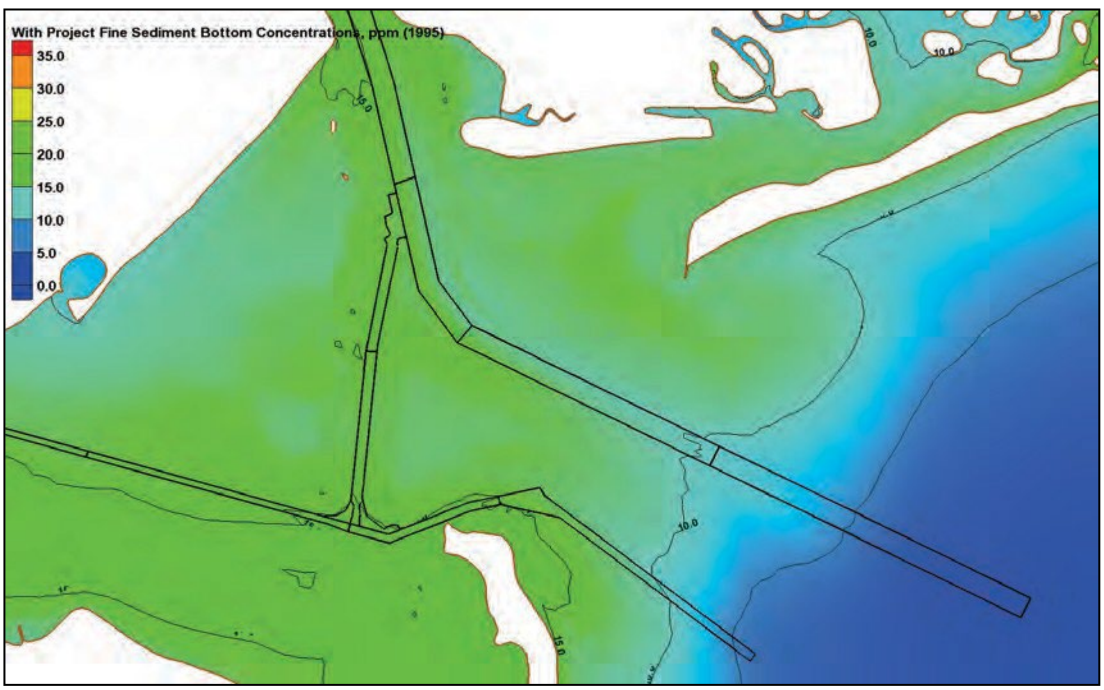
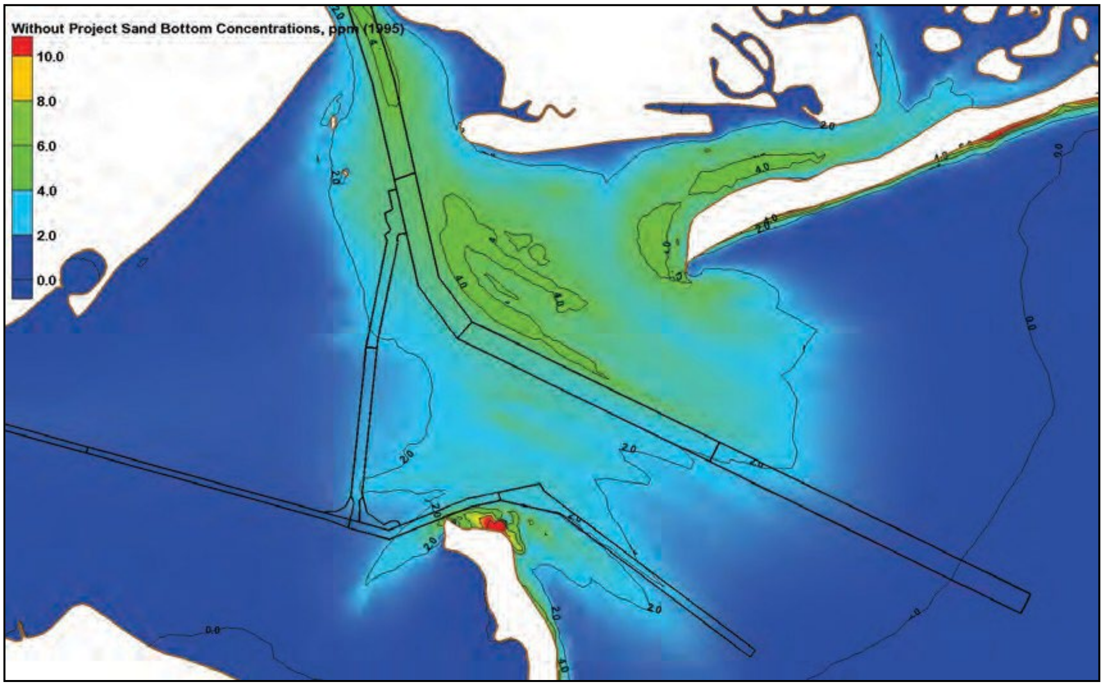


Figure 199. Without-project (top) and with-project (bottom) average sand bottom concentrations, ppm (1995).



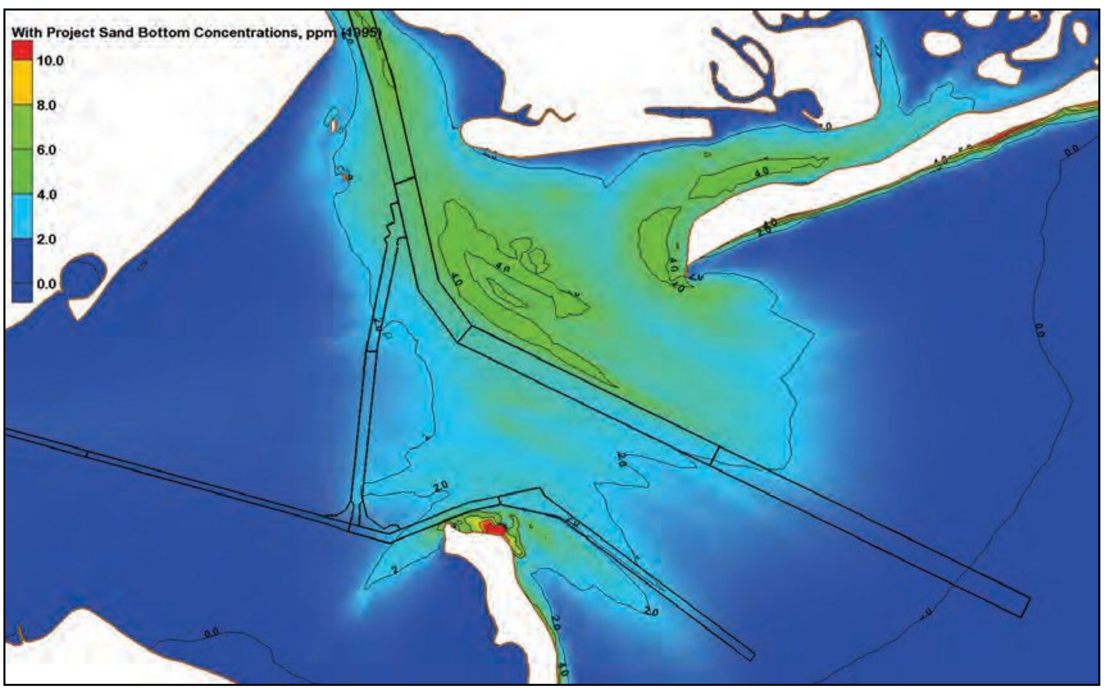


Figure 200. Without-project (top) and with-project (bottom) bed displacement, m (1995).

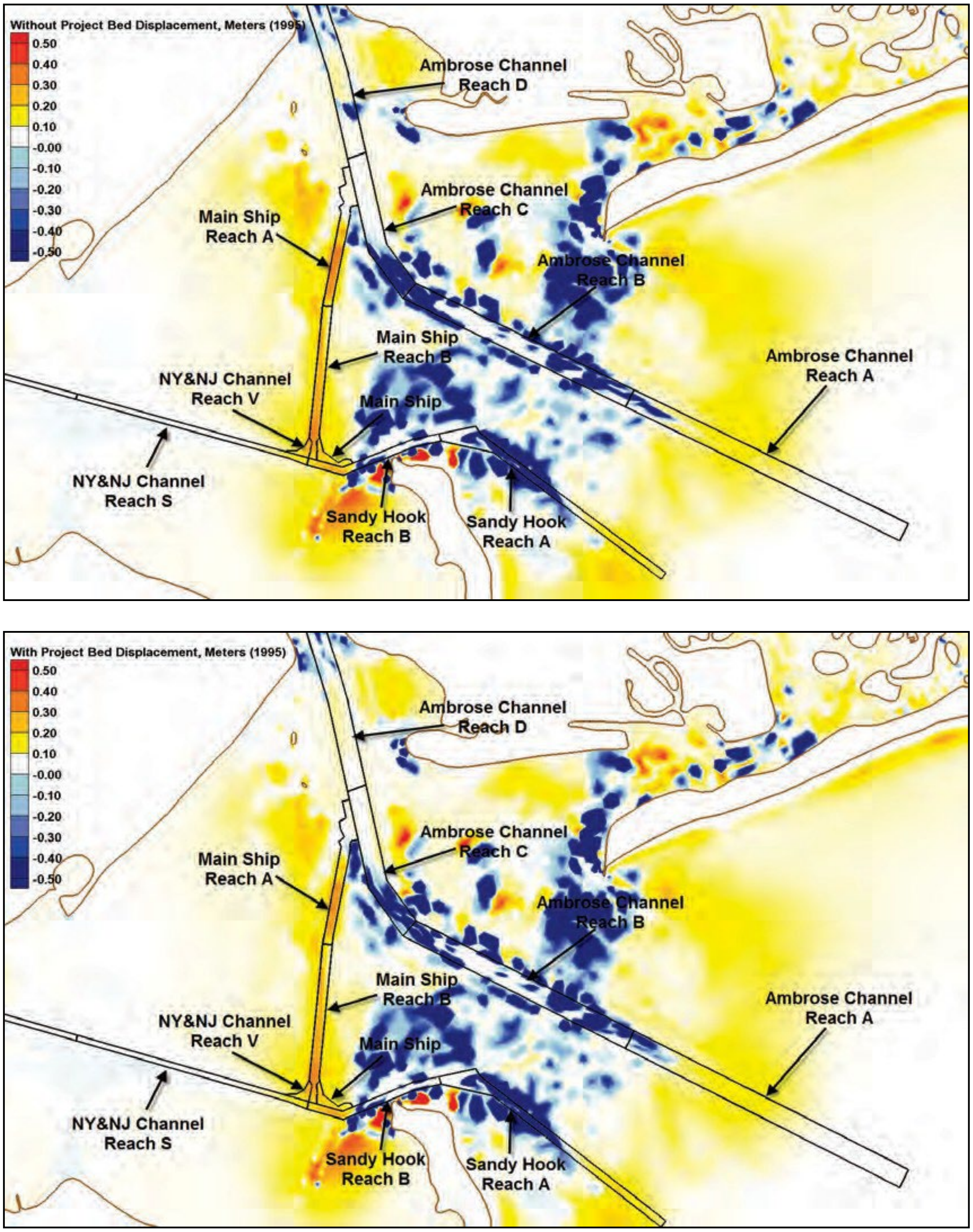
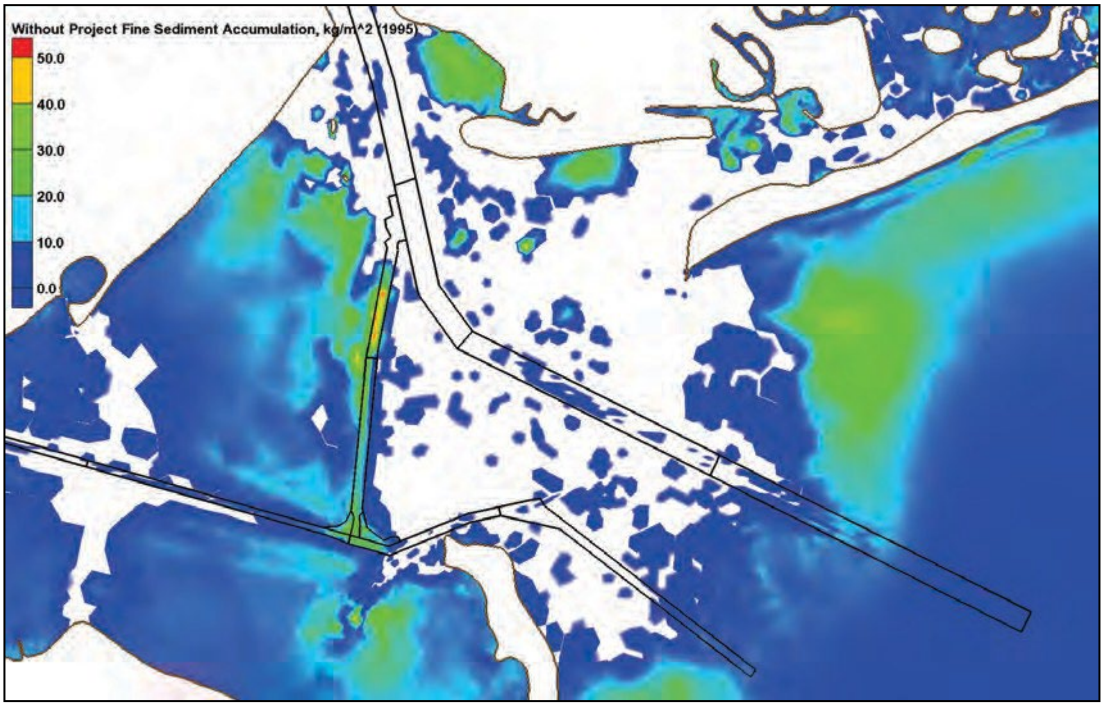


Figure 201. Without-project (top) and with-project (bottom) fine-sediment accumulation, kg/m² (1995),



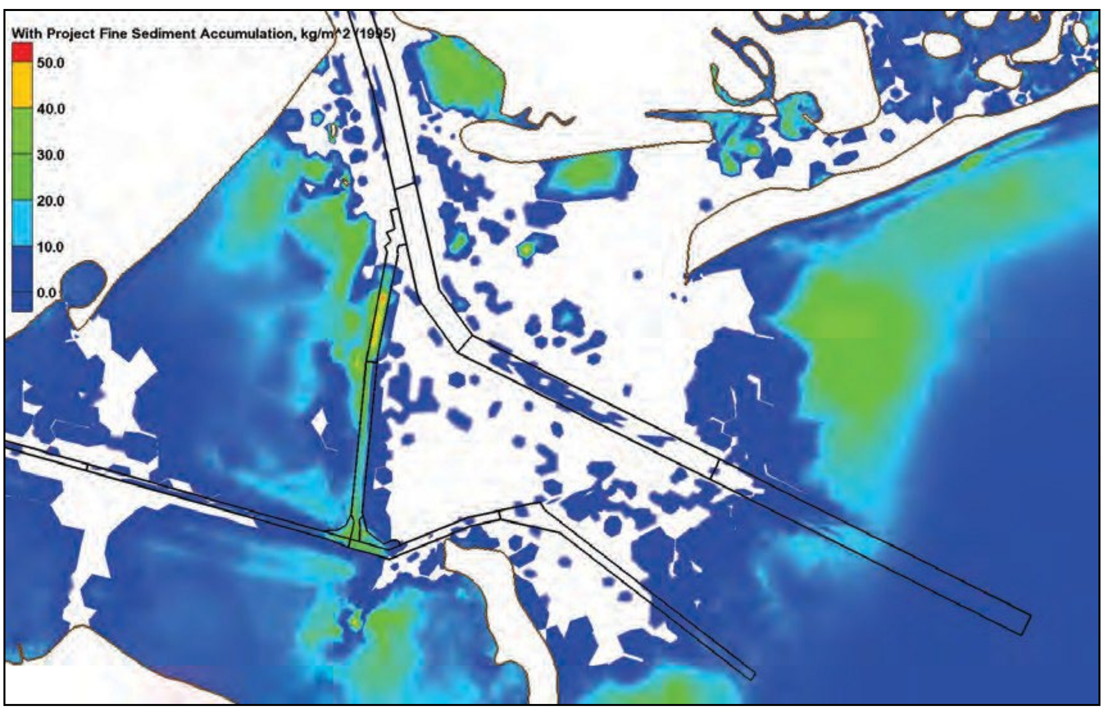


Figure 202. Without-project (top) and with-project (bottom) sand accumulation, kg/m² (1995).

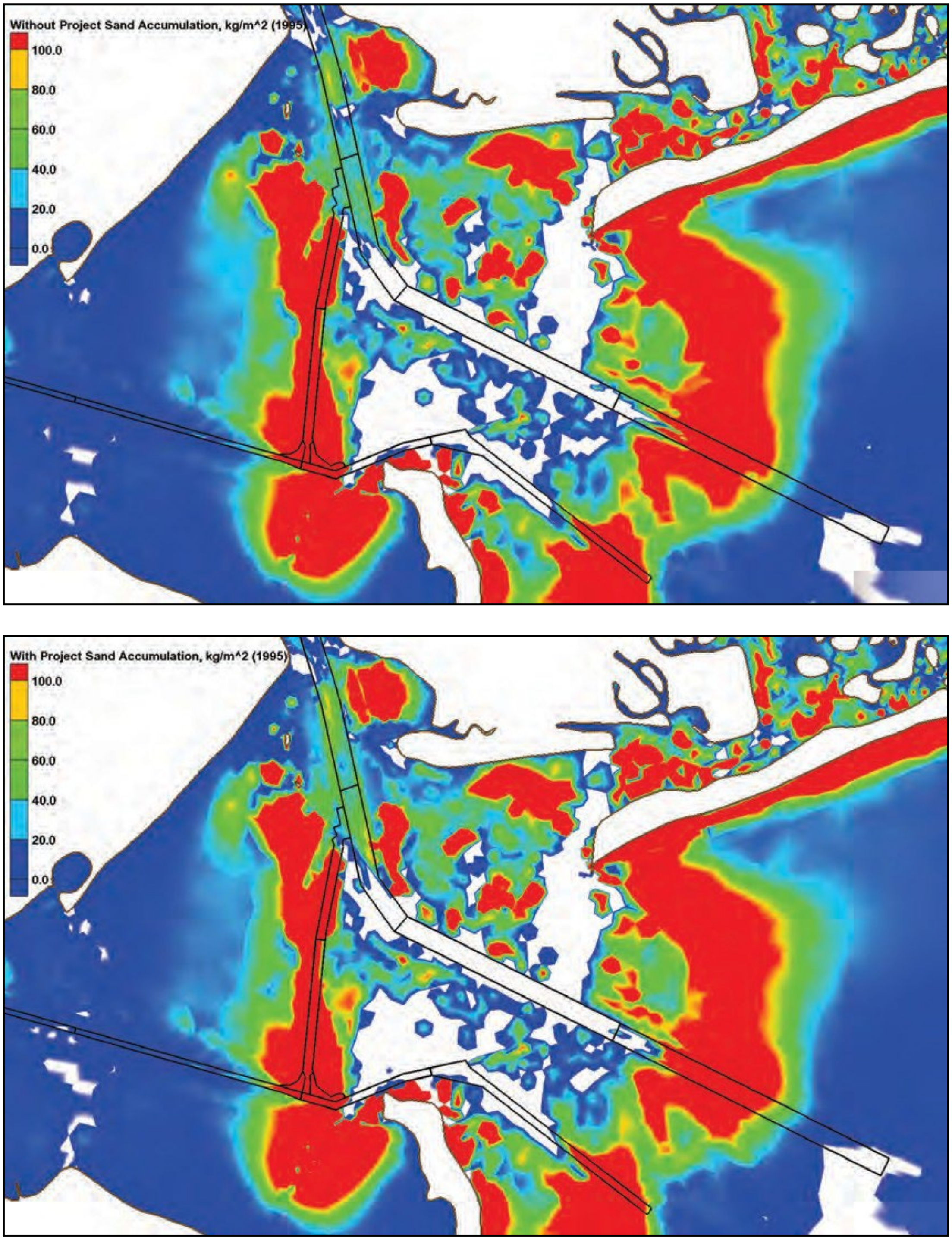


Figure 203. Dredge with-project/without-project percent differences (1995).

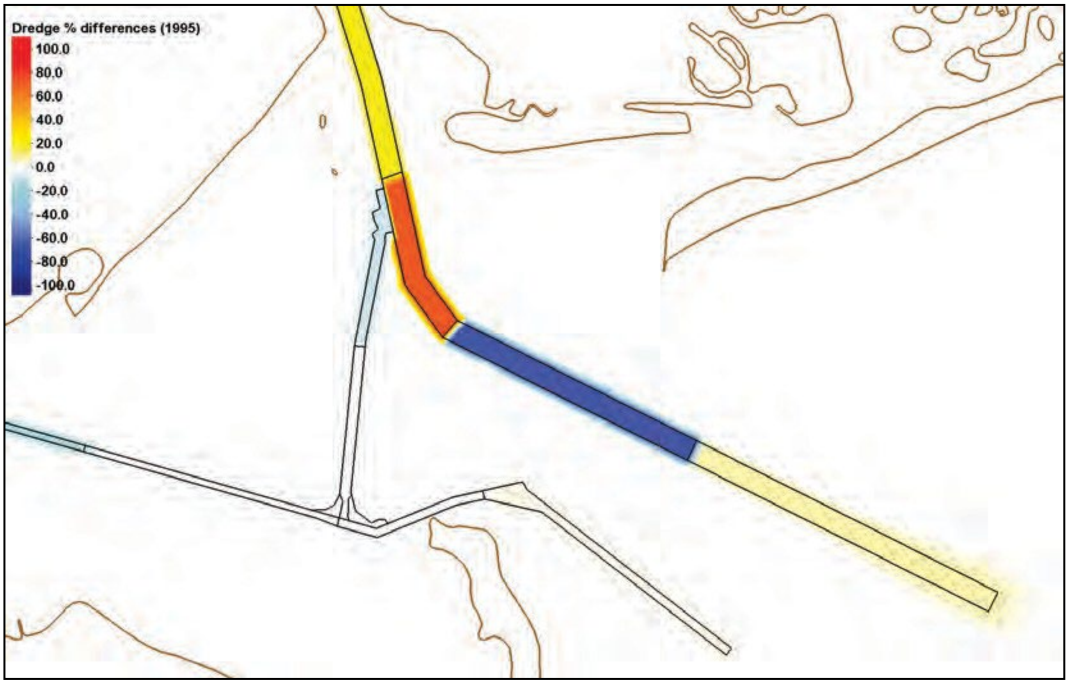


Table 19. Dredge volumes in Lower Bay (1995).

Depositional Volumes in Lower Bay, cy (1995)			
Reach	Without Project	With Project	With/Without Dredge Percentage
Ambrose Channel Reach A	273,941	292,521	107
Ambrose Channel Reach B	1,244	409	33
Ambrose Channel Reach C	13,675	23,399	171
Ambrose Channel Reach D	46,413	54,319	117
Main Ship	58,291	58,040	100
Main Ship Reach A	229,342	205,294	90
Main Ship Reach B	329,731	327,078	99
Sandy Hook Reach A	103,013	105,135	102
Sandy Hook Reach B	76,755	76,396	100
NY&NJ Channels Reach S	32,595	32,299	99
NY&NJ Channels Reach V	39,217	39,081	100

As would be expected, the salinity intrusion up the Ambrose ship channel is increased. This is expected due to a combination of the channel deepening and the redistribution of flow through Kill van Kull. The dredge volume for the Ambrose Channel Reach B was reduced. This is expected due to the increased salinity intrusion up the channel thereby resulting in increased dredging requirements in reaches C and D. Overall, the Ambrose channel experienced an increase in dredging of approximately 35,000 cy or approximately 10% for 1995. The Main Ship Reach A experienced a decrease of approximately 24,000 cy. This channel was not deepened as part of the with-project configuration. The deepened Ambrose channel results in more sediment farther down in the water column resulting in less transport of sediment into the adjacent Main Ship Reach A channel possessing a higher bed elevation. This reduces the Main Ship Reach A dredge volumes while increasing the Ambrose channel requirements.

Newark Bay, Kill van Kull, and Upper Bay results

Figure 204. Without-project (top) and with-project (bottom) average shear stresses, Pa (1995).

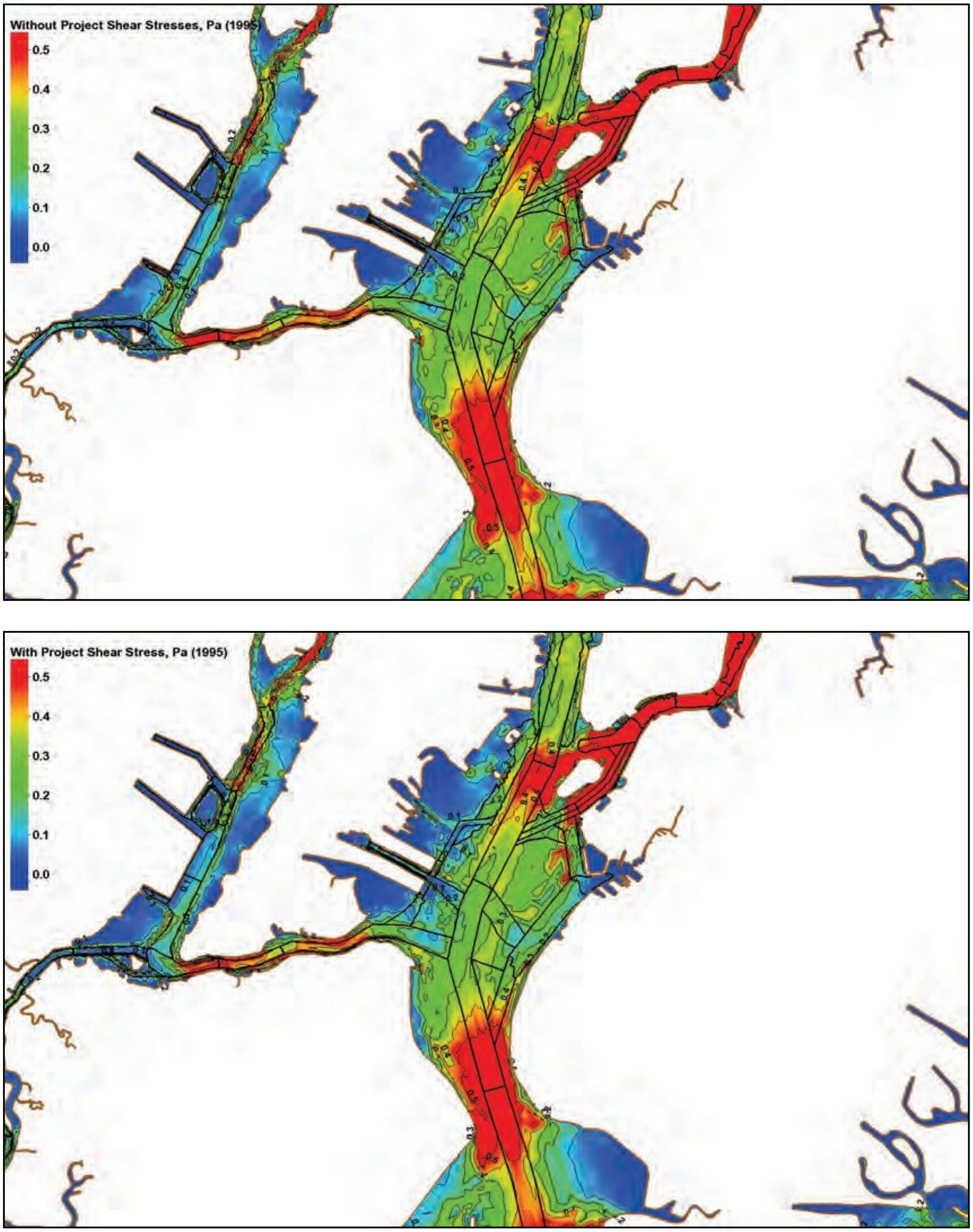


Figure 205. Without-project (top) and with-project (bottom) average bottom salinity, ppt (1995).

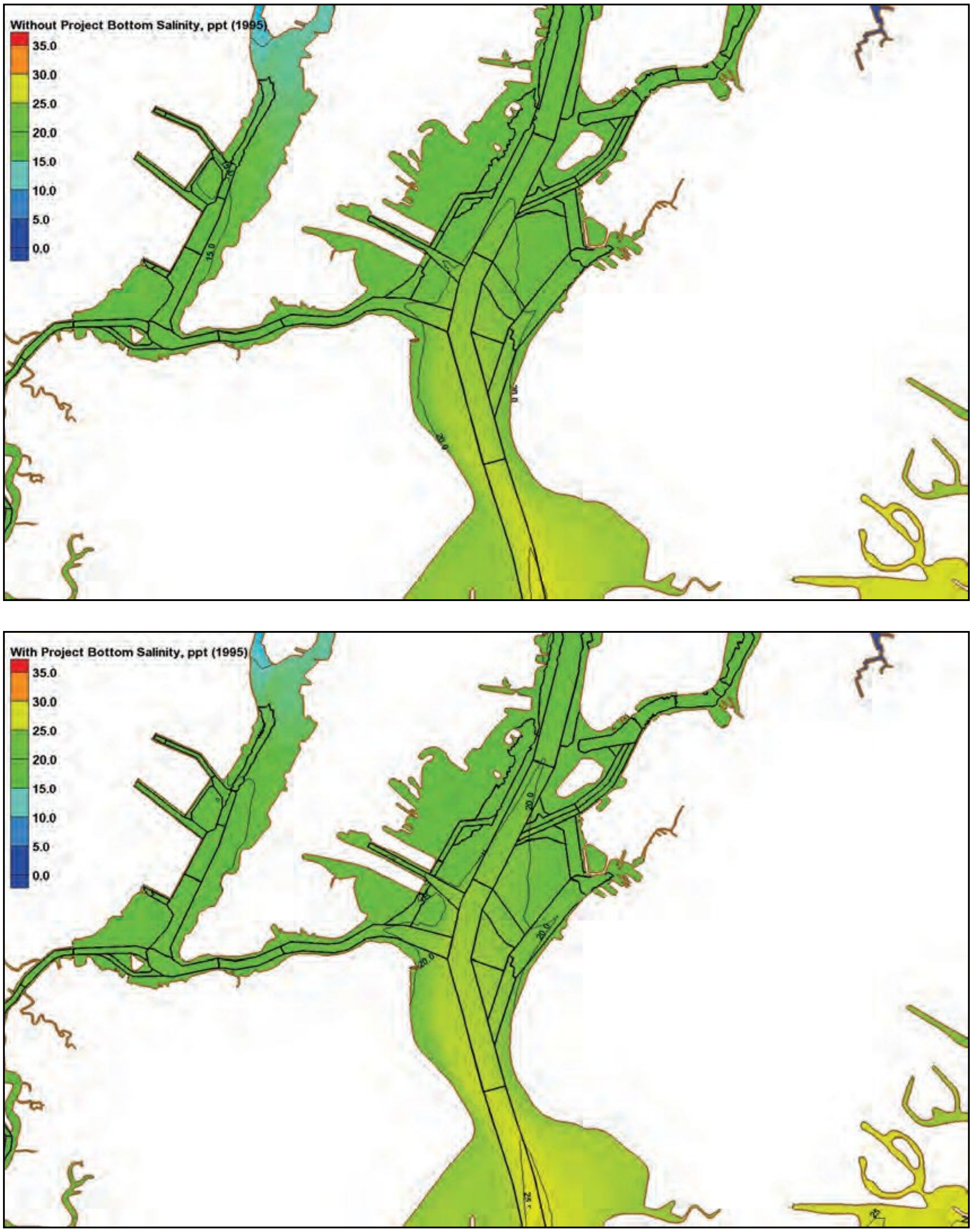


Figure 206. Without-project (top) and with-project (bottom) average fine bottom sediment concentrations, ppm (1995).

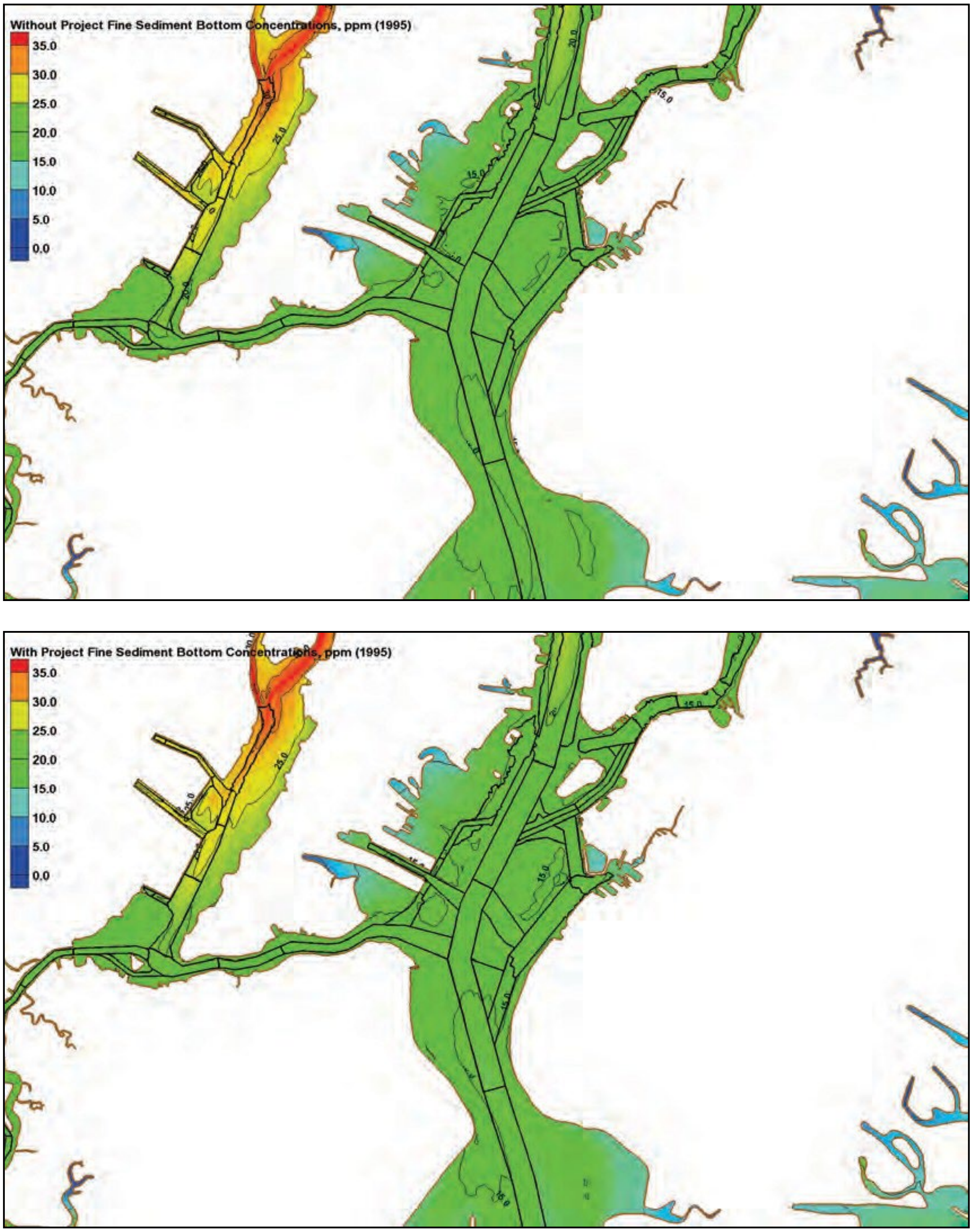


Figure 207. Without-project (top) and with-project (bottom) average sand bottom concentrations, ppm (1995).

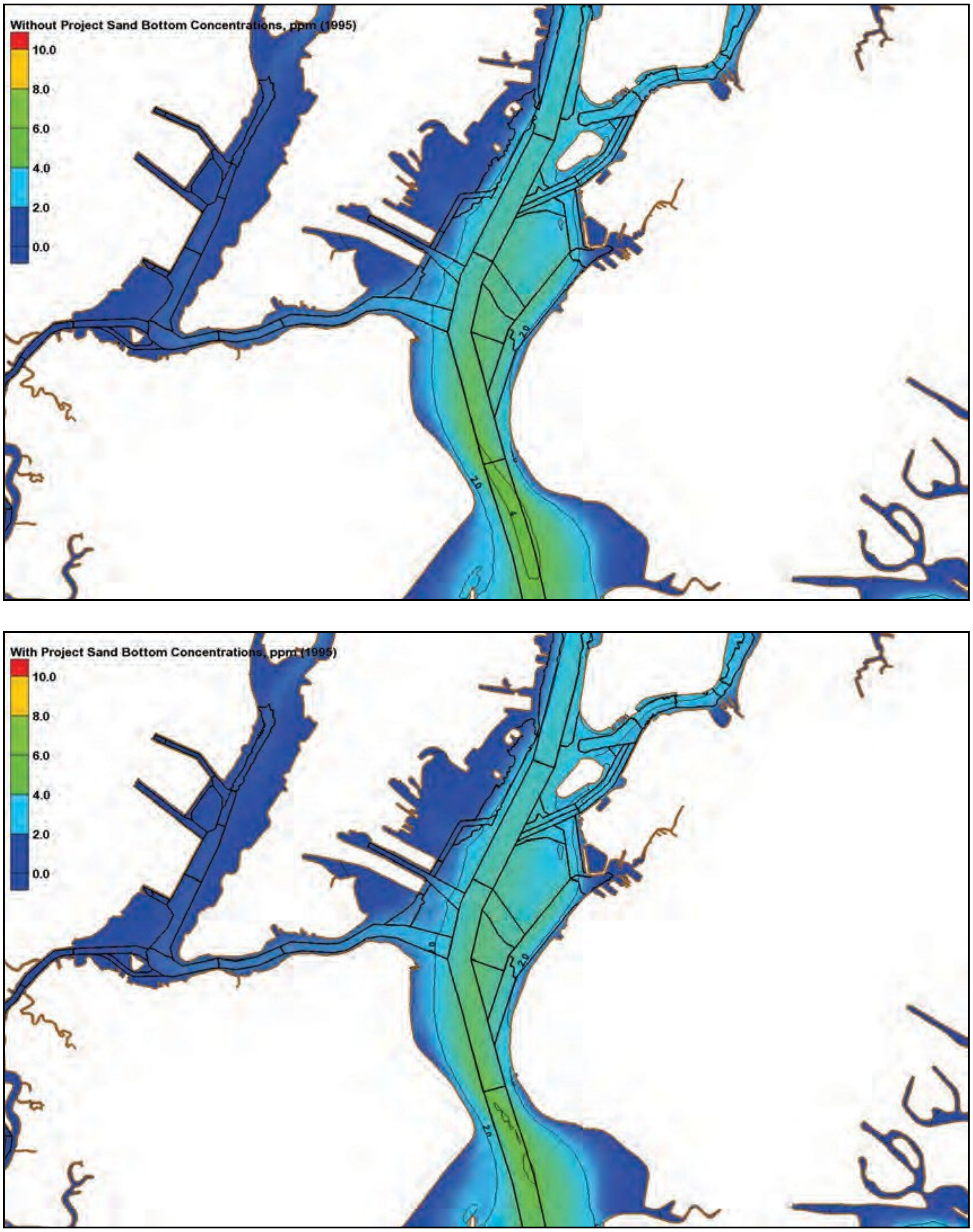


Figure 208. Without-project (top) and with-project (bottom) bed displacement, m (1995).

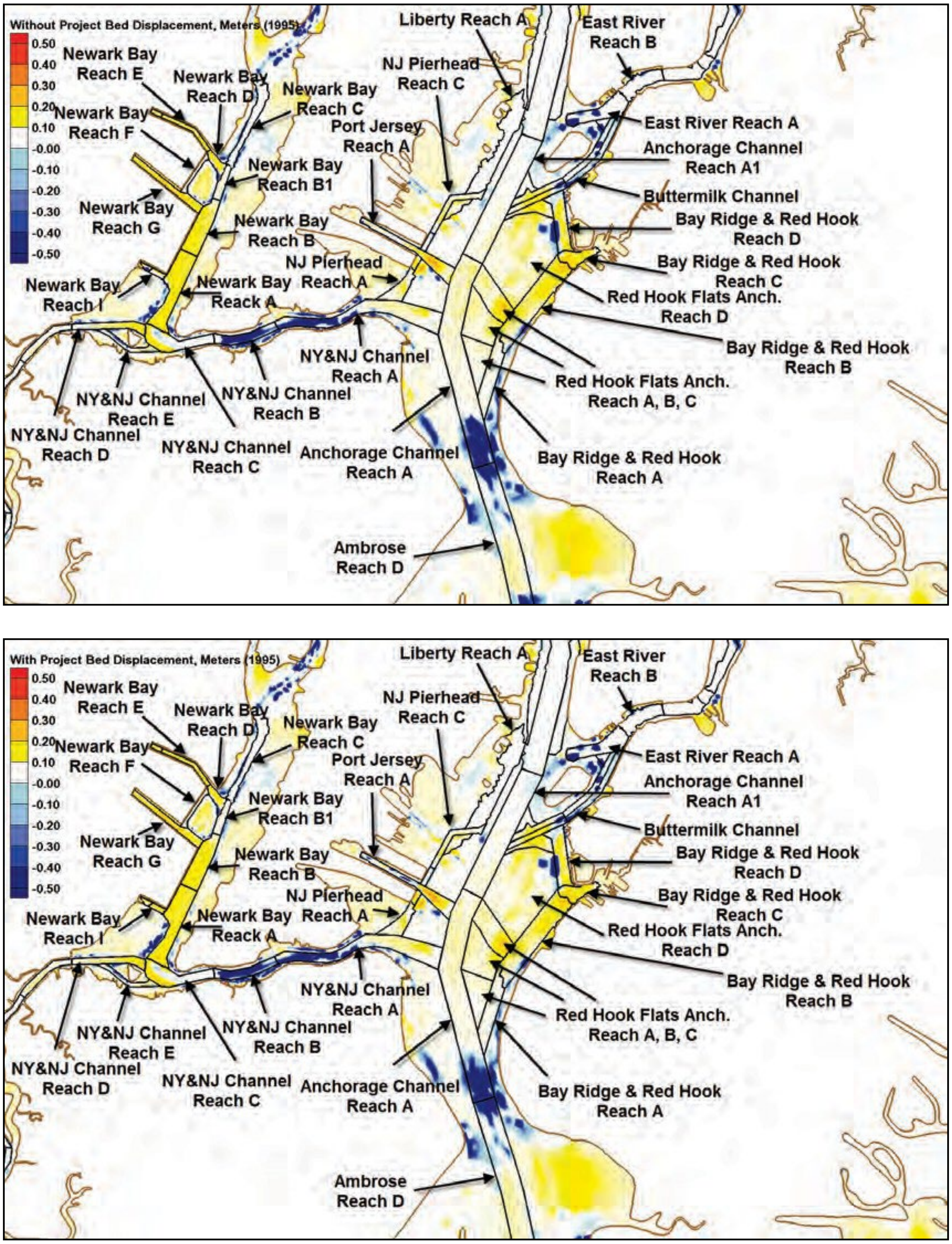
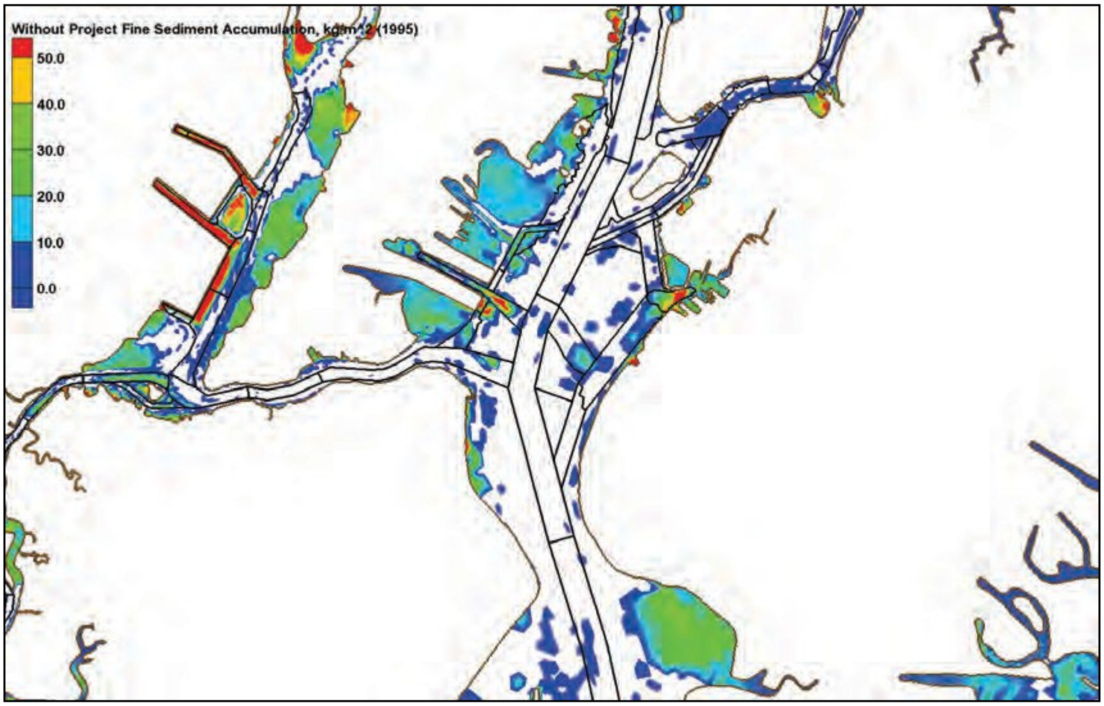


Figure 209. Without-project (top) and with-project (bottom) fine sediment accumulation, kg/m² (1995).



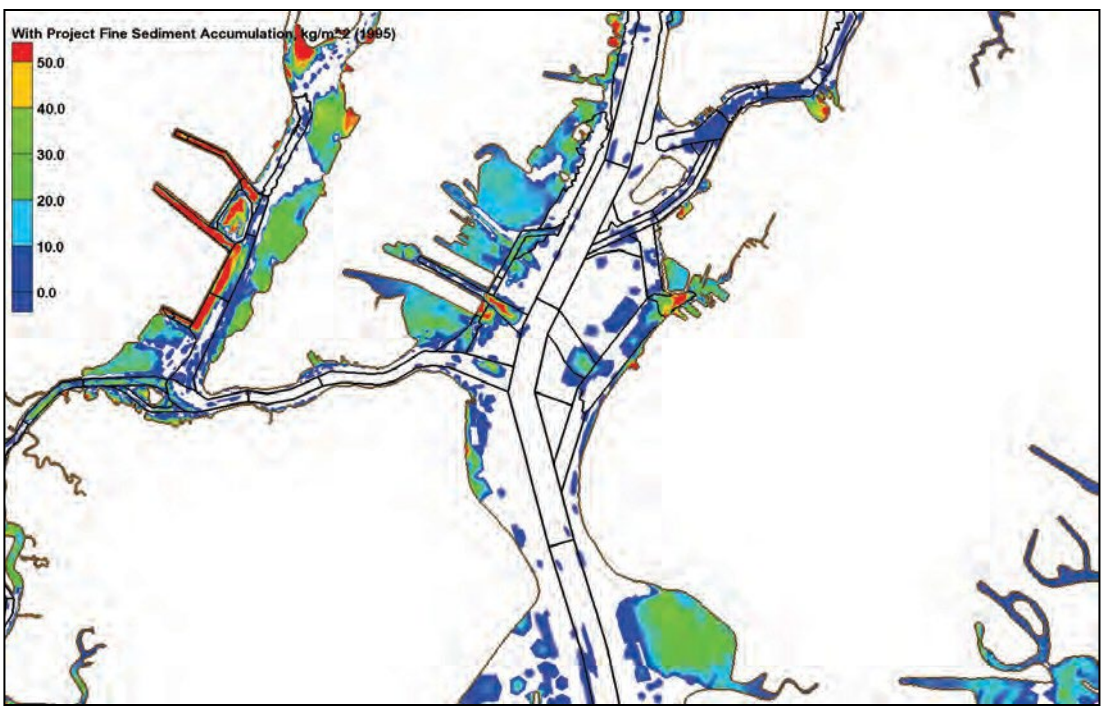
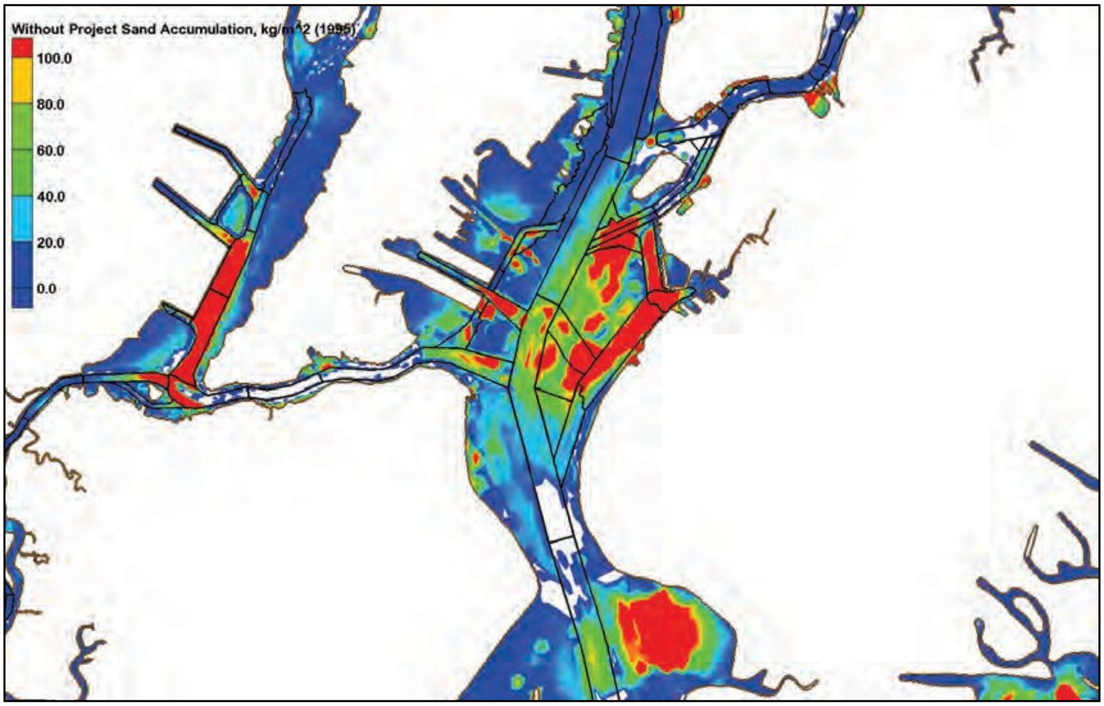


Figure 210. Without-project (top) and with-project (bottom) sand accumulation, kg/m² (1995).



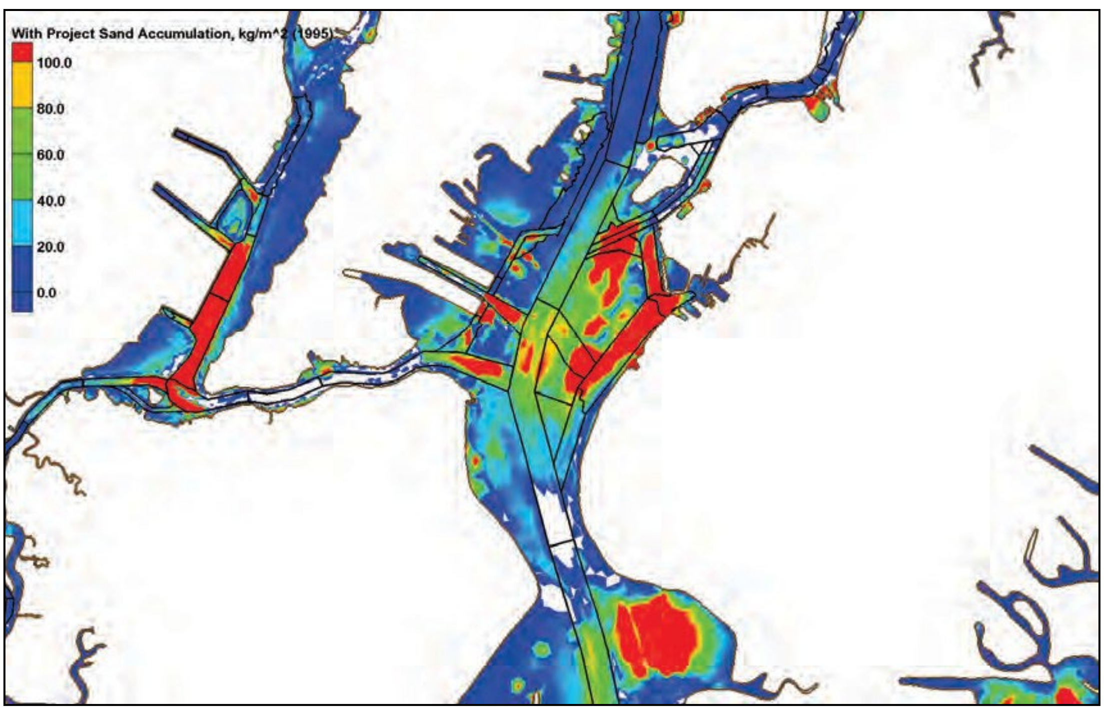
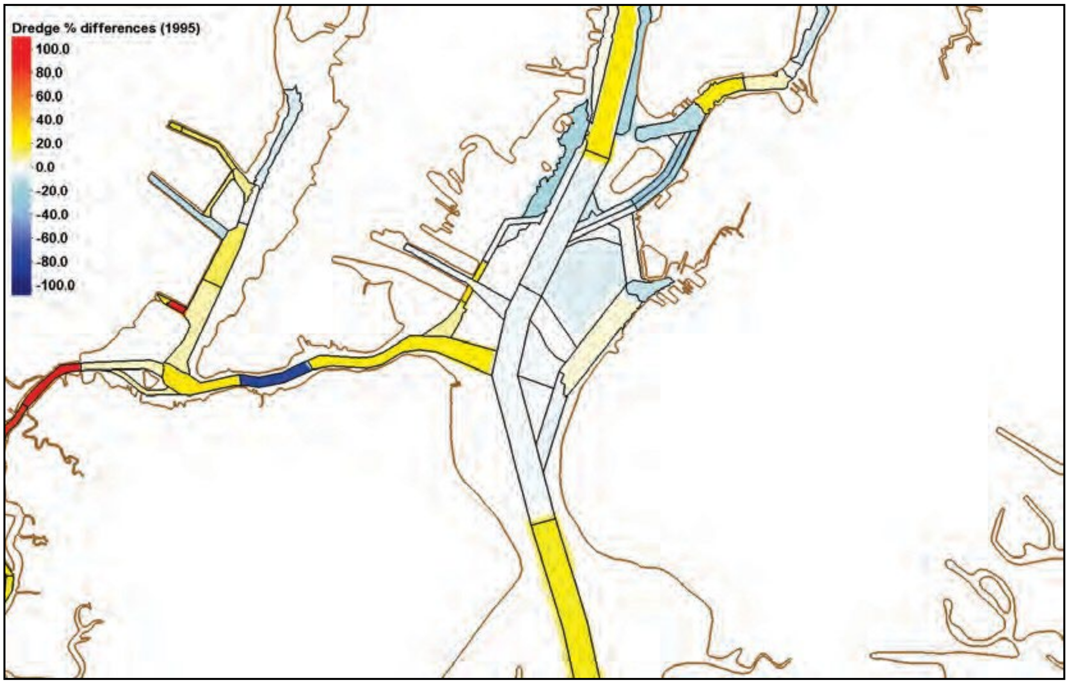


Figure 211. Dredge with-project/without-project percent differences (1995).



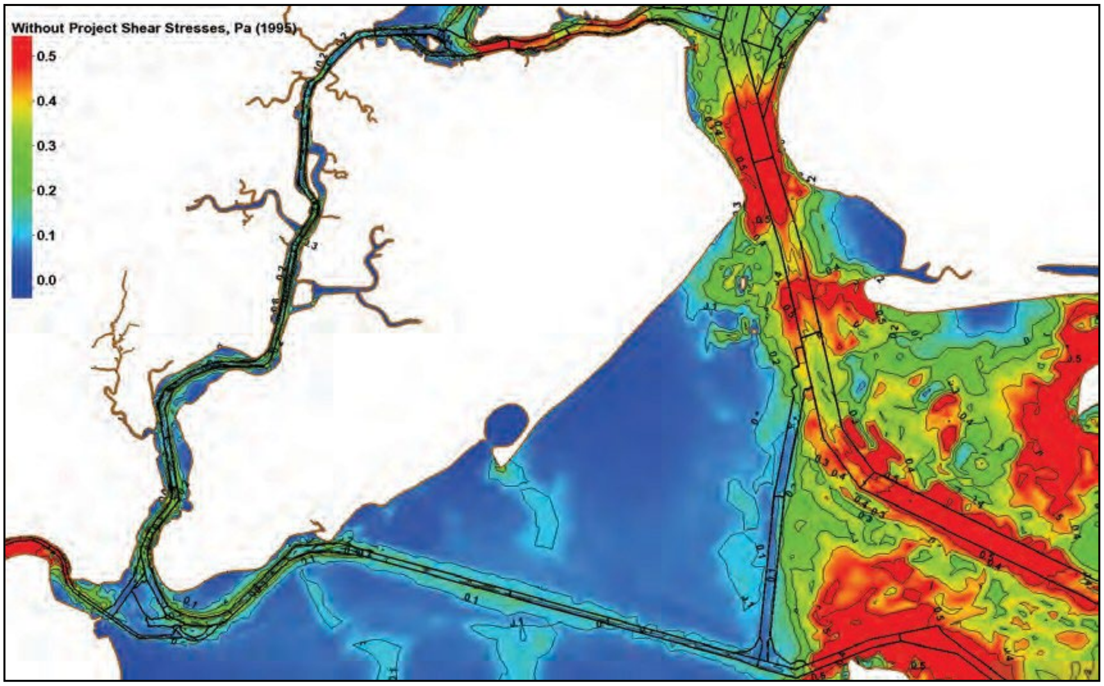
As would be expected, the salinity intrusion into Upper Bay and Newark Bay is increased for the with-project configuration. Overall, the Upper Bay channels experience a reduction in the dredge volumes with the Newark Bay and Kill van Kull having increases in dredge volumes of approximately 18,000 cy each or percentages of approximately 6% and 20%, respectively, for 1995. Newark Bay and Kill van Kull are the locations possessing the largest influences in terms of dredge volumes due to the with-project configuration.

Table 20. Dredge volumes in Newark Bay, Kill van Kull, and Upper Bay (1995).

Depositional Volumes in Newark Bay, Kill van Kull, and Upper Bay, cy (1995)			
Reach	Without Project	With Project	With/Without Dredge Percentage
Newark Bay			
Newark Bay Reach A	132,068	140,462	106
Newark Bay Reach B	77,020	87,119	113
Newark Bay Reach B1	2,483	2,437	98
Newark Bay Reach C	1,616	1,480	92
Newark Bay Reach D	14,550	15,802	109
Newark Bay Reach E	20,048	22,459	112
Newark Bay Reach E1	3,171	3,679	116
Newark Bay Reach F	2,749	3,042	111
Newark Bay Reach G	62,719	54,405	87
Newark Bay Reach I	2,621	6,131	234
Newark Bay Reach I1	2,025	2,662	131
Kill van Kull			
NY&NJ Channels Reach A	31,926	39,636	124
NY&NJ Channels Reach B	658	154	23
NY&NJ Channels Reach C	38,689	49,546	128
Upper Bay			
Anchorage Channel Reach A	62,733	61,232	98
Anchorage Channel Reach A1	20,061	19,179	96
Anchorage Reach C1	7,863	7,551	96
Bay Ridge & Red Hook Reach A	11,193	10,706	96
Bay Ridge & Red Hook Reach B	139,254	143,855	103
Bay Ridge & Red Hook Reach C	49,066	42,861	87
Bay Ridge & Red Hook Reach D	49,098	49,637	101
Red Hook Flats Anch. Reach A	12,849	12,689	99
Red Hook Flats Anch. Reach B	41,718	40,729	98
Red Hook Flats Anch. Reach C	67,621	67,428	100
Red Hook Flats Anch. Reach D	126,276	117,560	93
Port Jersey Reach A	49,730	47,978	96
NJ Pierhead Ch. Reach A	11,819	12,715	108
NJ Pierhead Ch. Reach B	6,963	8,532	123
NJ Pierhead Reach C	10,749	10,467	97
Liberty Reach A	6,105	4,953	81

Arthur Kill and Raritan Bay results

Figure 212. Without-project (top) and with-project (bottom) average shear stresses, Pa (1995).



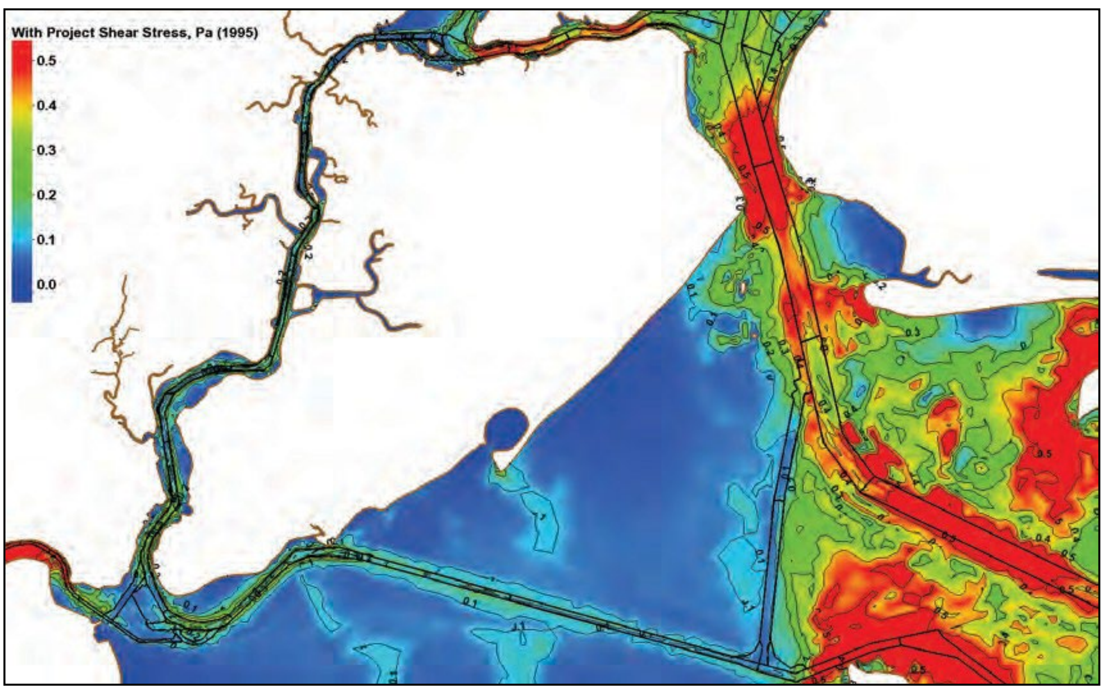


Figure 213. Without-project (top) and with-project (bottom) average bottom salinity, ppt (1995).

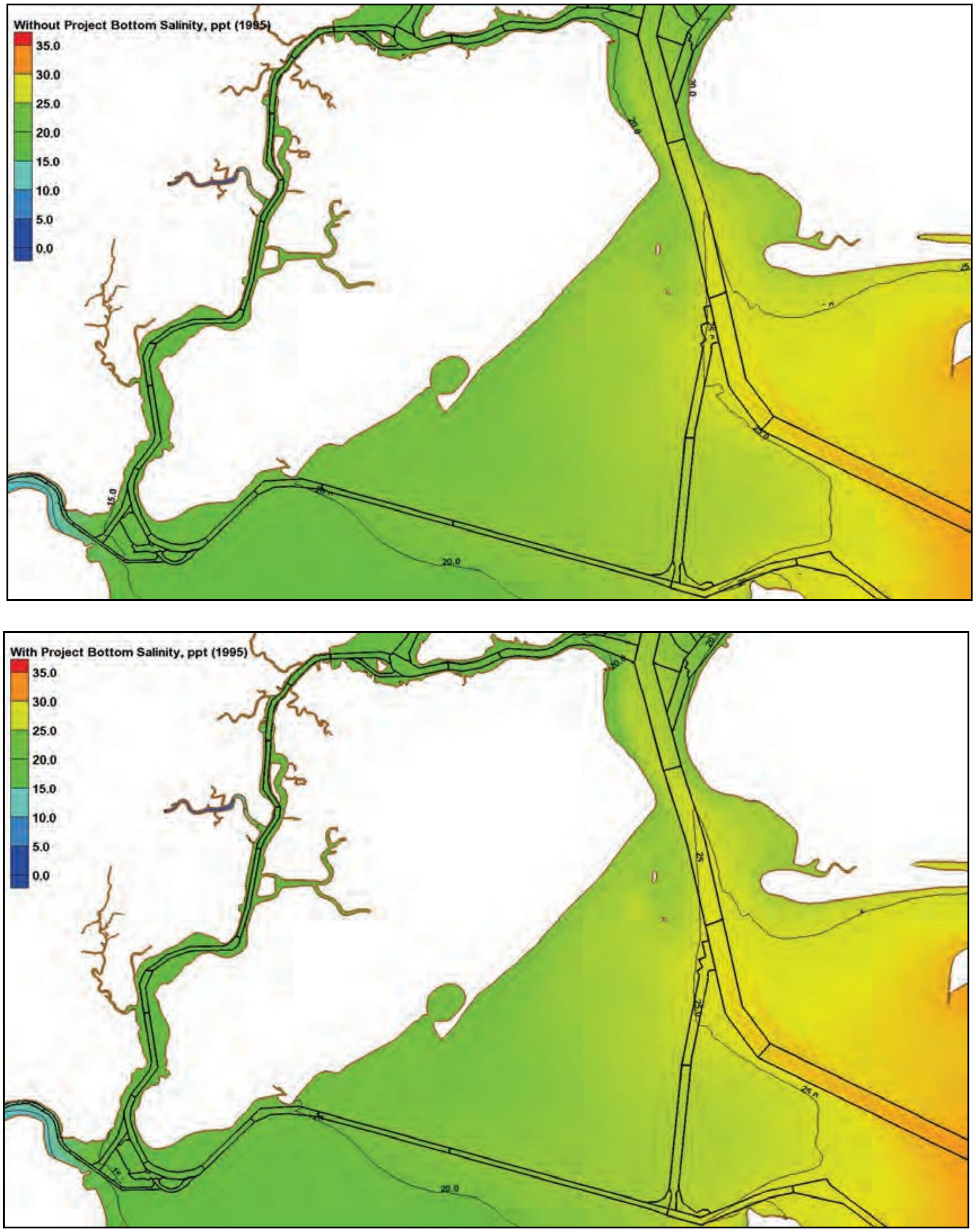
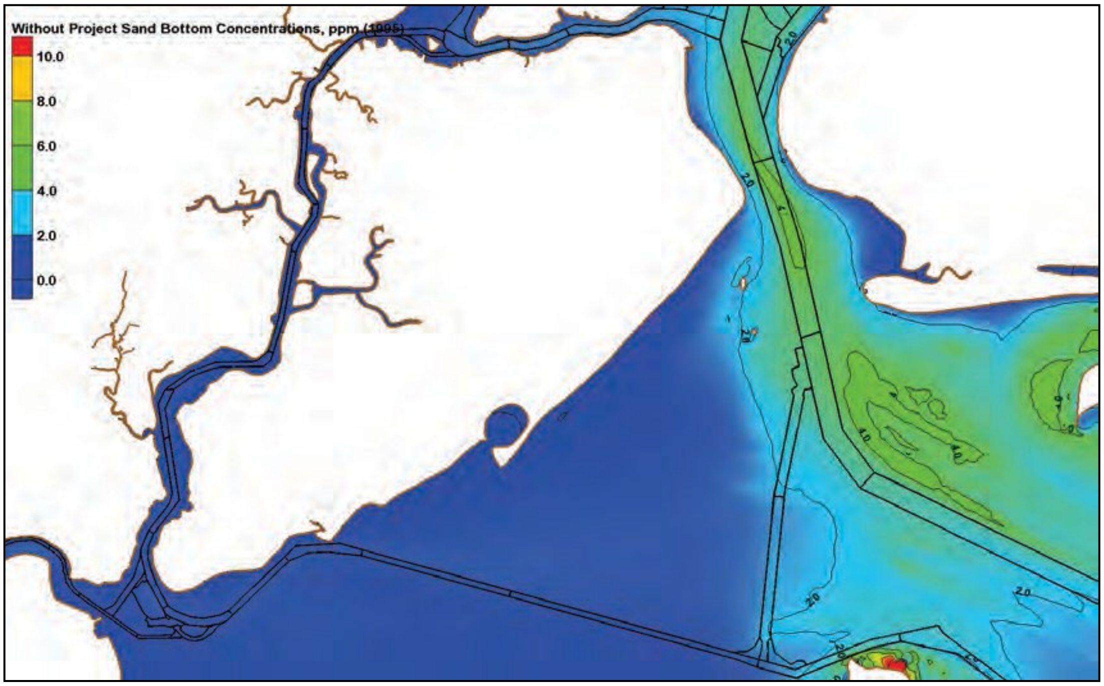


Figure 214. Without-project (top) and with-project (bottom) average fine sediment bottom concentrations, ppm (1995).

Figure 215. Without-project (top) and with-project (bottom) average sand bottom concentrations, ppm (1995).



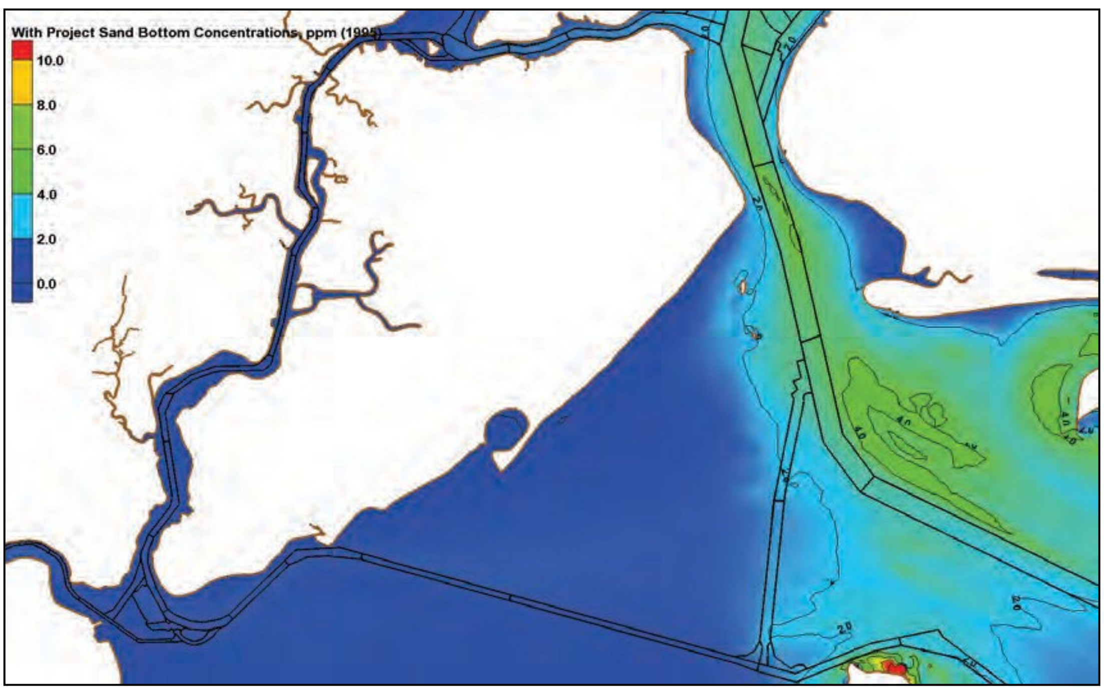
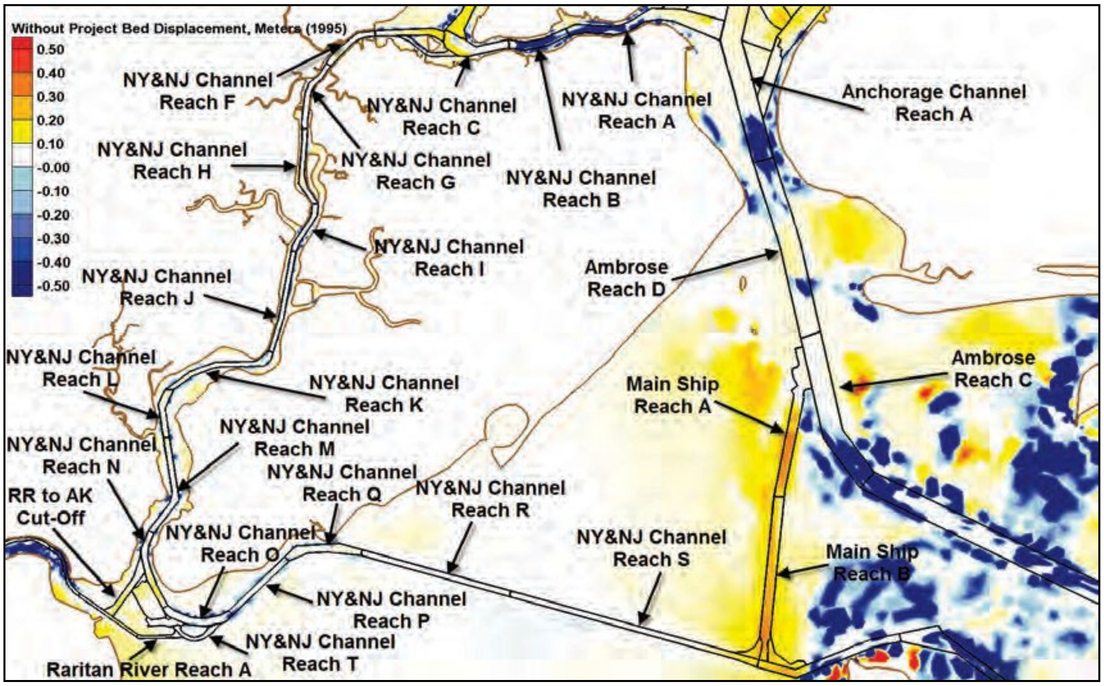


Figure 216. Without-project (top) and with-project (bottom) bed displacement, m (1995).



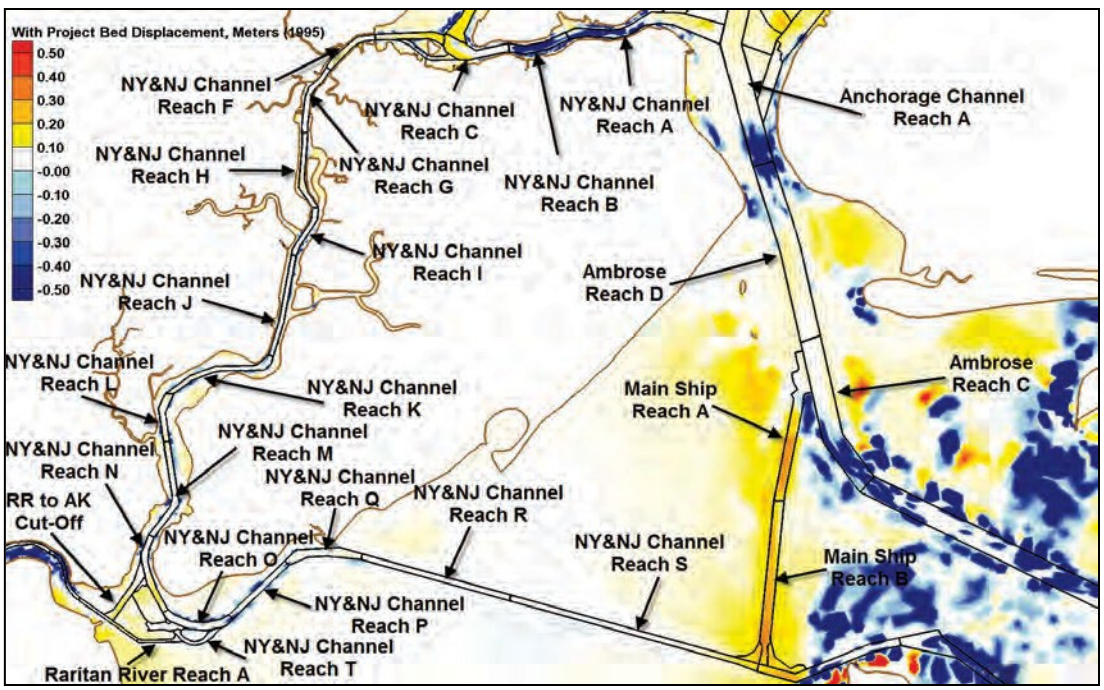
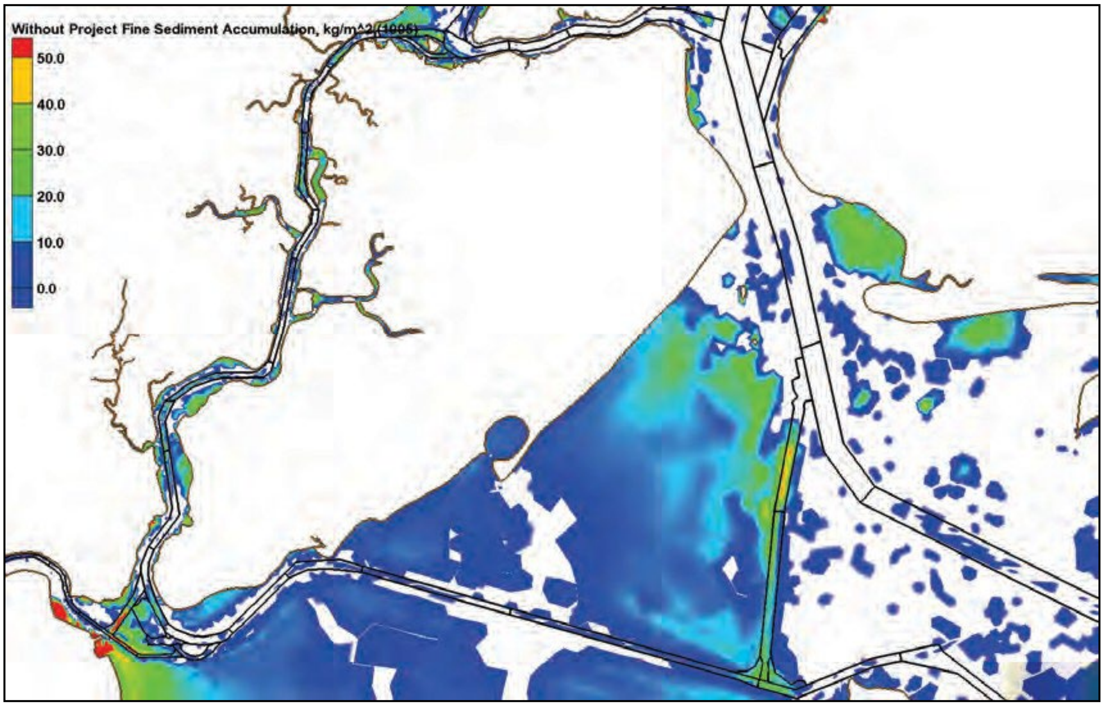


Figure 217. Without-project (top) and with-project (bottom) fine sediment accumulation, kg/m² (1995).



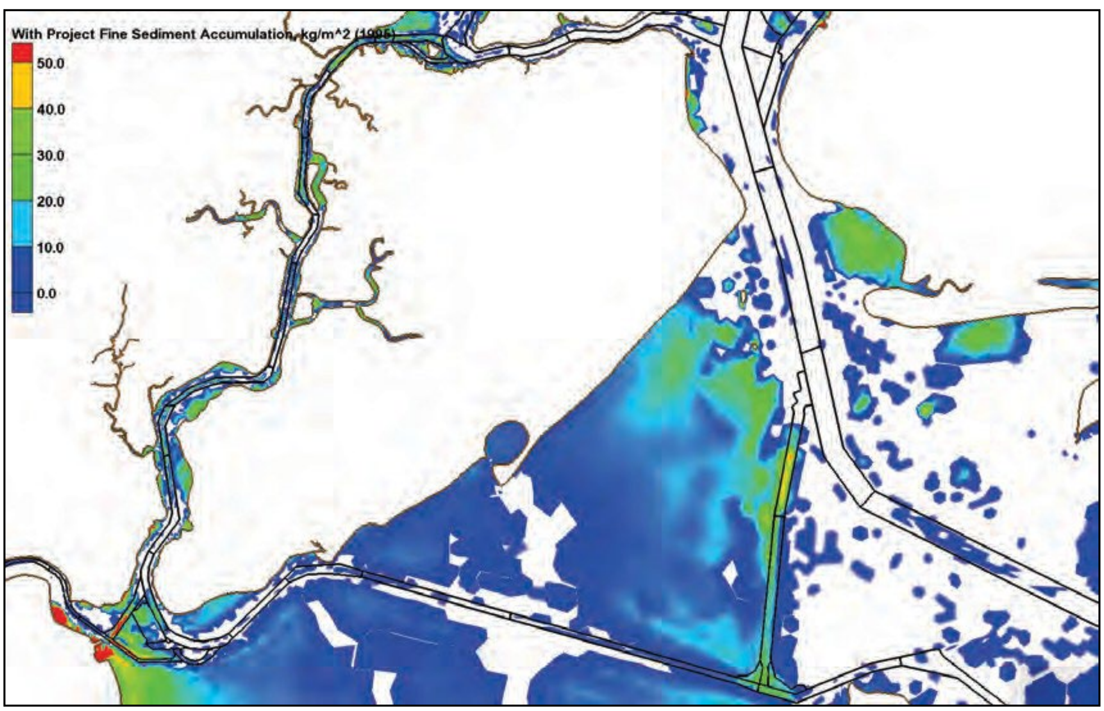
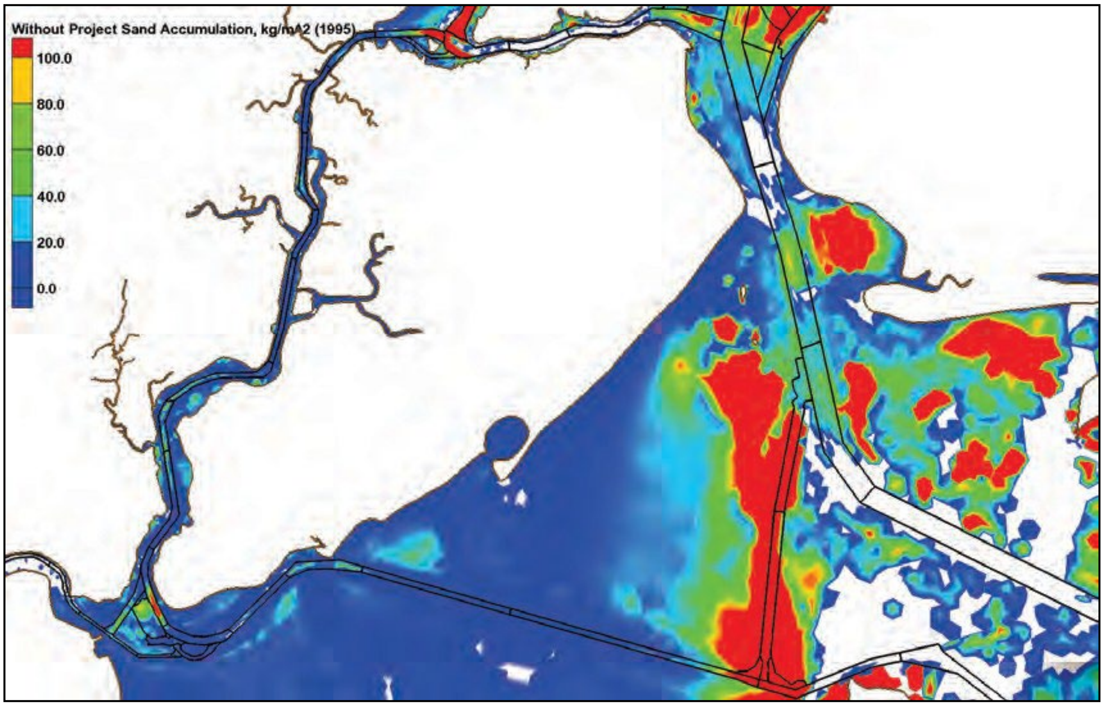


Figure 218. Without-project (top) and with-project (bottom) sand accumulation, kg/m² (1995).



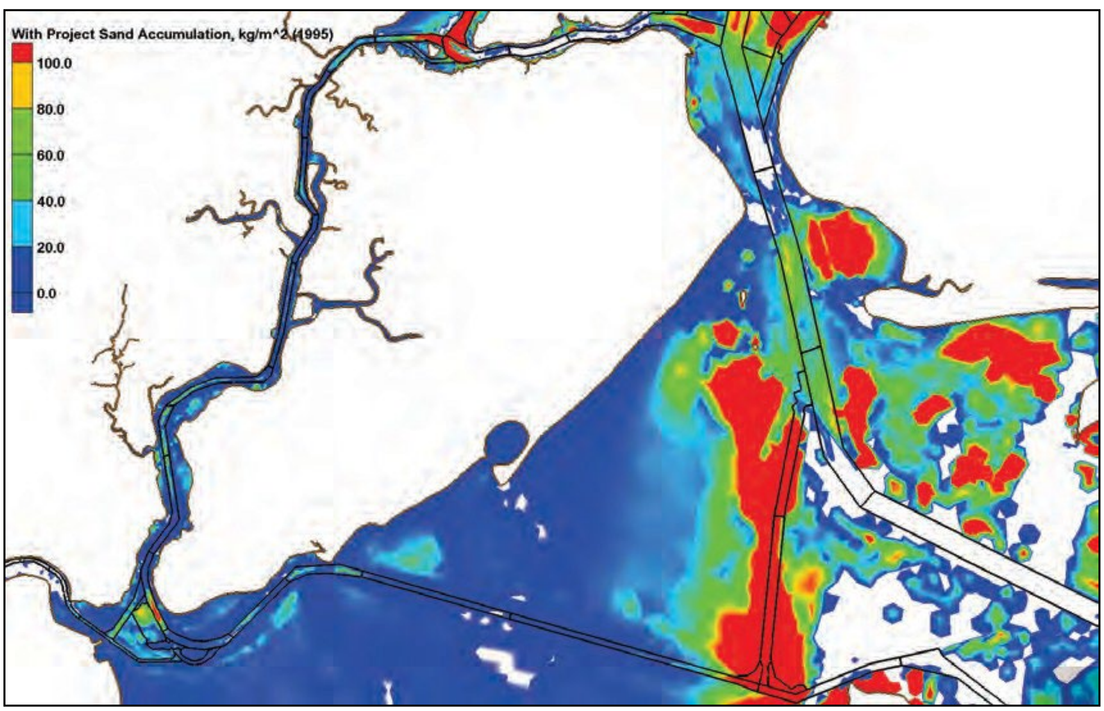


Figure 219. Dredge with-project/without-project percent differences (1995).

In general, the with-project impacts to the Arthur Kill and Raritan Bay areas are relatively minor. Some dredge volumes are redistributed among reaches, but the overall dredging requirements are similar. The redistribution of deposition across the reaches is to be expected due to the increased net flowrate through the Kill van Kull. This increased net flow rate also impacts the amount of water and sediment moving up the Arthur Kill from the Raritan River and Raritan Bay. Some of the dredge volume changes in Table 21 create large percentage changes, but these volumes are relatively small, so small changes in the dredge volumes can appear to be significant when in actuality the dredge volume (and change) is relatively small.

Table 21. Dredge volumes for Arthur Kill and Raritan Bay (1995).

Depositional Volumes in Arthur Kill and Raritan Bay, cy (1995)			
Reach	Without Project	With Project	With/Without Dredge Percentage
Arthur Kill			
NY&NJ Channels Reach D	26,484	27,844	105
NY&NJ Channels Reach E	4,555	4,874	107
NY&NJ Channels Reach F	3,240	6,977	215
NY&NJ Channels Reach G	385	687	179
NY&NJ Channels Reach H	2,477	2,959	119
NY&NJ Channels Reach I	146	170	117
NY&NJ Channels Reach J	230	741	322
NY&NJ Channels Reach K	3,587	4,716	131
NY&NJ Channels Reach L	4,269	4,991	117
NY&NJ Channels Reach M	2,513	3,237	129
NY&NJ Channels Reach N	12,141	11,589	95
Raritan Bay			
NY&NJ Channels Reach O	1,147	1,598	139
NY&NJ Channels Reach P	920	1,917	208
NY&NJ Channels Reach Q	4,617	4,395	95
NY&NJ Channels Reach R	935	758	81
NY&NJ Channels Reach T	586	778	133
RR to AK Cut-Off Reach A	12,243	13,164	108
Raritan River Reach A	2,390	2,624	110
Raritan River Reach B	6,517	6,603	101
Raritan River Reach C	764	772	101
Raritan River Reach D	277	274	99

Average dredge volumes for all reaches

The average annual dredge volumes over the five simulated years for each channel reach are provided in Table 22. These results indicate an increase in the Ambrose Channel, but that is almost offset by the decrease in the Main Ship Reach A channel. This offset appears to be somewhat of a trend with the primary deepened channels showing increases in dredging requirements with some other adjacent channels actually showing decreases in dredge volumes. The Kill van Kull and Newark Bay are the primary channels with increased dredging requirements.

Table 22. Average annual dredge volumes in cy by reach over the five simulated years.

Reaches	Average Without Dredge Volumes	Average With Dredge Volumes	Percentage Change
Lower Bay			
Ambrose Channel Reach A	255,407	271,730	6
Ambrose Channel Reach B	1,717	1,158	-33
Ambrose Channel Reach C	12,512	22,008	76
Ambrose Channel Reach D	33,303	39,313	18
Main Ship Reach A	216,092	191,440	-11
Total	519,030	525,649	1
Sandy Hook/Raritan Bay Channels			
Sandy Hook Reach A	104,664	104,970	0
Sandy Hook Reach B	85,669	85,920	0
Main Ship Reach B	277,208	271,402	-2
Main Ship	54,797	54,191	-1
NY&NJ Channels Reach O	3,072	3,558	16
NY&NJ Channels Reach P	6,471	6,361	-2
NY&NJ Channels Reach Q	10,580	10,069	-5
NY&NJ Channels Reach R	993	918	-8
NY&NJ Channels Reach S	30,872	30,917	0
NY&NJ Channels Reach T	1,727	1,895	10
NY&NJ Channels Reach V	36,948	36,507	-1
NY&NJ Channels Reach U Area 1	31,703	35,191	11
NY&NJ Channels Reach U Area 2	2,467	2,189	-11
NY&NJ Channels Reach U Area 3	49	50	2

NY&NJ Channels Reach U Area 4	1,175	1,163	-1
RR to AK Cut-Off Reach A	19,191	20,208	5
Raritan River Reach A	4,655	4,914	6
Raritan River Reach B	8,449	8,607	2
Raritan River Reach C	876	859	-2
Raritan River Reach D	146	133	-8
Total	681,713	680,023	0
Upper Bay Channels			
Anchorage Channel Reach A	68,020	64,656	-5
Anchorage Channel Reach A1	30,238	26,903	-11
Port Jersey Reach A	52,147	47,224	-9
NJ Pierhead Ch. Reach A	11,661	12,565	8
NJ Pierhead Ch. Reach B	7,699	9,266	20
NJ Pierhead Reach C	10,483	10,373	-1
Bay Ridge & Red Hook Reach A	14,946	14,337	-4
Bay Ridge & Red Hook Reach B	145,143	149,670	3
Bay Ridge & Red Hook Reach C	53,230	47,338	-11
Bay Ridge & Red Hook Reach D	54,588	53,925	-1
Red Hook Flats Anch. Reach A	17,373	16,793	-3
Red Hook Flats Anch. Reach B	43,684	39,127	-10
Red Hook Flats Anch. Reach C	133,715	125,352	-6
Red Hook Flats Anch. Reach C	65,486	63,389	-3
Anchorage Reach C1	7,814	7,637	-2
Liberty Id. Reach A	7,622	6,268	-18
Buttermilk Ch. Reach A	23,871	23,048	-3
Buttermilk Ch. Reach B	785	748	-5
Buttermilk Ch. Reach C	30,474	29,574	-3
Buttermilk Ch. Reach D	14,475	13,707	-5

Buttermilk Ch. Reach E	286	260	-9
Buttermilk Ch. Reach F	1,978	1,756	-11
Buttermilk Ch. Reach G	1	1	-31
Total	795,721	763,917	-4
Kill van Kull Channels			
NY&NJ Channels Reach A	51,302	61,571	20
NY&NJ Channels Reach B	643	383	-41
NY&NJ Channels Reach C	39,196	45,597	16
Total	91,142	107,551	18
Arthur Kill Channels			
NY&NJ Channels Reach D	35,082	31,860	-9
NY&NJ Channels Reach E	5,664	5,850	3
NY&NJ Channels Reach F	7,489	12,111	62
NY&NJ Channels Reach G	1,709	2,203	29
NY&NJ Channels Reach H	5,956	6,908	16
NY&NJ Channels Reach I	553	710	28
NY&NJ Channels Reach J	2,210	2,975	35
NY&NJ Channels Reach K	10,248	10,597	3
NY&NJ Channels Reach L	9,022	8,977	0
NY&NJ Channels Reach M	7,467	7,588	2
NY&NJ Channels Reach N	16,597	15,077	-9
Total	101,998	104,855	3
East River Channels			
East River Reach A	2,526	2,281	-10
East River Reach B	651	754	16
East River Reach C	229	254	11
East River Reach C1	0	0	33
East River Reach D	10	14	33

East River Reach E	32	33	2
East River Reach F	582	576	-1
East River Reach G	253	252	0
East River Reach H	85,432	76,992	-10
East River Reach I	109,929	109,671	0
East River Reach J	1,276	788	-38
East River Reach K	186	157	-16
Total	201,106	191,770	-5
Newark Bay			
Newark Bay Reach A	160,379	177,079	10
Newark Bay Reach B	129,822	157,190	21
Newark Bay Reach B1	3,190	3,124	-2
Newark Bay Reach C	2,674	2,718	2
Newark Bay Reach D	25,026	29,129	16
Newark Bay Reach E	30,636	37,599	23
Newark Bay Reach E1	4,129	5,429	31
Newark Bay Reach F	7,612	8,958	18
Newark Bay Reach G	110,043	100,850	-8
Newark Bay Reach I	3,530	8,333	136
Newark Bay Reach I1	3,226	4,393	36
Total	480,267	534,801	11
All Reaches	2,870,977	2,908,566	1

When considering all channel reaches, the increase in dredging is estimated at 1% as shown in Table 22. For the locations shown in Figure 86, the percentage increases in overall dredging were 6% (1985), 4% (1995), 3% (1996), 7% (2011), and 0% (2012) with an average annual increase in dredging of 4%. This would indicate the non-project channels experienced less increase and even some decreases in dredging as compared to the deepened project channels.

Variation in dredge volumes for the simulated years

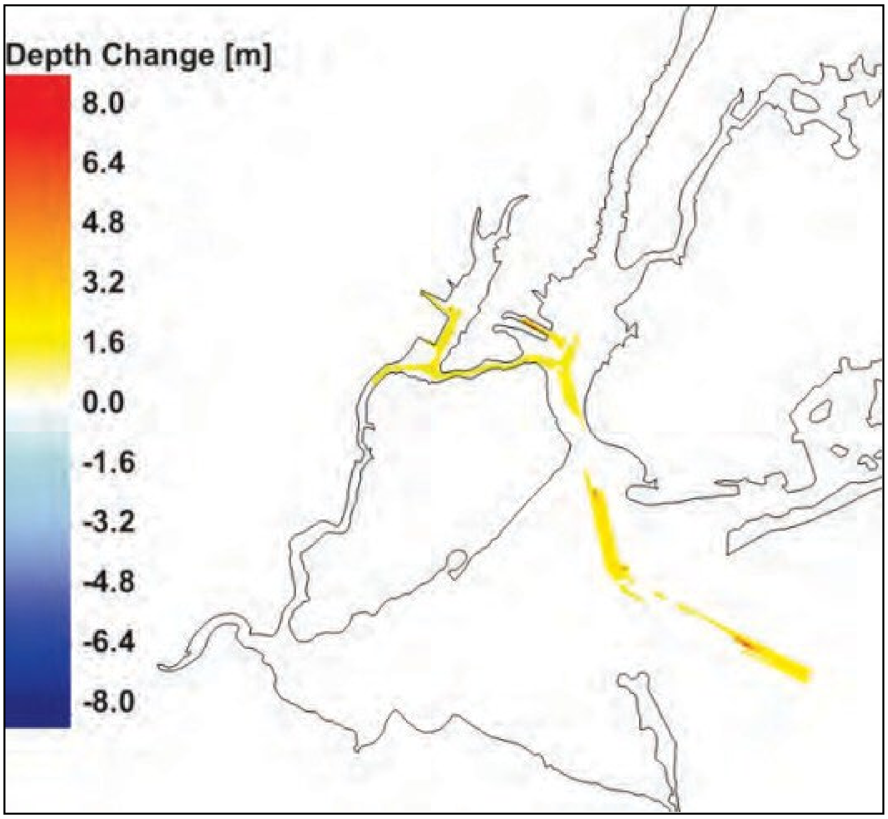
By simulating five different years, the variability in dredge volumes could be approximated. The total dredge volumes for all reaches ranged from approximately 2.5 million cy (1985) to approximately 3.4 million cy (2011) for the without project and approximately 2.5 million cy (1985) to approximately 3.6 million cy (2011) for the with project. From these results, it can be inferred the forcing conditions across years can result in a variation in the dredge volumes of as much as 1.1 million cy with larger yearly variations possible. The total average dredge volumes were approximately 2.9 million cy for both configurations and the with-project conditions has an increase in dredging of approximately 40,000 cy equating to a 1% increase over the without-project configuration (see Table 22).

The dredge volumes for the five simulated years for the commonly dredged locations shown in Figure 86 ranged from approximately 1.3 million cy (1985) to a high of 2.3 million cy (2011). The variation in the annual dredge volumes for these locations (~1 million cy) is an order of magnitude larger than the changes due to the project (~70,000 cy).

Wave impacts due to channel deepening

Like the AdH model, the STWAVE bathymetry was updated to reflect the deepening of the navigation channel. The extent of the channel deepening is indicated by the warm colors in Figure 220.

Figure 220. Channel deepening in STWAVE domain.



The impact of channel deepening on the mean wave climate is summarized below by comparing the mean significant wave height envelope for each year-long simulation. The left panels of Figure 221 through Figure 225 show the average significant wave height for each grid cell, and the right panel shows the difference in average significant wave height due to the channel deepening project. In the difference plots, warm colors indicated larger wave heights whereas cool colors indicate smaller wave heights.

Figure 221. Effect of channel deepening on mean significant wave height for 1985.

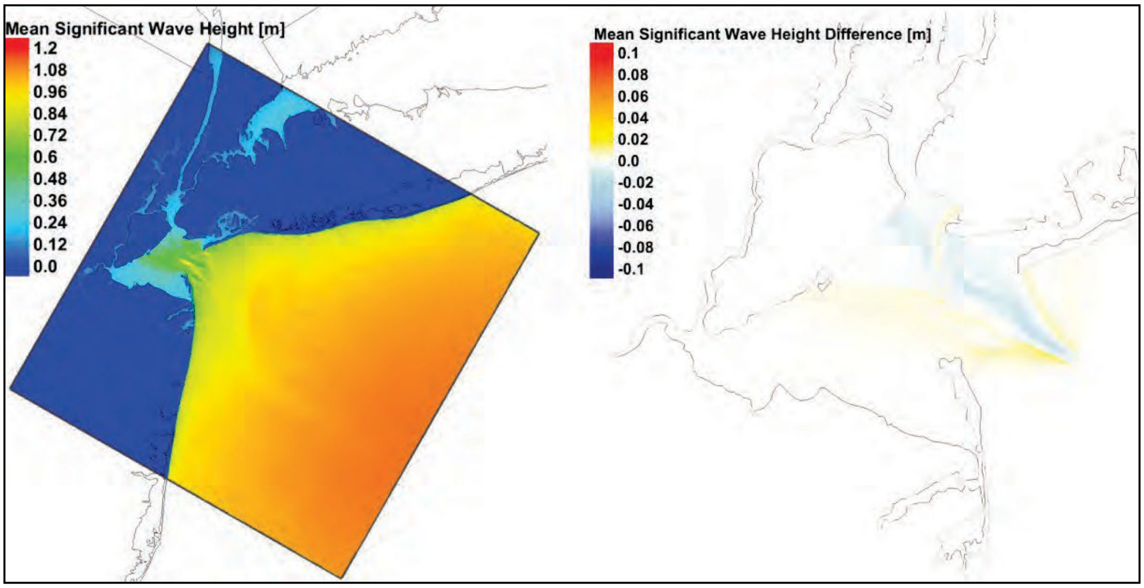


Figure 222. Effect of channel deepening on mean significant wave height for 1995.

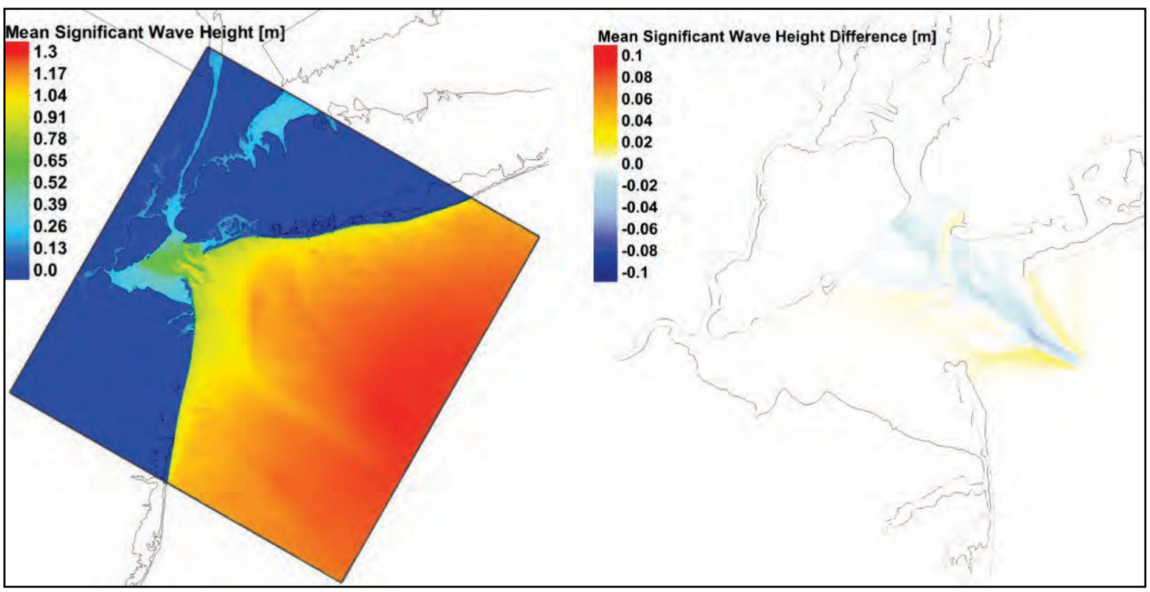


Figure 223. Effect of channel deepening on mean significant wave height for 1996.

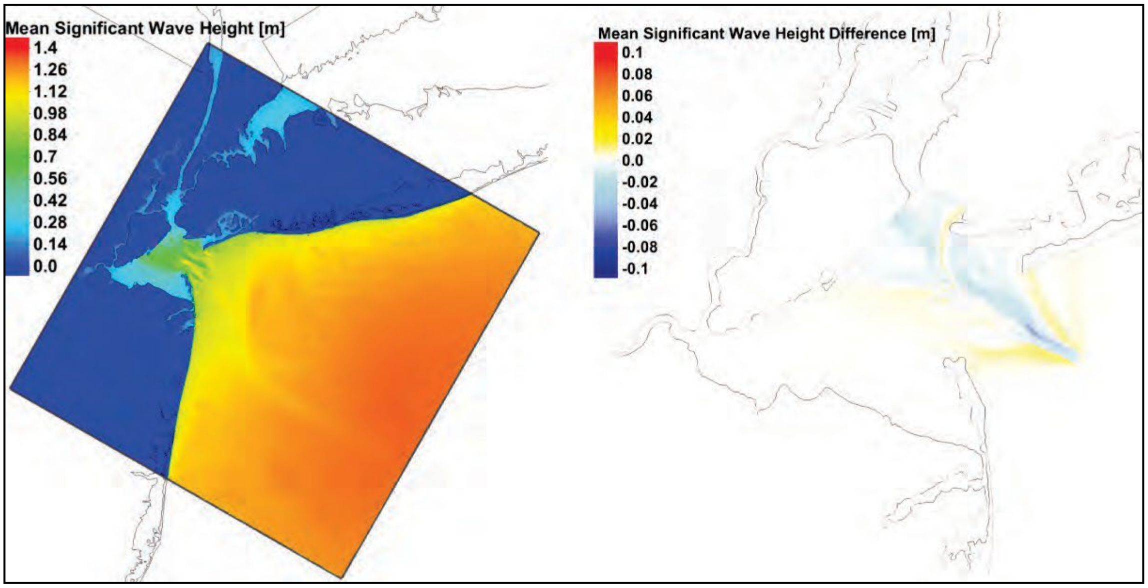


Figure 224. Effect of channel deepening on mean significant wave height for 2011.

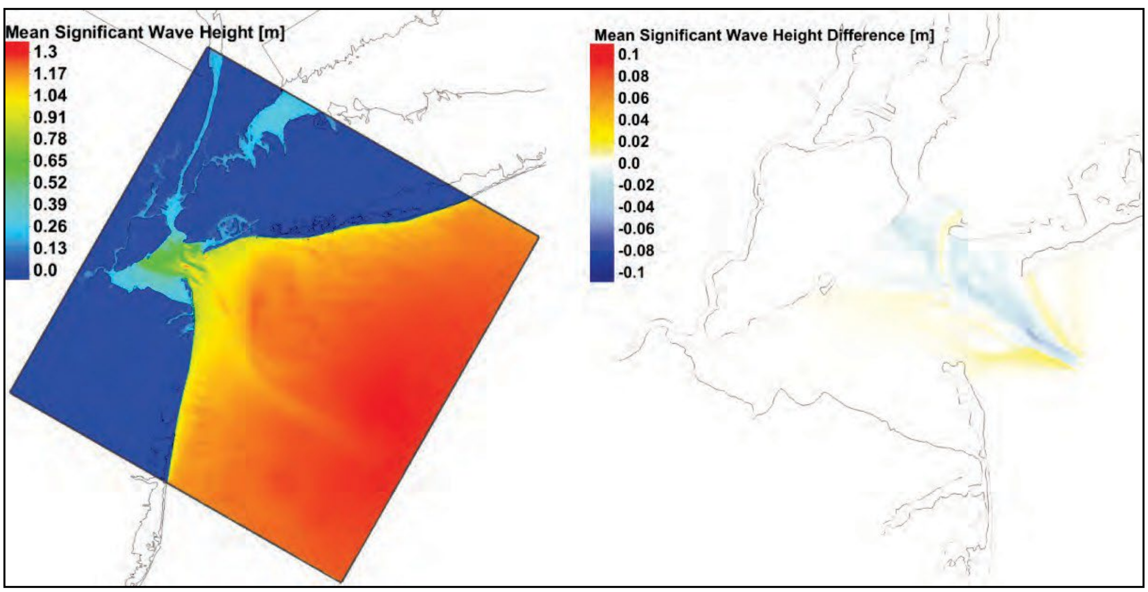
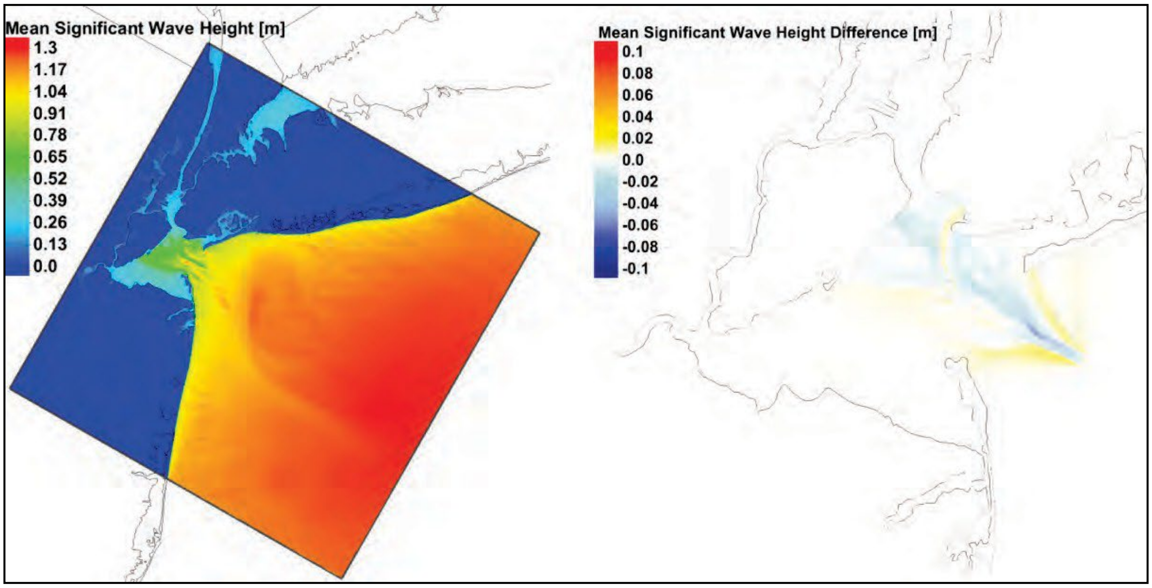


Figure 225. Effect of channel deepening on mean significant wave height for 2012.



The mean significant wave height envelope for all modeled timeframes is similar. The maximum average wave height ranges from 1.2 m in 1985 to 1.4 m in 1996. For all modeled timeframes, average significant wave heights within the Ambrose Navigation Channel are slightly smaller whereas waves adjacent to the channel are slightly larger. This pattern results from changes in the shoaling location of propagating waves due to the deeper channel (e.g., waves are influenced less by the deeper bathymetry). The effect of the channel deepening on the mean significant wave height is marginal, with differences on the order of 10 cm or less.

In addition to mean wave climate, it is important to look at the storm wave climate since larger waves can result in more sediment transport. The effect of channel deepening on the storm wave climate is generalized below by comparing the maximum wave envelope for each year-long simulation. As in the previous figures, the left panels of Figure 226 through Figure 230 show the maximum significant wave height and the right panel shows the difference in maximum significant wave height due to the channel deepening project. Note that the maximum wave height envelope is a single instance of the entire year-long simulation and may not occur at the same time-step for each grid cell.

Figure 226. Effect of channel deepening on max significant wave height for 1985.

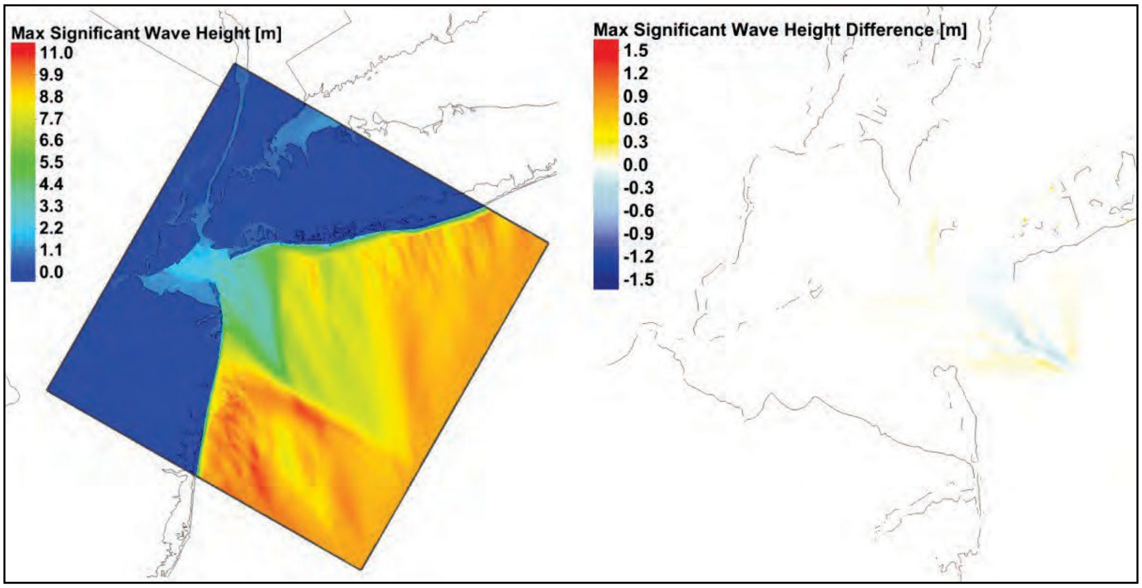


Figure 227. Effect of channel deepening on max significant wave height for 1995.

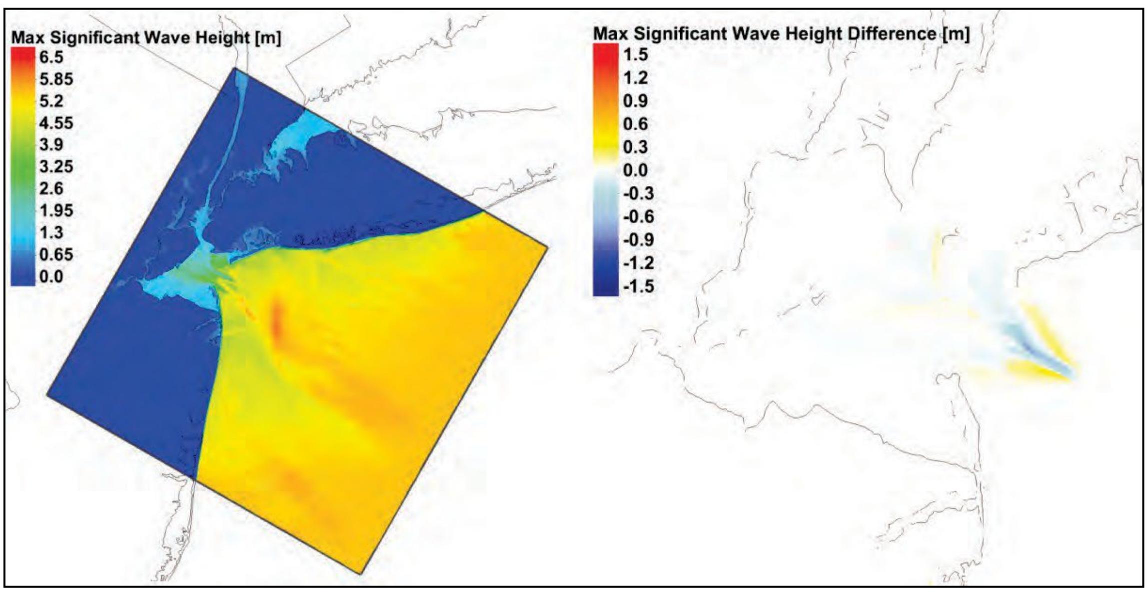


Figure 228. Effect of channel deepening on max significant wave height for 1996.

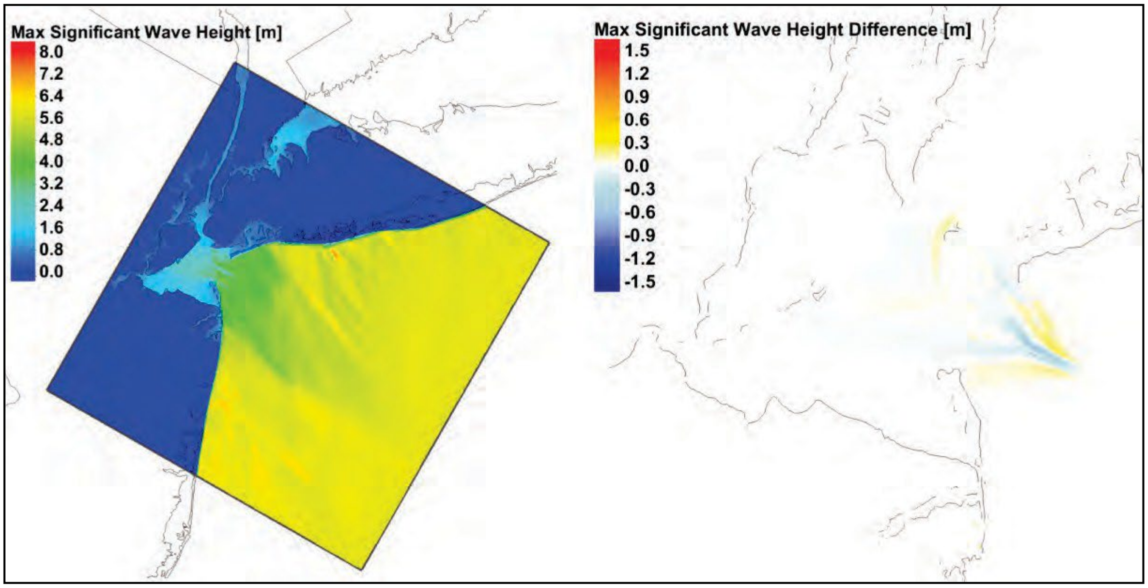


Figure 229. Effect of channel deepening on max significant wave height for 2011.

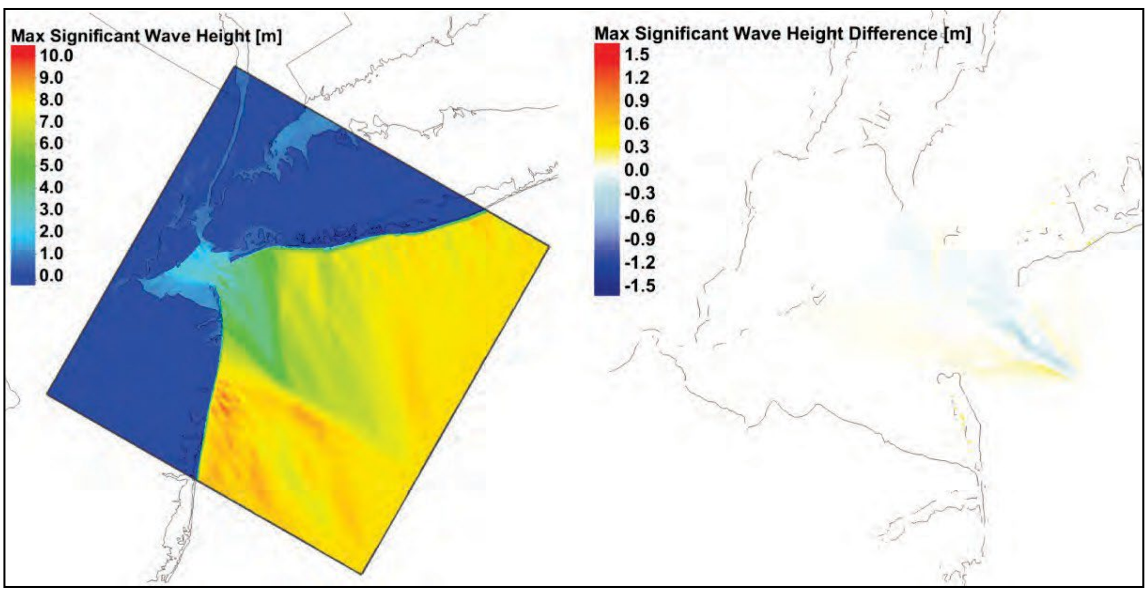
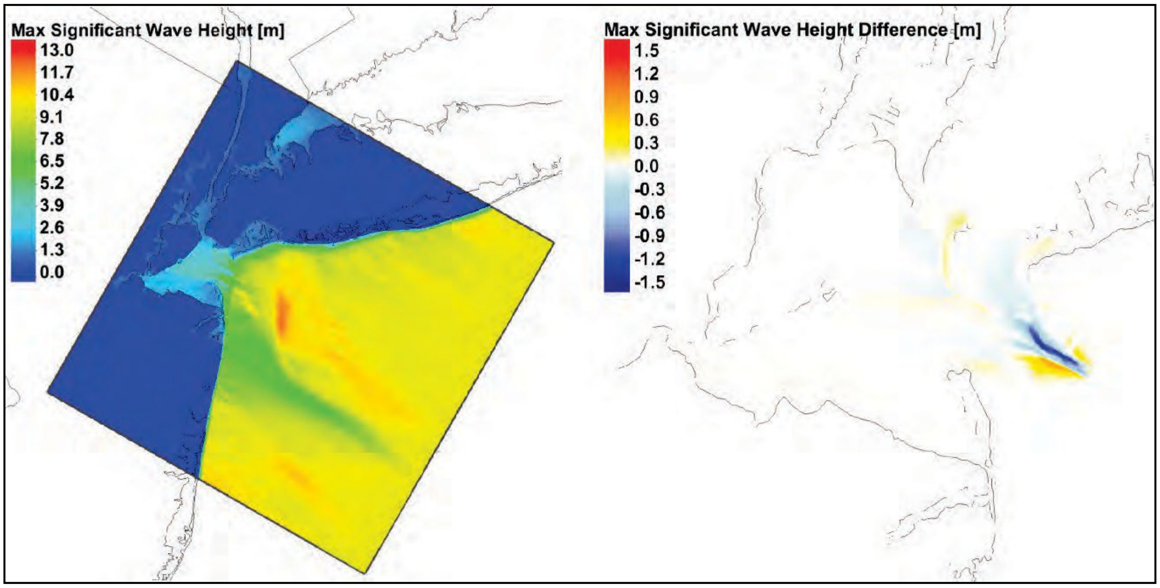


Figure 230. Effect of channel deepening on max significant wave height for 2012.



The smallest and largest significant wave height was found in 1995 and 2012, respectively. The greatest differences are localized within the entrance of the Ambrose Navigation Channel, and the magnitude of the difference is much larger than the mean wave climate of the same year. Except for 2011, the difference in maximum wave height exceeds 0.5 m. The largest differences, up to 1.5 m, are seen for 2012. The difference plots look similar to that of the mean wave climate analysis in that waves for the with-project configuration are again generally smaller within the channel and larger adjacent to the channel as compared to the without-project configuration. Like the mean wave climate, this pattern is a result of the channel deepening altering the transformation of the waves.

10 Extreme Event Analysis

Extreme events (primarily hurricanes) can have a significant impact on an estuarine system. This impact extends to the dredge volumes analyzed as part of this study. The 5 years simulated for this study included 3 years with major hurricanes — Hurricane Gloria (1985), Hurricane Irene (2011), and Hurricane Sandy (2012). While the actual events are relatively short in duration, the impacts in terms of inflows and/or sediment concentrations can linger for several weeks and even months. The modeled fine sediment bottom (water) concentrations were analyzed at the three locations in Figure 231 in an attempt to determine an approximate duration of influence due to these extreme events. From analysis of the results shown in Figures 232, 233, and 234, the start and stop times for these events were determined as provided in Table 23.

Also note that in 2011, there were two very large flows on the Passaic River that dominated the sediment concentrations in Newark Bay. These events were two to three times larger than any other event simulated for the remaining four years and as such resulted in very large impacts on the sediment concentrations and associated dredge volumes.

Figure 231. Three points to analyze for the duration of storm impacts on sediment concentrations.

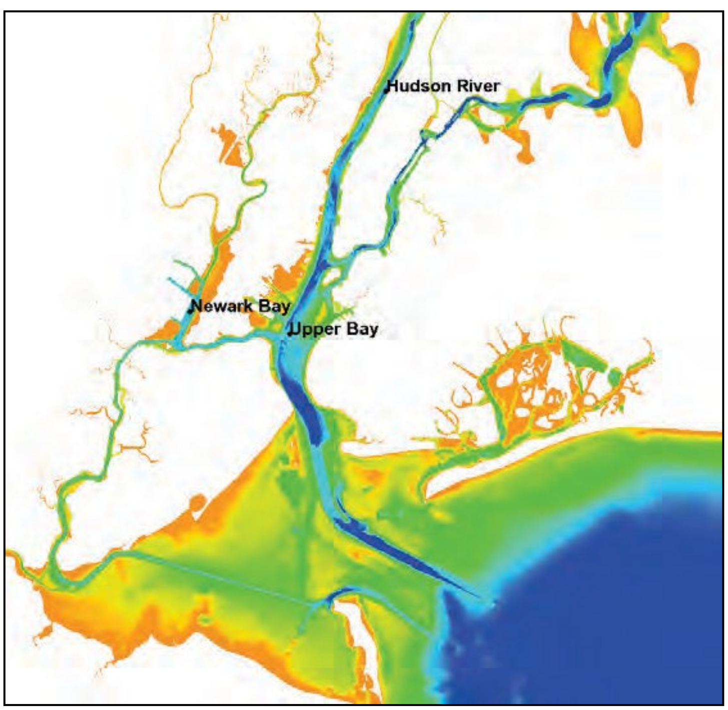


Figure 232. Hudson River bottom water layer fine sediment concentrations.

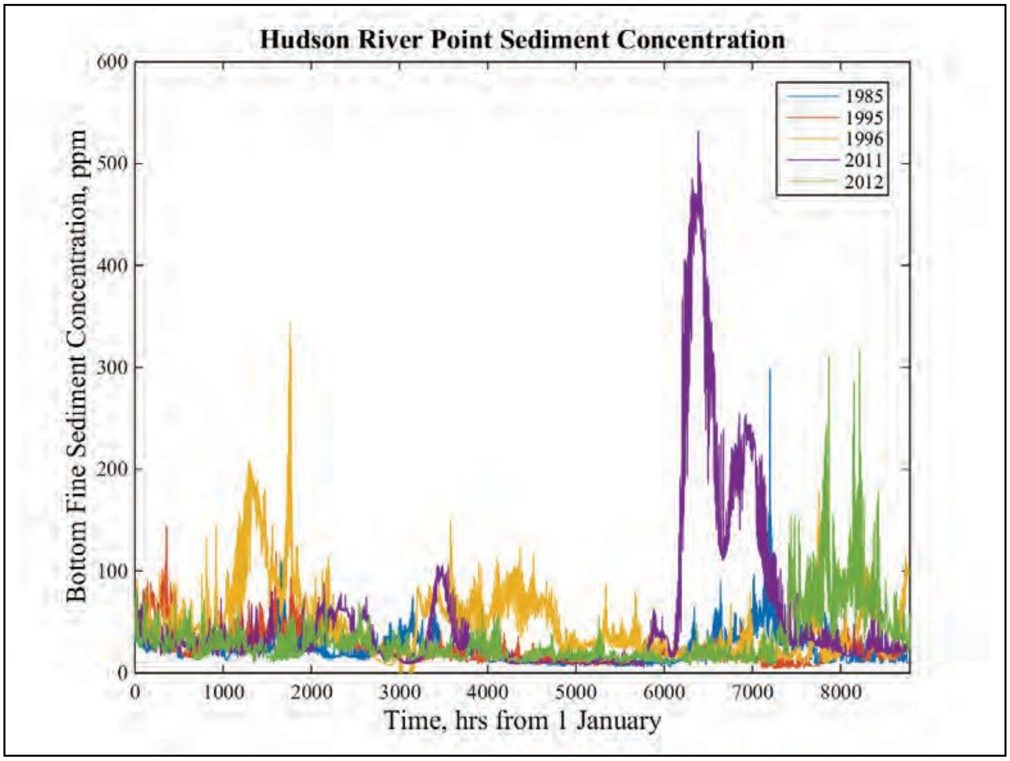


Figure 233. Upper Bay bottom water layer fine sediment concentrations.

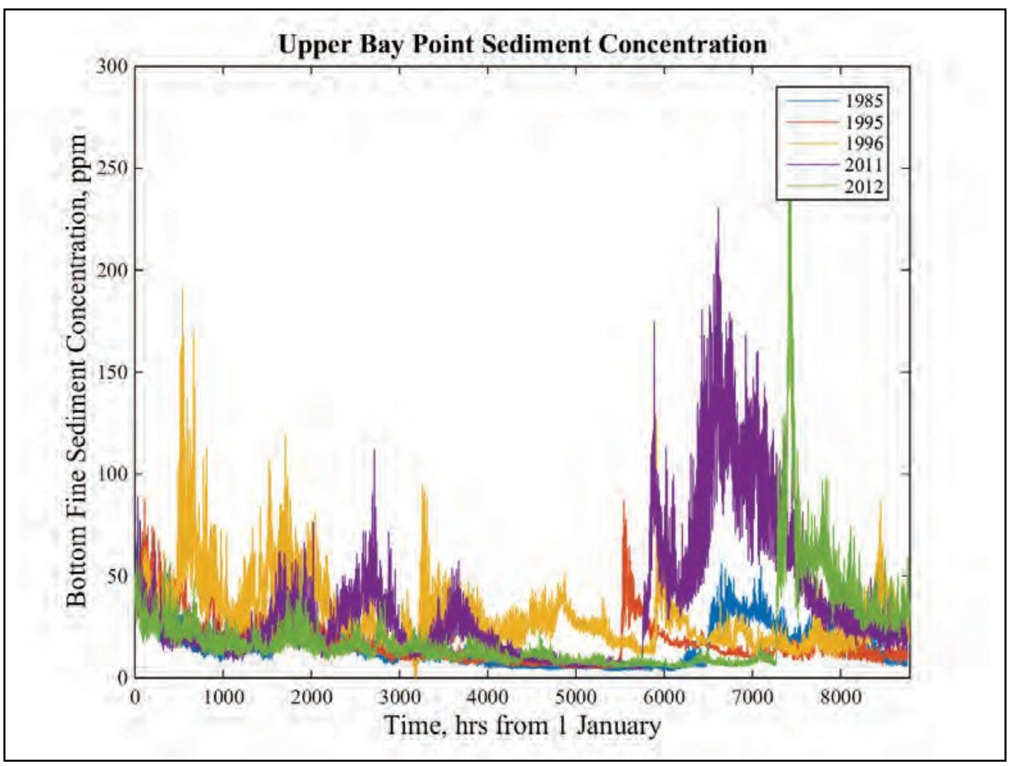


Figure 234. Newark Bay bottom water layer fine sediment concentrations.

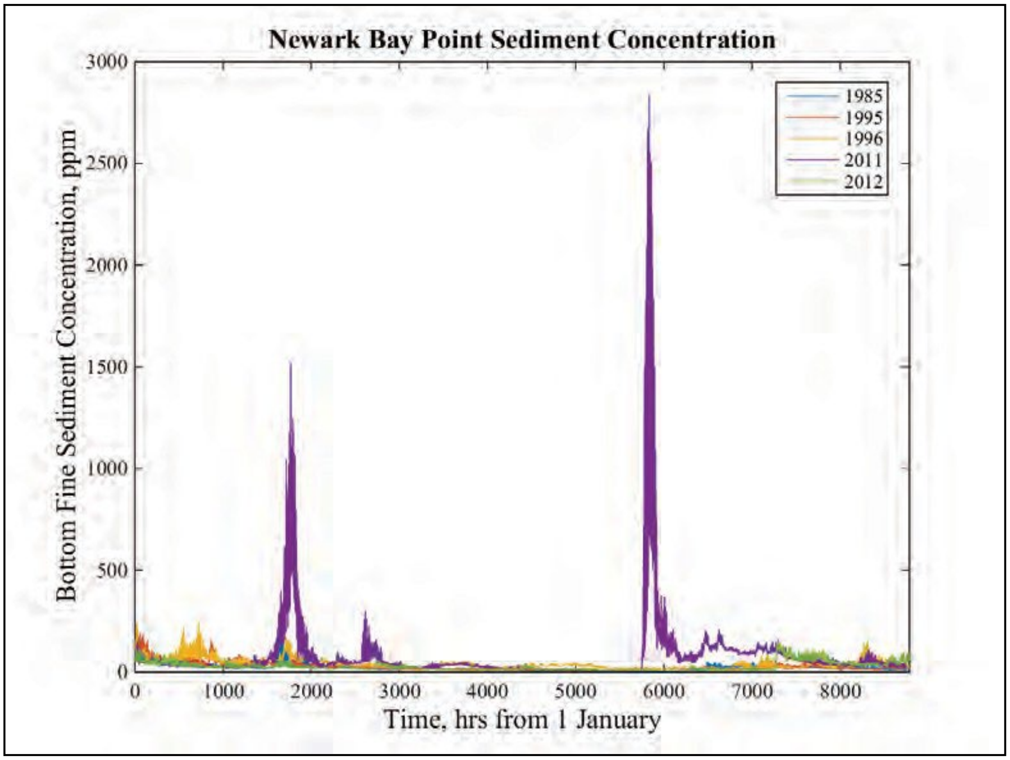


Table 23. Storm duration of influence on sediment transport.

Hurricane	Start Time (hours)	Stop Time (hours)
Gloria	09/27/1985 (6456)	11/07/1985 (7450)
Irene	08/27/2011 (5712)	11/30/2011 (8000)
Sandy	10/29/2012 (7248)	12/21/2012 (8500)

The reaches previously analyzed as part of the validation process (see Figure 86) were analyzed to determine an approximate percentage of dredging associated with the previously discussed hurricanes. A comparison of the dredge volumes due to hurricanes is presented in Figure 235 and Figure 236 and Table 24. Figure 237 shows a comparison of the impact of the hurricanes in the with-project and without-project configurations. These dredge volumes represent the deposition that occurred in the model between the start and stop times in Table 23. Deposition prior to or after this time period is not represented in the Hurricane-attributed values presented in Figure 235, Figure 236, and Figure 237.

Figure 235. Hurricane impacts of dredge volumes in the without-project configuration.

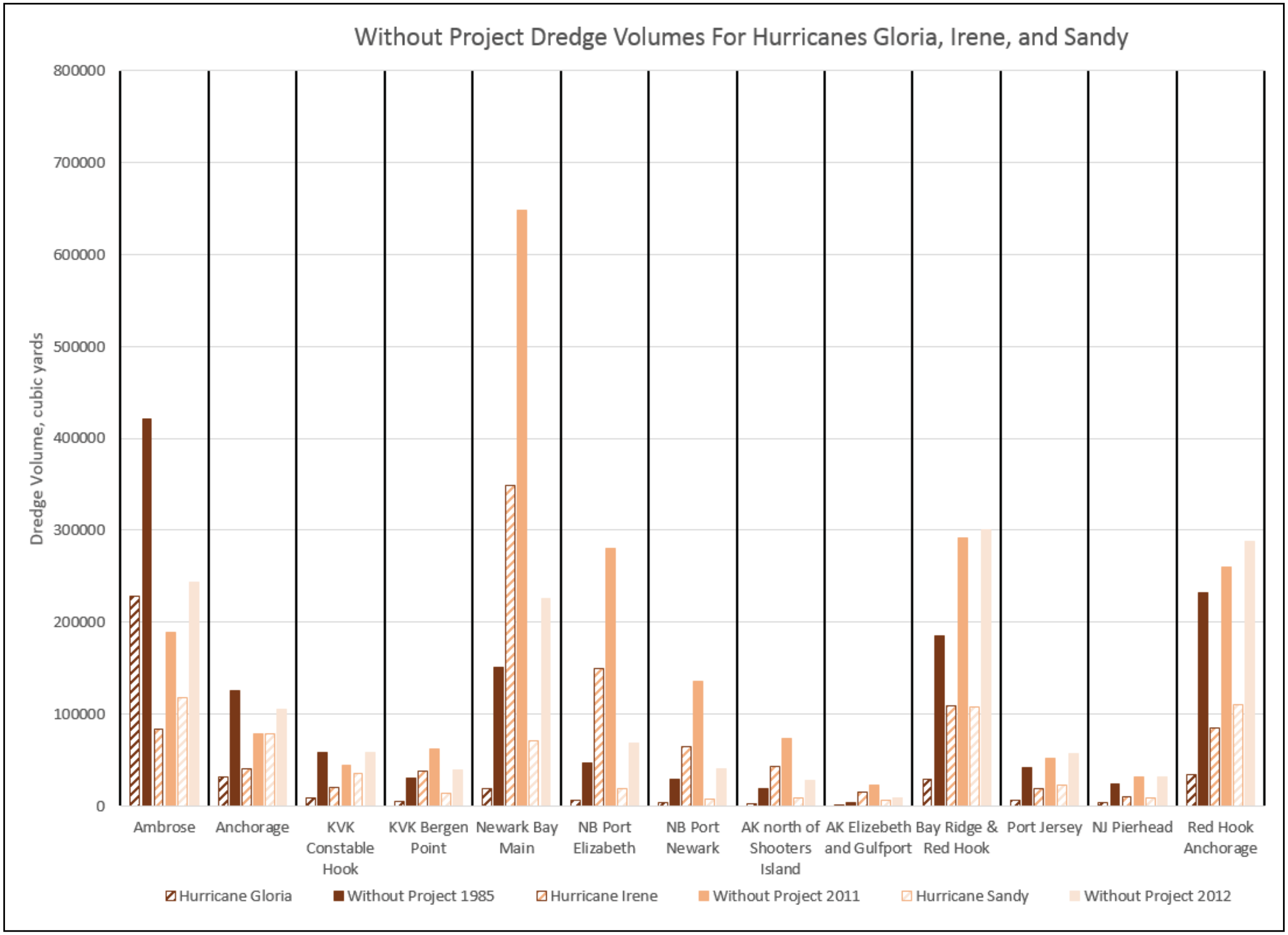


Figure 236. Hurricane impacts of dredge volumes in the with-project configuration.

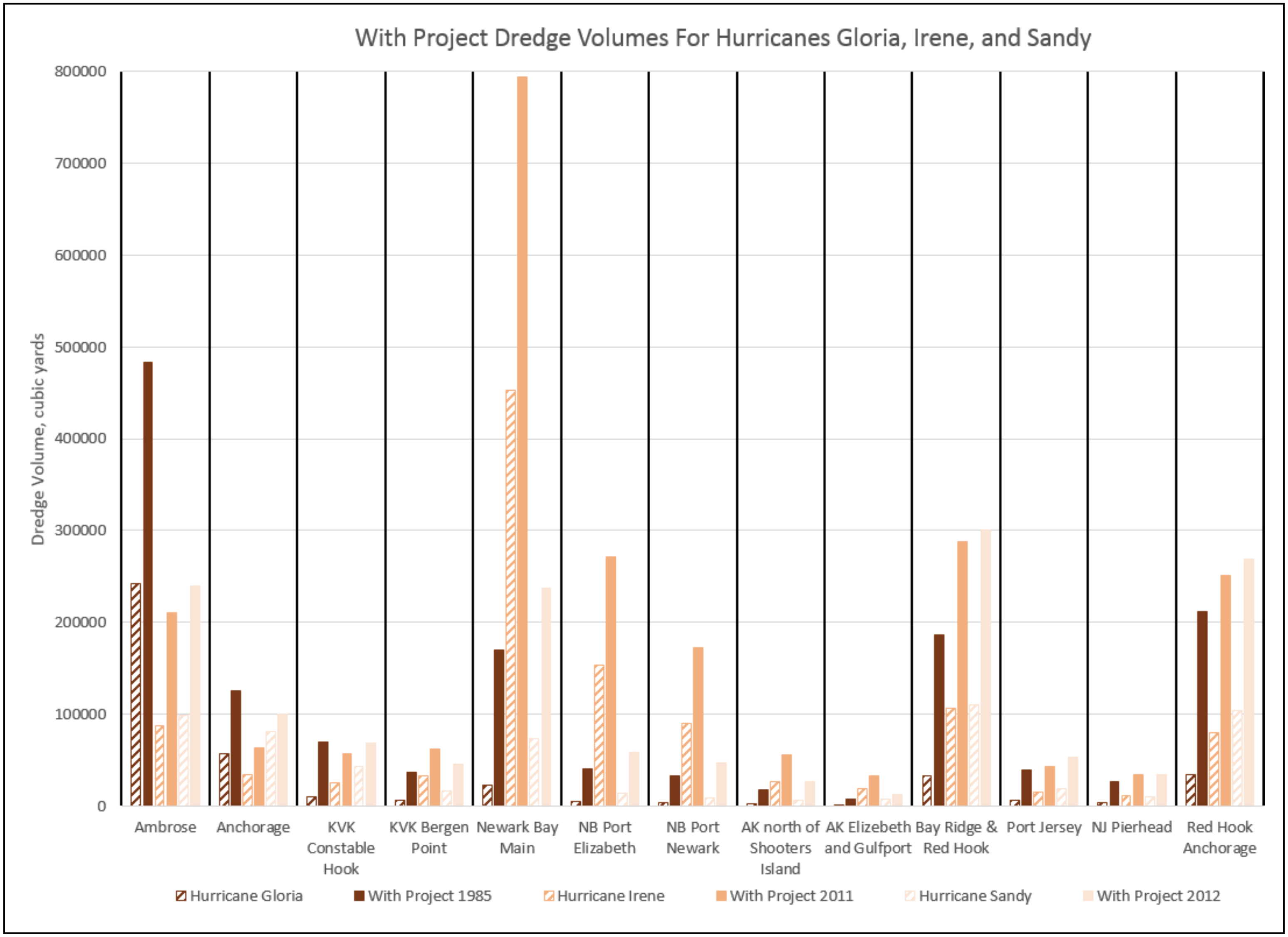


Figure 237. With-project versus without-project hurricane impacts.

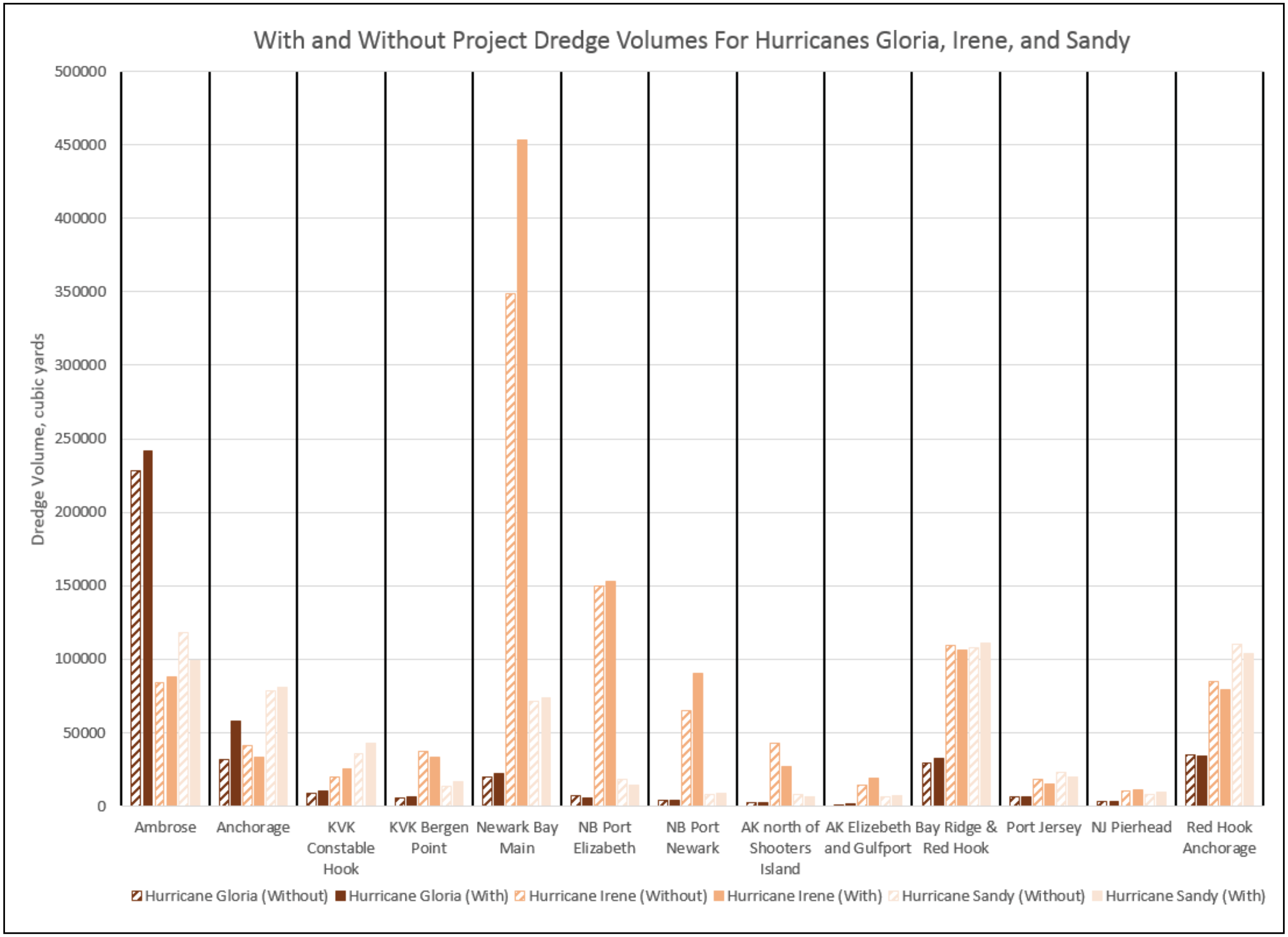


Table 24. Hurricanes Gloria, Irene, and Sandy dredge volumes, cy.

Channel Reach	Gloria (without project)	Gloria (with project)	Irene (without project)	Irene (with project)	Sandy (without project)	Sandy (with project)
Ambrose	228,133	241,961	83,628	87,807	117,810	98,672
Anchorage	31,521	57,350	40,663	33,480	78,029	80,444
Kill van Kull Constable Hook	8,560	9,946	19,498	24,768	35,376	42,578
Kill van Kull Bergen Point	5,162	6,258	37,444	33,084	13,613	16,145
Newark Bay Main	19,293	21,963	348,677	453,186	71,178	73,833
NB Port Elizabeth	6,601	5,346	149,384	152,811	18,045	13,733
NB Port Newark	3,502	4,079	64,759	89,907	7,741	8,853
AK north of Shooters Island	2,315	2,360	42,698	26,879	8,068	5,913

It is evident from these model results that extreme tropical hurricanes can have a significant impact on the dredging requirements in NYNJH. While the resulting dredge volumes due to hurricanes can vary over an order of magnitude, it is imperative any estimate of dredging requirements consider these factors. While the occurrences of such events are unpredictable, neglecting these events could result in a significant underprediction of long-term dredging requirements

Hurricane Gloria was responsible for approximately 28% of the dredging for 1985. Hurricane Irene was responsible for approximately 48% of the dredge volumes for 2011. The dredge volumes induced by Hurricane Irene were over 70% of the total dredge volumes for 1985 (78%), 1995 (77%), and 2012 (76%), illustrating the severity of this event and 2011 in general. Hurricane Sandy was responsible for approximately 40% of the dredge volumes for 2012.

Considering the variation in dredge volumes for the with-project and without-project configurations (Figure 237), it is apparent the increase/decrease in dredging varies both by event and location and does not appear to be consistent across storm events. This variation is to be expected. While all these events are hurricanes, they possess varying characteristics (forward speed, pressure, wind field, etc.) and therefore are expected to result in differing system impacts. For these particular reaches (Figure 86), it appears for Gloria and Irene that the with-project configuration results in increases in dredge volumes of 12% and 10%, respectively. However, Sandy produces a slight decrease (2%) for these reaches. Note these numbers change if a different start/stop time was chosen beyond those listed in Table 23. The previously shown comparisons of the without-project to with-project configurations over the entire year indicated increases of 6% for 1985, 7.5% for 2011, and 0% for 2012.

11 Sensitivity Simulations

In an effort to investigate the uncertainty in the numerical model results, sensitivity simulations were completed to quantify the impact of specific model parameters, inputs, and processes. A brief description is provided for each of the sensitivity simulations with a comparison of the model results compiled. Performing these sensitivity simulations over each of the 5 years would have been a significant computational effort. Therefore, a single year was chosen, and the sensitivity simulations were completed by modifying the individual parameters with the forcings from 1995. The 1995 calendar year was a median year in terms of the dredge volume increase due to the project and as such deemed the most appropriate for this endeavor. The sensitivity simulations were completed by making single, independent modifications to the model input to investigate the impact of the various parameters. These sensitivity simulations were simulated for both the with-project and without-project configurations to evaluate both the impact to the absolute numbers and the implied impact due to the system modifications.

Sewage flow sensitivity

In the previously shown results, the sewage flows were held constant for the entirety of the simulations due to a lack of time-series data for all the wastewater treatment facilities which is not representative of the true system. A sensitivity simulation was completed whereby the sewage flows were removed completely from the boundary conditions file to investigate the impact of the wastewater treatment facility flows on the dredge volumes. Completely removing these freshwater inflows is the extreme case but was utilized to bracket the impact of wastewater treatment flows.

Diffusion specification sensitivity

Vertical turbulent diffusion is handled by Mellor-Yamada 2.0 (Mellor and Yamada 1982) closure with vertical mixing reduced based on Richardson number for cases of stratification (Savant 2015). For stability purposes, a minimum diffusion value is specified in the boundary conditions file. This sensitivity simulation doubled that minimum value to investigate the impact of this model input parameter on the dredge volumes.

Friction specification sensitivity

The bed friction was implemented using a Manning's n value for the entire model domain. A specification of 0.025 produced reasonable water levels as compared to the observations (see Chapter 8 for model to field comparisons). This sensitivity increased the 0.025 Manning's n value to 0.030. This was deemed the higher limit of reasonable Manning's n values for this system.

Wind wave sensitivity

In an effort to quantify the impact of the wind wave generation and propagation on the sedimentation, simulations were performed without linking to STWAVE. These simulations included no wind-wave generation or propagation.

Inflow sensitivity

The inflows were observations obtained from the USGS, but uncertainty exists in these measurements. This set of sensitivity simulations investigates the impact of varying the riverine inflows by increasing each of the riverine inflows by 20%. Note that the boundary sediment concentrations were not updated to represent the higher flows. This approach was utilized to prevent changes of multiple parameters in a single set of simulations.

Sea level rise sensitivity

A common concern is the impact of climate change on coastal systems and the impact any proposed alternatives have in conjunction with sea level rise. This set of simulations increased the sea level value by 6 ft. This set of simulations required the 1-month hydrodynamic spinups be re-done to allow the hydrodynamics and salinity transport to adjust to this new water level. All other input and model parameters were left unchanged.

Initial bed specification

The initial bed specification can have a significant impact on the sediment erosion and transport. As previously discussed, the initial bed was specified based on available data with a 1-year spin-up time period being simulated to allow the bed to adjust to the hydrodynamics. This step was completed for both the with- and without- project configurations. The impact of this change is the reported sediment transport is more representative of the longer-term behavior. This sensitivity utilized the without-project bed spinup for the with-project simulations. This would be more representative of an instantaneous creation of the with-project configuration while also assuming no change to the bed composition. For this study, this sensitivity is an attempt to quantify the impact of the bed specification on the dredge volumes.

Model results

A brief discussion of the results of these sensitivity simulations is provided for the locations shown in Figure 86. The dredge volume results are provided in Figure 238 and Figure 239 with the actual numbers provided in Table 25 and Table 26. These results indicate the largest sensitivity is associated with the sea level rise (6 ft) which is to be expected given this is a large change in the mean water level and could be considered more a representation of future conditions than a true sensitivity test. The friction changes provided the next largest impact on the absolute dredge volumes. The total dredge volumes for these channel reaches were analyzed to determine the impact of these parameters on the with- versus without-project percentage differences. As expected, all simulations showed an increase in the dredge volumes for the with-project configuration. The results are as follows:

1. Original 1995 comparisons of with- versus without-project indicated an increase of approximately 4%.
2. The sewage sensitivity simulations indicate an increase of approximately 5%.
3. The diffusion sensitivity simulations indicate an increase of approximately 2.5%.
4. The friction sensitivity simulations indicate an increase of approximately 6.5%.
5. The wave sensitivity simulations indicate an increase of approximately 3.5%.
6. The inflow sensitivity simulations indicate an increase of approximately 3%.
7. The sea level rise sensitivity simulations indicate an increase of approximately 1.5% but has a large redistribution of sedimentation (see Figure 238 and Figure 239).
8. The initial bed sediment sensitivity simulations indicate an increase of approximately 10.5%.

While these results illustrate the uncertainty in the results of this model study, these sensitivity simulations reinforce the previously reported 4% increase for 1995 is a reasonable value since the sensitivity results tended to be slightly higher and lower than the reported value. These values are also within the range of values obtained for varying meteorological conditions (yearly variation).

Note that the sea level rise sensitivity of 6 ft is more of a future prediction of impacts than a true sensitivity due to the large change, but it provides an indication of the expected impact of sea level rise and brackets the changes. The initial bed sediment sensitivity is also somewhat unrealistic in that the bed utilized was initialized based on the without-project spinup. As shown in previous results the flow is redistributed due to the alternative and as such this is a somewhat unrealistic scenario. It was completed to bracket the results.

Table 25. With-project sensitivity simulation results.

Channel	With Project 1995, cy							
	Base	Sewage	Diffusion	Friction	Waves	Inflow	Sea Level Rise	Initial Bed Sediment
Ambrose	370,648	400,229	340,691	368,952	321,254	353,135	213,908	398,968
Anchorage	80,410	79,329	58,511	89,581	76,159	81,200	107,576	102,381
Kill van Kull Constable Hook	39,636	39,189	33,571	53,807	37,021	40,752	34,850	50,627
Kill van Kull Bergen Point	49,700	50,287	45,870	57,959	49,582	50,303	43,367	49,454
Newark Bay Main	231,498	226,829	194,784	218,948	232,301	238,706	205,369	236,549
NB Port Elizabeth	54,405	54,872	45,646	54,821	53,764	57,458	59,625	54,276
NB Port Newark	41,940	42,604	35,027	46,199	41,668	44,559	50,068	42,873
AK north of Shooters Island	27,844	26,918	26,628	27,452	27,876	28,707	23,818	26,720
AK Elizebeth and Gulfport	7,664	7,098	7,275	20,022	7,287	7,872	3,548	8,783
Bay Ridge & Red Hook	247,059	245,448	231,640	141,995	240,636	249,939	461,572	258,073
Port Jersey	47,978	50,570	42,089	36,766	46,294	48,001	49,824	62,294
NJ Pierhead	31,714	32,855	31,996	29,225	30,644	32,322	42,923	35,114
Red Hook Anchorage	238,406	226,638	191,592	141,095	229,187	243,081	367,173	232,018

Table 26. Without-project sensitivity simulation results.

Channel	Without Project 1995, cy						
	Base	Sewage	Diffusion	Friction	Waves	Inflow	Sea Level Rise
Ambrose	335,272	361,111	322,328	326,423	298,025	324,667	189,876
Anchorage	82,794	78,107	64,352	91,674	79,131	86,450	118,302
Kill van Kull Constable Hook	31,926	30,651	27,812	44,440	30,421	32,356	29,522
Kill van Kull Bergen Point	39,347	39,921	36,280	47,690	39,762	39,491	35,847
Newark Bay Main	213,186	207,841	178,638	190,805	213,800	219,159	196,644
NB Port Elizabeth	62,719	62,506	51,846	63,106	61,176	65,343	69,059
NB Port Newark	37,770	38,362	31,785	39,816	37,013	39,342	46,026
AK north of Shooters Island	26,484	25,765	25,548	28,770	26,738	27,103	23,880
AK Elizebeth and Gulfport	3,625	3,072	3,204	16,227	3,354	3,603	772
Bay Ridge & Red Hook	248,612	245,973	235,786	142,689	243,812	256,378	468,551
Port Jersey	49,730	52,345	45,040	40,175	47,478	49,828	50,277
NJ Pierhead	29,532	30,556	29,535	25,954	28,261	29,727	40,748
Red Hook Anchorage	248,463	232,301	202,469	149,125	237,463	259,850	370,370

Figure 238. Sensitivity simulation results for 1995 for the without-project configuration.

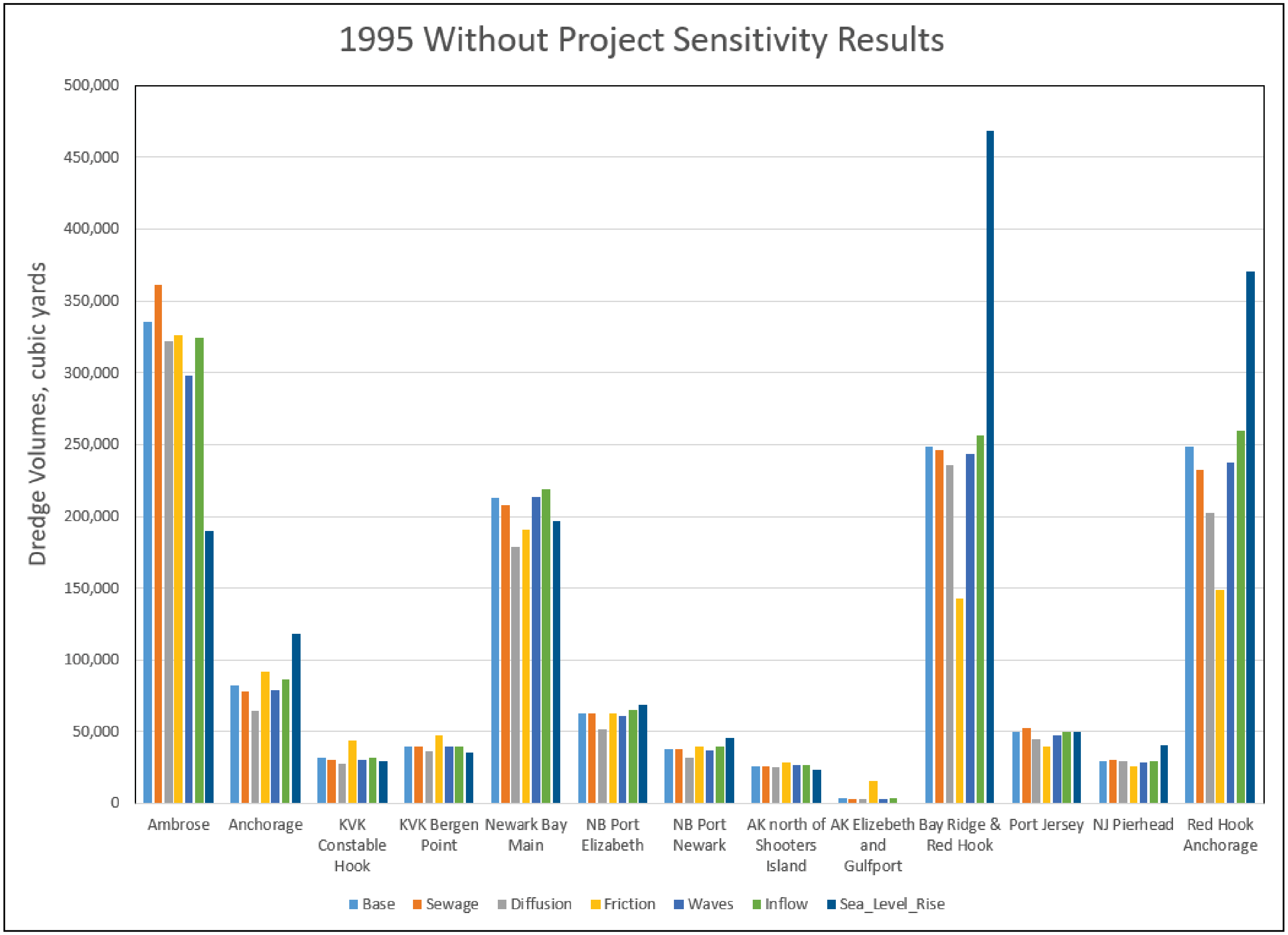
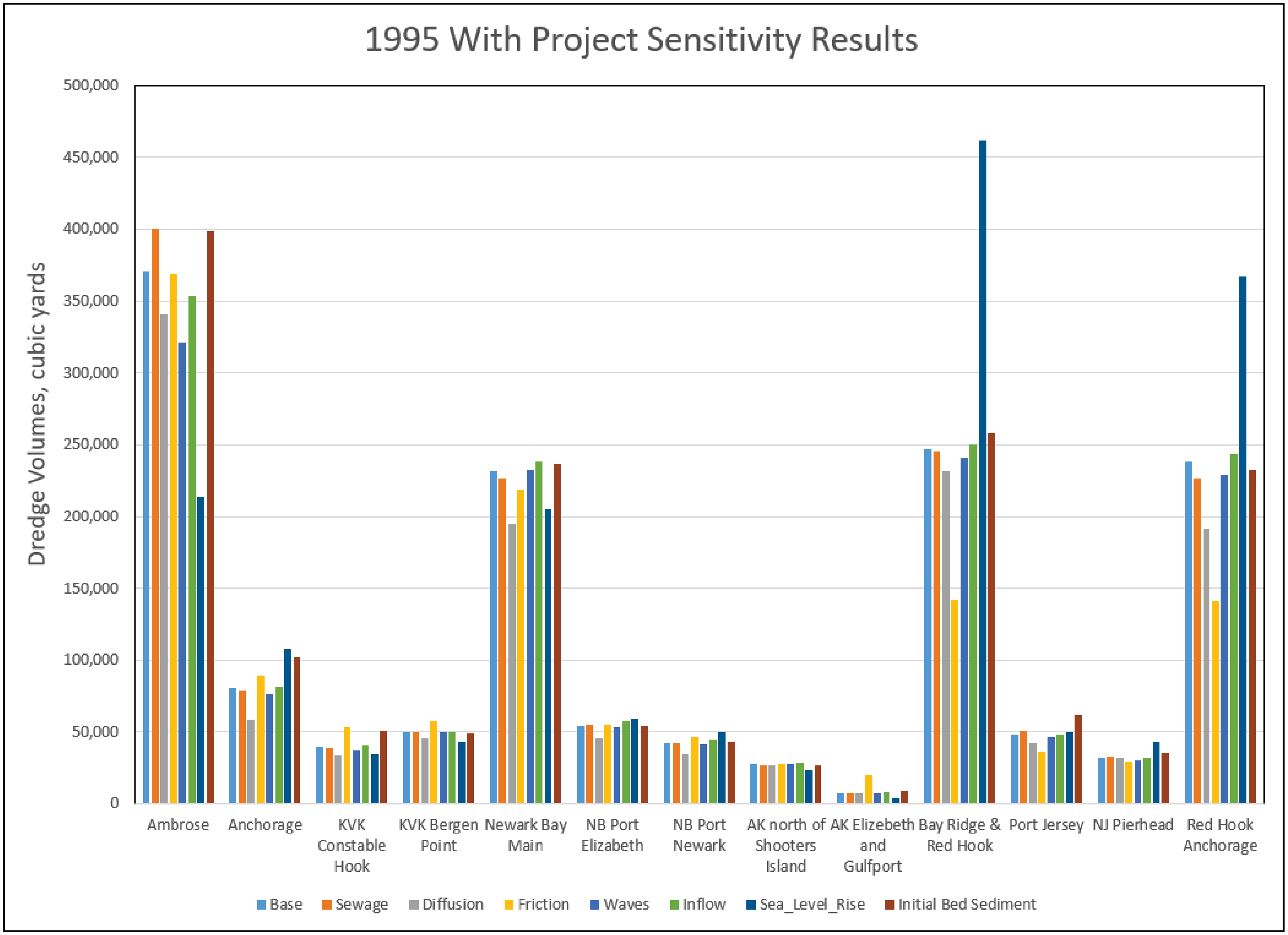


Figure 239. Sensitivity simulation results for 1995 for the with-project configuration.



12 Conclusions

Analysis of the model results provides insight into several impacts associated with the channel deepening. The primary impacts are as follows:

1. The flow through the Kill van Kull is increased by approximately 36% with increased flow of salinity and sediment as well.
2. As would be expected, the salinity intrusion up the Ambrose ship channel is increased. This is expected to be due to a combination of the channel deepening and the redistribution of flow through Kill van Kull.
3. The Kill van Kull and Newark Bay are the primary channels with increased dredging requirements with expected increases of 18% and 11% respectively. This equates to increases in the dredge volumes of approximately 16,500 cy (Kill van Kull) and 54,500 cy (Newark Bay).
4. The variation in the total annual dredge volumes of 1.1 million cy is an order of magnitude larger than the changes due to the project (approximately 40,000 cy).
5. The dredge volumes for the five simulated years for the commonly dredged locations shown in Figure 86 ranged from approximately 1.3 million cy (1985) to a high of 2.3 million cy (2011) indicating a possible variation across years of approximately 1 million cy. The average dredge volume was approximately 1.61 million cy for the without project and approximately 1.68 million cy for the with project indicating an increase of approximately 70,000 cy or 4%.
6. For the locations shown in Figure 86, the yearly percentage increases (with project compared to without project) in overall dredging were 6% (1985), 4% (1995), 3% (1996), 7% (2011), and 0% (2012) with an average annual increase in dredging of 4%.
7. When considering all channel reaches, the increase in dredging is only 1% as shown in Table 22. This would indicate the non-project channels experienced less increase and even some decreases in dredging as compared to the deepened project channels.
8. Sensitivity simulations were performed to evaluate the variability in the results due to certain input parameters using the 1995 forcing conditions. These results reinforced the previously reported increase of approximately 4% for the with-project configuration as it was in the median range of the sensitivity simulations. All of the sensitivity

simulations indicated the same direction of change for the project condition (increased dredging) with some of the results indicating larger increases and some indicating smaller increases.

9. Extreme events like Hurricanes Irene and Sandy can have significant impacts on the dredging requirements. Simulations of Hurricanes Gloria (1985), Irene (2011), and Sandy (2012) accounted for approximately 28% (1985), 48% (2011), and 40% (2012) of the dredge volumes for the given years.

One limitation of this study is the exclusion of ship traffic impacts. While the model appears to replicate the historical dredge volumes adequately, larger ships traveling at higher speeds create large bow waves that can increase shoreline erosion and erosion of surrounding shallow bays. Any impact associated with these larger/faster ships would not be captured in this modeling effort.

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Appendix A: Ungauged Flows on the Hudson River

There are numerous secondary tributaries that discharge into the Hudson River below Troy Lock and Dam. There were four of these tributaries that had USGS discharge data during the 5 years simulated for this study. These four tributaries are the following:

1. Rondout Creek at Rosendale, NY (USGS station 01367500)
2. Croton River at New Croton, Dam (USGS station 01375000)
3. Esopus Creek at Mount Marion, NY (USGS station 01364500)
4. Wappinger Creek near Wappinger Falls, NY (USGS station 01372500).

These four creeks have a collective drainage area of 1,361 mi^2, which is approximately 17% of the drainage basin area above Green Island on the Hudson (8,070 mi^2). There are no sediment concentration data for these smaller tributaries, and they enter the Hudson in the tidal zone, minimizing their influence. The local ungauged drainage area along the Hudson was estimated to add an additional 24% to the drainage area. The local ungauged contribution is also within the tidal zone.

The contributions of these added inflows are presented in Figure 240 through Figure 244 for the five simulated years. Adding the additional tributaries explicitly into the model computational mesh would require a considerable increase in mesh resolution and computer requirements. Sensitivity tests were performed using the full estimated Hudson flows as inflow at Green Island. This bulking of the flow also increased the sediment load by the implied assumption that the suspended sediment concentrations were the same for the added flows as what passes Green Island. The results of the sensitivity simulations were that there was no discernable difference in the sedimentation results in the harbor for the additional flow volume.

In addition, this numerical model study ignored tributary inflows into Long Island Sound. Those flows were assumed to have no significant impact on the sedimentation environment in the vicinity of the proposed channel deepening.

Figure 240. Additional tributary inflows below the Hudson River at Green Island for 1985.

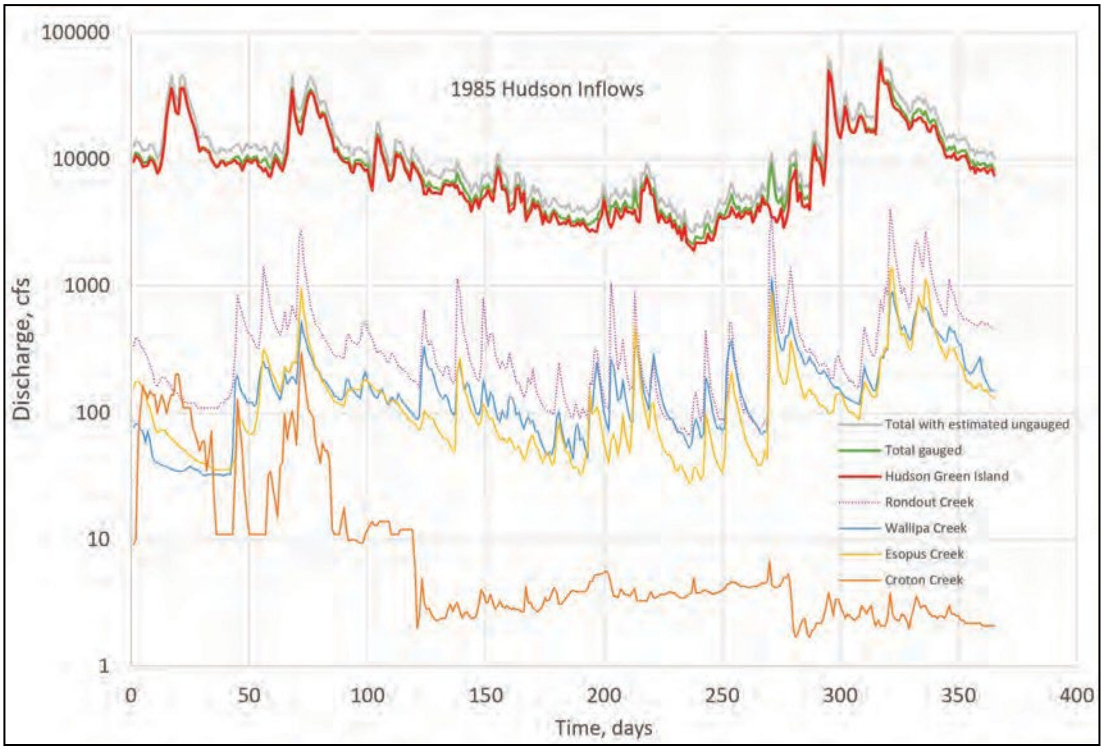


Figure 241. Additional tributary inflows below the Hudson River at Green Island for 1995.

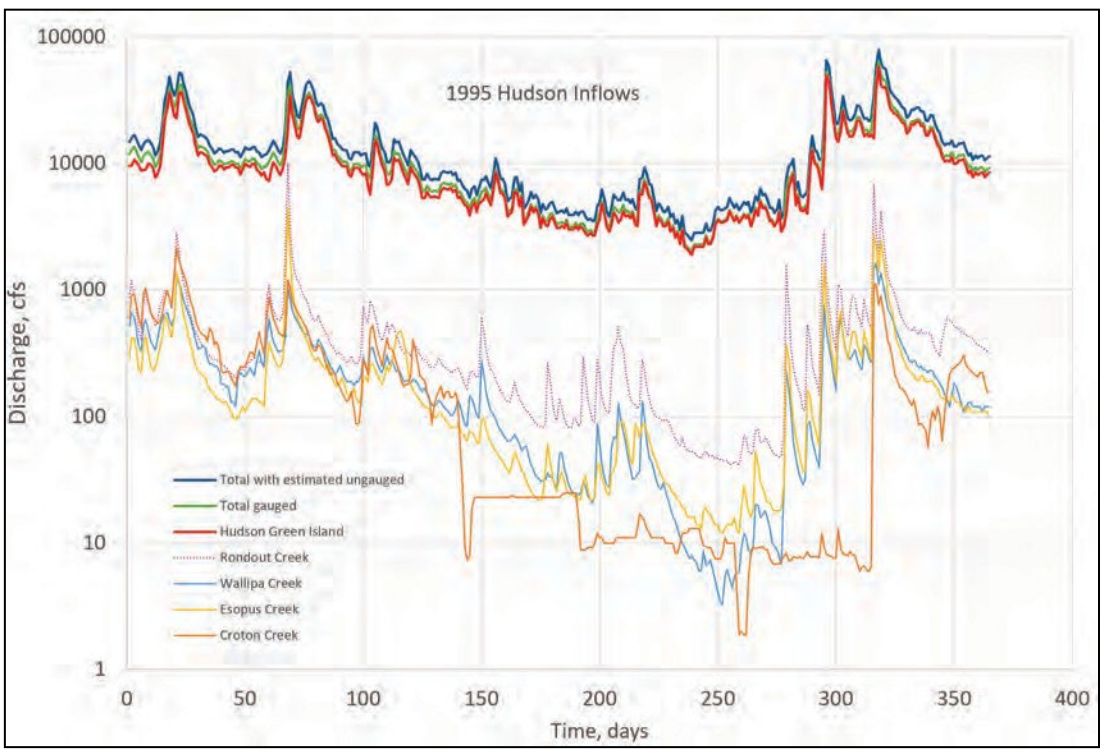


Figure 242. Additional tributary inflows below the Hudson River at Green Island for 1996.

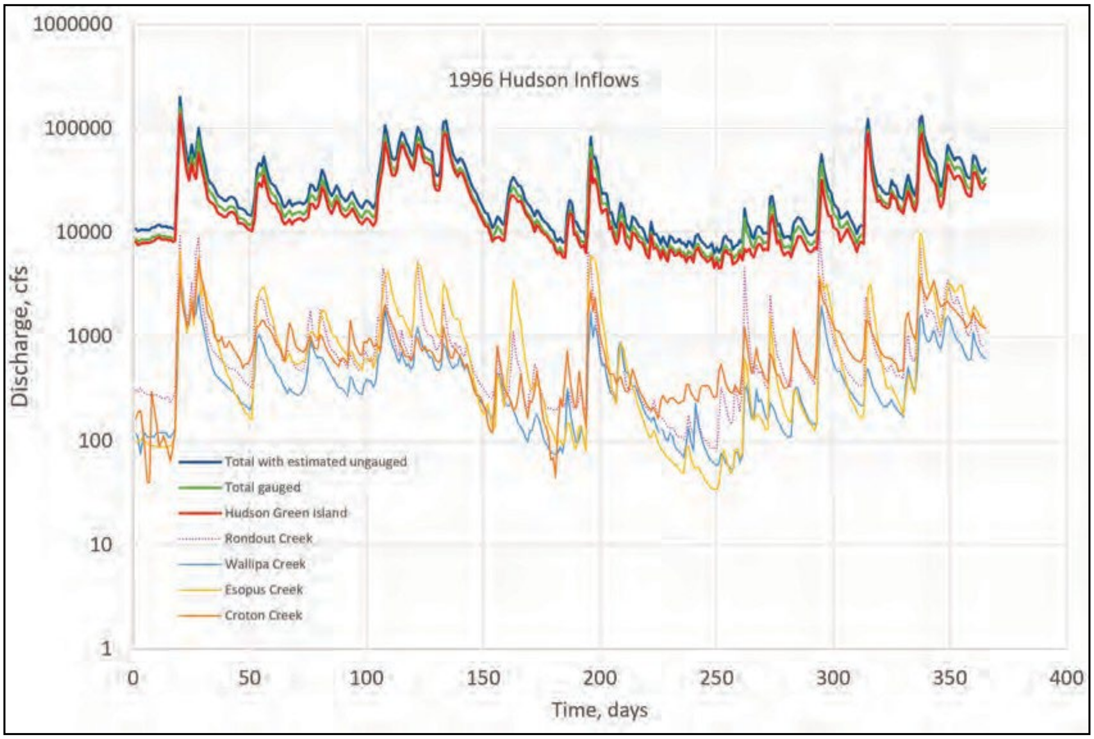


Figure 243. Additional tributary inflows below the Hudson River at Green Island for 2011.

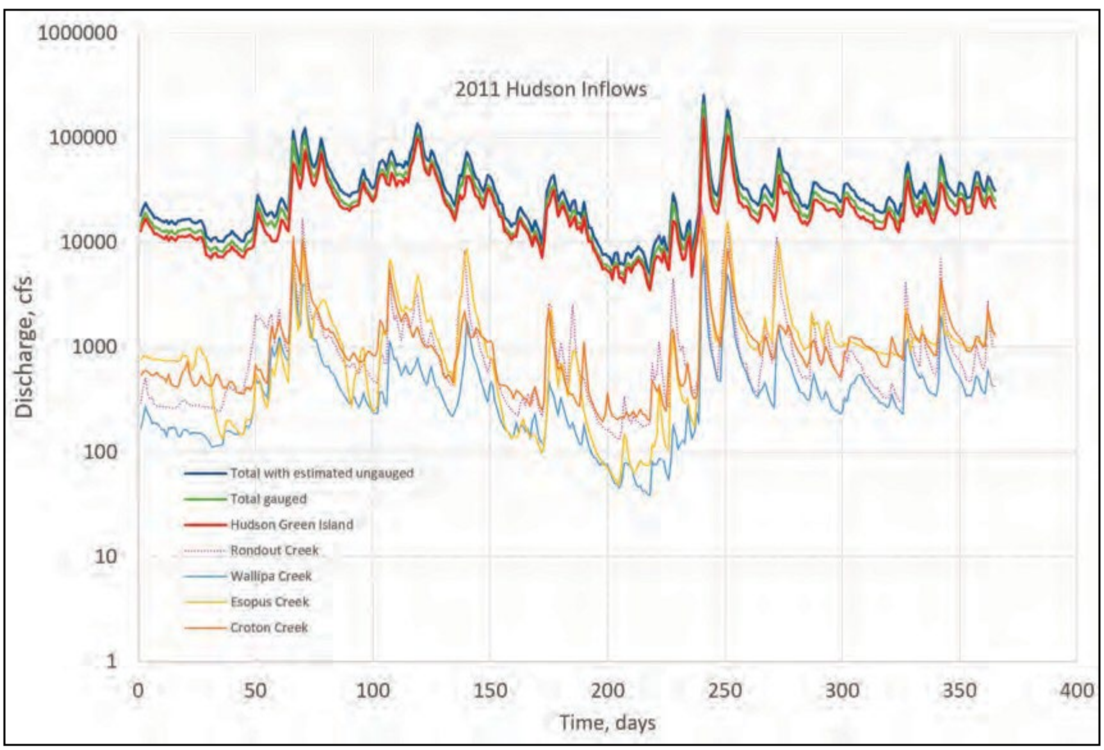
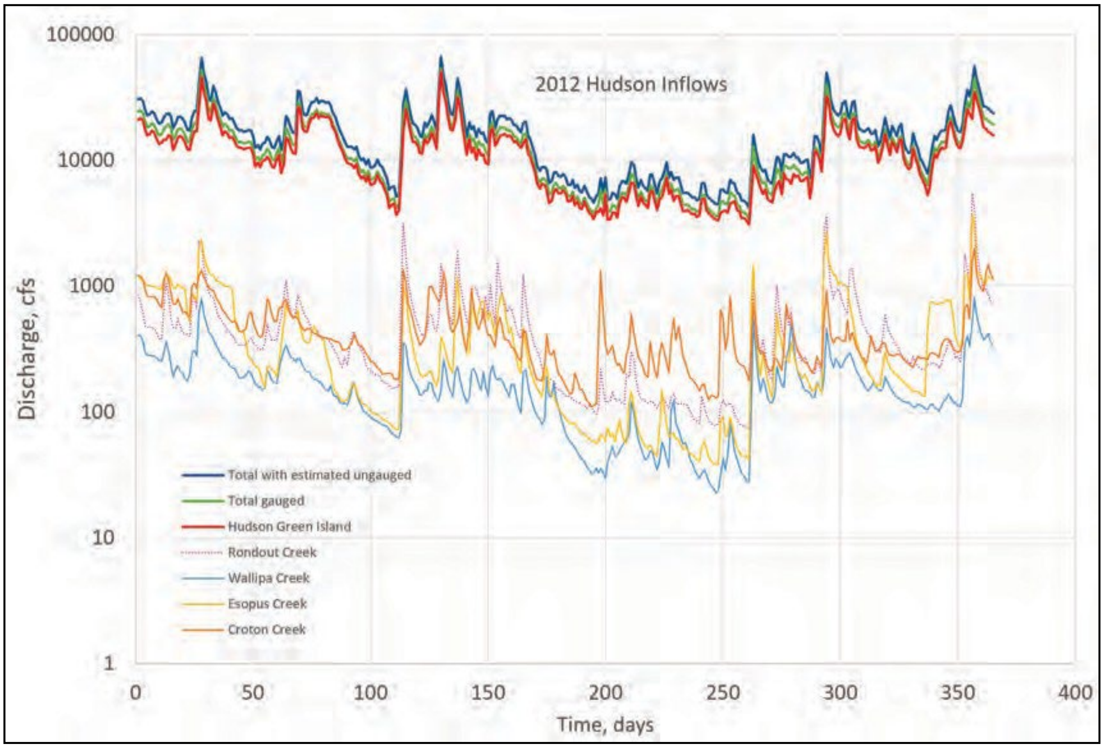


Figure 244. Additional tributary inflows below the Hudson River at Green Island for 2012.



Appendix B: NOAA Tide Gauge Information

Table 27 shows the tidal information for the NOAA gauges analyzed as part of this project taken from NOAA (2005).

Table 27. NOAA tidal data.

Locations	Latitude		Longitude		Lag to SH		HW ratio	LW ratio	Tide Range (ft)		MTL (ft MLLW)
	deg	min	deg	min	HW	LW			mean	spring	
Point Judith harbor of refuge	41	21.8	71	29.4	0.0	6.1	0.87	0.54	3.10	3.10	1.70
Block Island Old harbor	41	10.4	71	33.4	-0.2	5.8	0.82	0.86	2.85	3.51	1.54
Block Island SW point	41	9.8	71	36.6	0.1	6.3	0.75	0.79	2.60	3.20	1.41
Weekapaug Pt, Block Isl Sound	41	19.7	71	45.7	0.7	6.7	0.74	0.93	2.53	3.11	1.39
Watch Hill point	41	18.3	71	51.6	0.7	6.8	0.74	0.71	2.60	3.20	1.40
New London	41	21.6	72	5.5	1.7	7.9	1.00	1.00	2.56	3.09	1.47
Long Neck Point	41	2.3	73	28.8	3.3	9.6	1.06	0.96	7.17	8.17	3.82
Rye Beach	40	57.7	73	40.3	3.4	9.8	1.00	0.93	7.29	7.89	3.88
New Rochelle	40	53.6	73	46.9	3.5	10.4	1.01	1.11	7.29	8.46	3.90
Throg's Neck	40	48.3	73	47.7	4.0	10.4	0.98	0.96	7.00	8.20	3.80
Whitestone	40	47.9	73	48.8	3.9	10.3	1.00	1.04	7.10	8.30	3.80
College Point, Flushing Bay	40	47	73	51.4	4.1	10.4	0.95	1.04	6.80	7.90	3.70
Hunts point	40	48	73	52.4	4.0	10.3	0.97	1.07	6.92	7.57	3.75
North Brother Island	40	48.1	73	54	4.1	10.4	0.93	1.11	6.60	7.80	3.60
Port Morris (Stony Point)	40	48.1	73	54.4	3.9	10.3	0.87	0.96	6.24	6.85	3.39
He3ll Gate	40	47.2	73	55.3	3.5	10.5	1.33	1.59	6.00	7.30	3.40
Horn's Hook, E 90th St	40	46.6	73	56.5	2.4	8.3	1.03	0.90	4.68	5.18	2.53
Queensboro Bridge	40	45.5	73	57.5	1.9	7.7	0.96	1.00	4.33	5.24	2.38
E 41st St	40	44.8	73	58.1	1.6	7.5	0.95	1.09	4.31	4.89	2.40

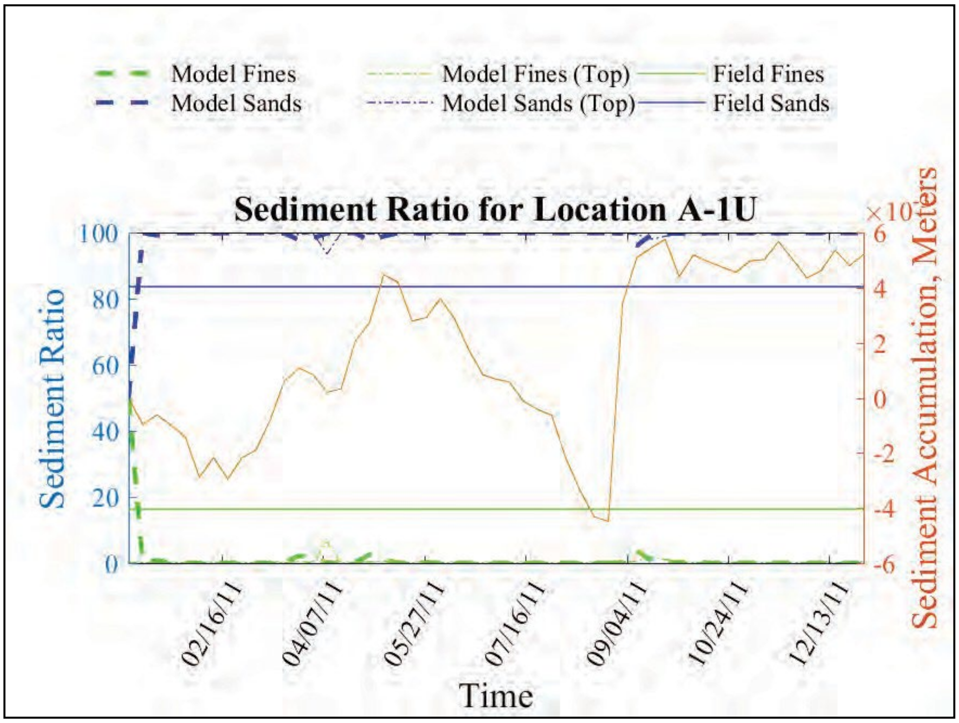
Locations	Latitude		Longitude		Lag to SH		HW ratio	LW ratio	Tide Range (ft)		MTL (ft MLLW)
	deg	min	deg	min	HW	LW			mean	spring	
Hunters Pt, Newtown Creek	40	44.4	73	57.7	1.9	7.7	0.89	0.90	4.10	4.90	2.20
Williamsburg Bridge	40	42.7	73	58.1	1.3	7.2	0.93	0.95	4.22	5.11	2.31
Wallabout Bat, Brooklyn Navy yard	40	42.4	73	58.5	1.1	7.1	0.94	1.05	4.30	5.20	2.40
Brooklyn Bridge	40	42.2	73	59.3	0.9	6.7	0.99	1.00	4.53	5.13	2.48
Harlem River, Randals Island	40	48	73	55.7	2.2	8.2	1.02	1.09	4.60	5.60	2.50
Willets point	40	47.6	73	46.9	3.8	10.1	1.00	1.04	7.15	8.21	3.88
Kings Point	40	48.6	73	45.9	3.8	10.1		1.00	7.16	8.46	3.86
Port Washington, Manhasset Bay	40	49.9	73	42.2	3.6	9.9	1.02	0.96	7.29	8.46	3.92
Glen Cove, Hempstead Harbor	40	51.8	73	39.3	3.4	9.7	1.01	0.82	7.27	7.87	3.87
Eaton's neck Point	40	57.2	73	24	3.5	9.7	1.05	1.04	7.10	8.20	3.90
Cedar Beach	40	57.9	73	2.6	3.6	9.7	0.96	1.00	6.43	7.01	3.46
Northville	40	58.9	72	38.7	3.6	9.6	0.81	0.96	5.40	5.95	2.94
Plum Island	41	10.3	72	12.3	2.2	8.2	1.01	1.01	2.60	3.10	1.50
Montauk, Fort Pond Bay	41	2.9	71	57.6	1.4	7.6			2.07	2.66	1.21
Norton Point	40	34	73	59.9	0.0	6.3	1.02	1.15	4.70	5.70	2.60
Ft. Hamilton	40	36.5	74	2.1	0.0	6.3	1.01	1.00	4.70	5.70	2.50
St. George, Staten Island	40	38.6	74	4.4	0.3	6.5	0.99	0.99	4.50	5.40	2.40
The Battery	40	42	74	0.9	0.5	6.7			4.63	5.50	2.47
Weehawken, Union City	40	45.9	74	1.1	0.8	7.0	0.96	0.96	4.37	5.29	2.41
Edgewater	40	48.8	73	58.7	1.1	7.2	0.93	0.93	4.24	5.13	2.33
Spuyten Duyvil	40	52.7	73	55.5	1.4	7.5	0.84	0.84	3.85	4.66	2.20
Riverdale, NY	40	54.2	73	54.9	1.3	7.6	0.85	0.85	3.86	4.67	2.13
Alpine, NJ	40	56.7	73	55.1	1.6	7.8	0.83	0.83	3.78	4.57	2.09
Tarrytown	41	4.7	73	52.2	2.4	8.7	0.70	0.70	3.20	3.70	1.80

Locations	Latitude		Longitude		Lag to SH		HW ratio	LW ratio	Tide Range (ft)		MTL (ft MLLW)
	deg	min	deg	min	HW	LW			mean	spring	
Haverstraw	41	13.1	73	57.8	2.8	9.4	0.72	0.81	3.23	3.91	1.78
Peekskill	41	17	73	56	3.0	9.8	0.64	0.64	2.90	3.40	1.80
Newburgh	41	30	74	0.4	4.3	10.8	0.62	0.64	2.80	3.20	1.50
New Hamburg	41	35	73	57	4.6	11.2	0.64	0.64	2.90	3.30	1.60
Poughkeepsie	41	42	73	57	5.1	11.5	0.68	0.68	3.10	3.50	1.70
Hyde Park	41	47	73	57	5.5	11.9	0.70	0.68	3.20	3.60	1.80
Kingston	41	55	73	59	5.9	12.3	0.81	0.82	3.70	4.20	2.00
Tivoli	42	4	73	56	6.4	12.8	0.86	0.86	3.90	4.40	1.90
Hudson	41	15	73	48	7.5	13.9	0.88	0.86	4.00	4.40	2.20
Castleton	42	32	73	46	9.3	15.6			4.30	4.70	2.20
Albany	42	39	73	44.8	9.5	16.1			4.60	5.00	2.50
Troy	42	44	73	42	9.7	16.2	1.00	1.00	4.70	5.10	2.30
Constable Hook	40	39.3	74	5.2	0.2	6.6	1.02	1.02	4.63	5.60	2.54
Bayonne bridge	40	38.4	74	8.8	0.5	6.7	1.00	1.00	4.98	5.52	2.70
Port Elizabeth	40	40.4	74	8.4	0.5	7.0	1.11	0.95	5.05	5.59	2.73
Port Newark terminal	40	41	74	8	0.6	7.1	1.12	1.12	5.10	6.10	2.70
Point No Point	40	43.9	74	7	0.5	7.1	1.15	1.15	5.24	6.34	2.86
Belleville	40	47.2	74	8.8	0.7	7.6	1.23	1.19	5.60	6.78	3.08
East Rutherford	40	50.8	74	7.2	0.7	7.8	1.29	1.29	5.87	7.10	3.20
Garfield	40	52.1	74	6.7	0.7		na	na	na	na	na
Kearny Point	40	43.7	74	6.2	0.7	7.1	1.15	1.14	5.21	6.30	2.85
Amtrak RR swing Bridge	40	45.1	74	5.8	1.1	7.4	1.16	1.16	5.29	6.40	2.89
Fish Creek, Berry's Creek	40	47.6	74	5.5	1.6	7.7	1.17	1.17	5.33	6.45	2.90
Carlstadt	40	48.4	74	3.6	1.5	7.5	1.26	1.29	5.71	6.29	3.12
North Secaucus	40	48.4	74	2.6	1.5	7.7	1.23	1.23	5.61	6.79	3.06
Mill Creek	40	47.9	74	3	2.1		na	na	na	na	na
Cromakill Creek	40	48.2	74	2	1.5		na	na	na	na	na
Ridgeland Park	40	51	74	1.8	1.5	7.7	1.26	1.26	5.73	6.93	

Locations	Latitude		Longitude		Lag to SH		HW ratio	LW ratio	Tide Range (ft)		MTL (ft MLLW)
	deg	min	deg	min	HW	LW			mean	spring	
Hackendack	40	52.8	74	2.4	1.6	7.7	1.33	1.33	6.01	7.27	3.29
New Milford	40	56.1	74	1.8	1.9	9.7	1.04	1.04	4.72	5.71	2.44
Port Ivory	40	38.7	74	10.8	0.5	6.9	1.09	1.09	5.10	6.12	2.78
Rahway River, RR Bridge	40	35.9	74	13.9	0.3	6.7	1.14	1.14	5.32	6.38	2.89
Chelsea	40	36	74	12	0.4	6.8	1.07	1.05	5.00	6.00	2.70
Carteret	40	35.2	74	12.6	0.4	6.8	1.09	1.09	5.10	6.20	2.80
Rossville	40	33.3	74	13.4	0.3	6.7	1.12	1.12	5.22	5.84	2.89
Woodbridge Creek	40	32.7	74	15.9	0.1	6.6	1.11	1.11	5.15	6.18	2.78
Great Kills harbor	40	32.6	74	8.4	0.1	6.6	1.01	1.00	4.70	5.70	2.60
Princes Bay	40	30.7	74	12	0.0	6.3	1.05	1.05	4.90	5.90	2.60
South Amboy	40	29.5	74	16.9	-0.1	6.3	1.09	1.09	5.09	6.11	2.77
Keasbey	40	30.5	74	18.7	0.1	6.5	1.11	1.11	5.16	6.19	2.81
Sayerville	40	28.7	74	21.4	0.2	6.6	1.15	1.15	5.37	6.44	2.92
Old Bridge, south river	40	25	74	21.8	0.8	7.2	1.20	1.20	5.61	6.73	3.05
New Brunswick	40	29.3	74	26.1	0.5	7.0	1.21	1.21	5.65	6.78	3.06
Cheesequake Creek	40	27.2	74	16.4	0.2	6.4	1.09	1.09	5.08	6.10	2.76
Keyport	40	26.4	74	11.9	-0.1	6.3	1.07	1.07	5.00	6.00	2.72
Matawan Creek	40	26	74	13.1	0.0	6.3	1.07	1.07	5.00	6.00	2.75
Waackaack Creek	40	26.9	74	8.6	-0.1	6.6	0.99	0.99	4.62	5.54	2.47
Sandy Hook	40	28	74	0.6	0.0	6.2			4.70	5.71	2.54

Appendix C: Sediment Core Comparisons

Figure 245. Sediment bed composition comparisons at location A-1U for 2011 (top) and 2012 (bottom).



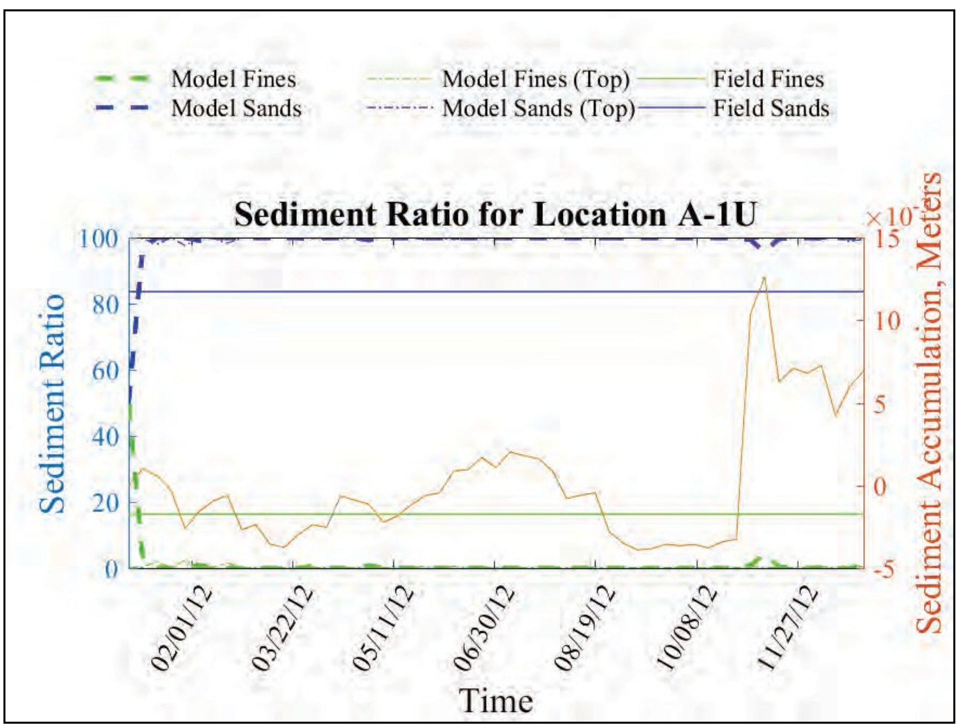
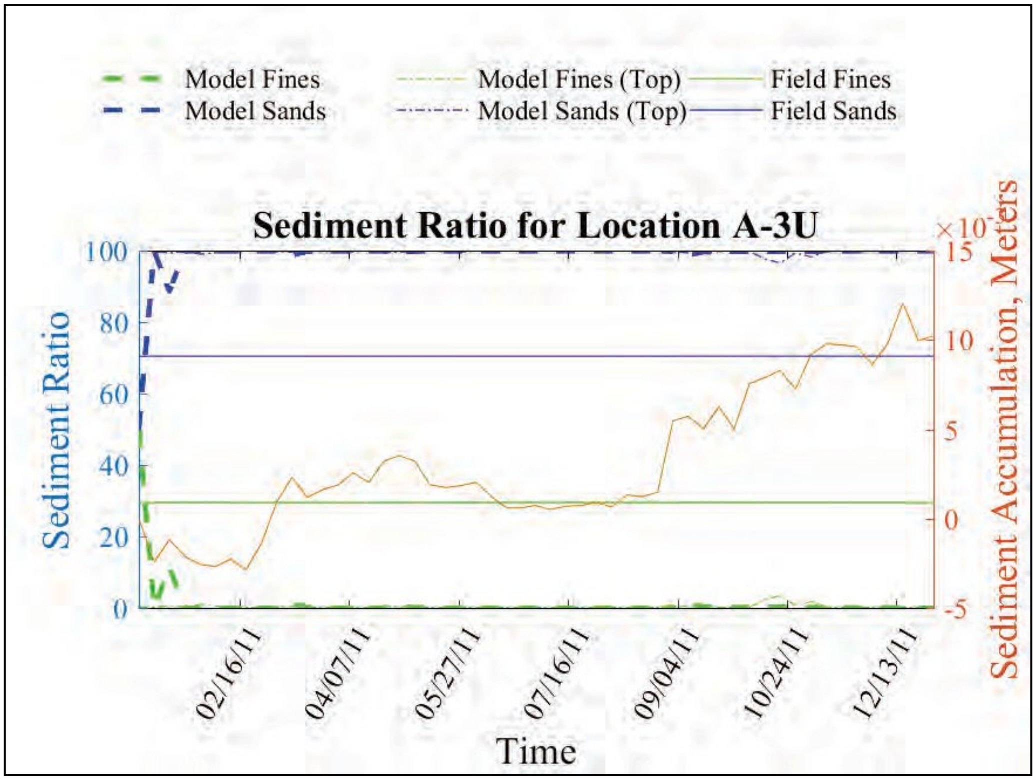


Figure 246. Sediment bed composition comparisons at location A-3U for 2011 (top) and 2012 (bottom).



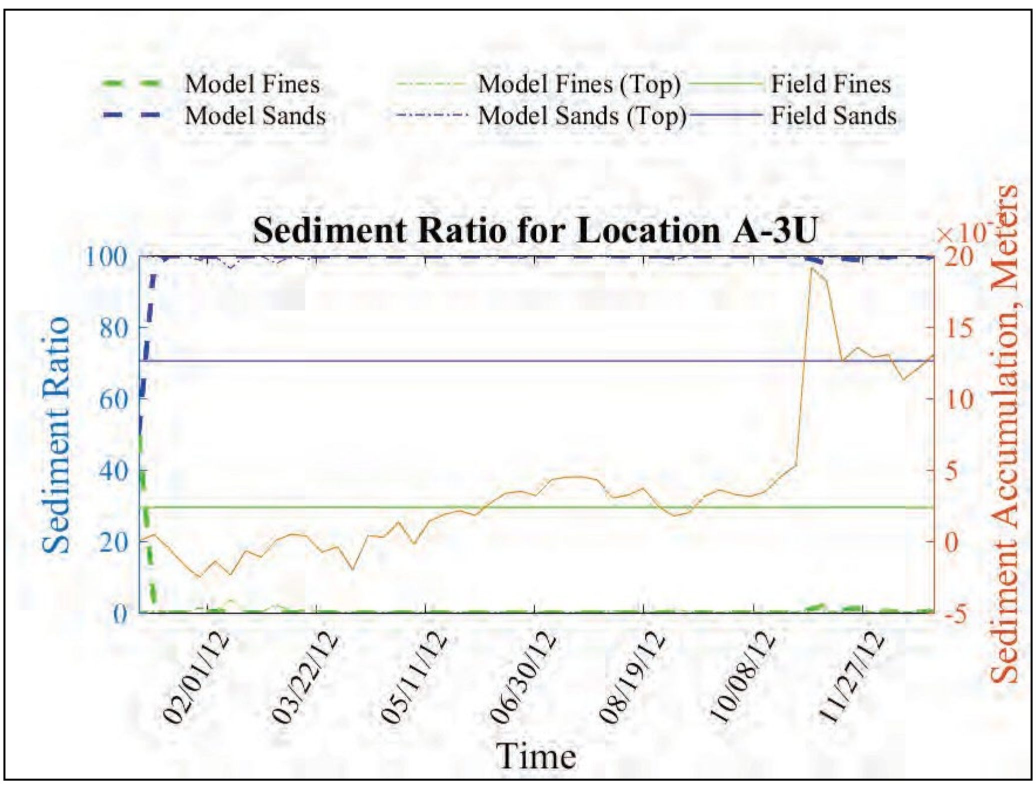
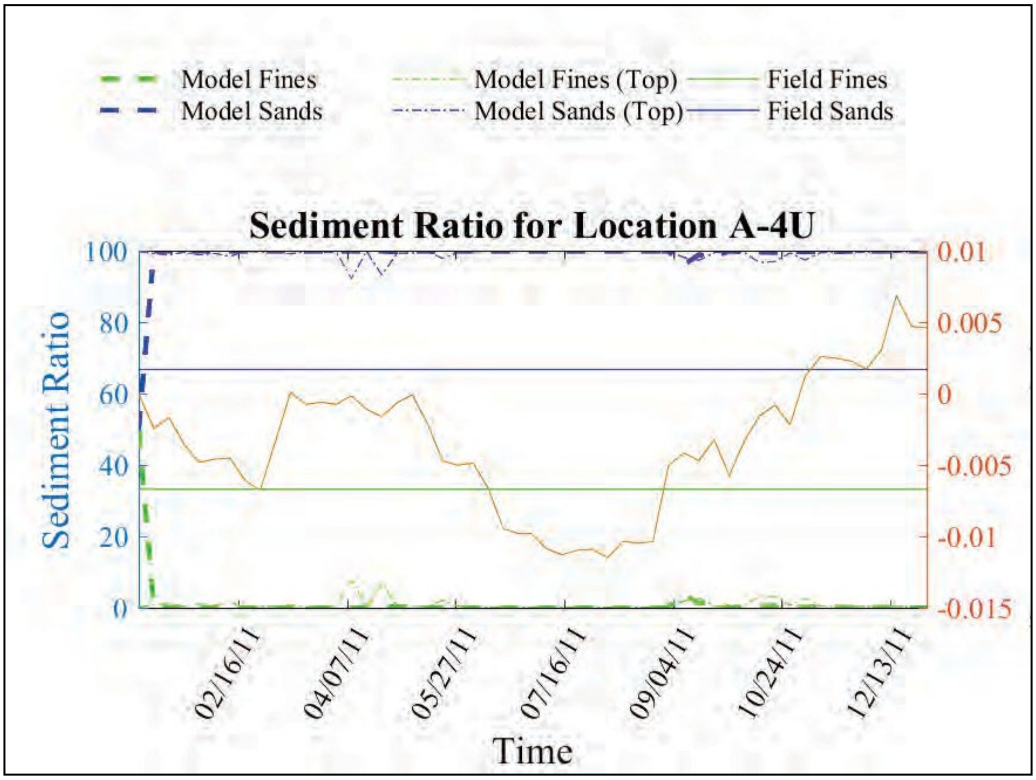


Figure 247. Sediment bed composition comparisons at Location A-4U for 2011 (top) and 2012 (bottom).



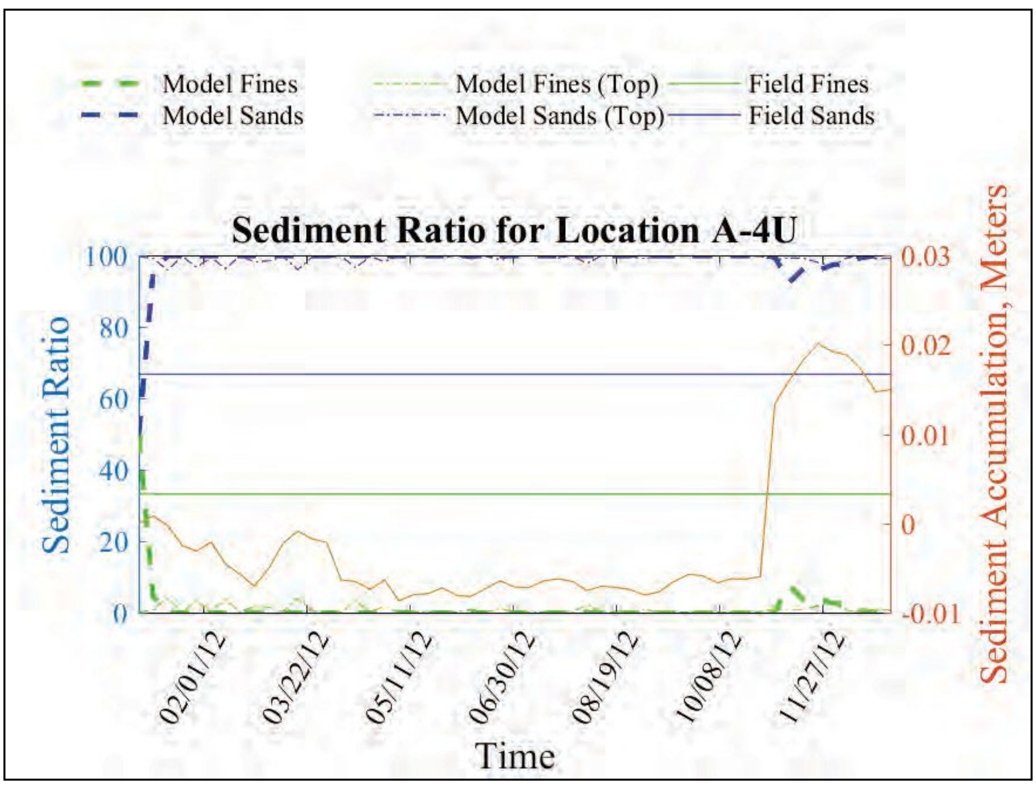
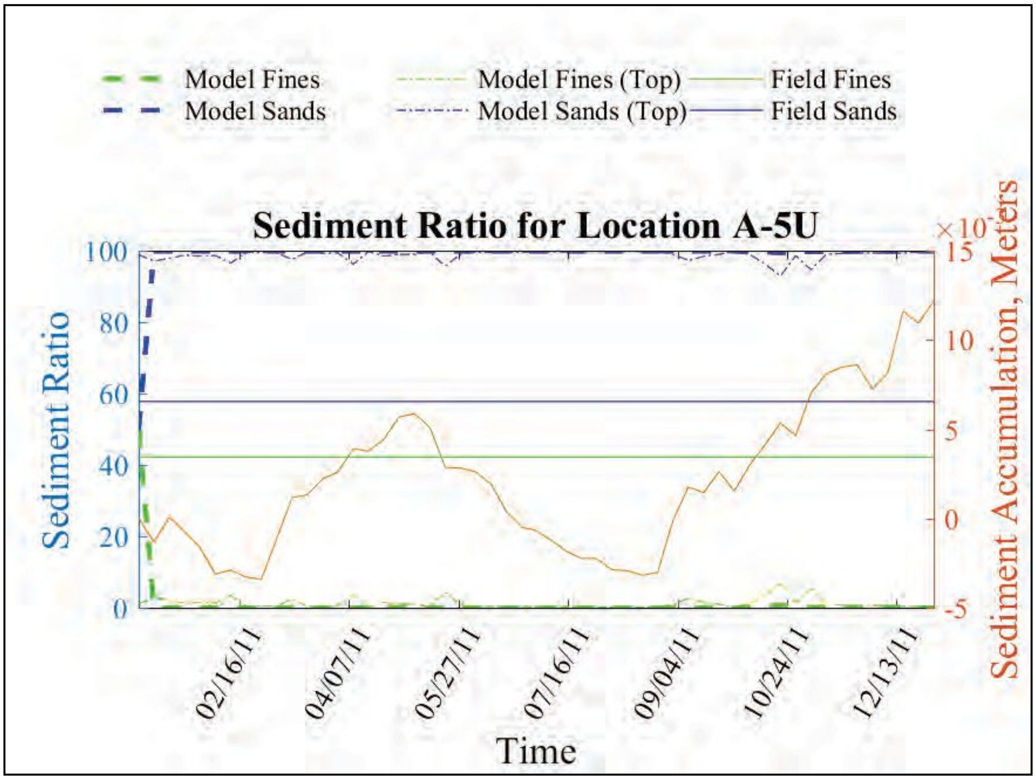


Figure 248. Sediment bed composition comparisons at location A-5U for 2011 (top) and 2012 (bottom).



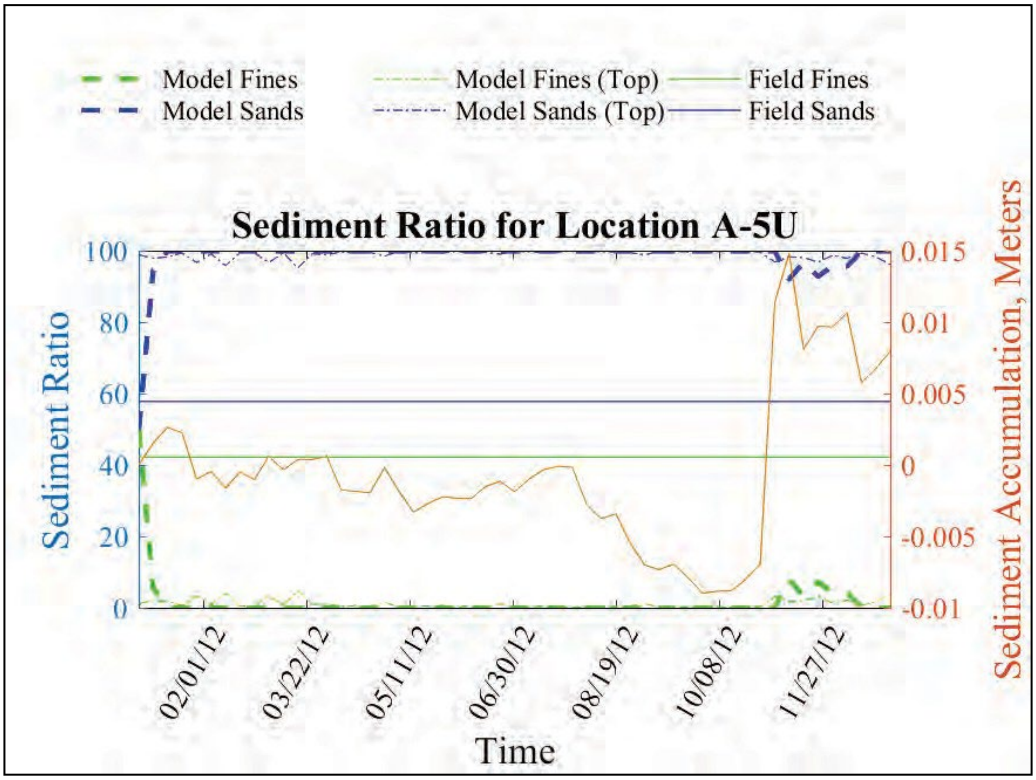
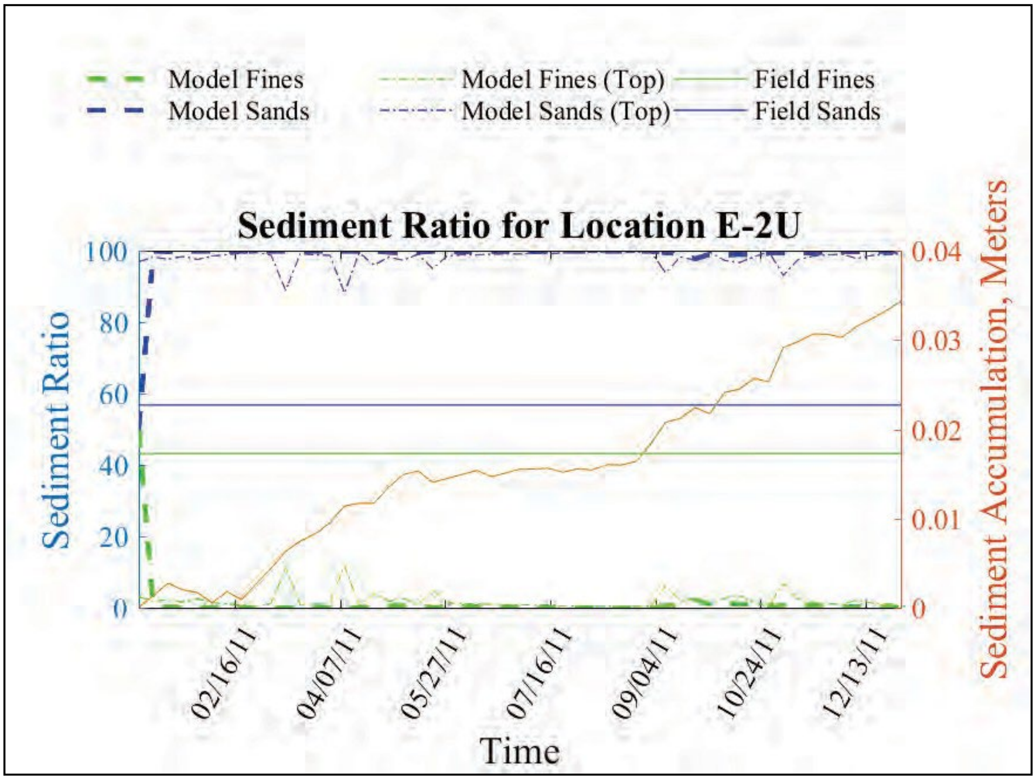


Figure 249. Sediment bed composition comparisons at location E-2U for 2011 (top) and 2012 (bottom).



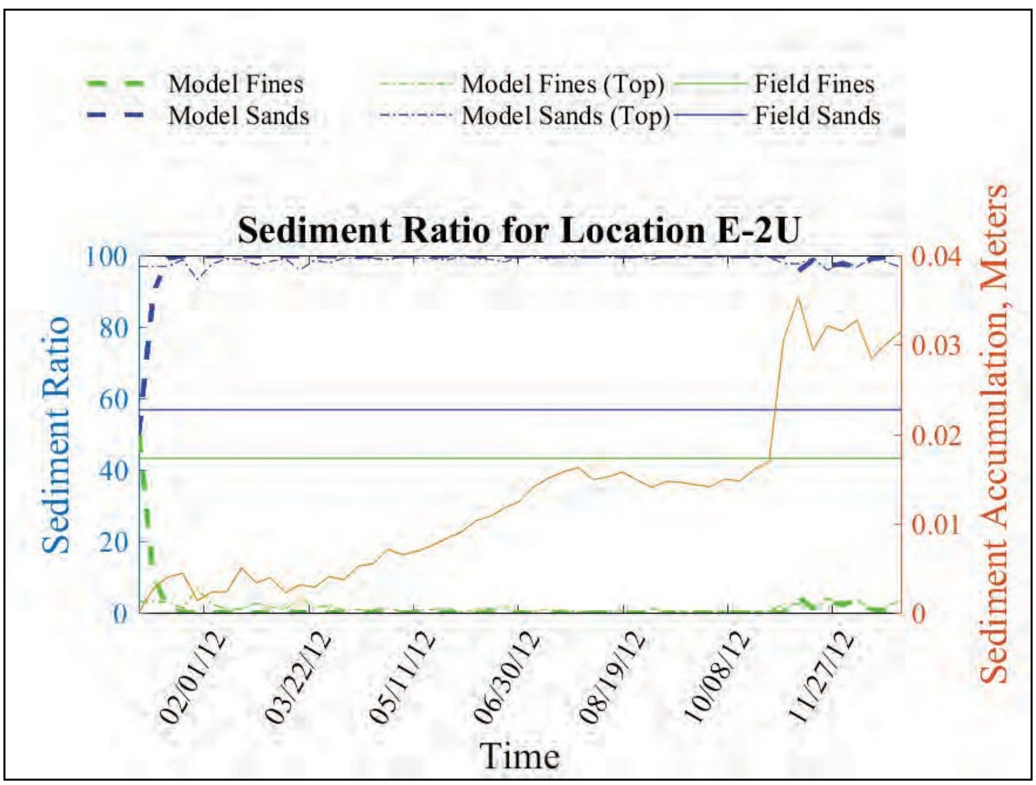
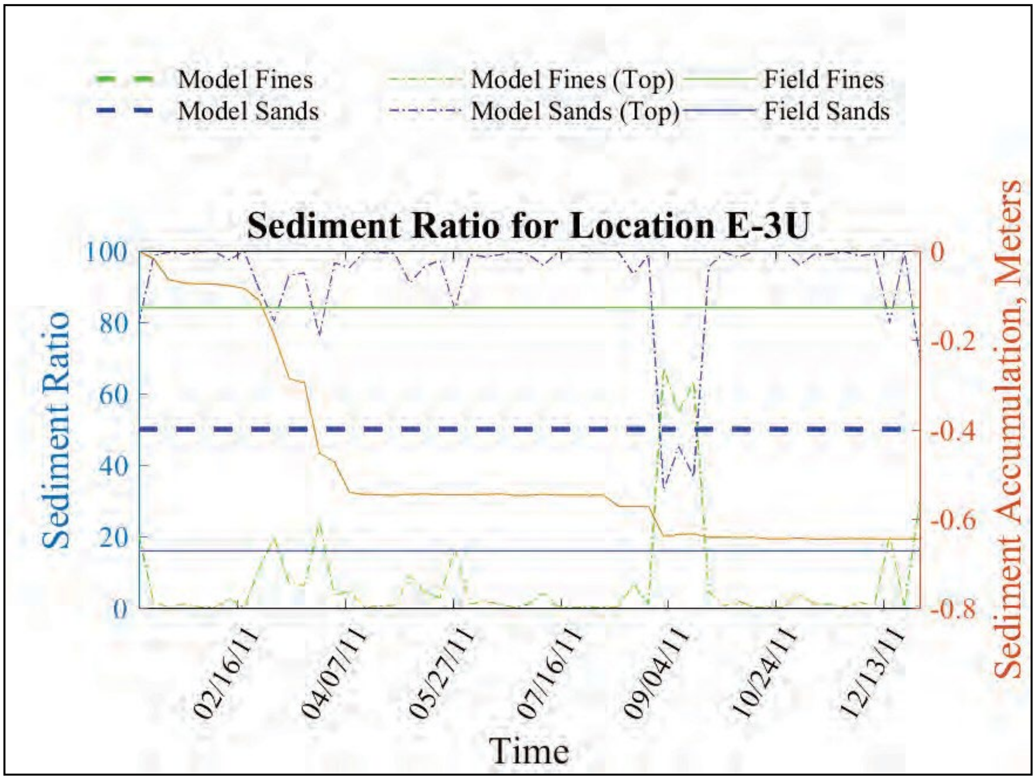


Figure 250. Sediment bed composition comparisons at location E-3U for 2011 (top) and 2012 (bottom).



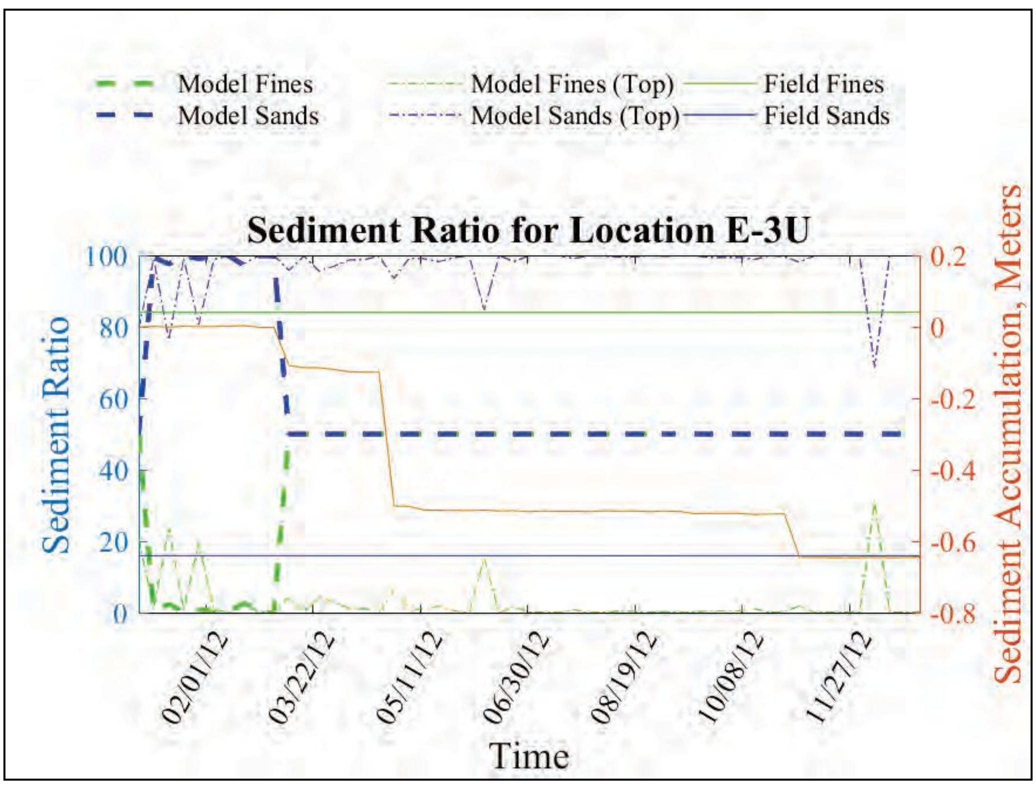
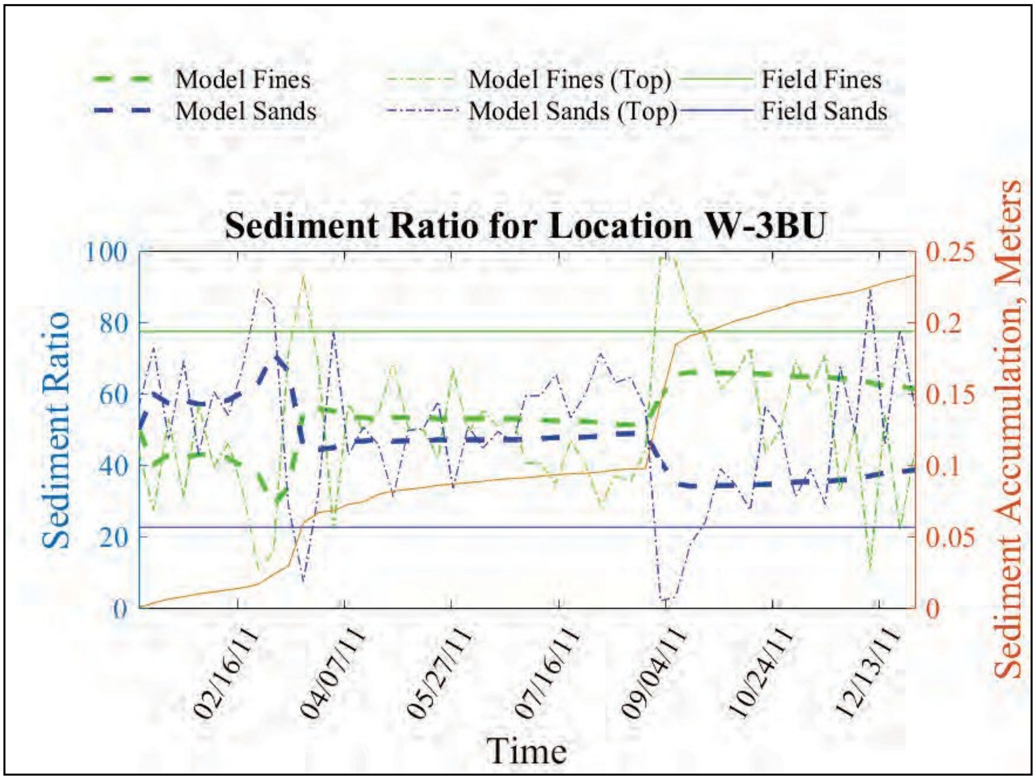


Figure 251. Sediment bed composition comparisons at location W-3BU for 2011 (top) and 2012 (bottom).



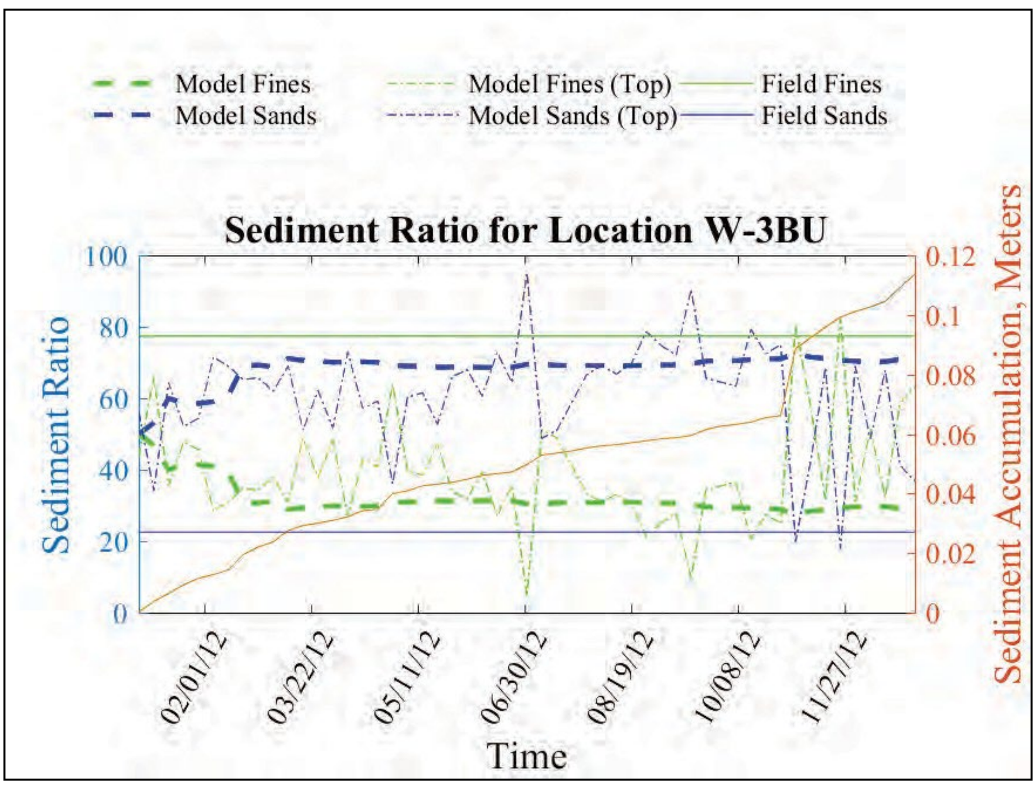
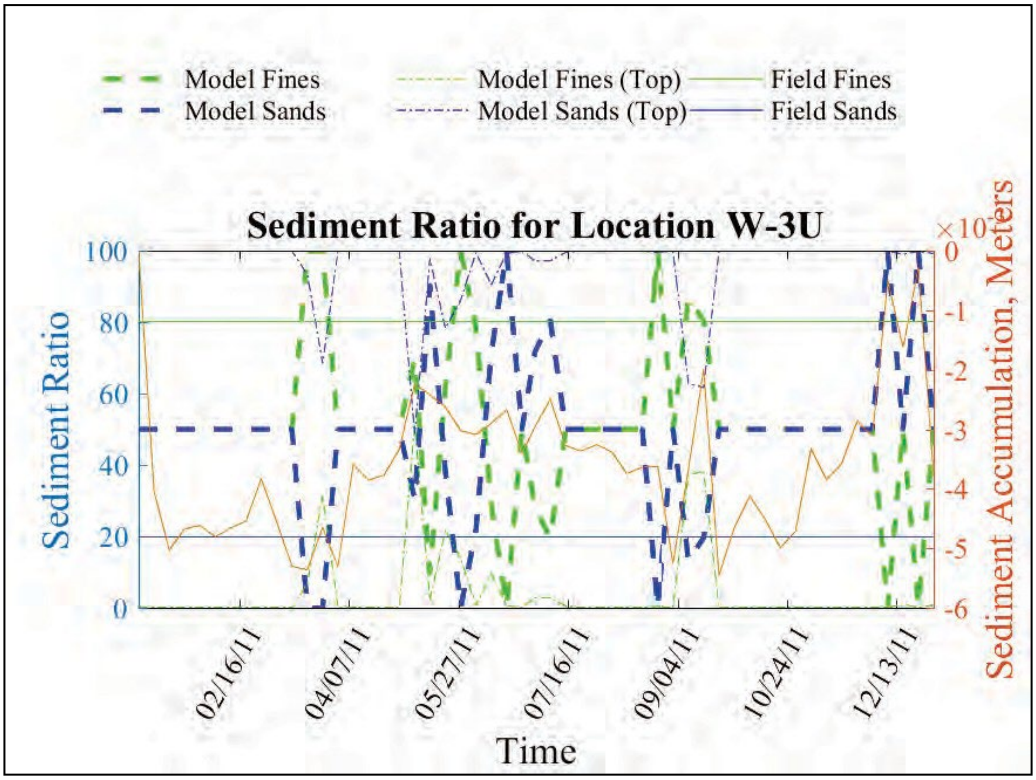


Figure 252. Sediment bed composition comparisons at location W-3U for 2011 (top) and 2012 (bottom).



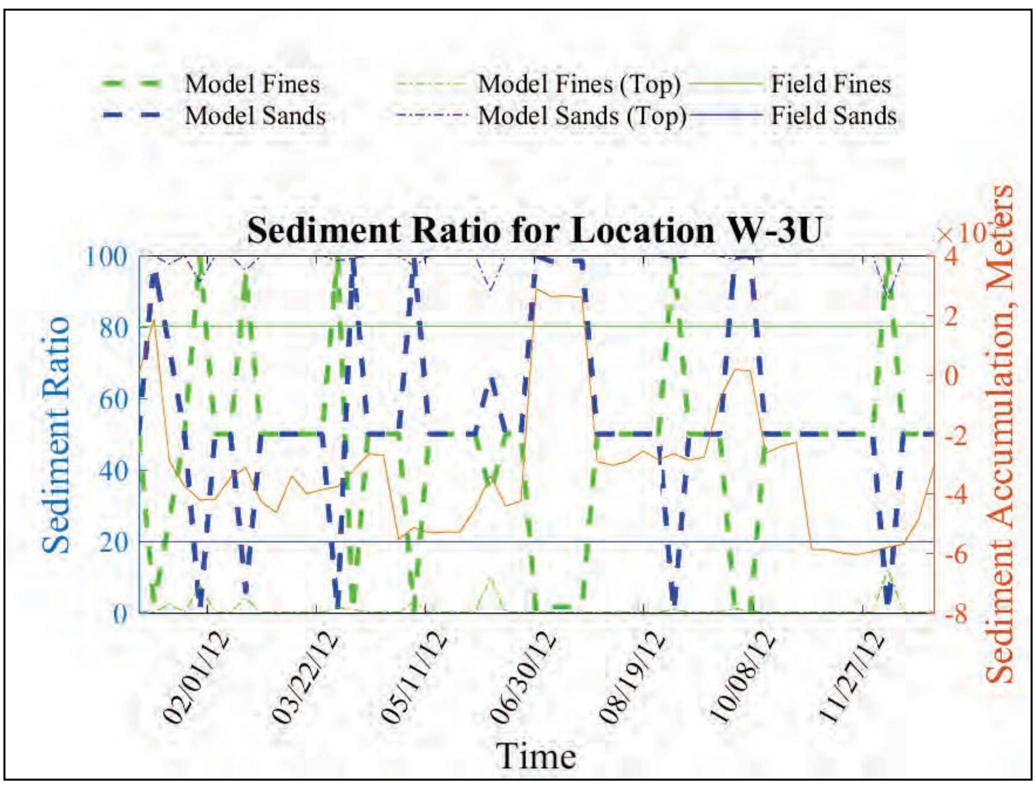
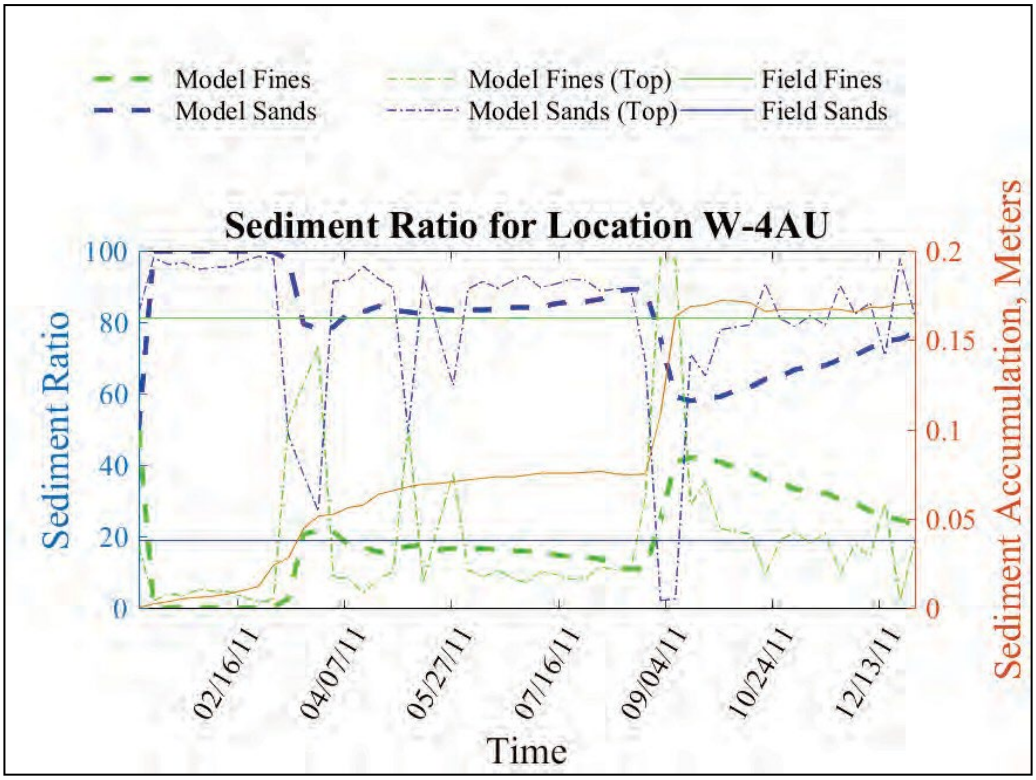


Figure 253. Sediment bed composition comparisons at location W-4AU for 2011 (top) and 2012 (bottom).



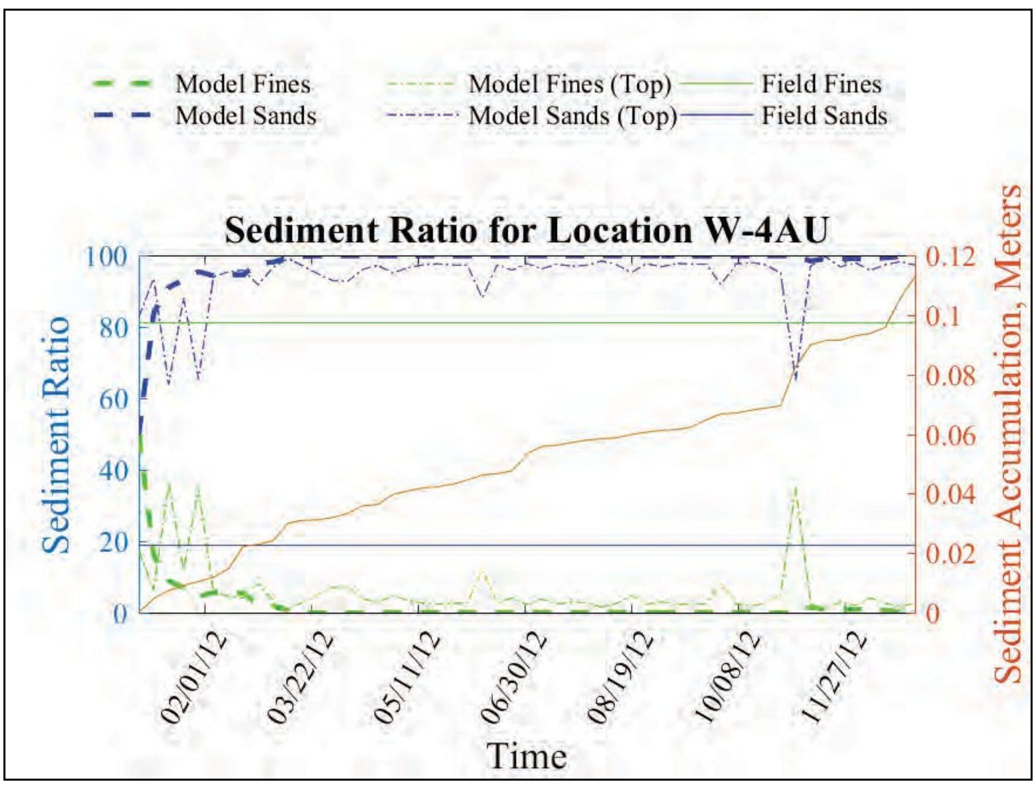
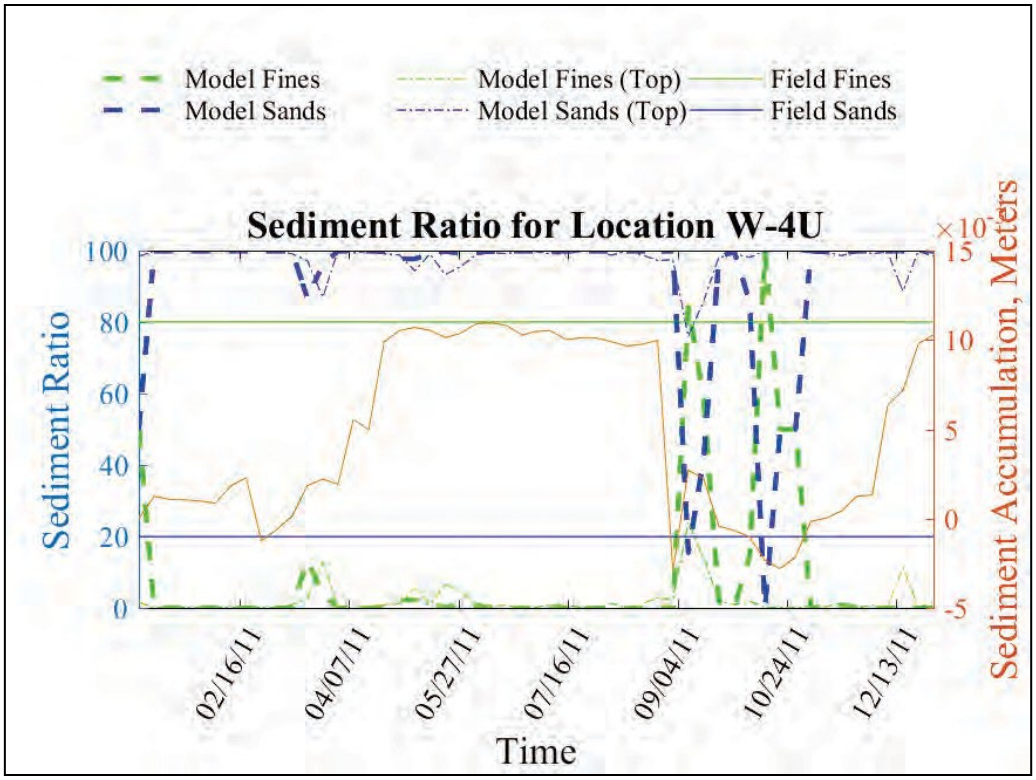


Figure 254. Sediment bed composition comparisons at location W-4U for 2011 (top) and 2012 (bottom).



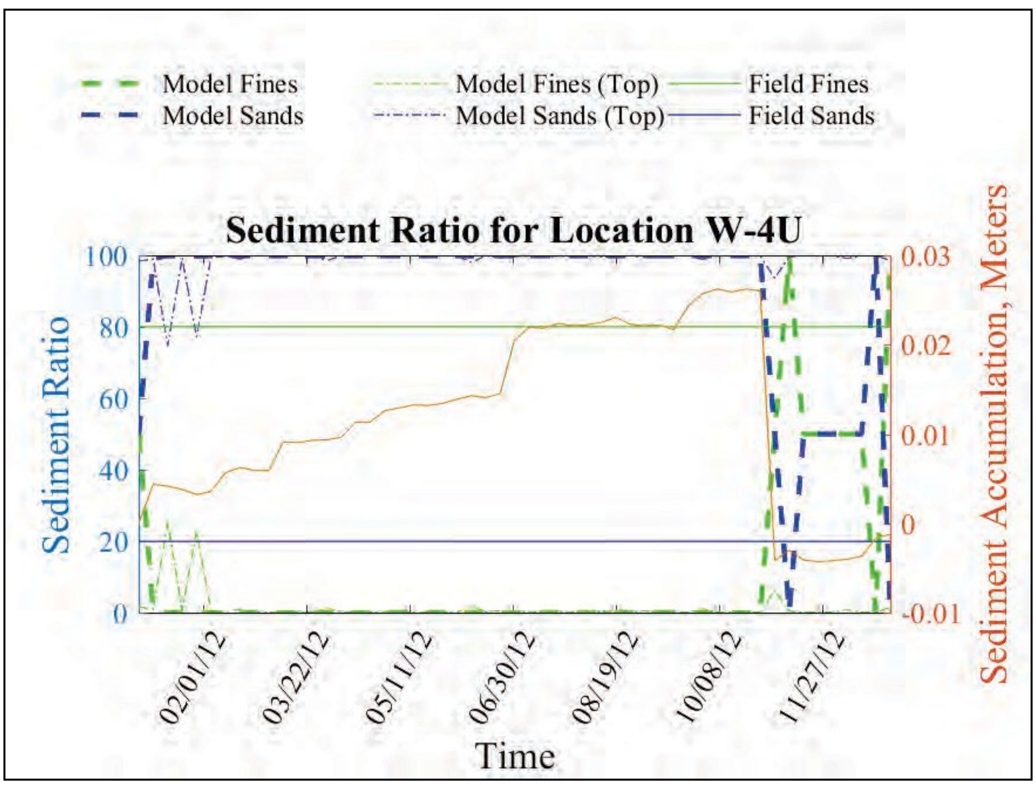
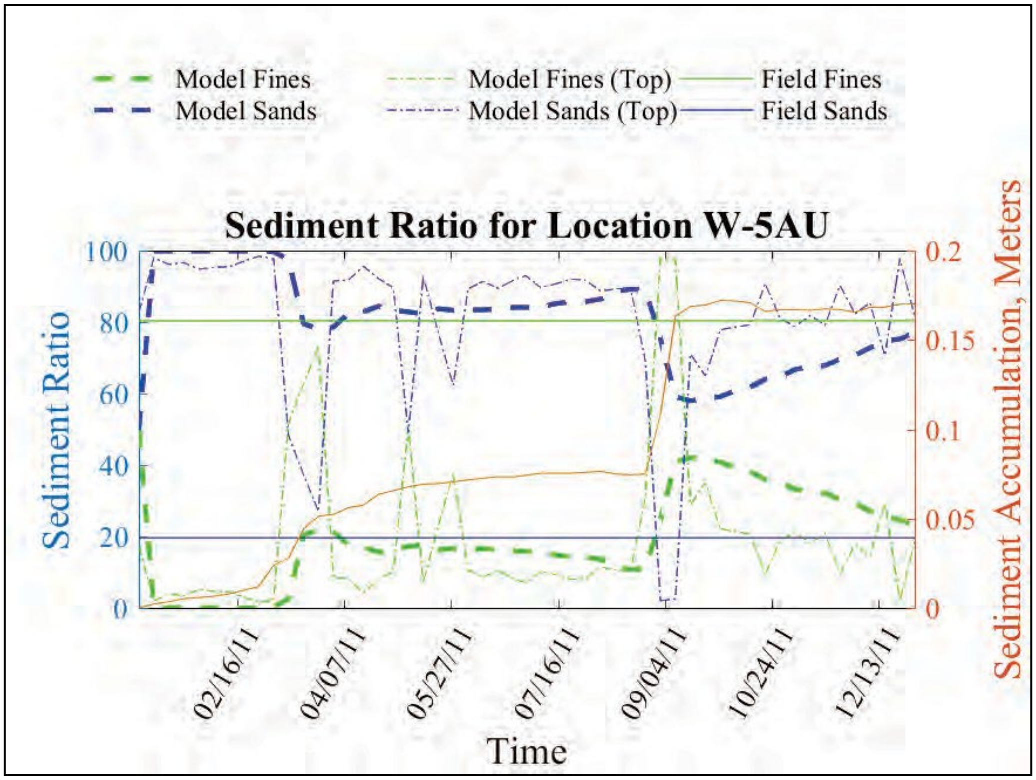


Figure 255. Sediment bed composition comparisons at location W-5AU for 2011 (top) and 2012 (bottom).



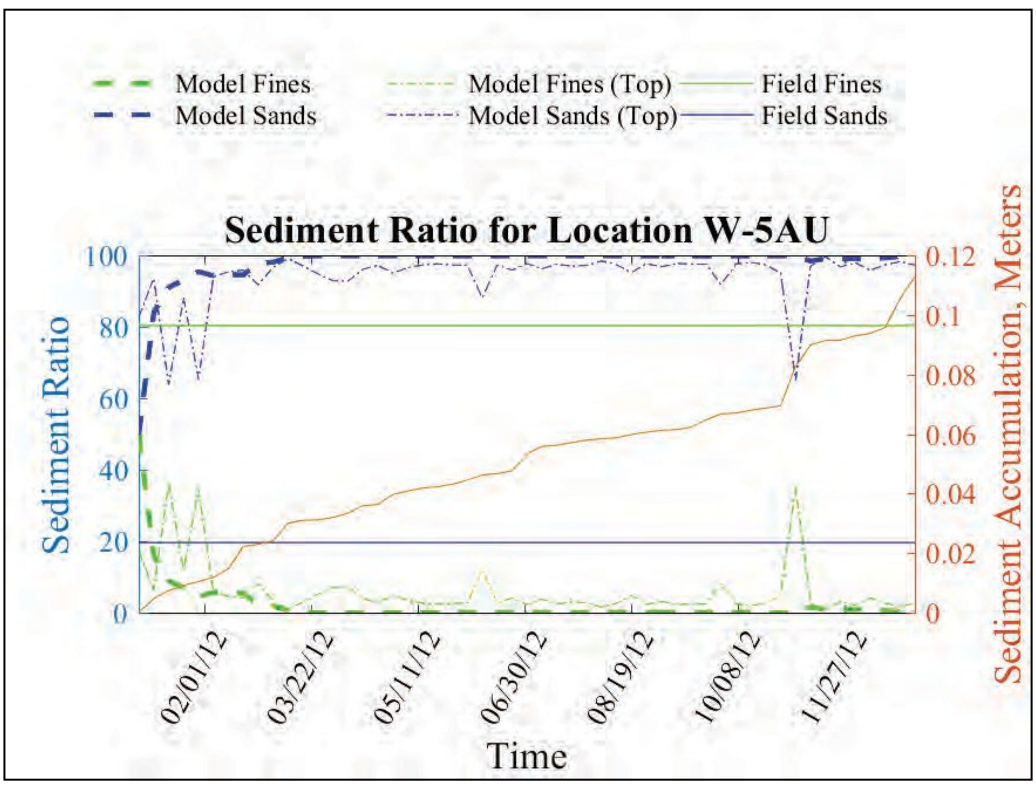
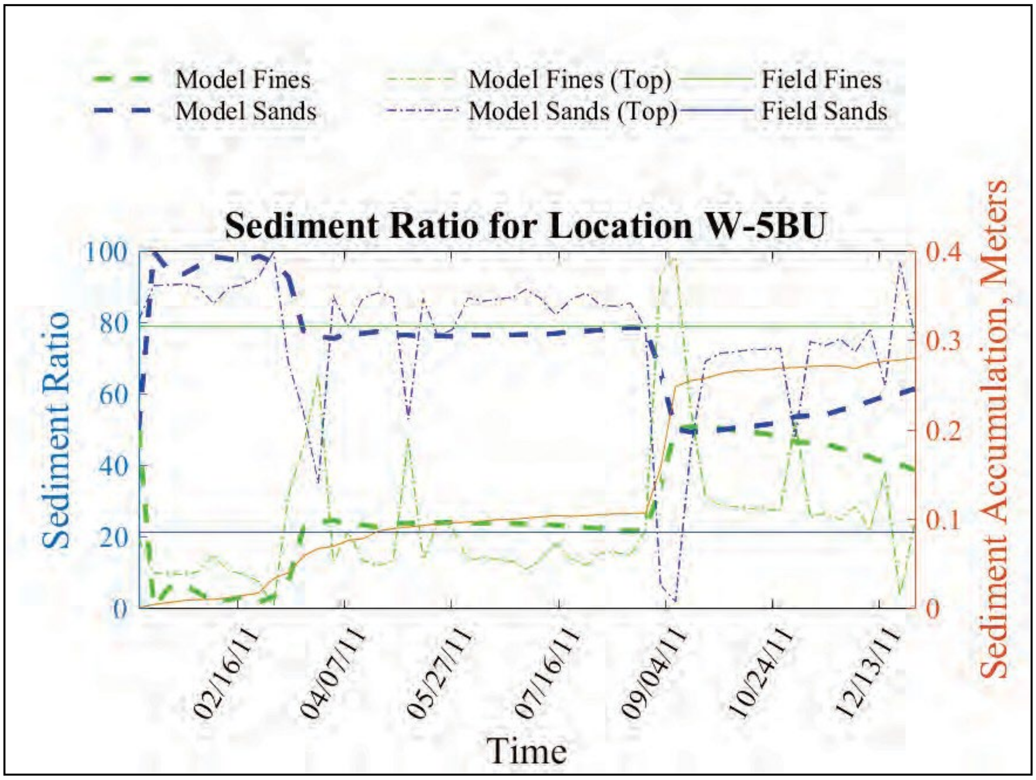


Figure 256. Sediment bed composition comparisons at location W-5BU for 2011 (top) and 2012 (bottom).



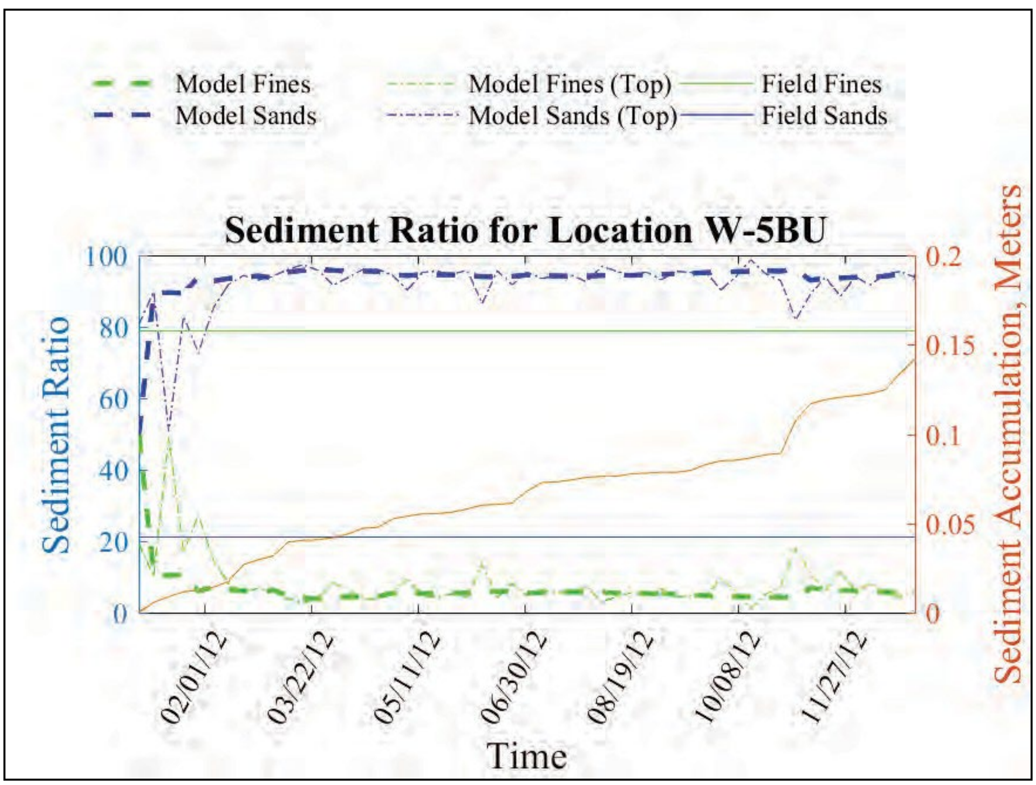
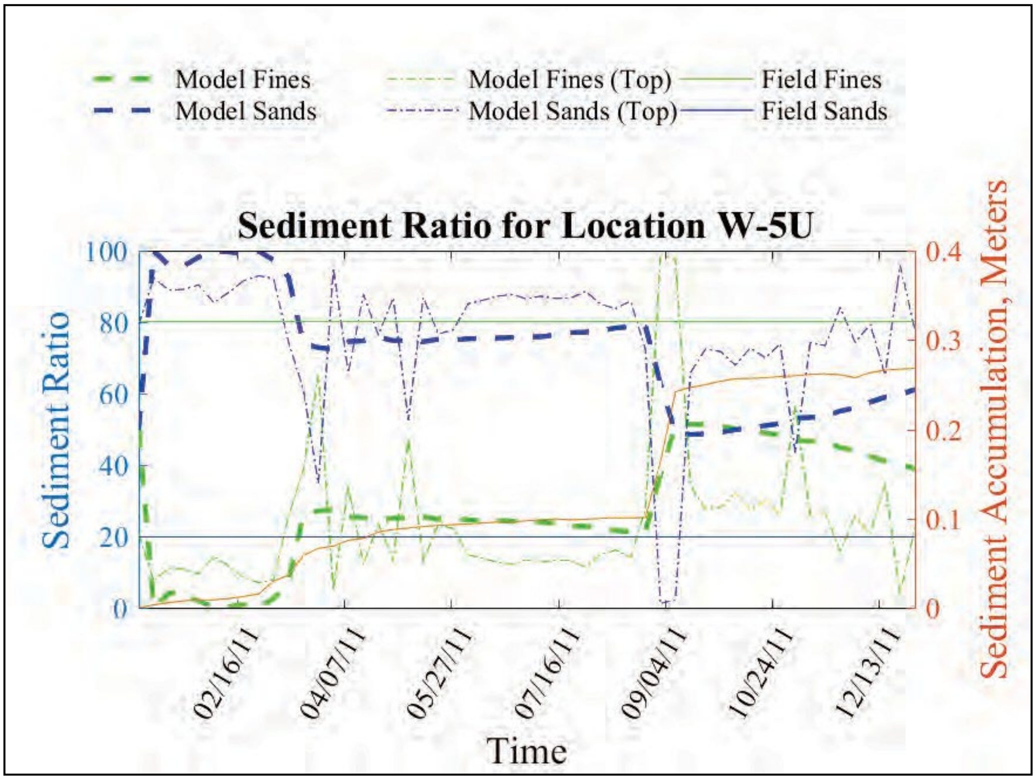


Figure 257. Sediment bed composition comparisons at location W-5U for 2011 (top) and 2012 (bottom).



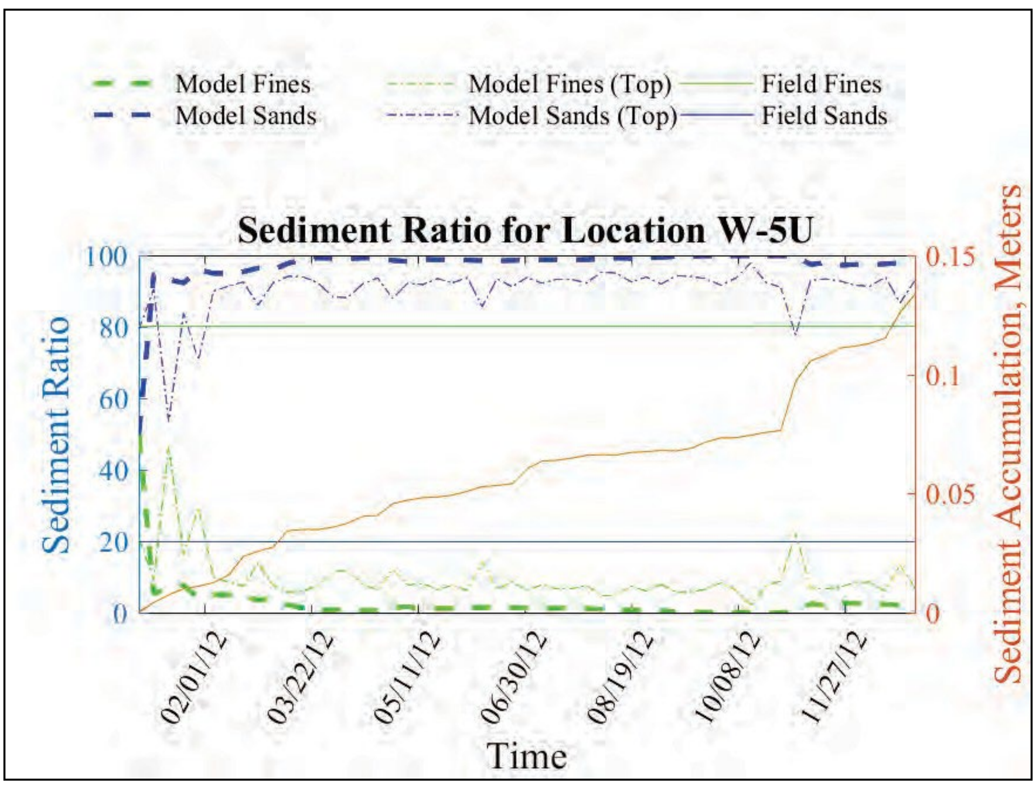
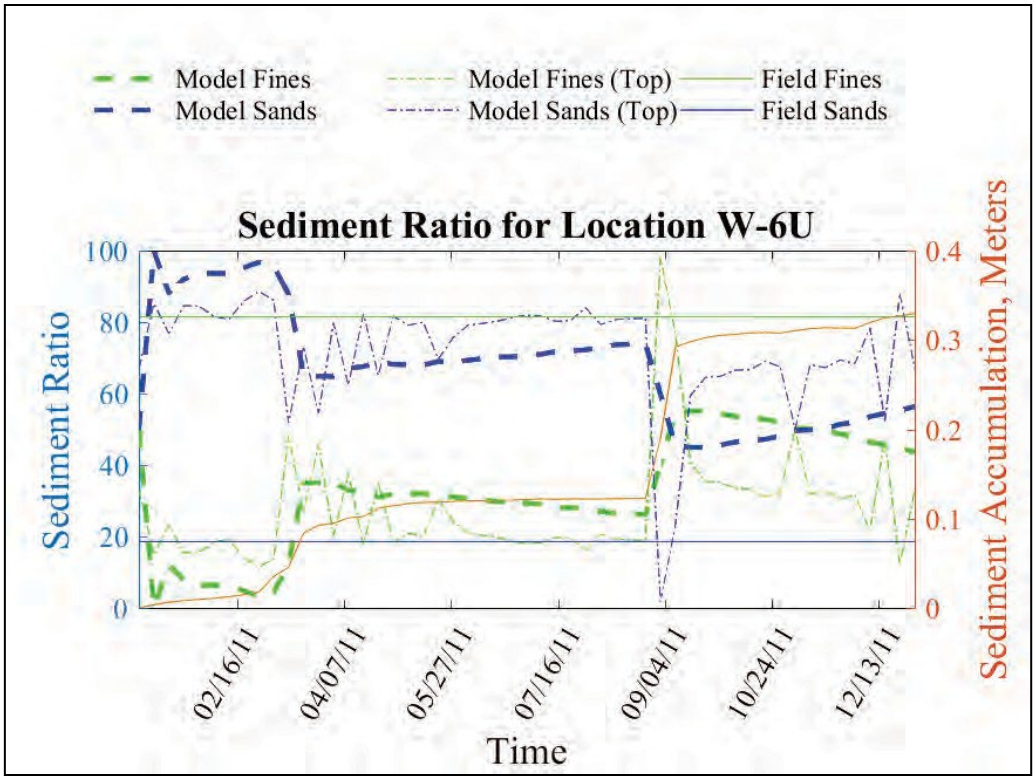
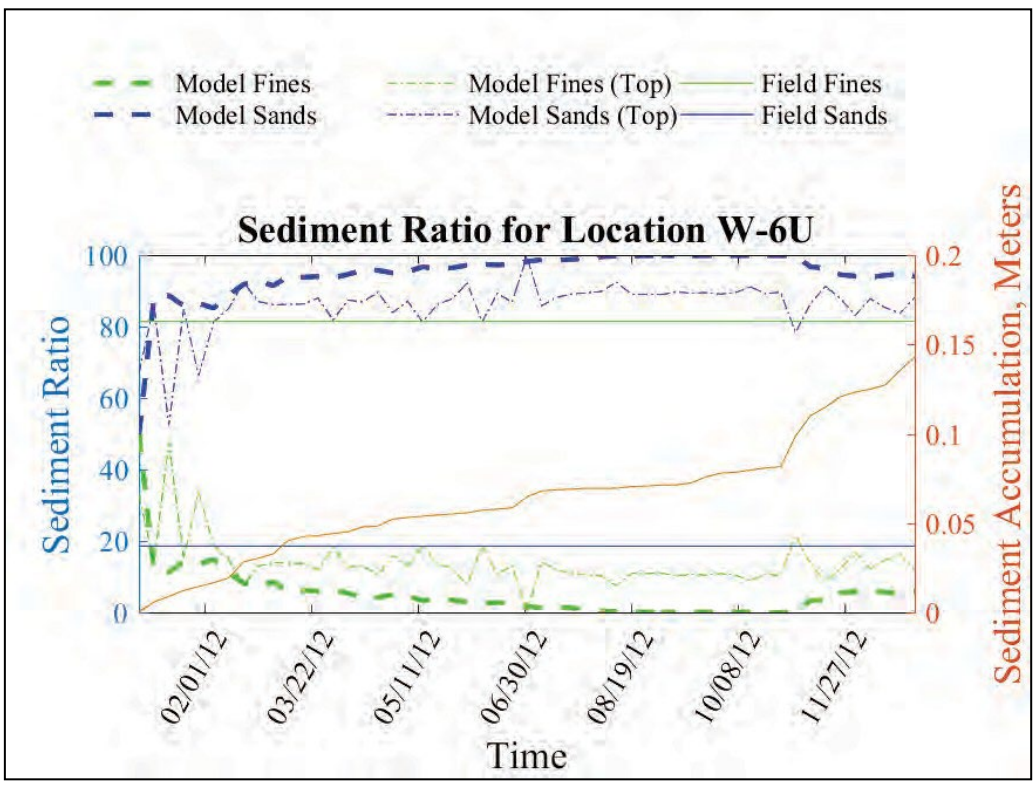


Figure 258. Sediment bed composition comparisons at location W-6U for 2011 (top) and 2012 (bottom).





Appendix D: Results for 1985

Lower Bay results

Figure 259. Without-project (top) and with-project (bottom) average shear stresses, Pa (1985).

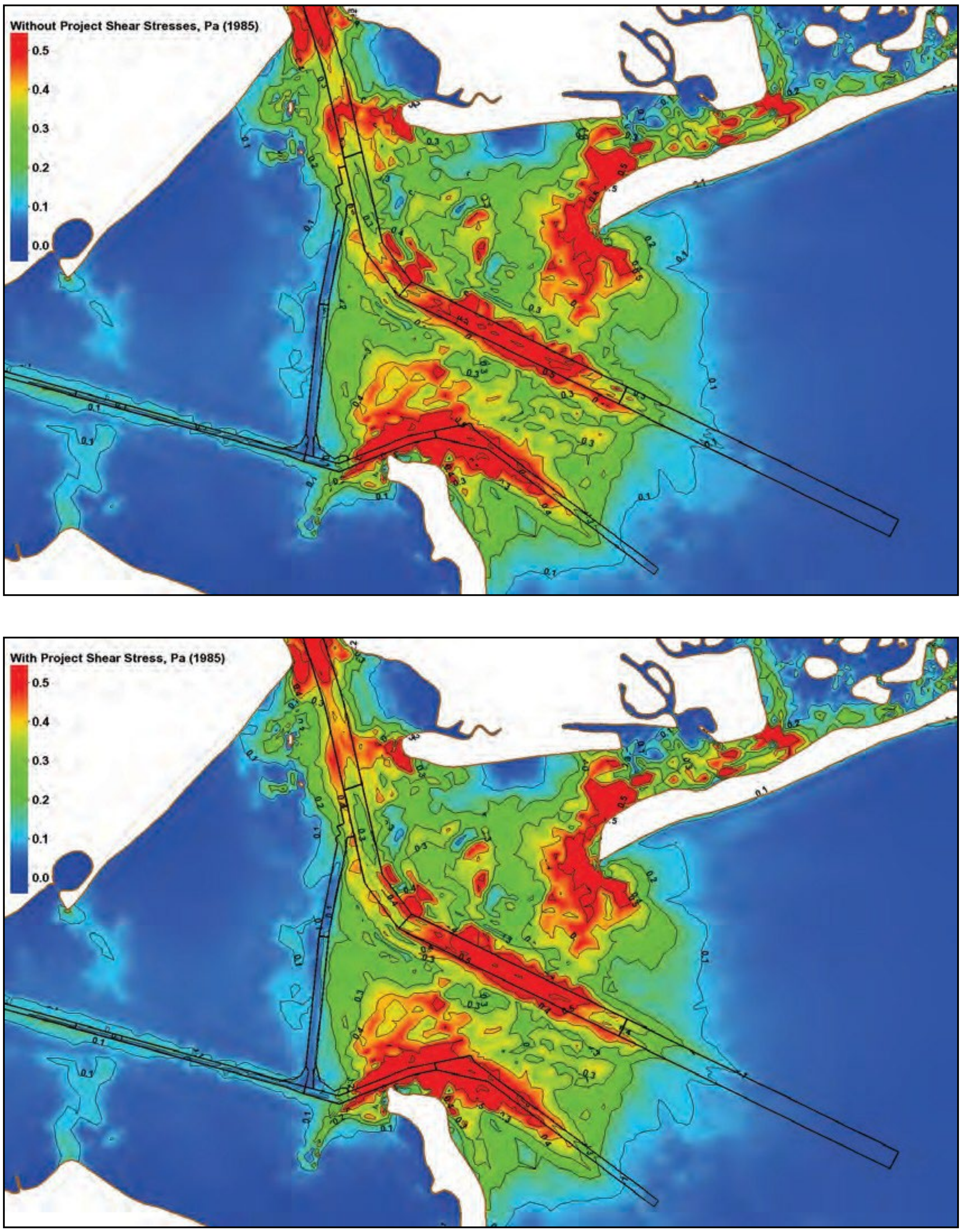
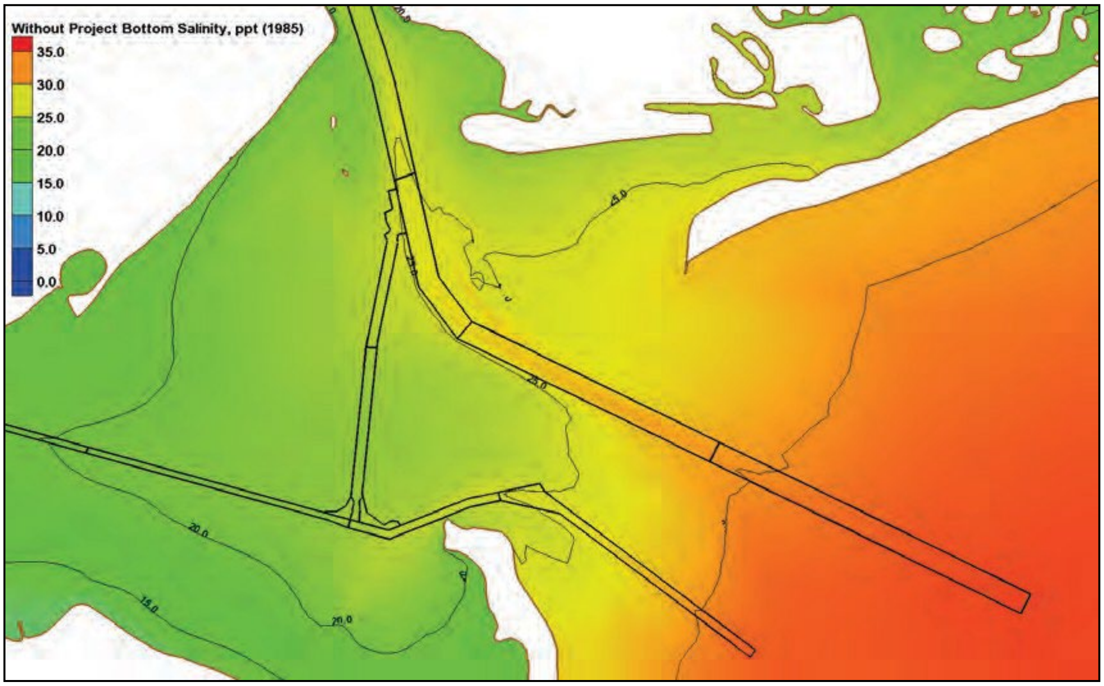


Figure 260. Without-project (top) and with-project (bottom) average bottom salinity, ppt (1985).



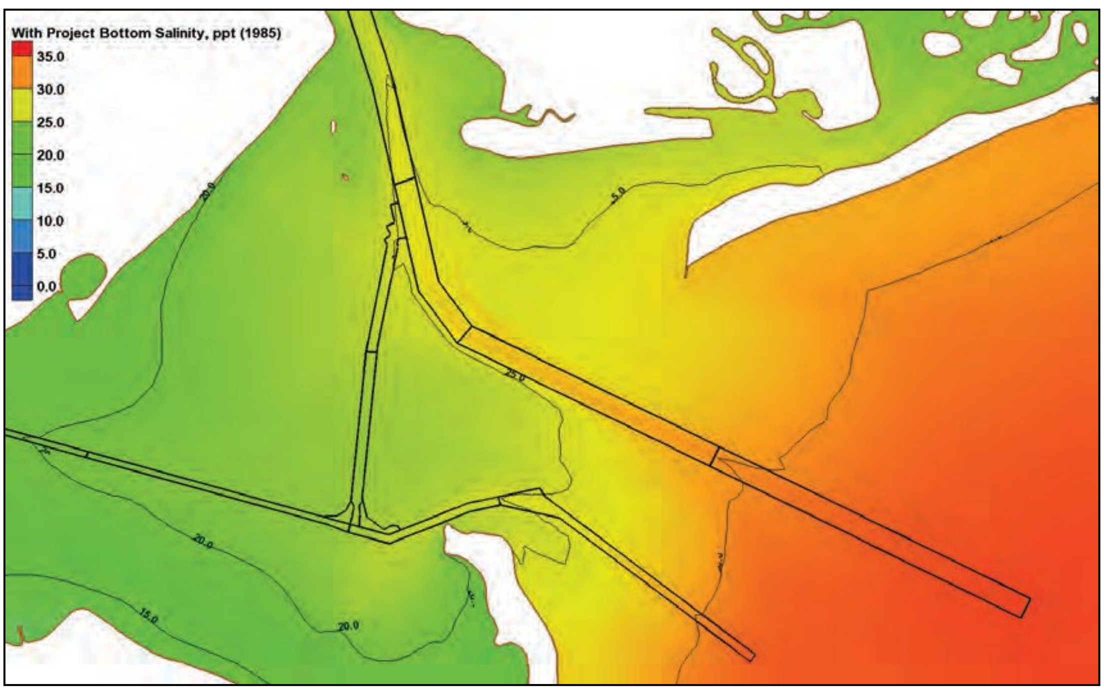


Figure 261. Without-project (top) and with-project (bottom) average fine sediment bottom concentrations, ppm (1985).

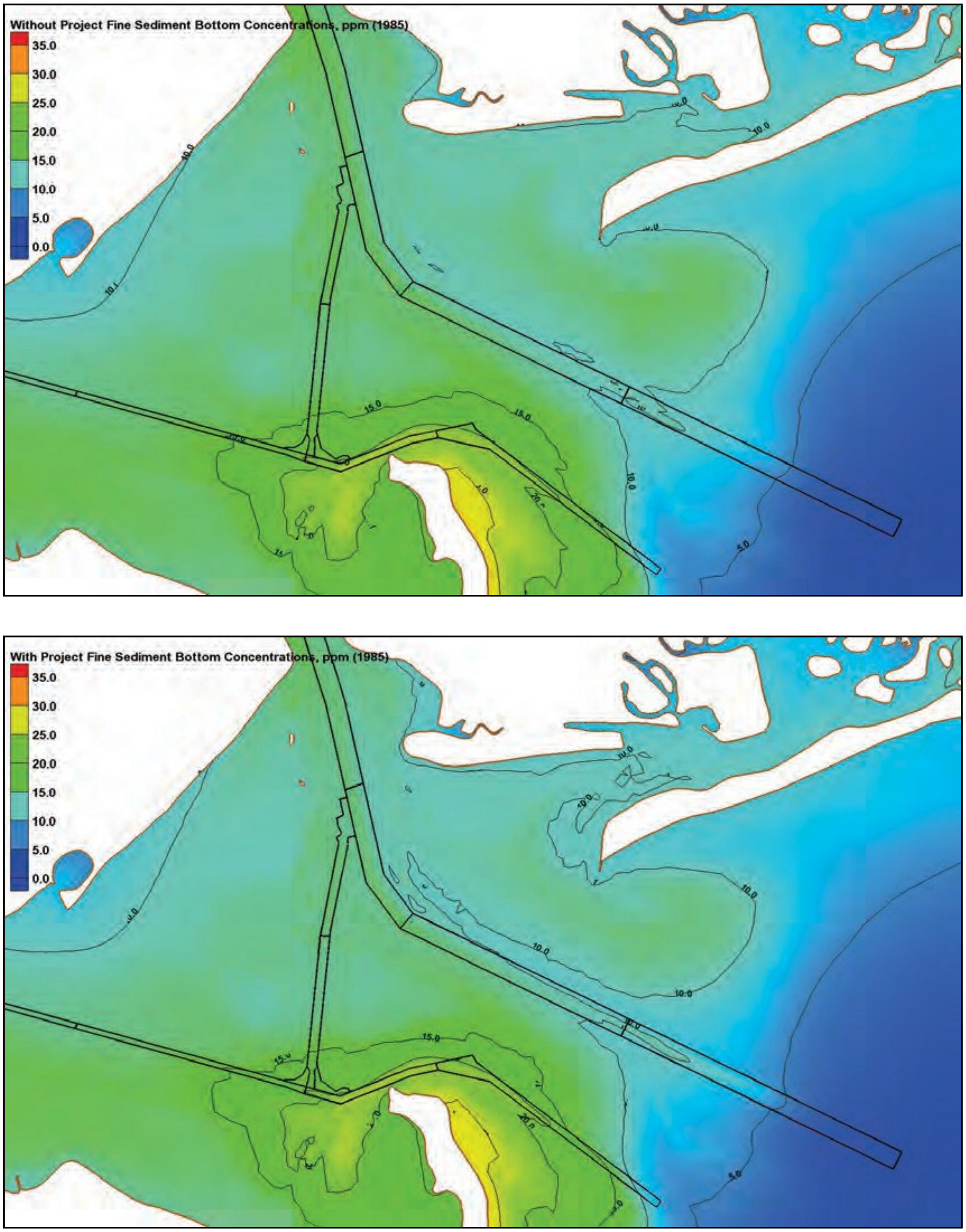
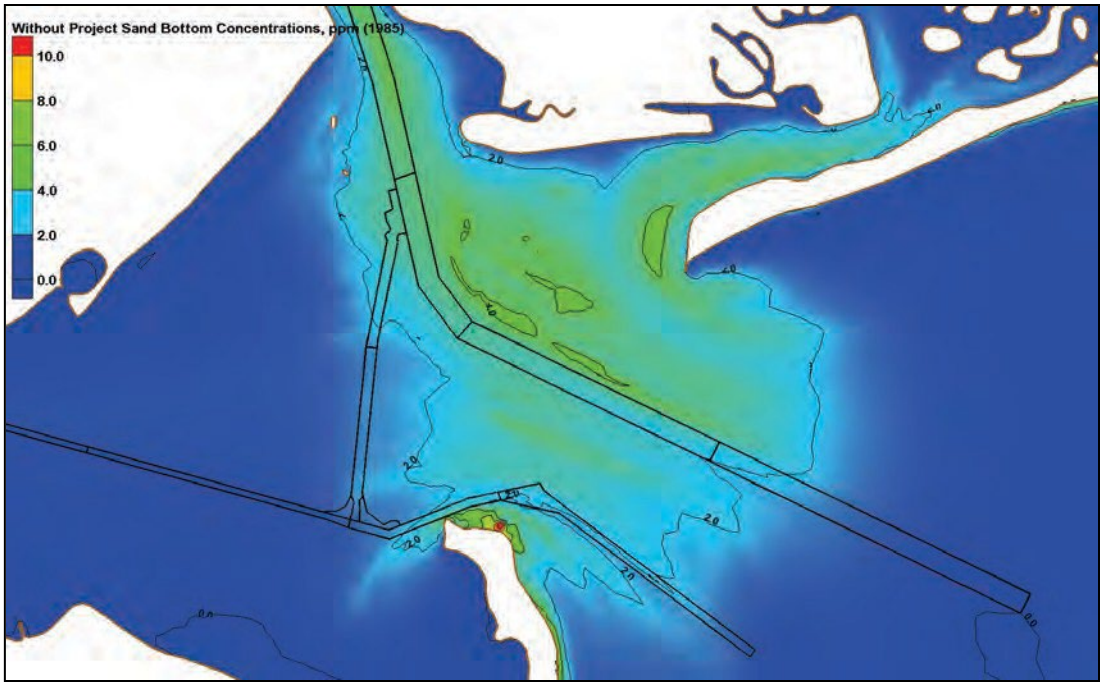


Figure 262. Without-project (top) and with-project (bottom) average sand bottom concentrations, ppm (1985).



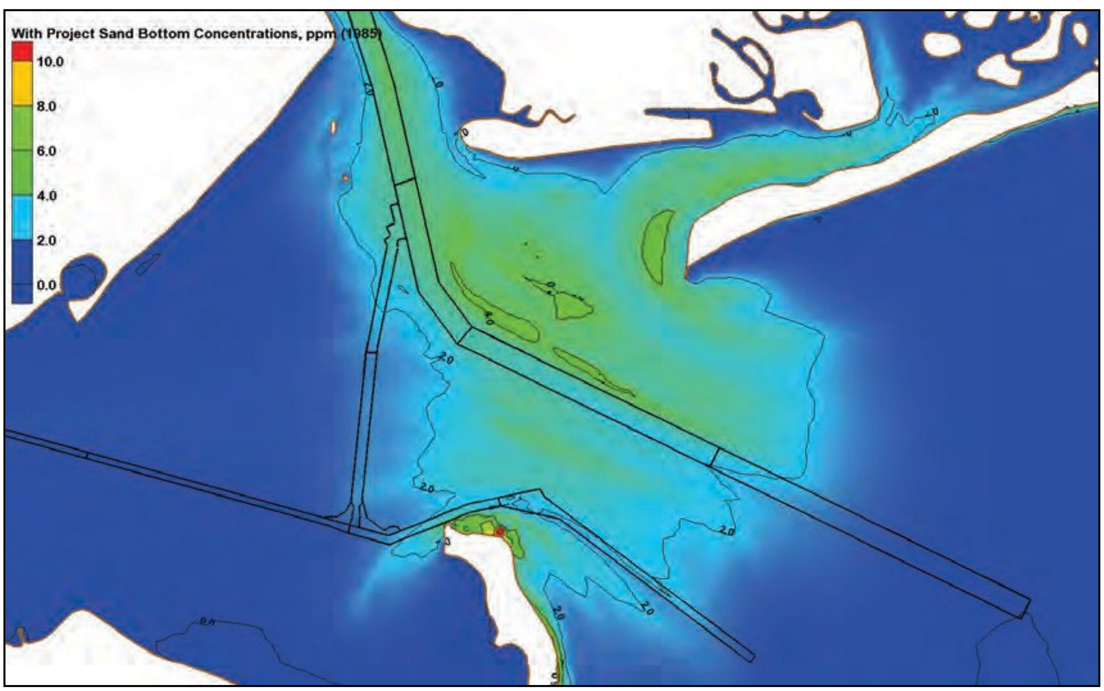
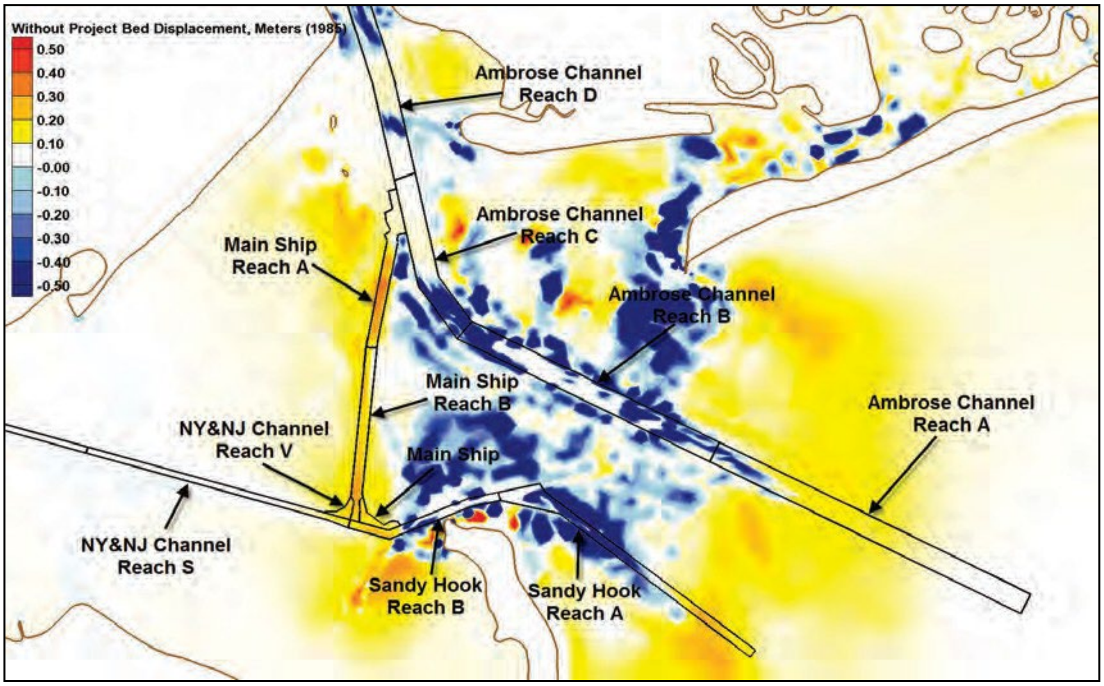


Figure 263. Without-project (top) and with-project (bottom) bed displacement, m (1985).



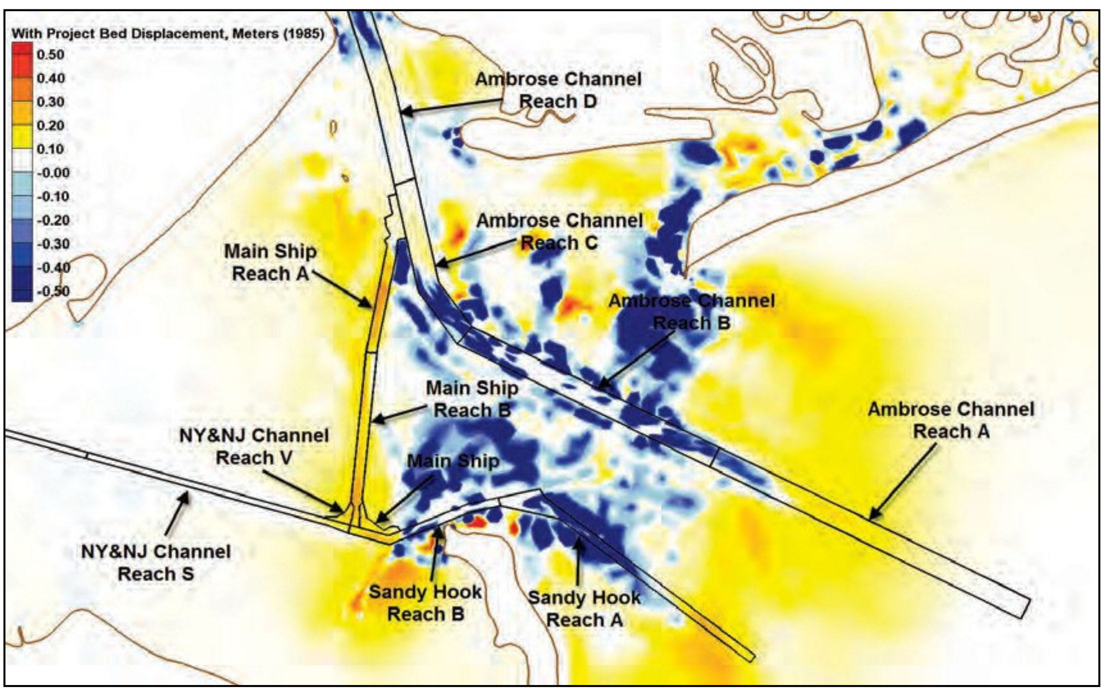
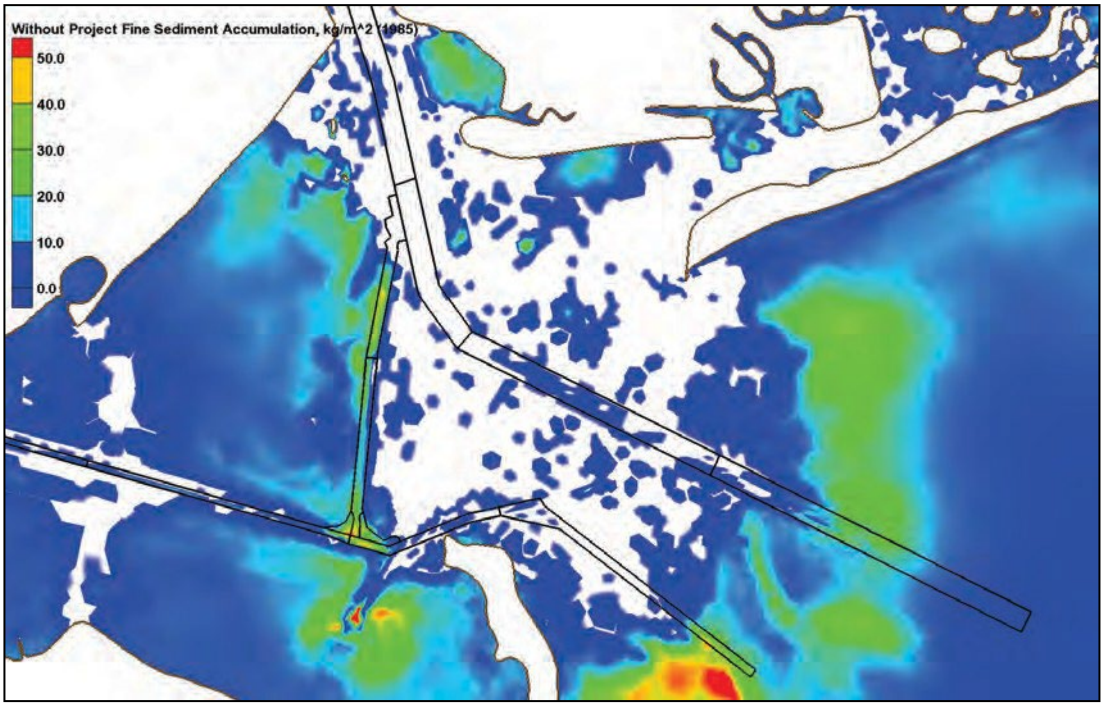


Figure 264. Without-project (top) and with-project (bottom) fine sediment accumulation, kg/m² (1985).



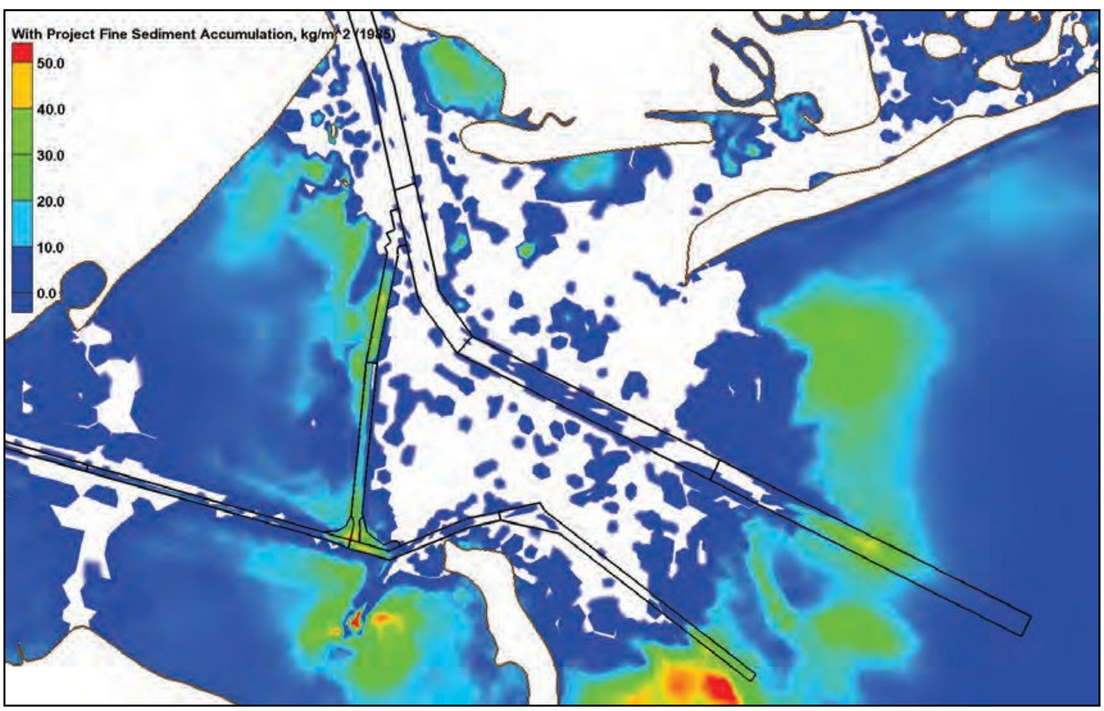
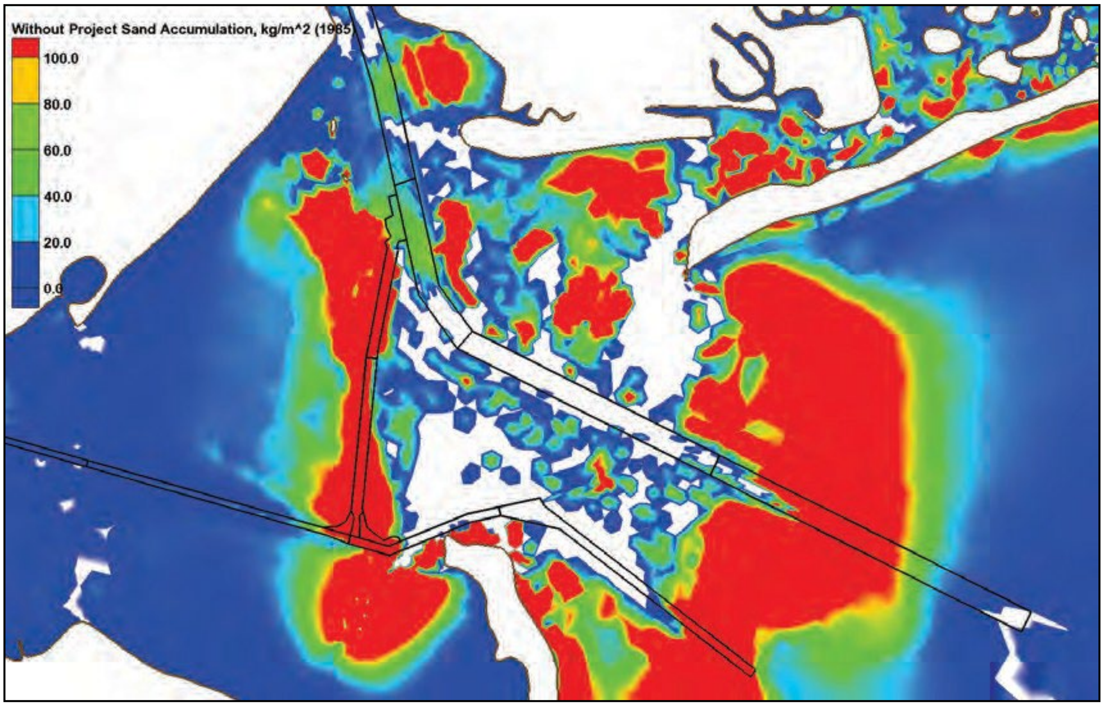


Figure 265. Without-project (top) and with-project (bottom) sand accumulation, kg/m²
(1985).



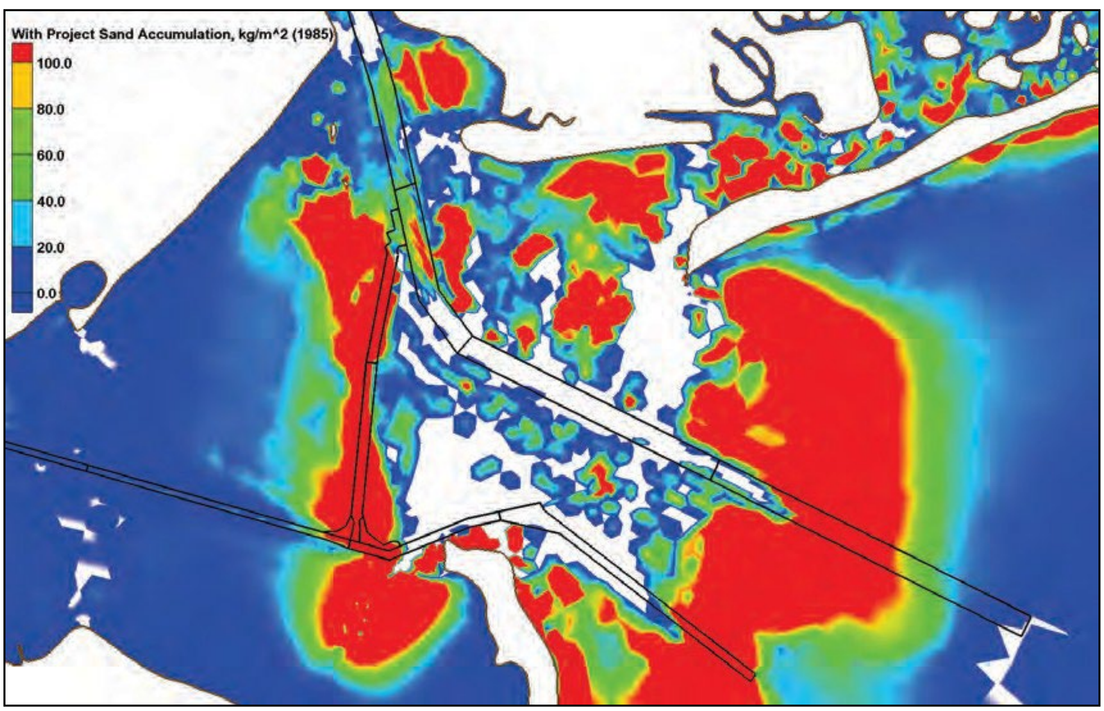


Figure 266. Dredge with-project/without-project percent differences (1985).

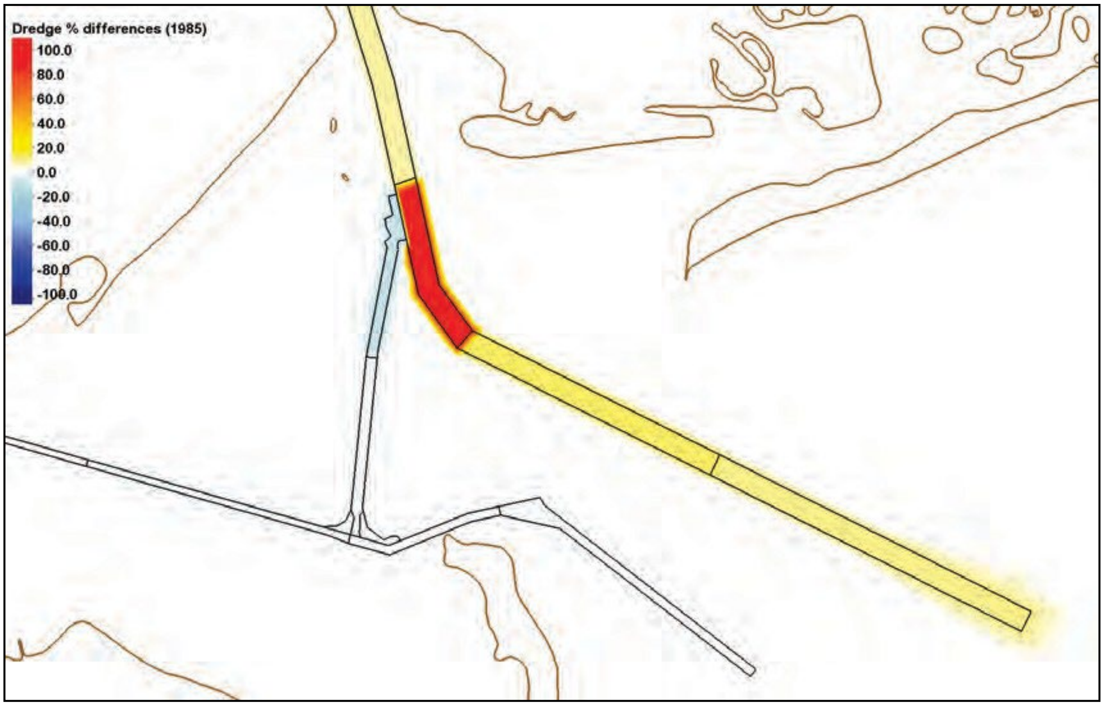
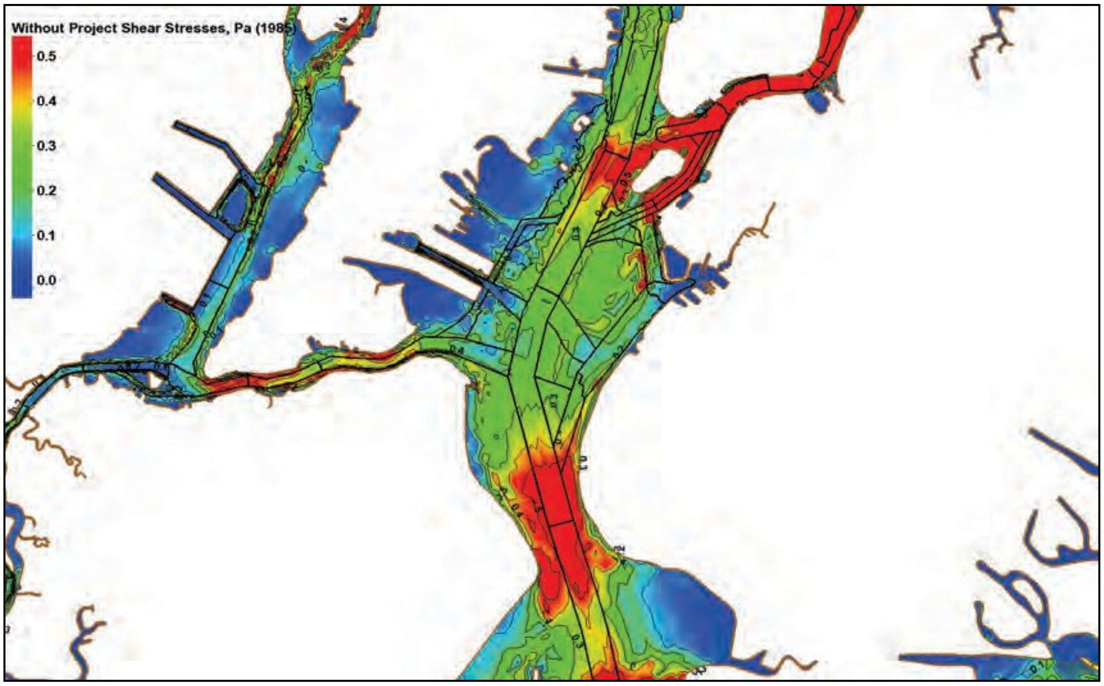


Table 28. Dredge volumes for Lower Bay (1985).

Depositional Volumes in Lower Bay, cy (1985)			
Reach	Without Project	With Project	With/Without Dredge Percentage
Ambrose Channel Reach A	356,513	390,125	109
Ambrose Channel Reach B	3,730	4,185	112
Ambrose Channel Reach C	28,854	53,873	187
Ambrose Channel Reach D	32,401	34,763	107
Main Ship	47,779	46,348	97
Main Ship Reach A	231,922	203,453	88
Main Ship Reach B	263,941	256,636	97
Sandy Hook Reach A	134,405	131,859	98
Sandy Hook Reach B	65,695	65,491	100
NY&NJ Channels Reach S	25,414	24,447	96
NY&NJ Channels Reach V	34,131	32,647	96

Newark Bay, Kill van Kull, and Upper Bay results

Figure 267. Without-project (top) and with-project (bottom) average shear stresses, Pa (1985).



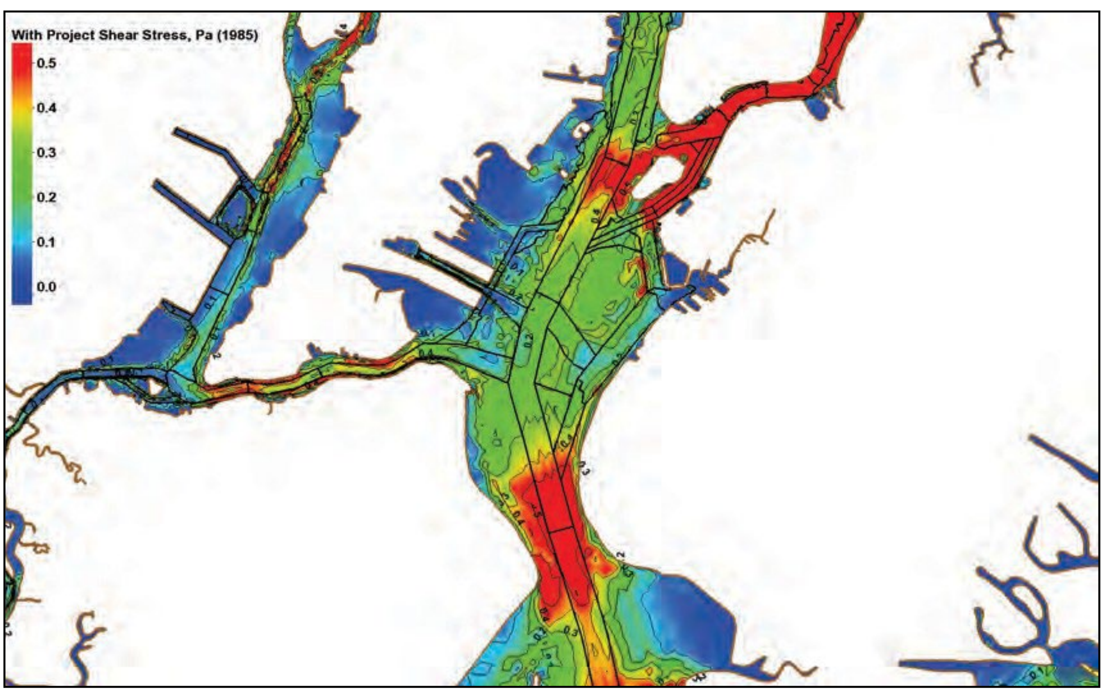


Figure 268. Without-project (top) and with-project (bottom) average bottom salinity, ppt (1985).

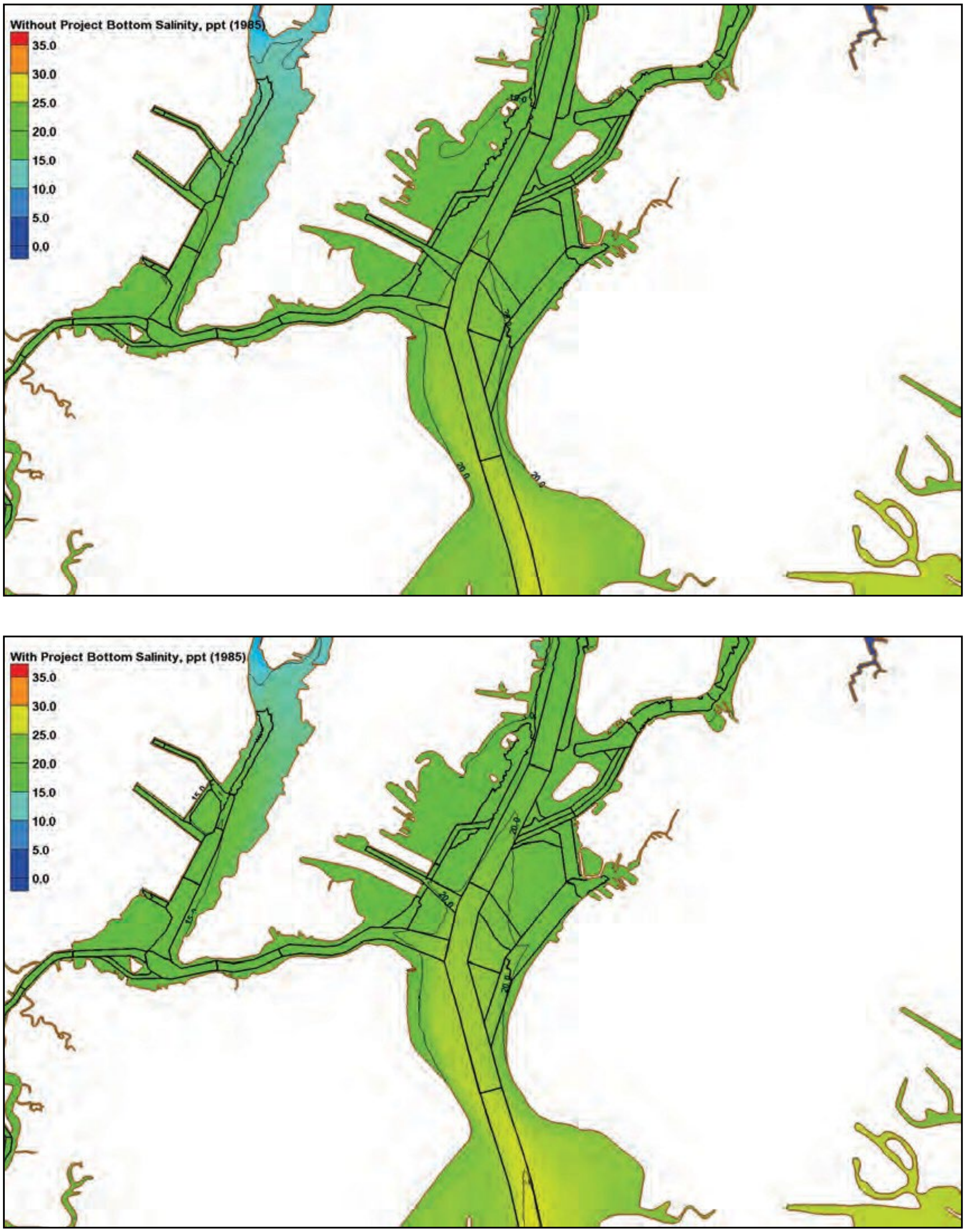
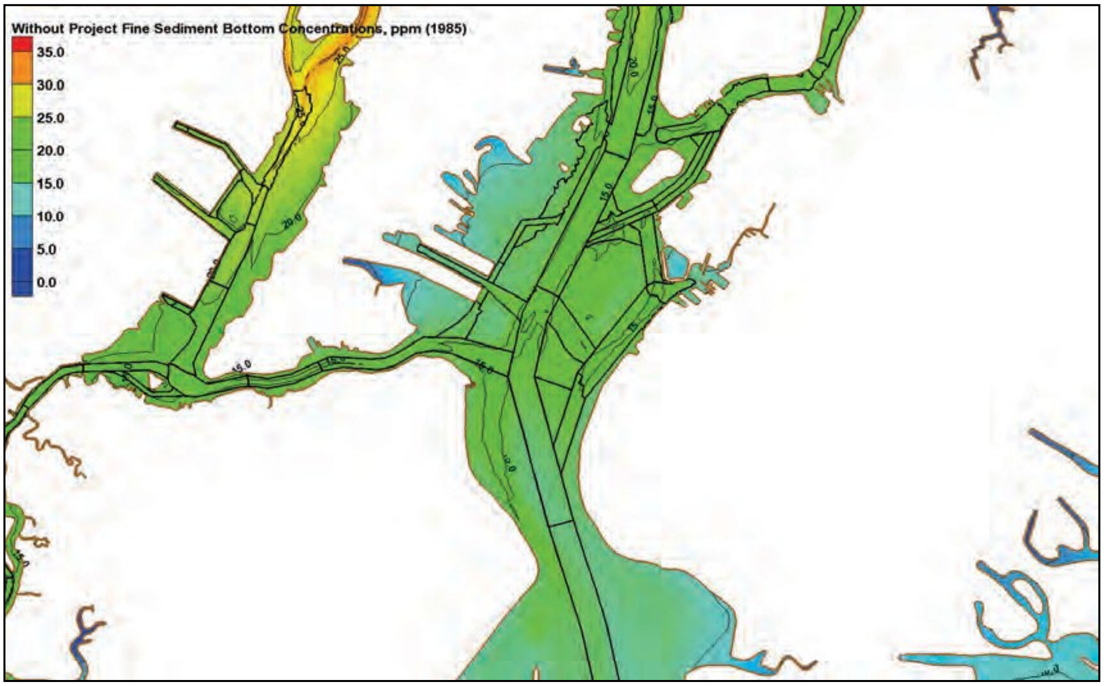


Figure 269. Without-project (top) and with-project (bottom) average fine sediment bottom concentrations, ppm (1985).



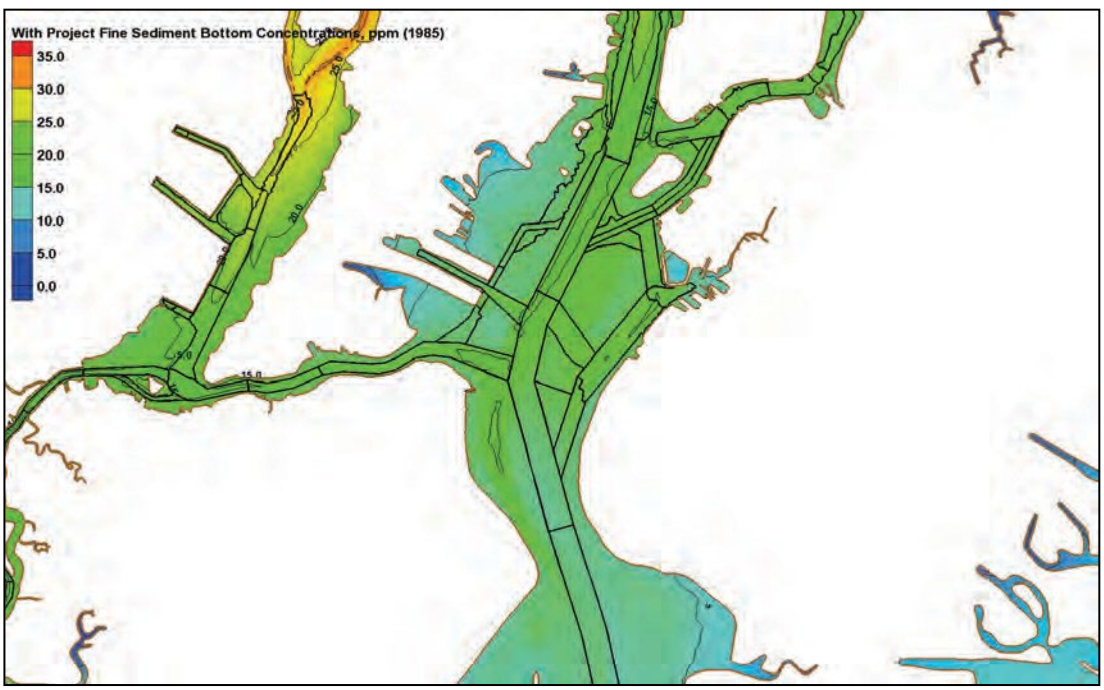
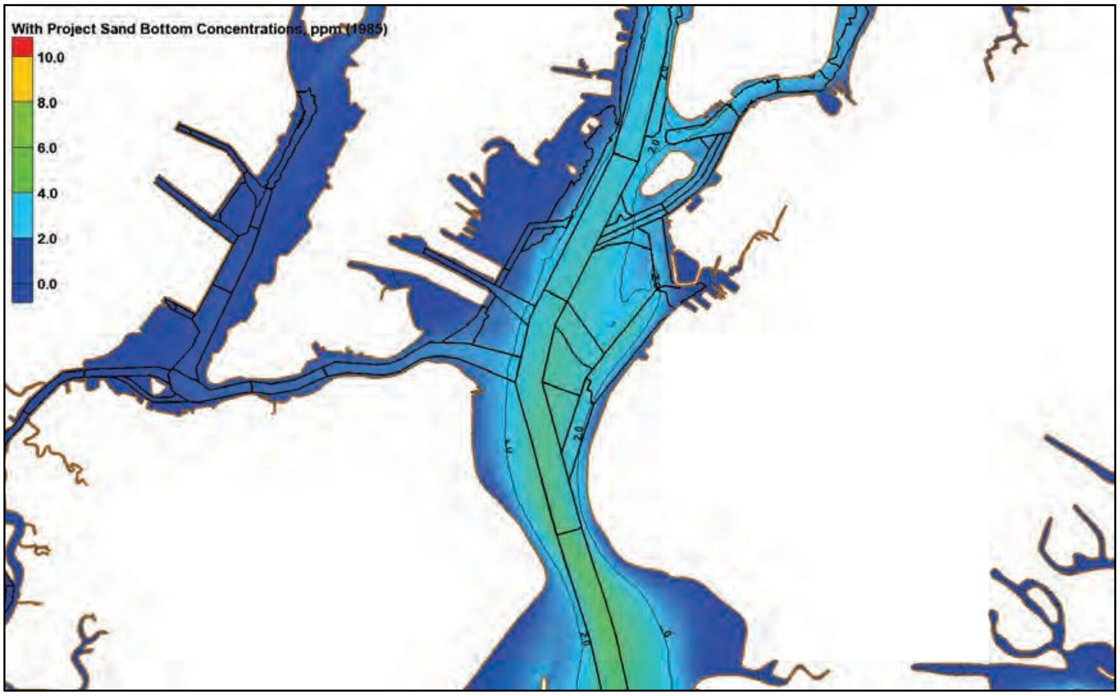


Figure 270. Without-project (top) and with-project (bottom) average sand bottom concentrations, ppm (1985).



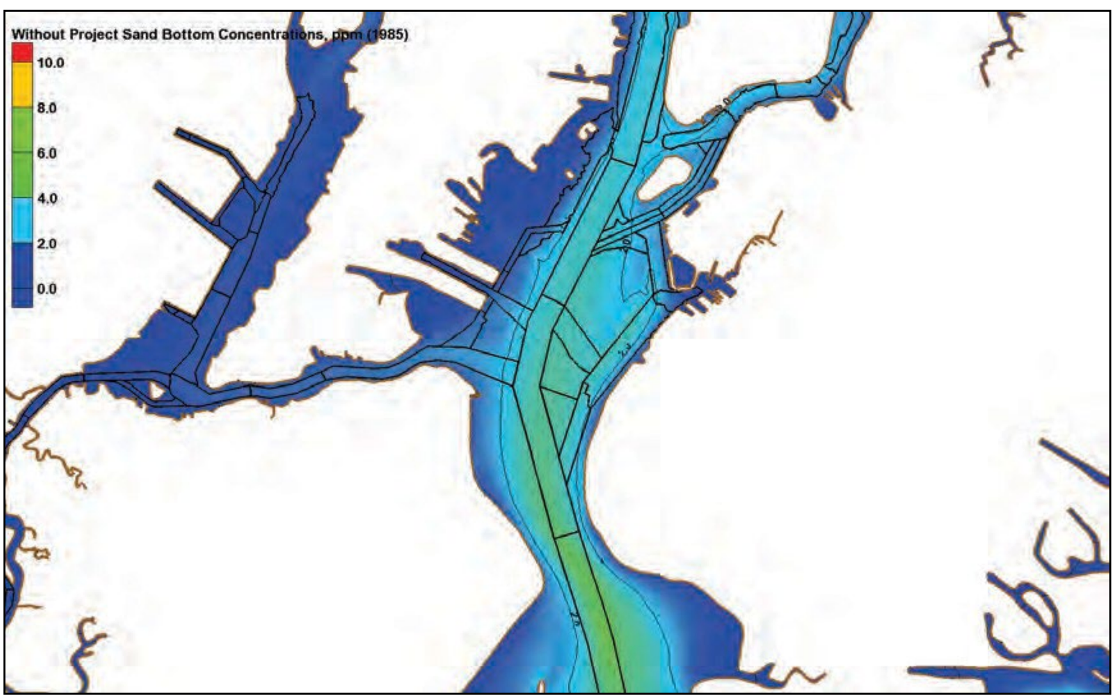
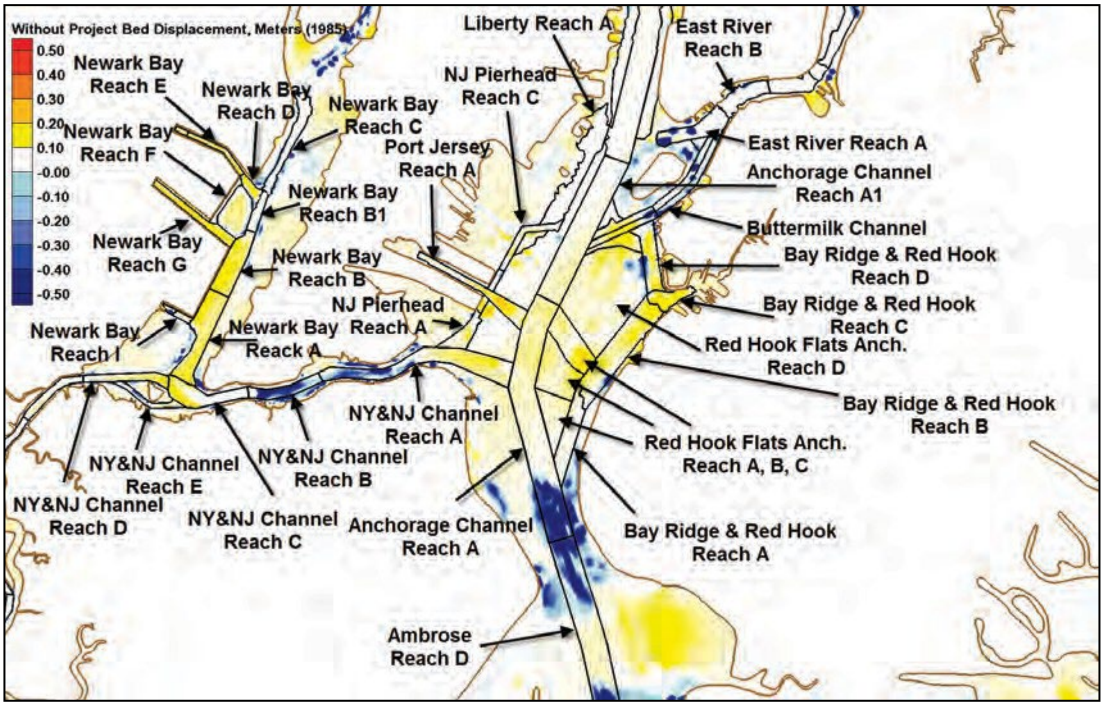


Figure 271. Without-project (top) and with-project (bottom) bed displacement, m (1985).



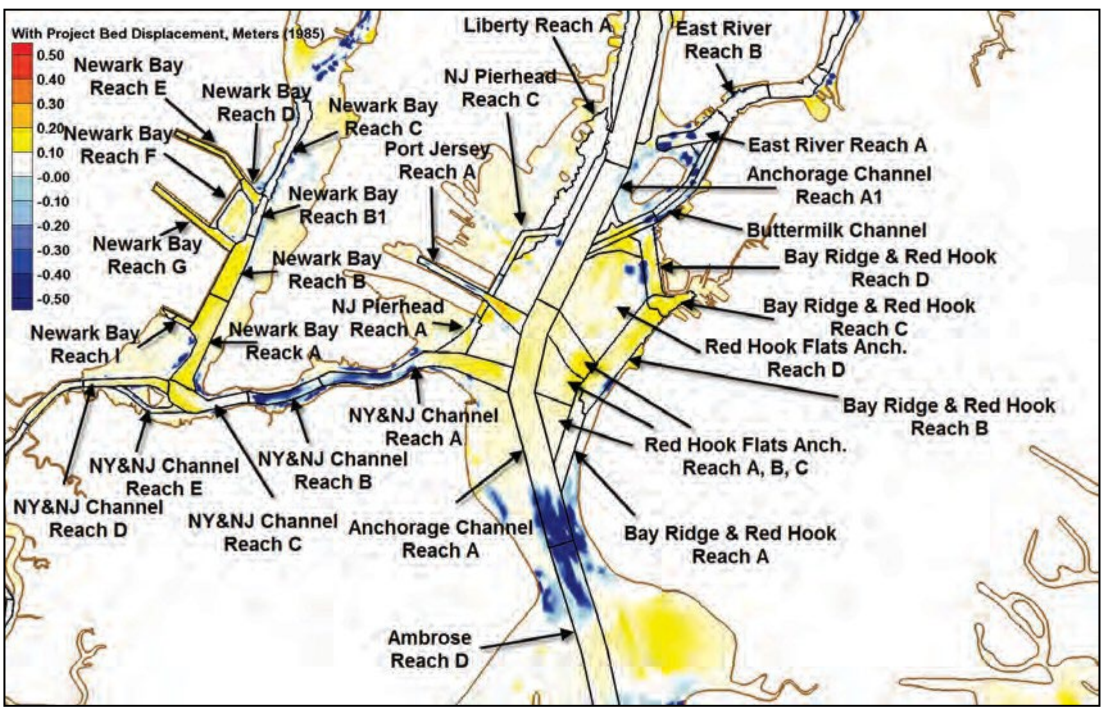


Figure 272. Without-project (top) and with-project (bottom) fine sediment accumulation, kg/m² (1985).

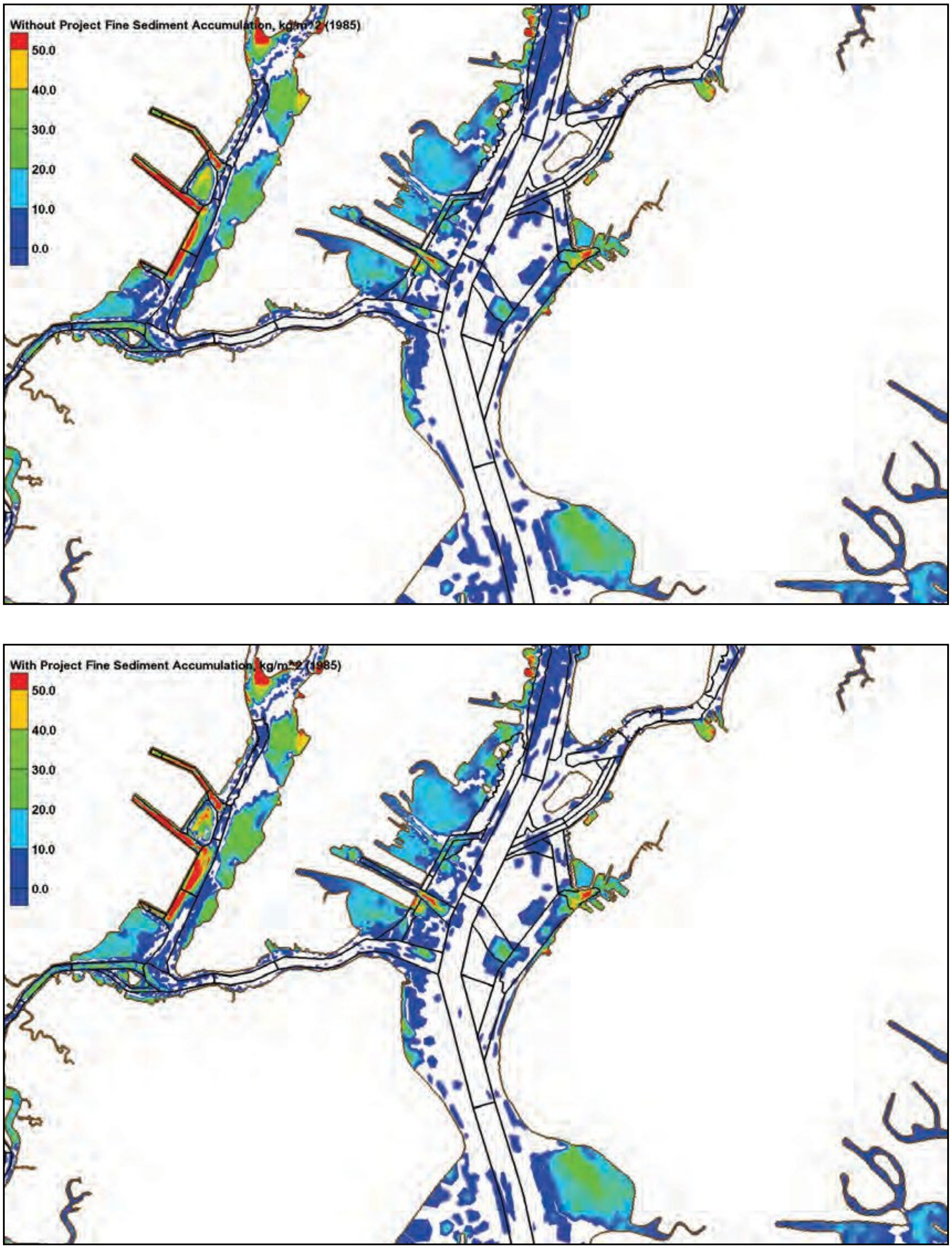
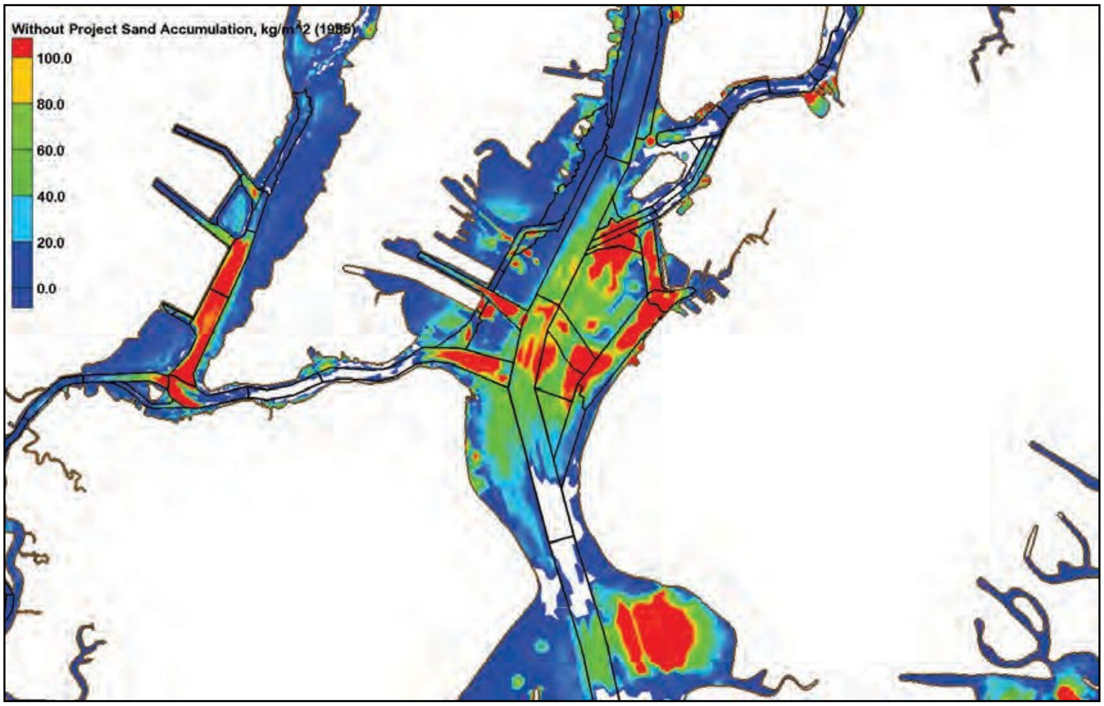


Figure 273. Without-project (top) and with-project (bottom) sand accumulation, kg/m^2 (1985).



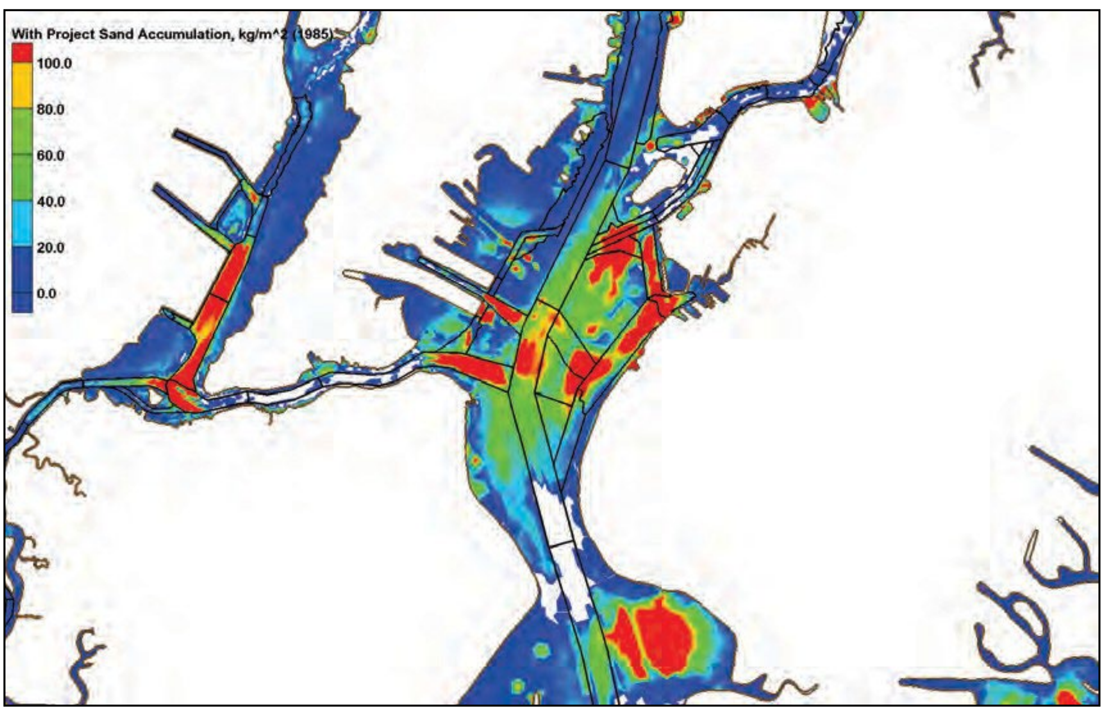


Figure 274. Dredge with-project/without-project percent differences (1985).

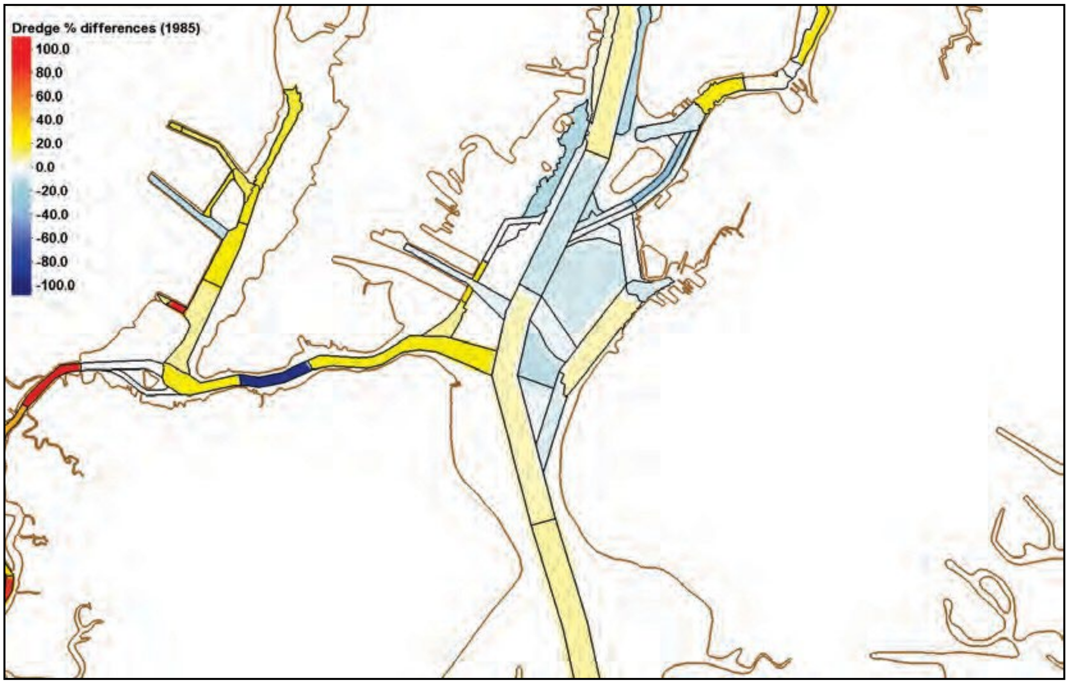


Table 29. Dredge Volumes for Newark Bay, Kill van Kull, and Upper Bay (1985).

Depositional Volumes in Newark Bay, Kill van Kull, and Upper Bay, cy (1985)			
Reach	Without Project	With Project	With/Without Dredge Percentage
Newark Bay			
Newark Bay Reach A	83,633	90,229	108
Newark Bay Reach B	63,839	76,130	119
Newark Bay Reach B1	1,298	1,606	124
Newark Bay Reach C	1,741	2,012	116
Newark Bay Reach D	11,322	12,840	113
Newark Bay Reach E	15,131	16,915	112
Newark Bay Reach E1	2,152	2,461	114
Newark Bay Reach F	2,107	2,558	121
Newark Bay Reach G	46,599	40,565	87
Newark Bay Reach I	1,727	3,731	216
Newark Bay Reach I1	1,573	1,741	108
Kill van Kull			
NY&NJ Channels Reach A	57,569	68,980	120
NY&NJ Channels Reach B	112	6	5
NY&NJ Channels Reach C	29,663	36,588	123
Upper Bay			
Anchorage Channel Reach A	84,791	89,554	106
Anchorage Channel Reach A1	39,864	35,324	89
Anchorage Reach C1	5,777	5,725	99
Bay Ridge & Red Hook Reach A	9,670	8,908	92
Bay Ridge & Red Hook Reach B	96,808	102,447	106
Bay Ridge & Red Hook Reach C	38,422	35,095	91
Bay Ridge & Red Hook Reach D	40,052	39,790	99
Red Hook Flats Anch. Reach A	17,103	16,515	97
Red Hook Flats Anch. Reach B	48,438	41,589	86
Red Hook Flats Anch. Reach C	59,992	57,640	96
Red Hook Flats Anch. Reach D	106,452	95,808	90
Port Jersey Reach A	42,073	39,577	94
NJ Pierhead Ch. Reach A	10,531	11,387	108
NJ Pierhead Ch. Reach B	5,832	6,993	120
NJ Pierhead Reach C	7,481	7,508	100
Liberty Reach A	4,327	3,600	83

Arthur Kill and Raritan Bay results

Figure 275. Without-project (top) and with-project (bottom) average shear stresses, Pa (1985).

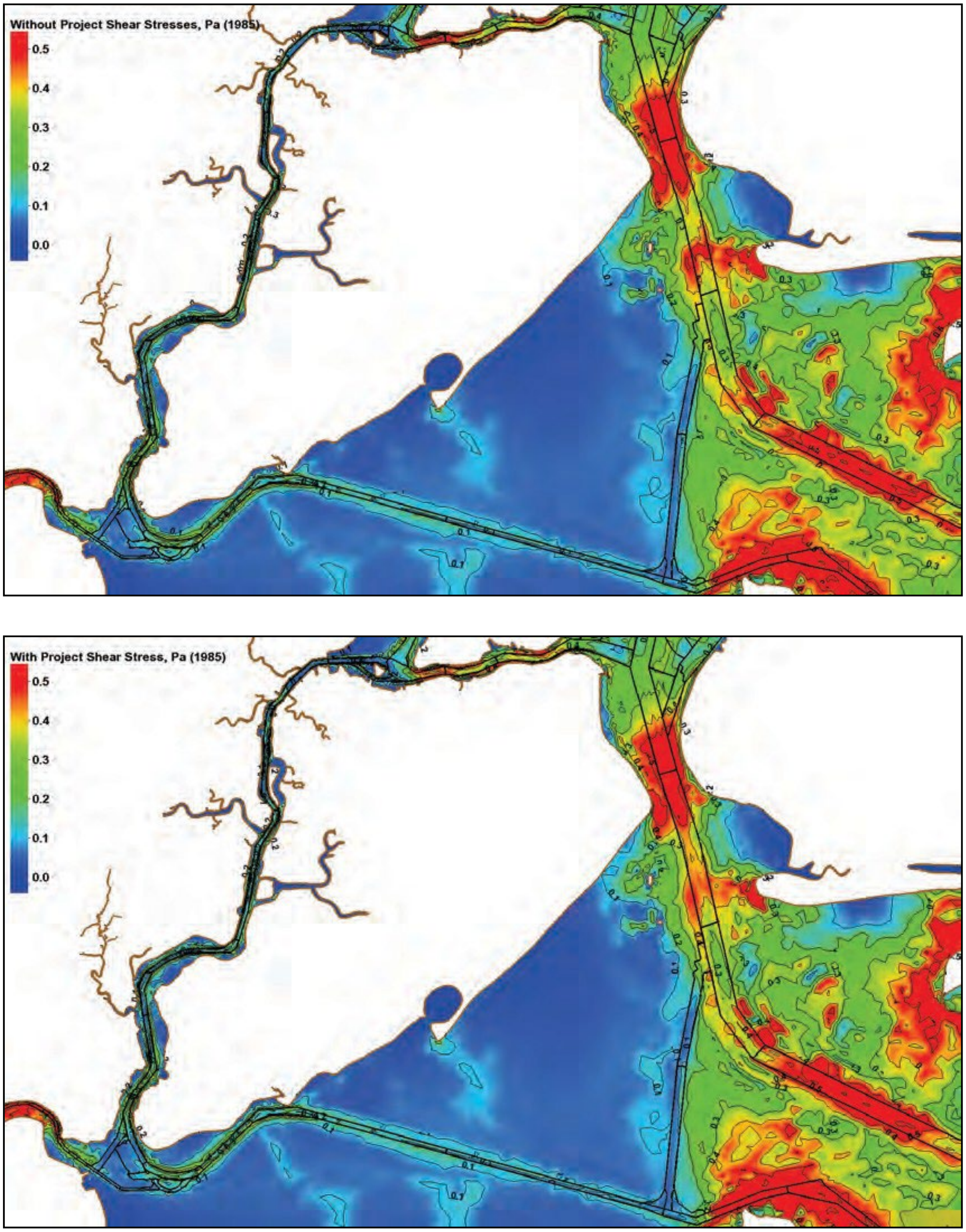


Figure 276. Without-project (top) and with-project (bottom) average bottom salinity, ppt (1985).

Figure 277. Without-project (top) and with-project (bottom) average fine sediment bottom concentrations, ppm (1985).

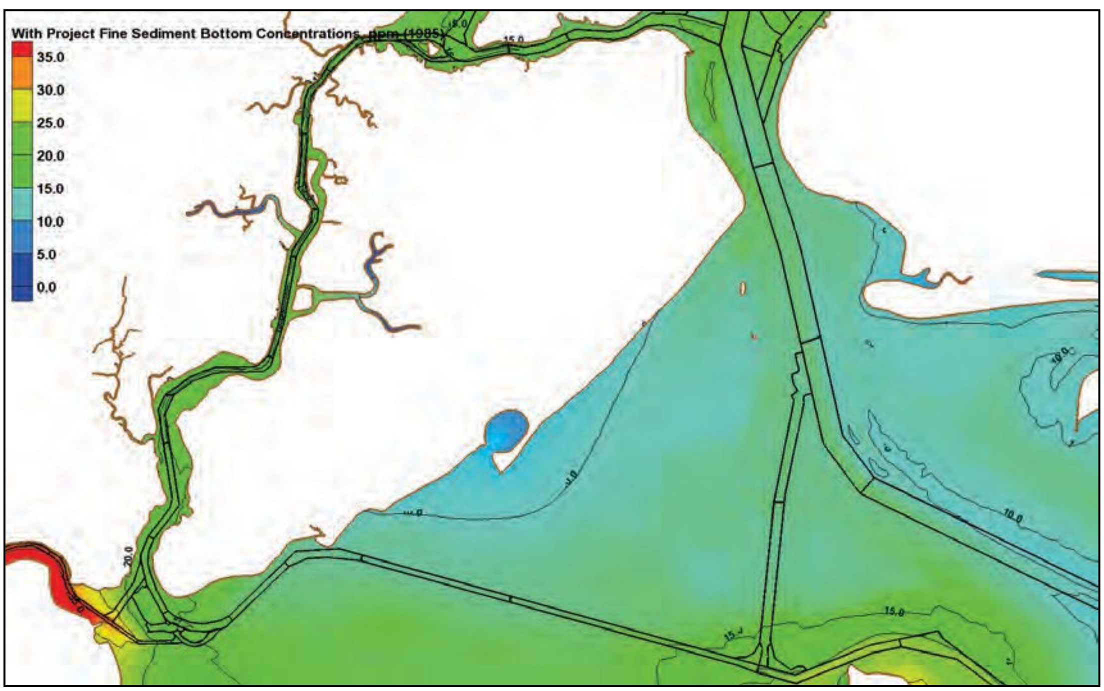
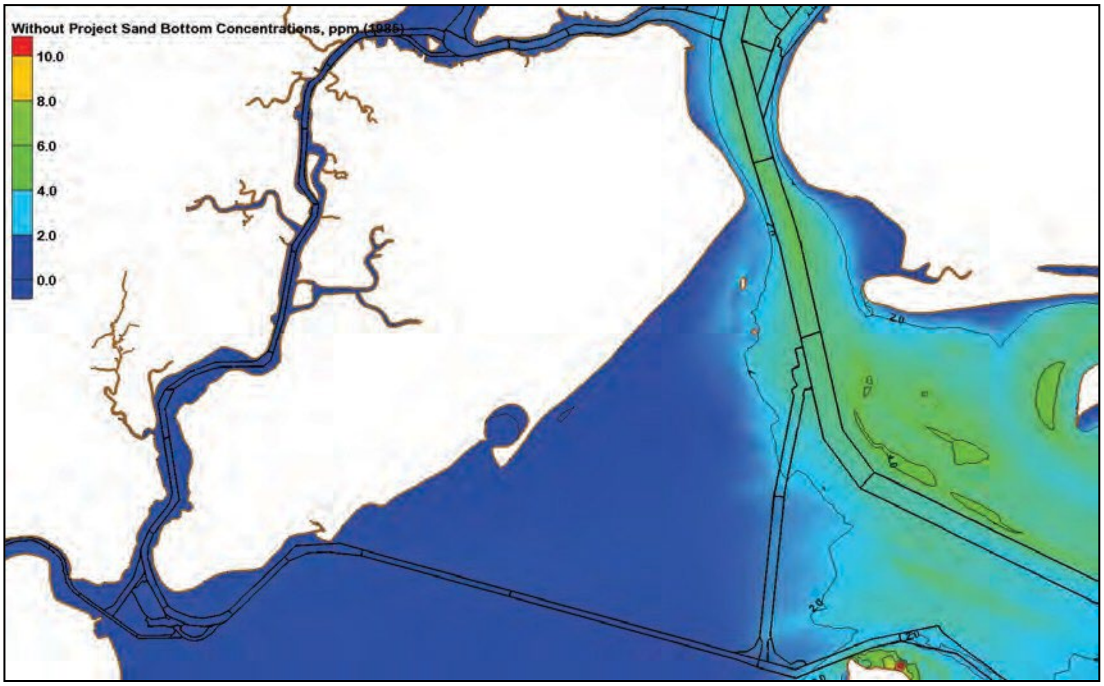


Figure 278. Without-project (top) and with-project (bottom) average sand bottom concentrations, ppm (1985).



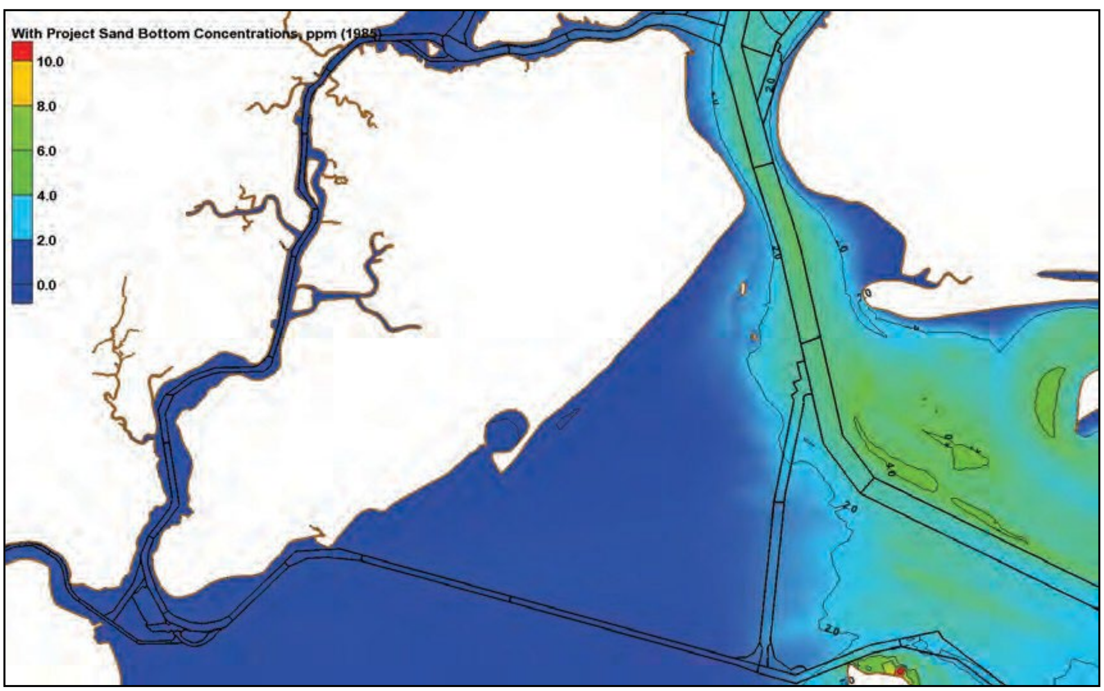


Figure 279. Without-project (top) and with-project (bottom) bed displacement, m (1985).

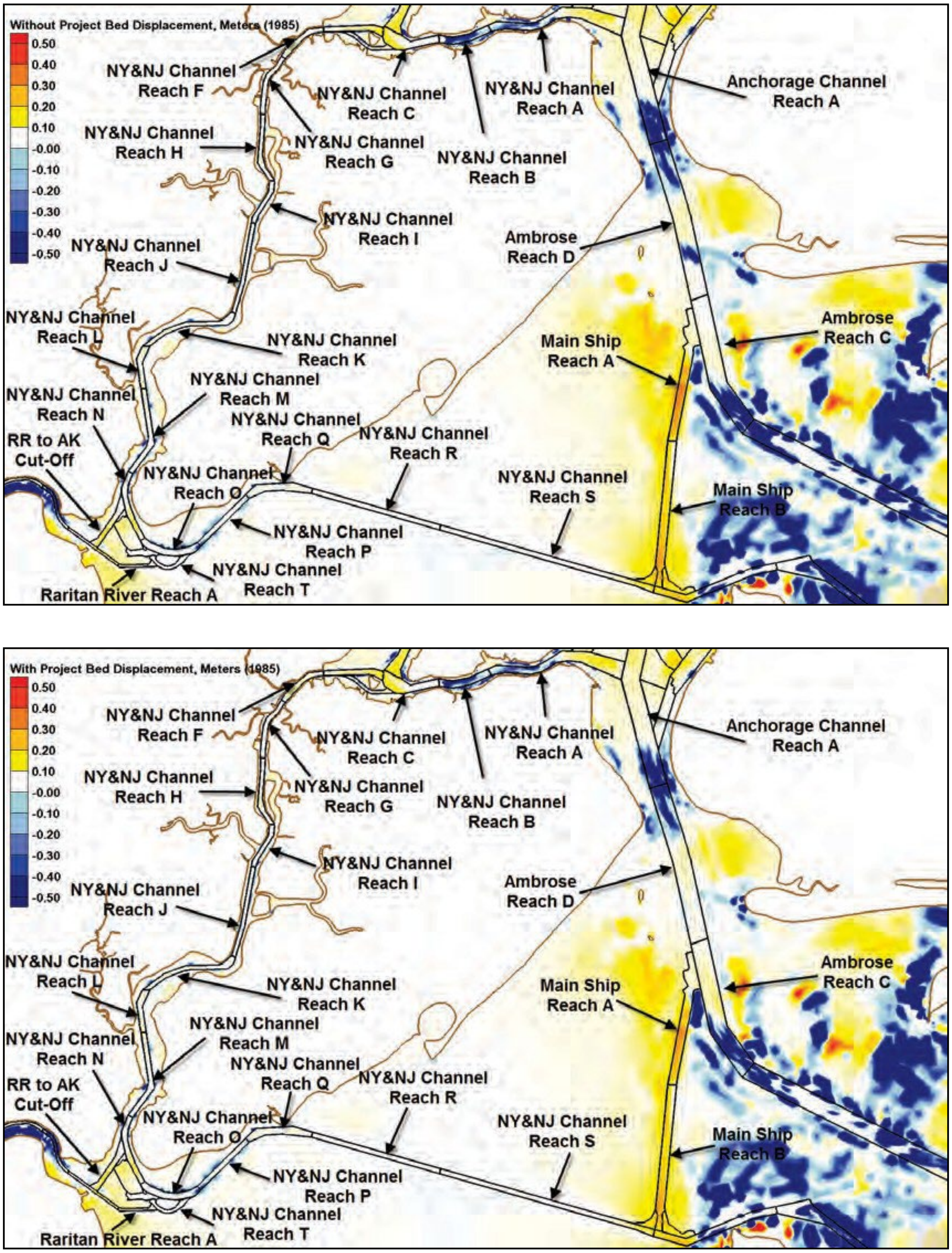
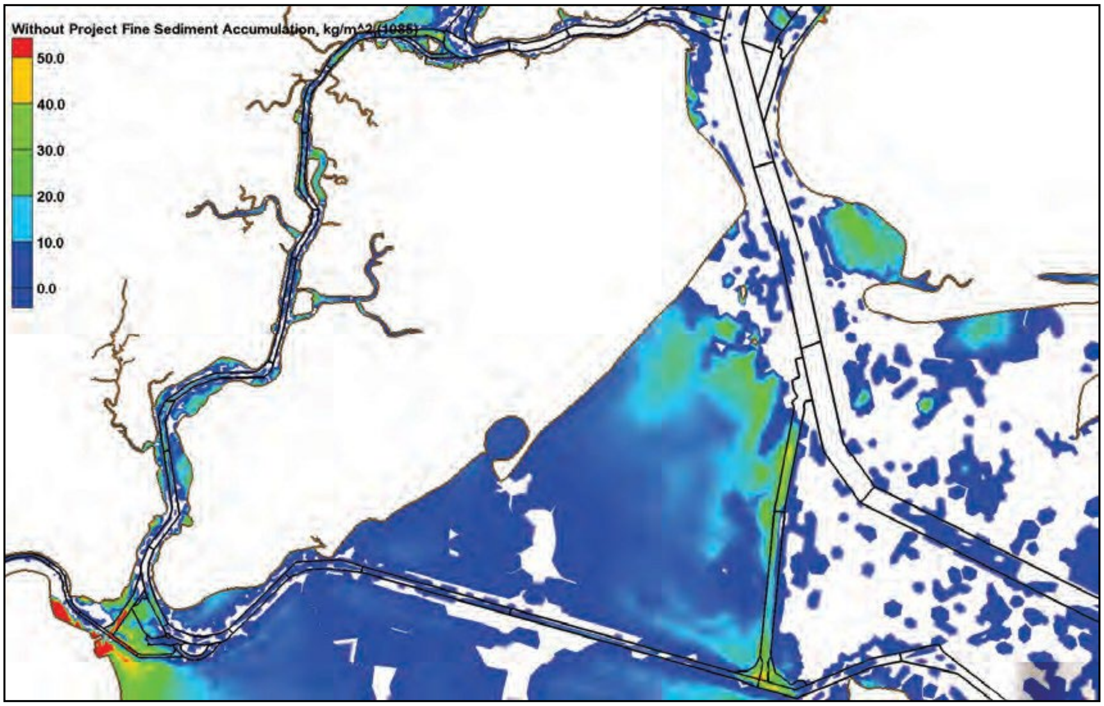


Figure 280. Without-project (top) and with-project (bottom) fine sediment accumulation, kg/m² (1985).



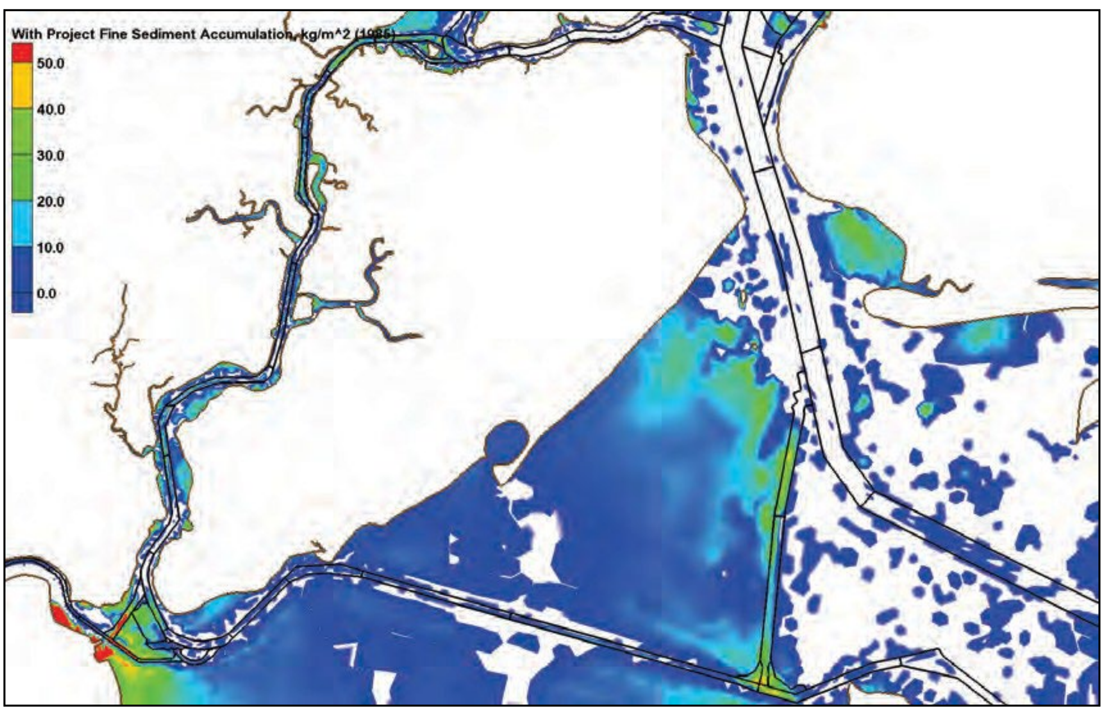
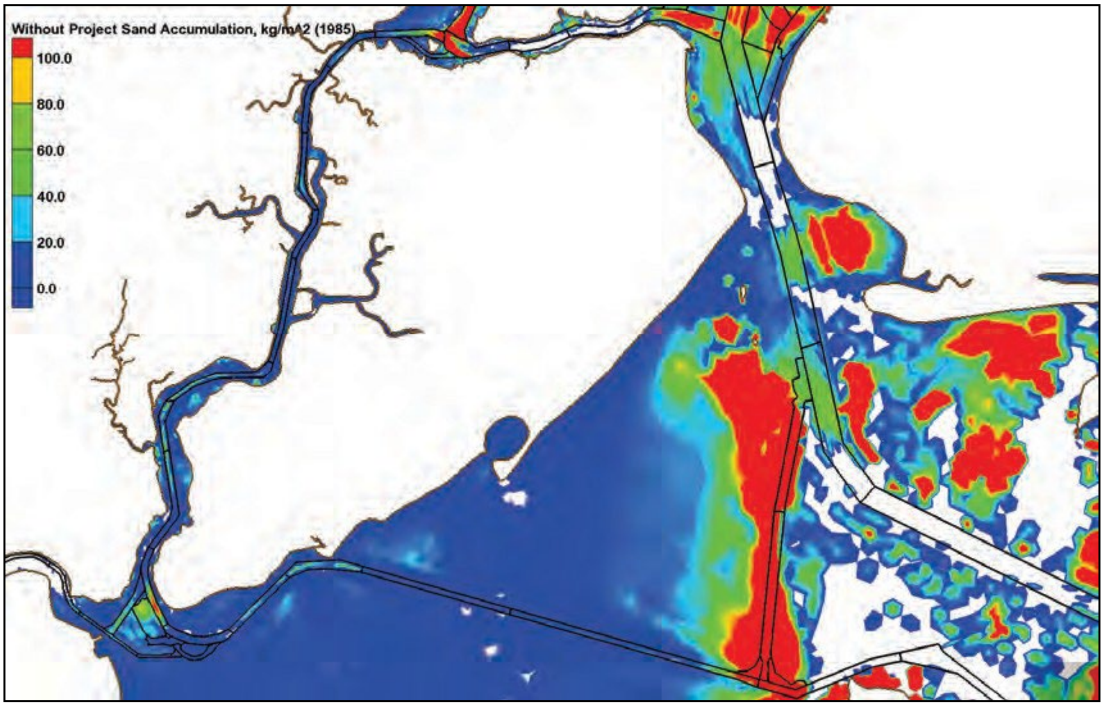


Figure 281. Without-project (top) and with-project (bottom) sand accumulation, kg/m^2 (1985).



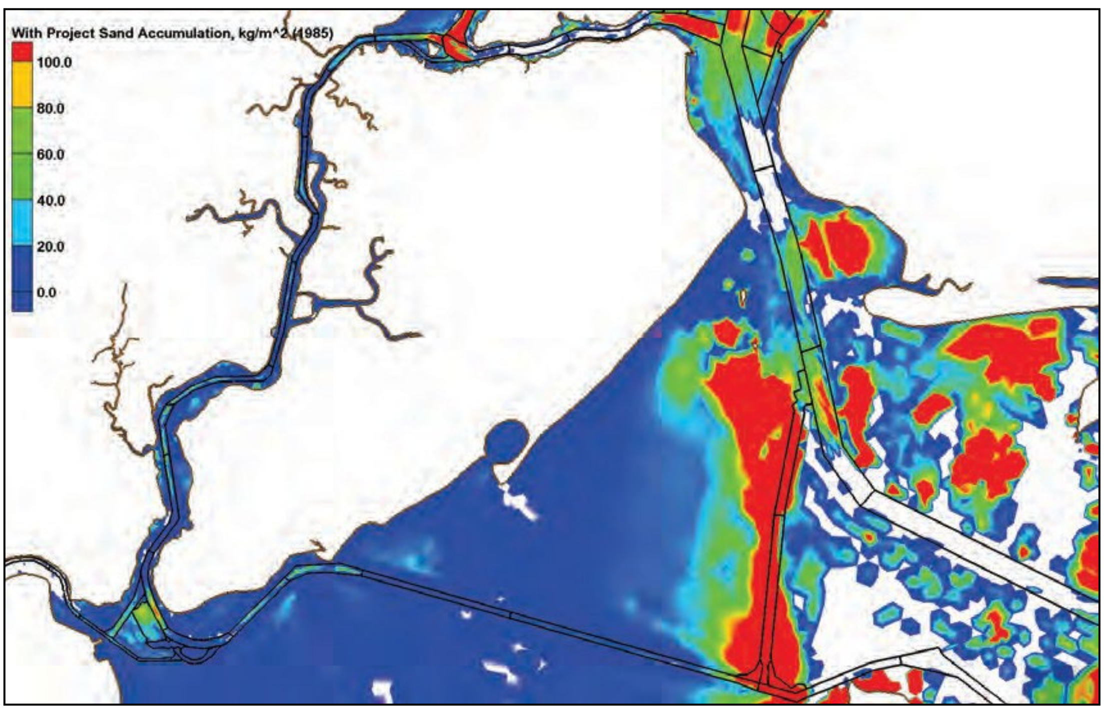


Figure 282. Dredge with-project/without-project percent differences (1985).

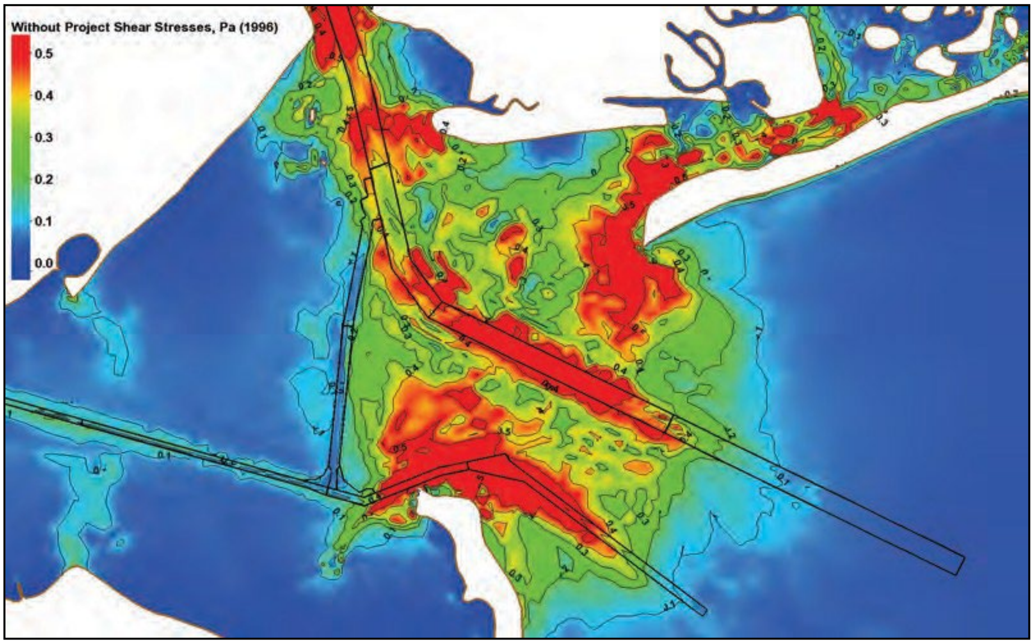
Table 30. Dredge Volumes for Arthur Kill (1985).

Depositional Volumes in Arthur Kill and Raritan Bay, cy (1985)			
Reach	Without Project	With Project	With/Without Dredge Percentage
Arthur Kill			
NY&NJ Channels Reach D	18,194	17,866	98
NY&NJ Channels Reach E	2,933	2,953	101
NY&NJ Channels Reach F	3,254	6,357	195
NY&NJ Channels Reach G	575	836	145
NY&NJ Channels Reach H	2,092	2,759	132
NY&NJ Channels Reach I	95	170	179
NY&NJ Channels Reach J	176	856	487
NY&NJ Channels Reach K	3,626	4,004	110
NY&NJ Channels Reach L	4,157	4,098	99
NY&NJ Channels Reach M	2,936	2,796	95
NY&NJ Channels Reach N	11,151	10,378	93
Raritan Bay			
NY&NJ Channels Reach O	975	1,411	145
NY&NJ Channels Reach P	1,918	2,419	126
NY&NJ Channels Reach Q	4,468	4,747	106
NY&NJ Channels Reach R	1,137	1,134	100
NY&NJ Channels Reach T	336	386	115
RR to AK Cut-Off Reach A	14,154	15,191	107
Raritan River Reach A	2,808	2,973	106
Raritan River Reach B	8,227	8,201	100
Raritan River Reach C	622	618	99
Raritan River Reach D	39	48	123

Appendix E: Results for 1996

Lower Bay results

Figure 283. Without-project (top) and with-project (bottom) average shear stresses, Pa (1996).



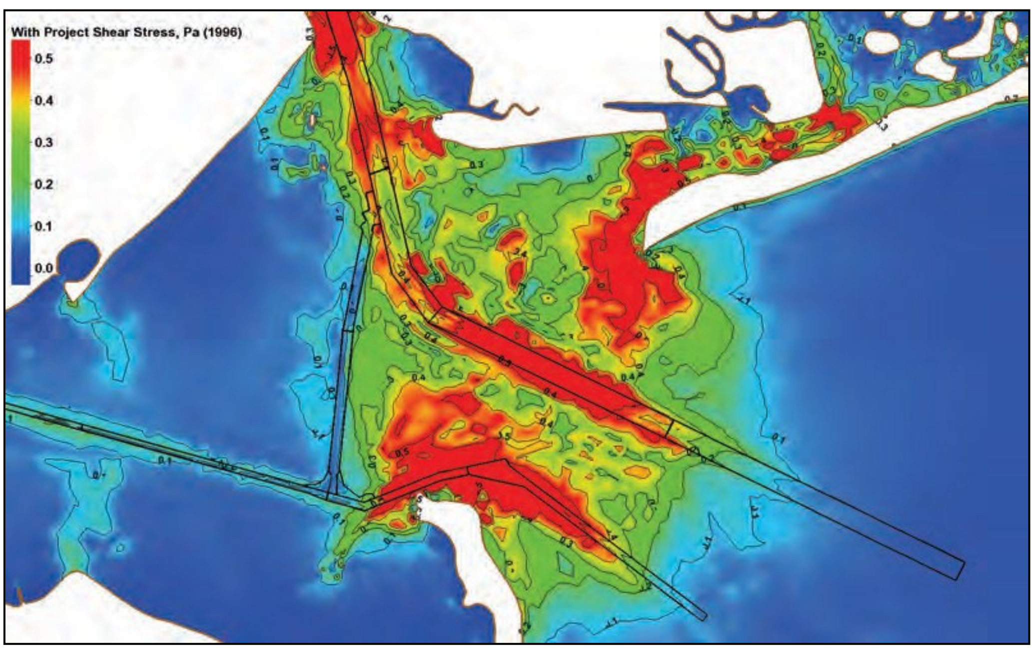
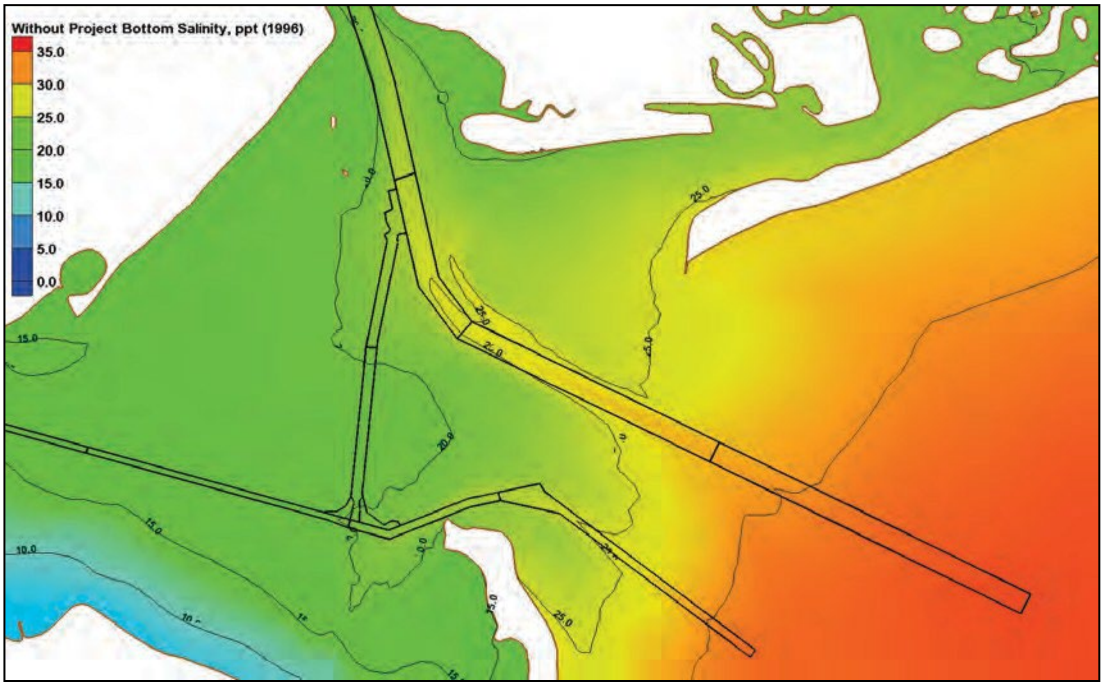


Figure 284. Without-project (top) and with-project (bottom) average bottom salinity, ppt (1996).



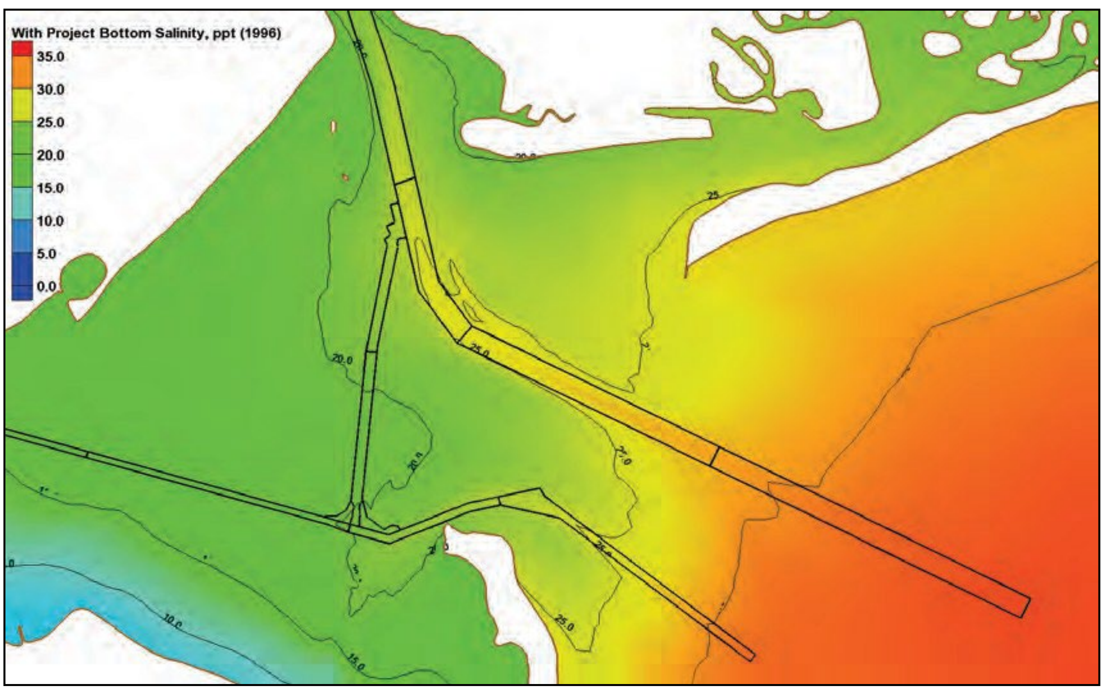
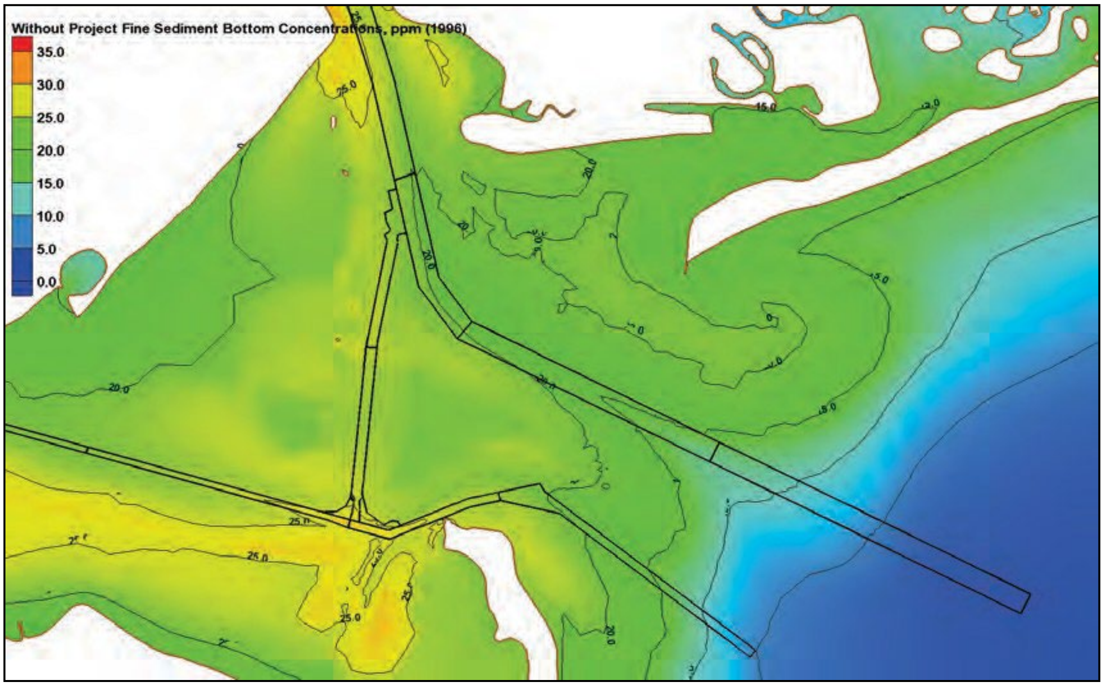


Figure 285. Without-project (top) and with-project (bottom) average fine sediment bottom concentrations, ppm (1996).



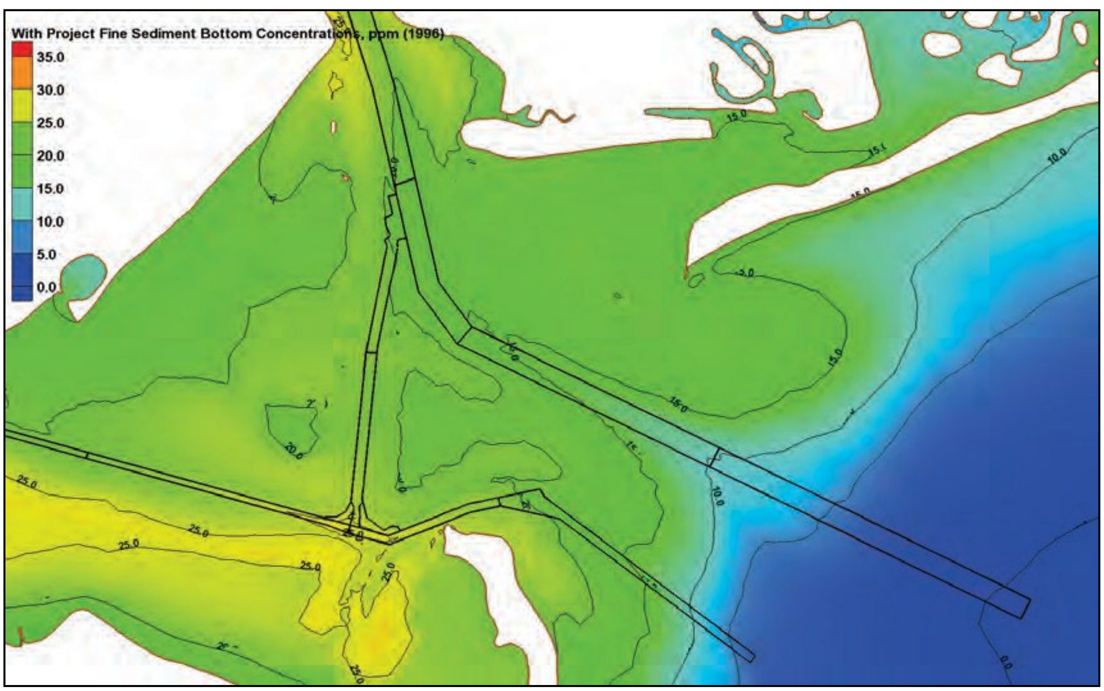


Figure 286. Without-project (top) and with-project (bottom) average sand bottom concentrations, ppm (1996).

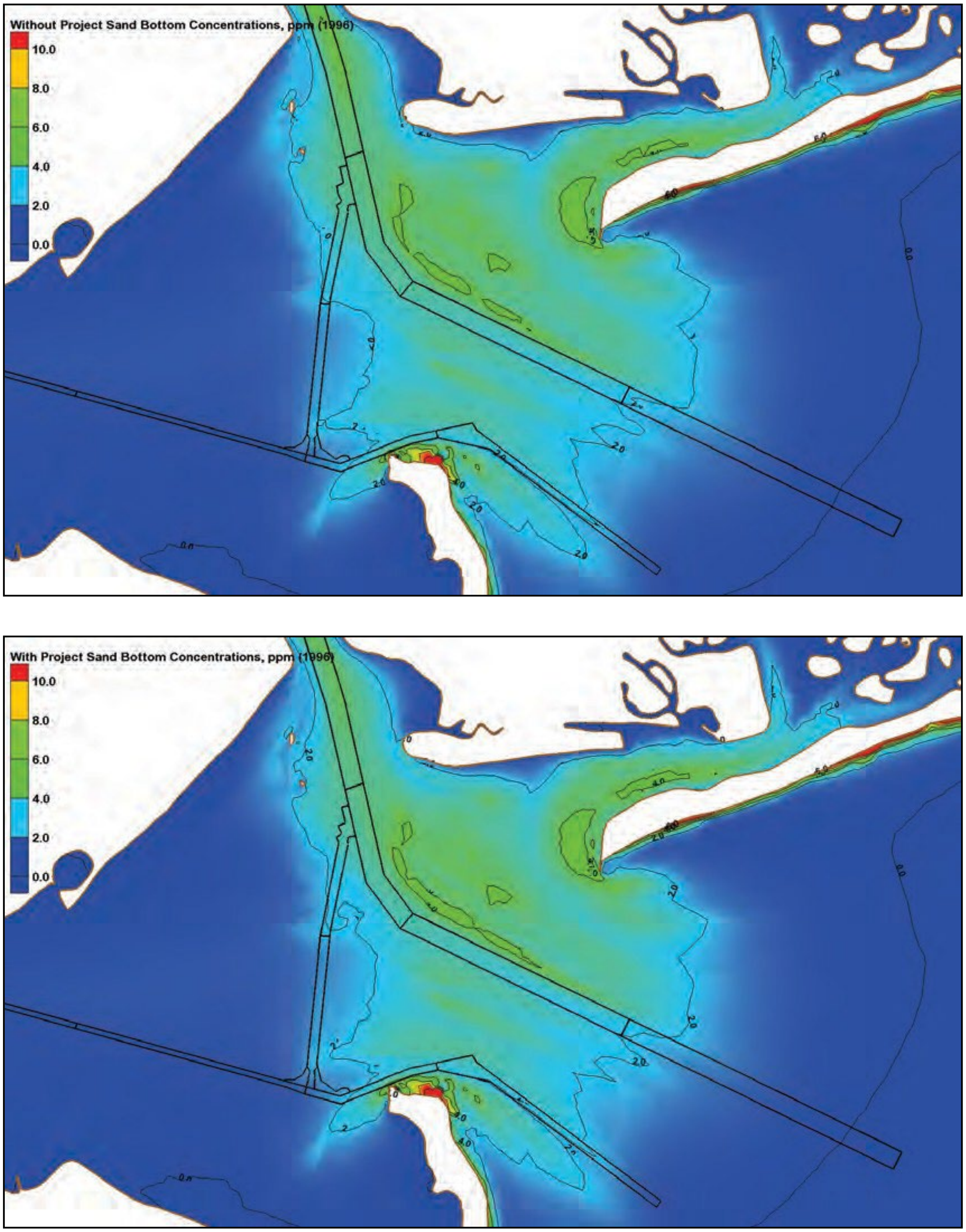


Figure 287. Without-project (top) and with-project (bottom) bed displacement, m (1996).

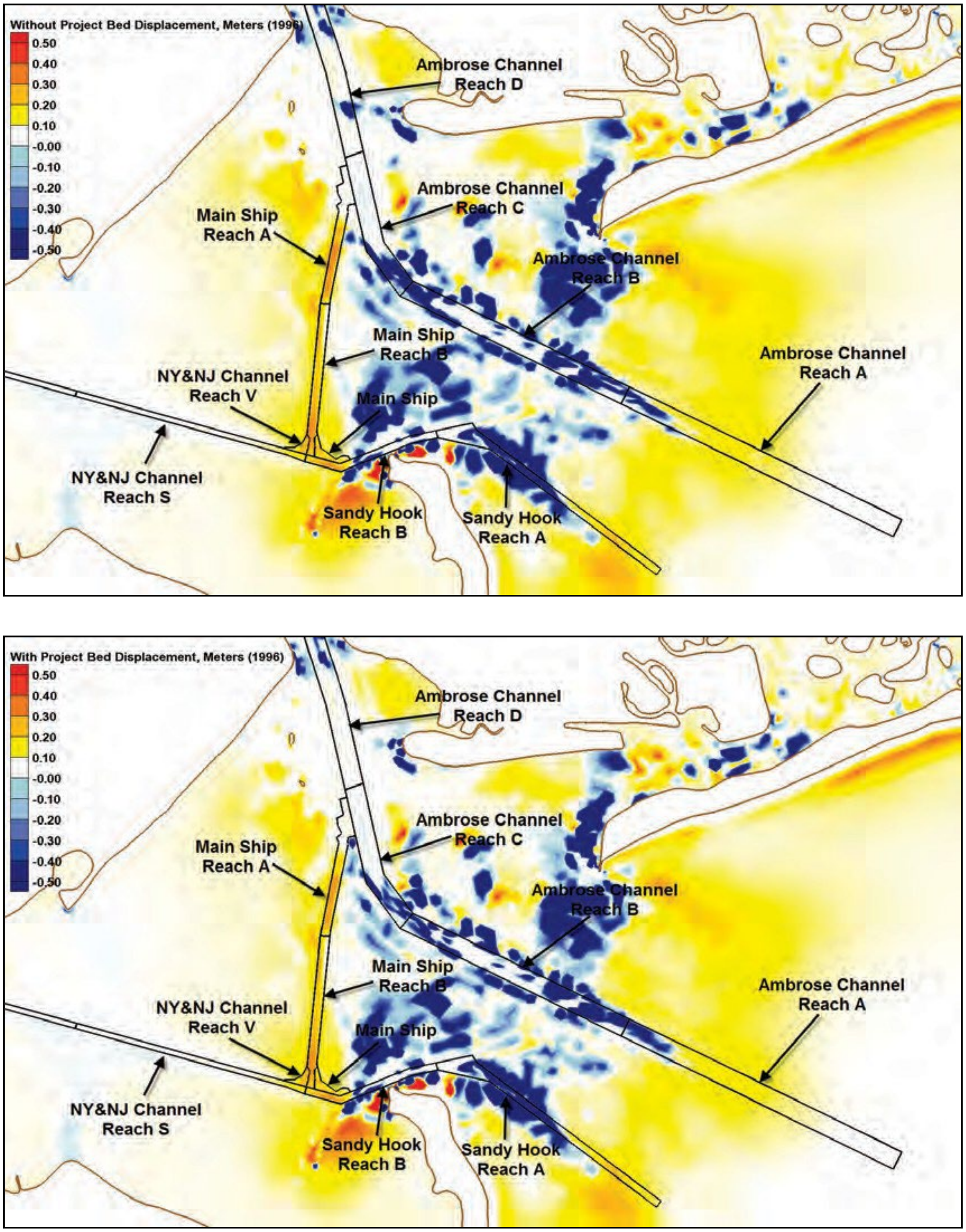
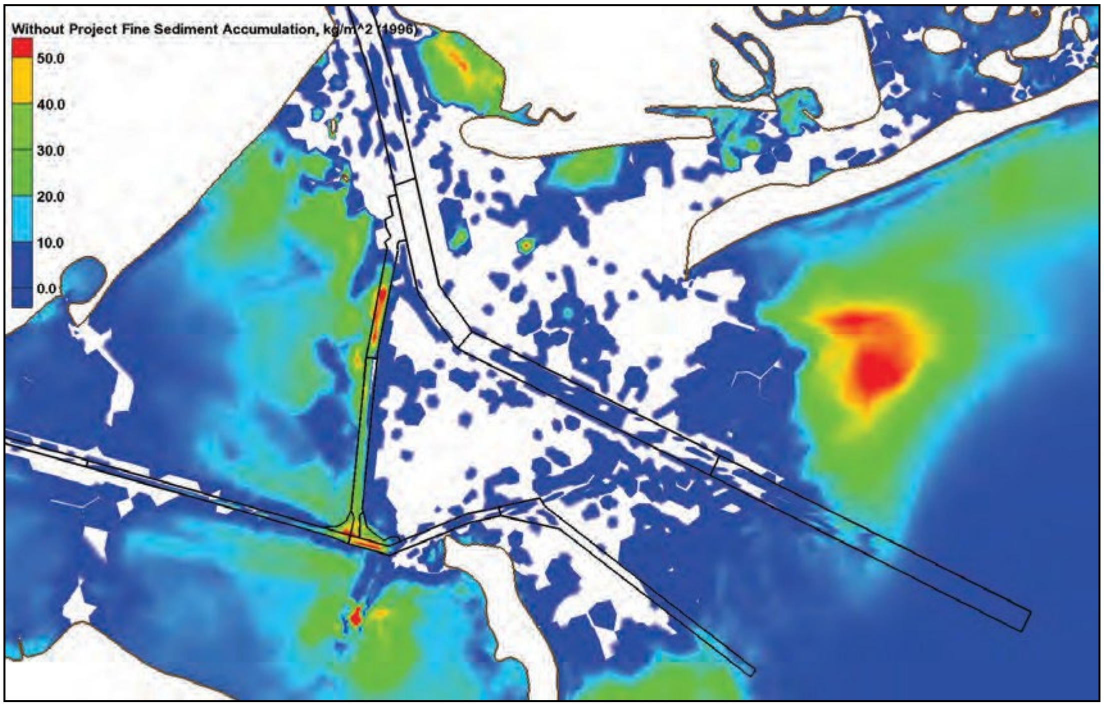


Figure 288. Without-project (top) and with-project (bottom) fine sediment accumulation, kg/m² (1996).



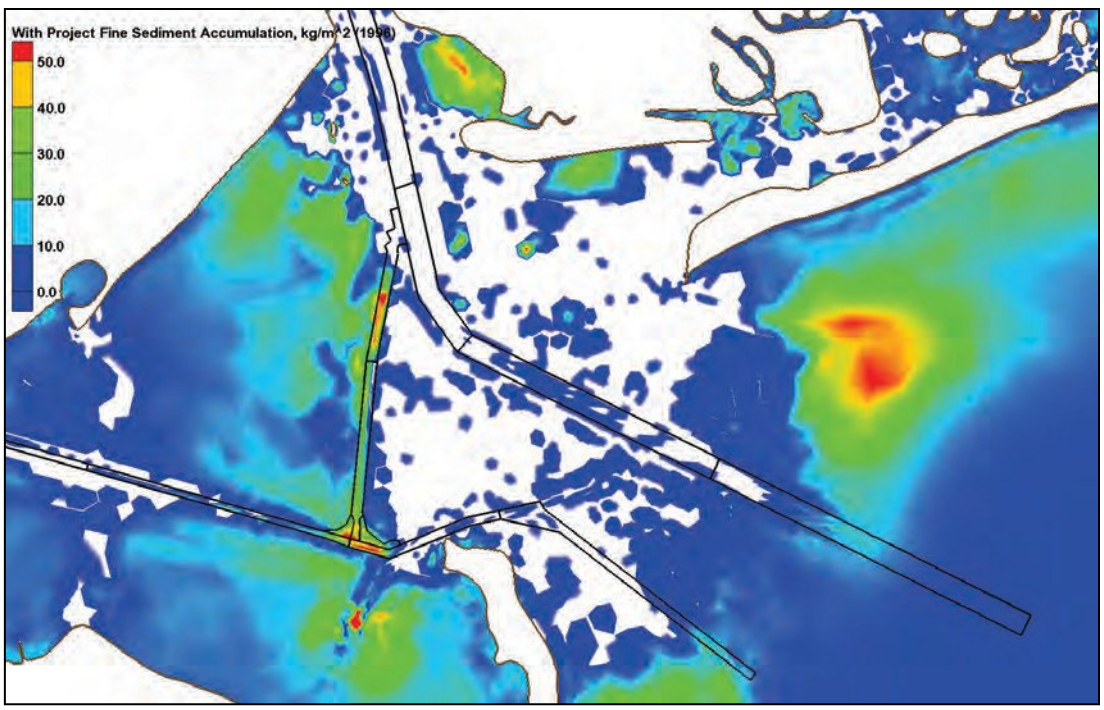
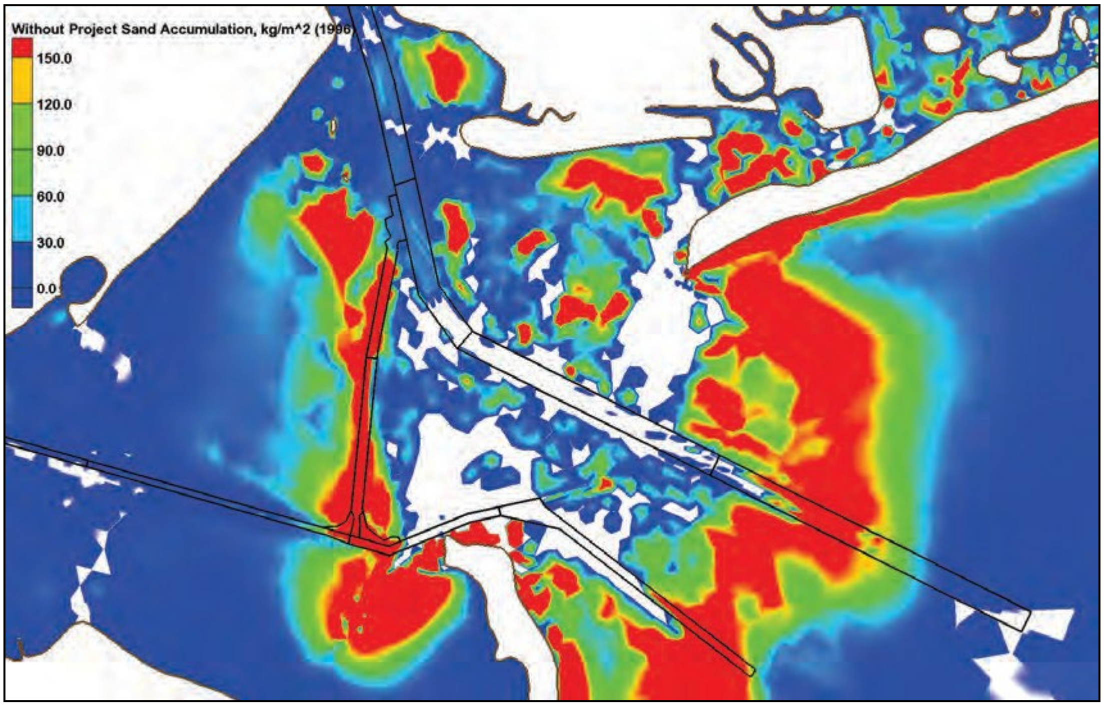


Figure 289. Without-project (top) and with-project (bottom) sand accumulation, kg/m^2 (1996).



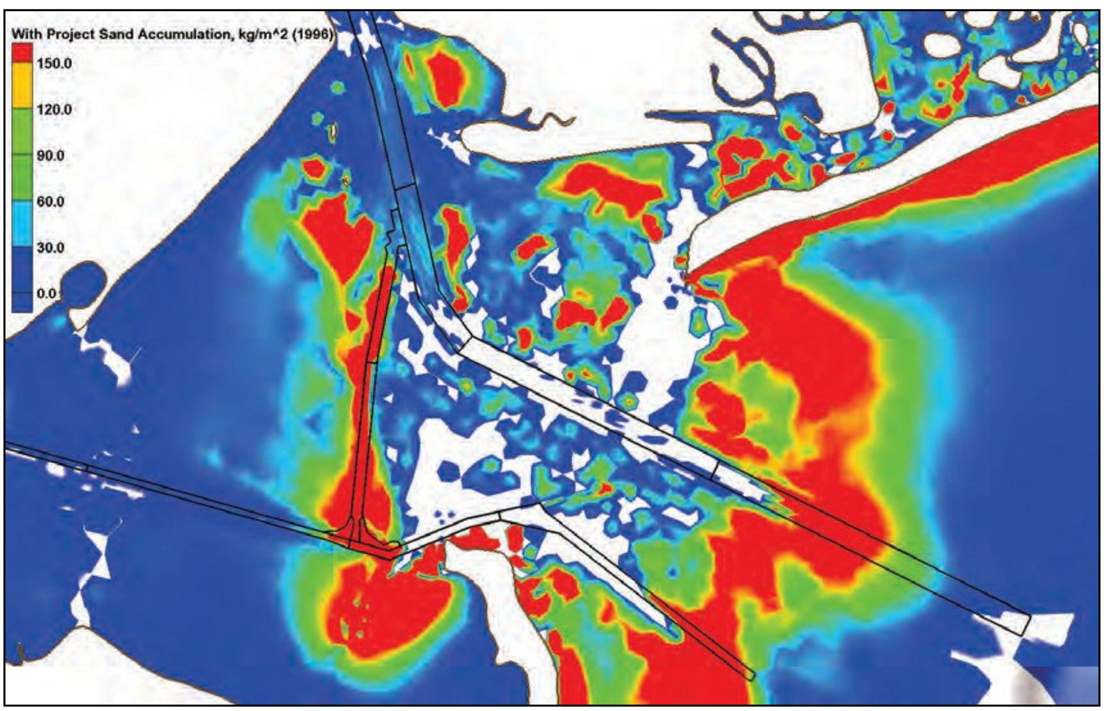


Figure 290. Dredge with-project/without-project percent differences (1996).

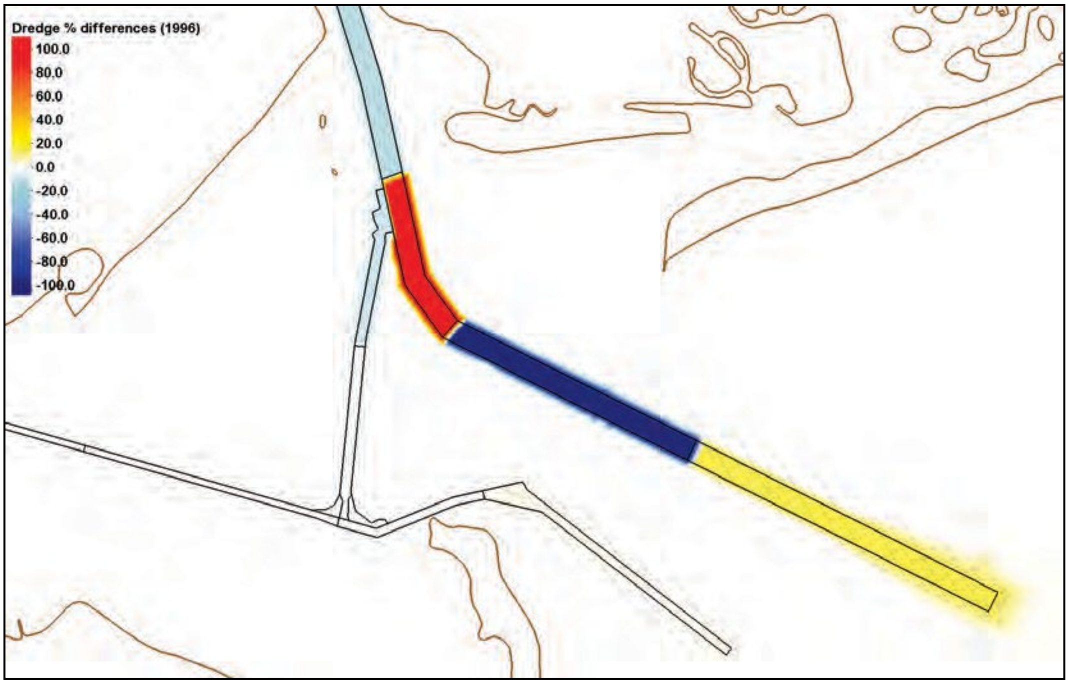
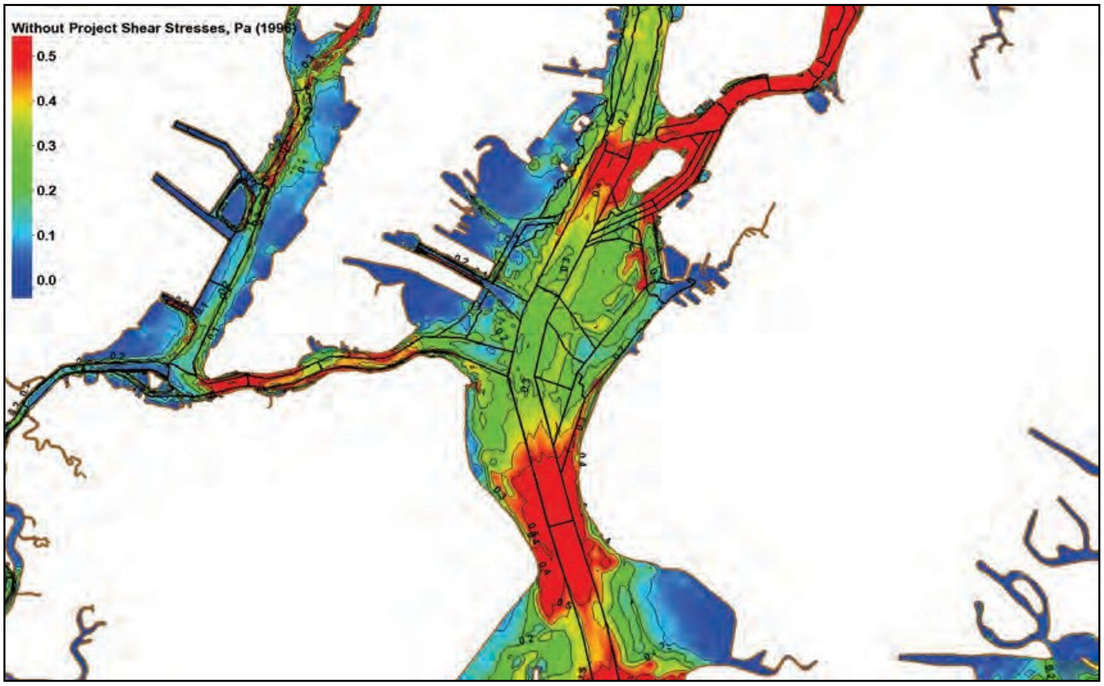


Table 31. Dredge volumes for Lower Bay (1996).

Depositional Volumes in Lower Bay, cy (1996)			
Reach	Without Project	With Project	With/Without Dredge Percentage
Ambrose Channel Reach A	302,560	344,359	114
Ambrose Channel Reach B	2,611	12	0
Ambrose Channel Reach C	4,012	8,774	219
Ambrose Channel Reach D	16,457	13,966	85
Main Ship	55,294	54,680	99
Main Ship Reach A	203,061	182,102	90
Main Ship Reach B	284,896	280,059	98
Sandy Hook Reach A	131,610	133,995	102
Sandy Hook Reach B	80,436	80,864	101
NY&NJ Channels Reach S	34,242	34,111	100
NY&NJ Channels Reach V	39,236	39,121	100

Newark Bay, Kill van Kull, and Upper Bay results

Figure 291. Without-project (top) and with-project (bottom) average shear stresses, Pa (1996).



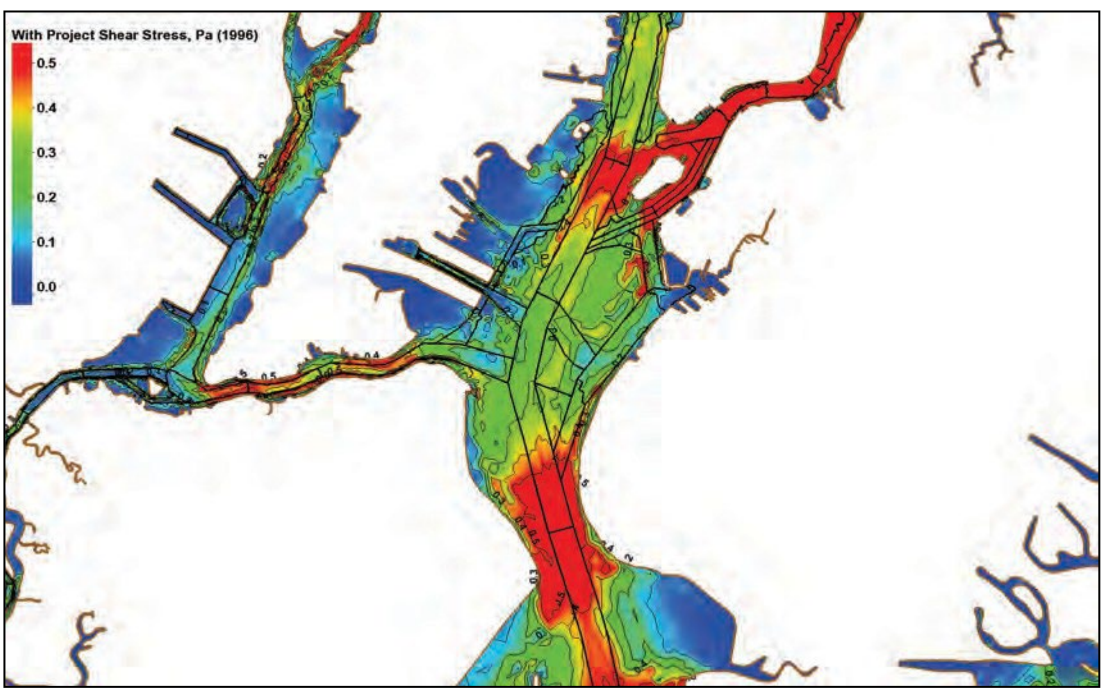
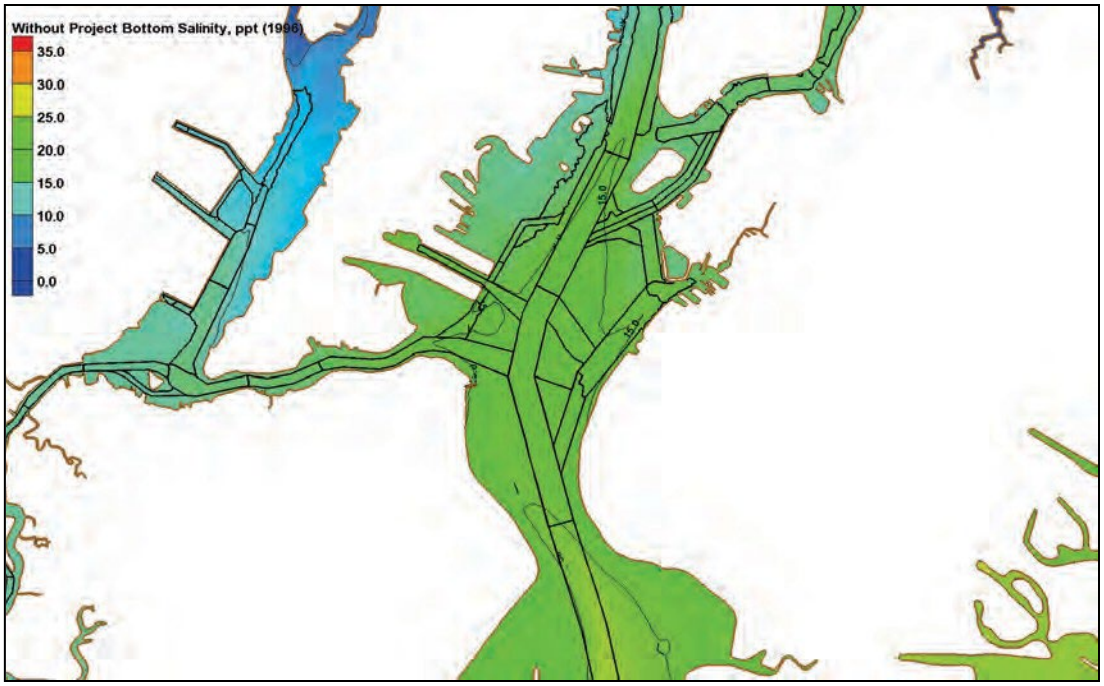


Figure 292. Without-project (top) and with-project (bottom) average bottom salinity, ppt (1996).



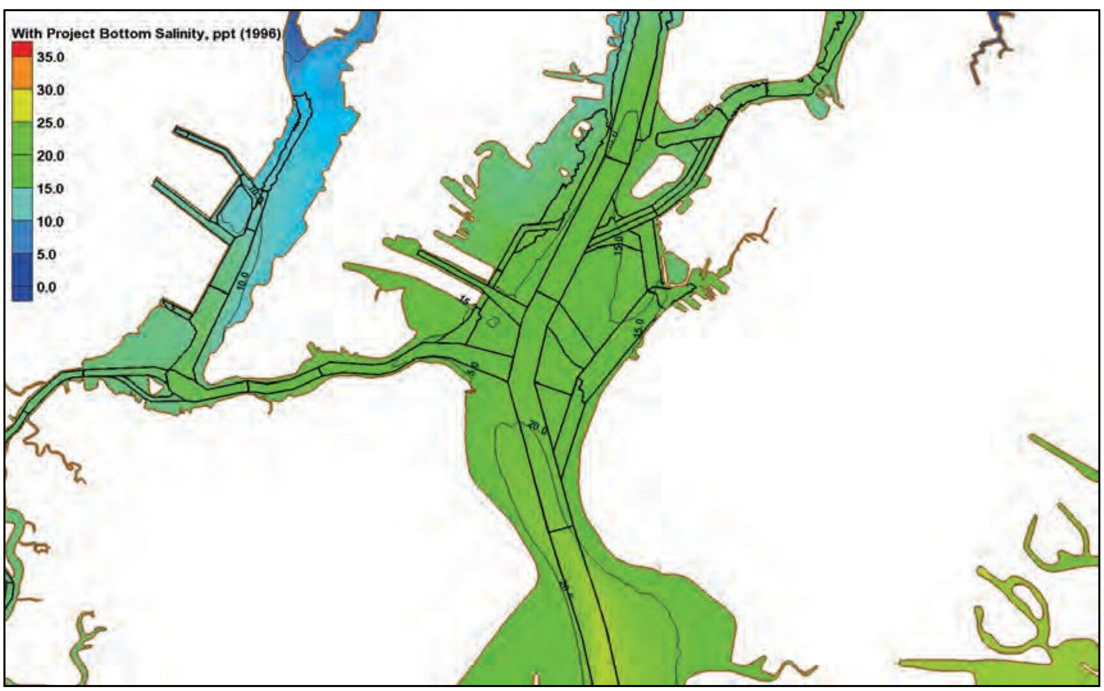


Figure 293. Without-project (top) and with-project (bottom) average fine sediment bottom concentrations, ppm (1996).

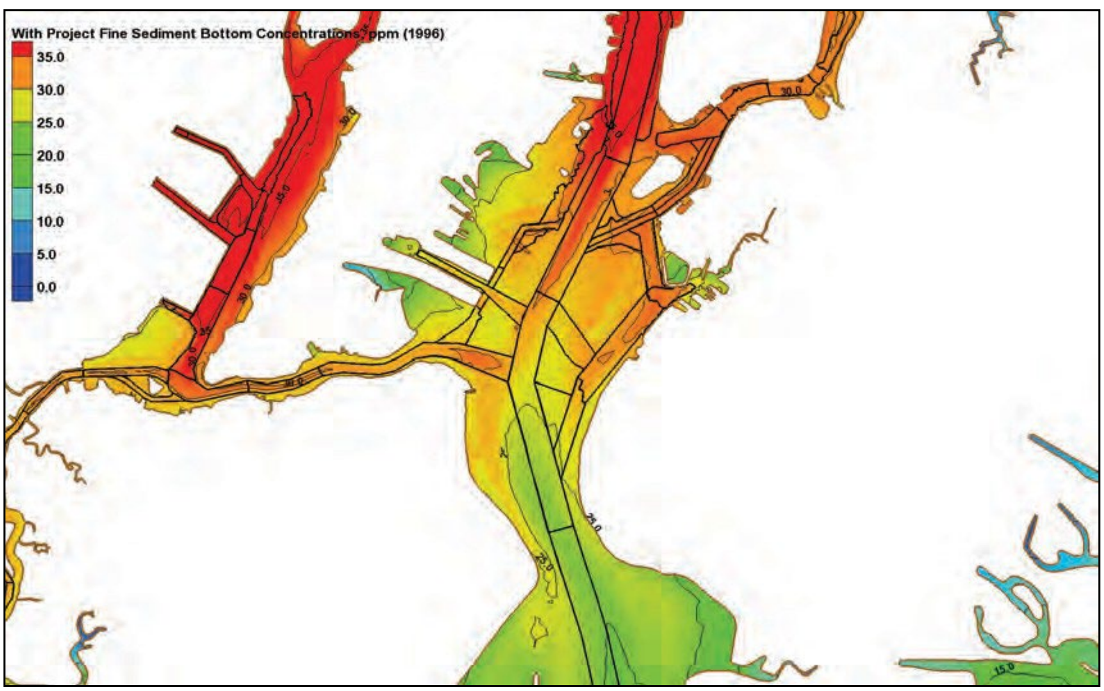


Figure 294. Without-project (top) and with-project (bottom) average sand bottom concentrations, ppm (1996).

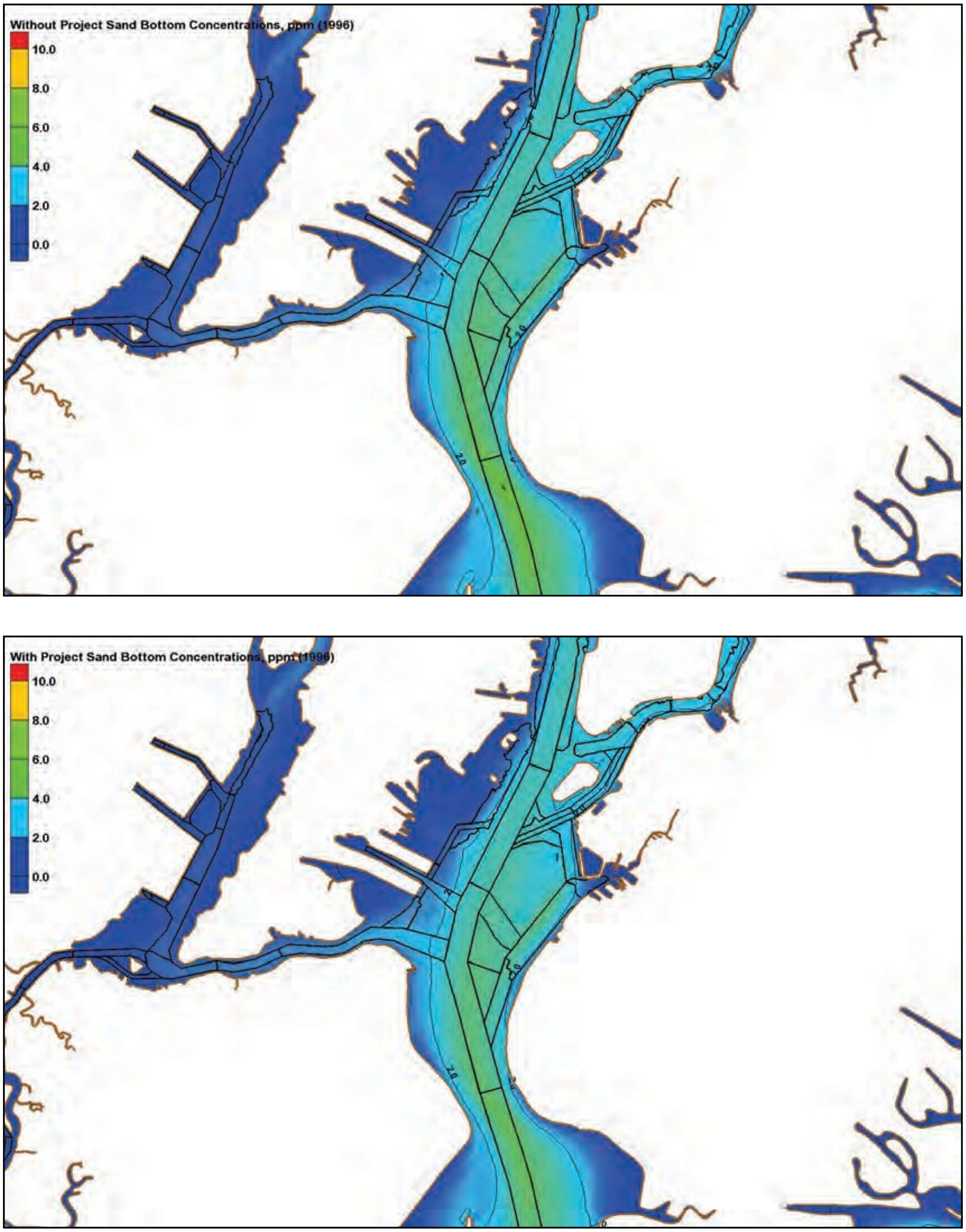
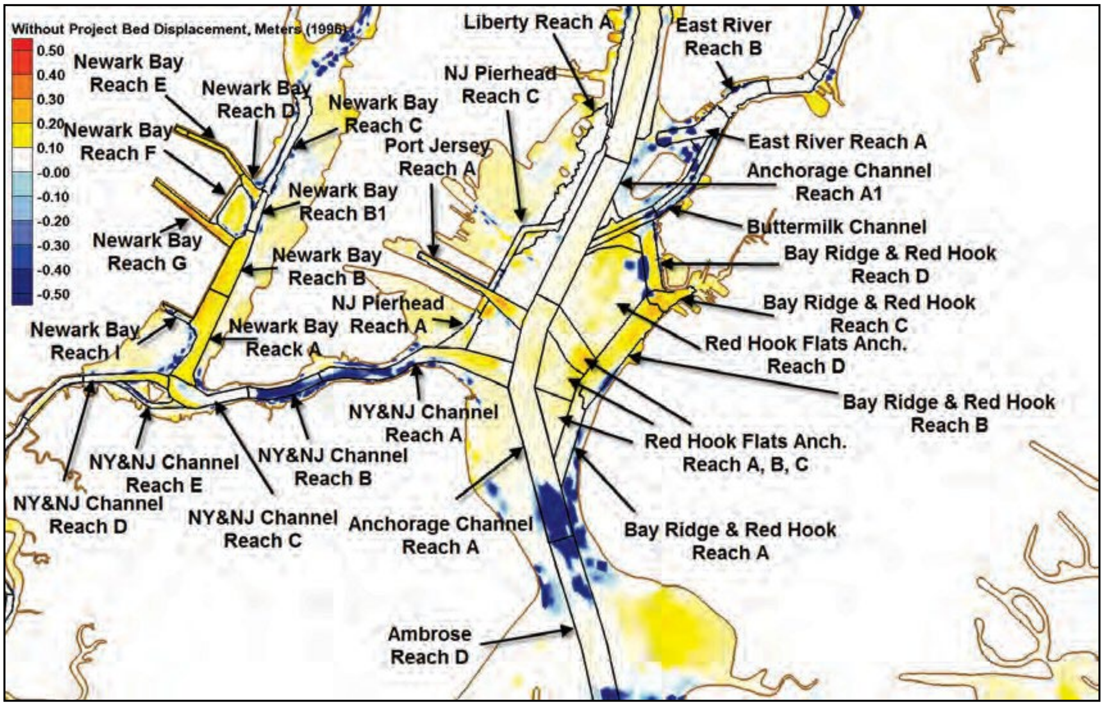


Figure 295. Without-project (top) and with-project (bottom) bed displacement, m (1996).



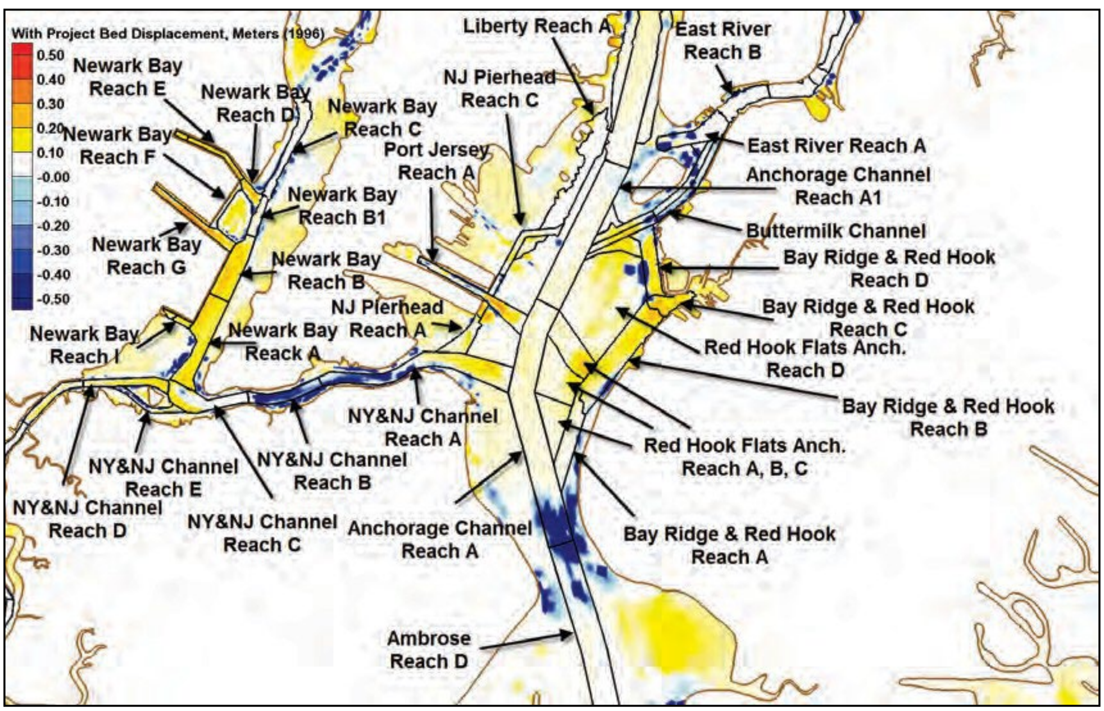
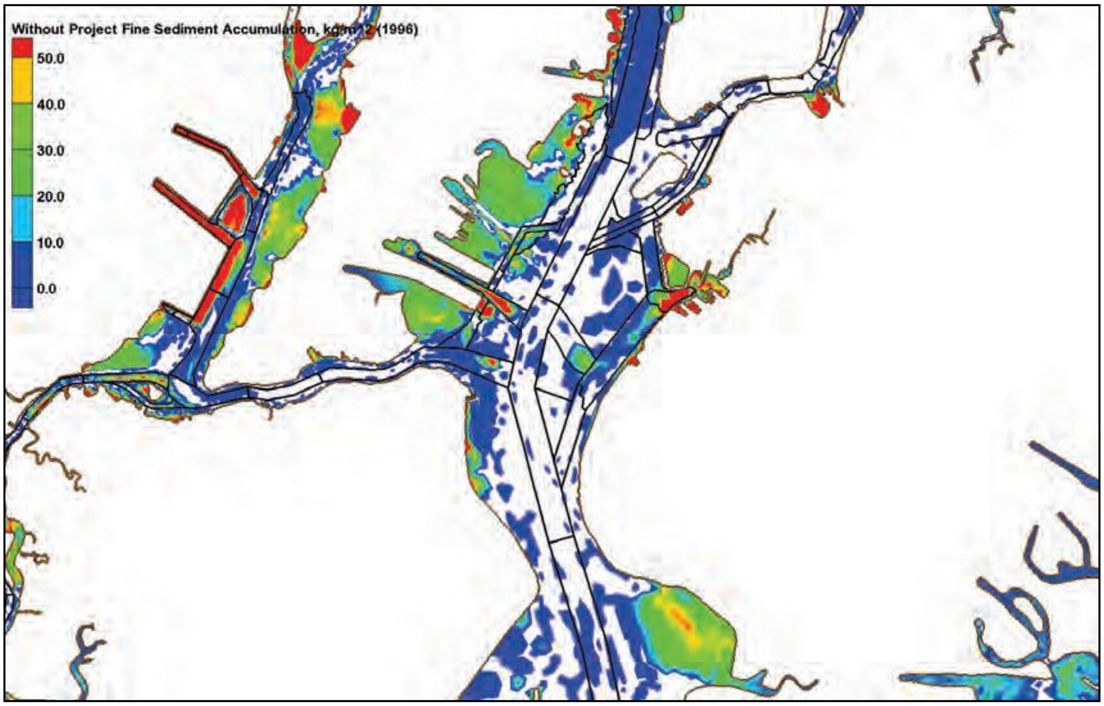


Figure 296. Without-project (top) and with-project (bottom) fine sediment accumulation, kg/m² (1996).



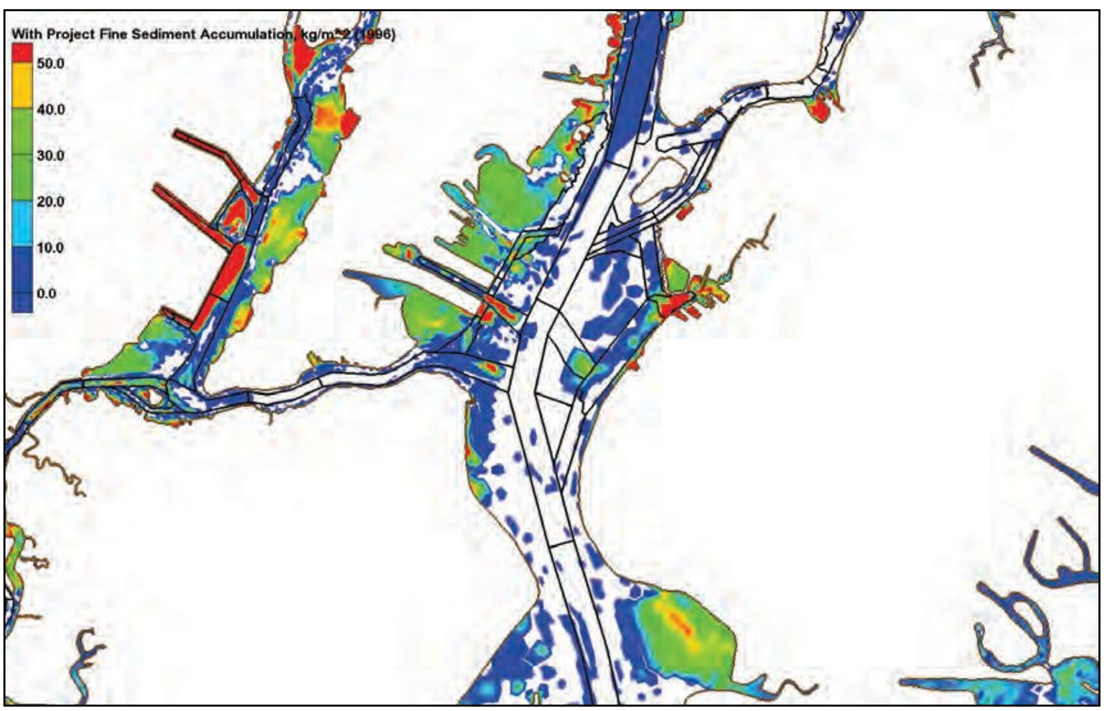
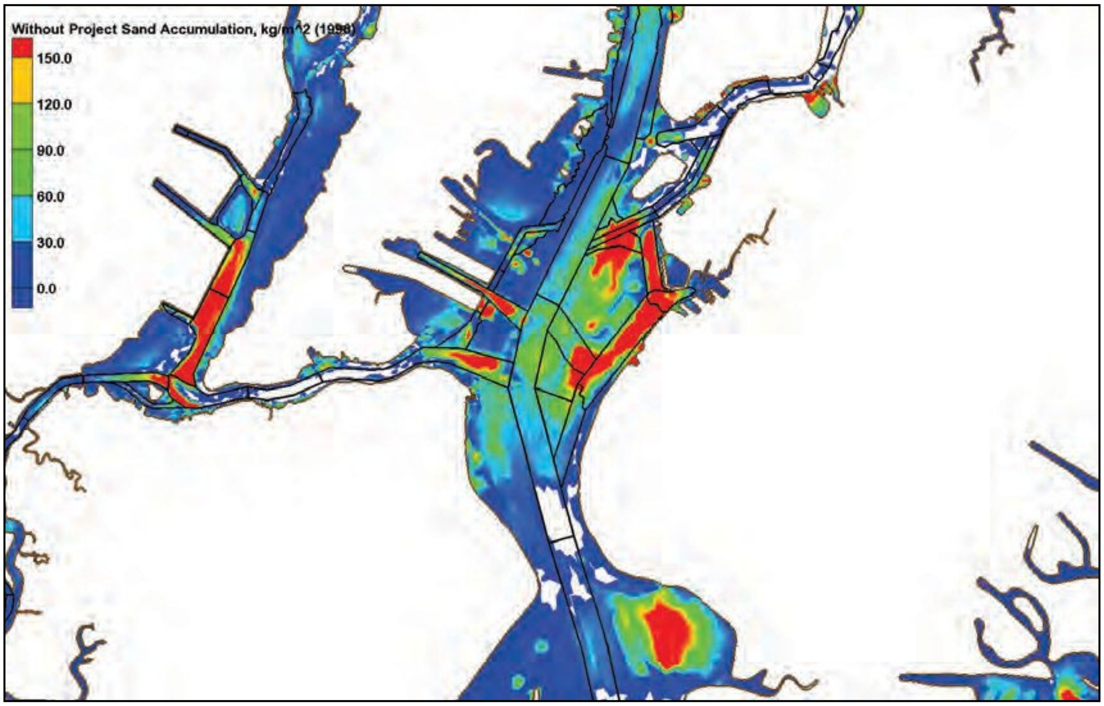


Figure 297. Without-project (top) and with-project (bottom) sand Accumulation, kg/m^2 (1996).



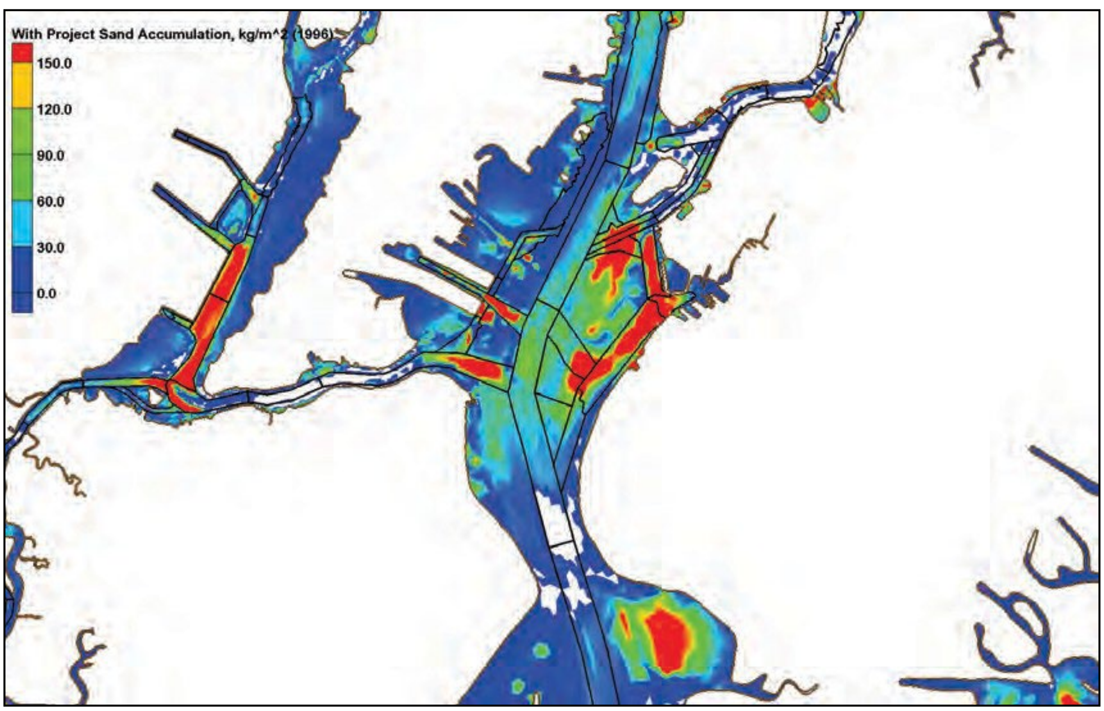


Figure 298. Dredge with-project/without-project percent differences (1996).

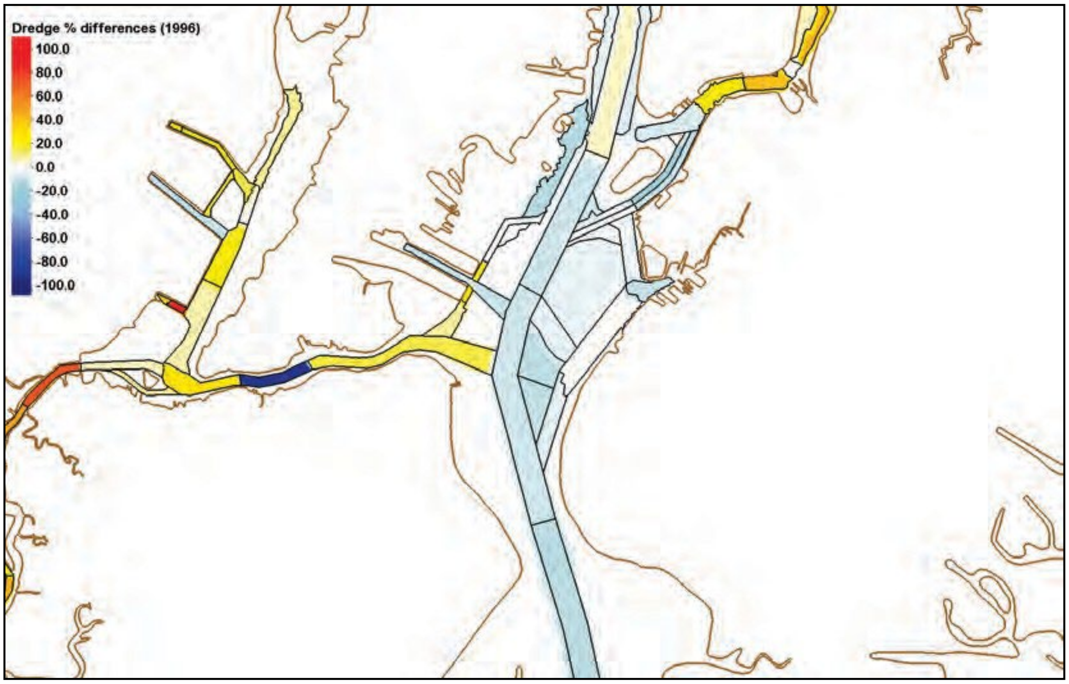
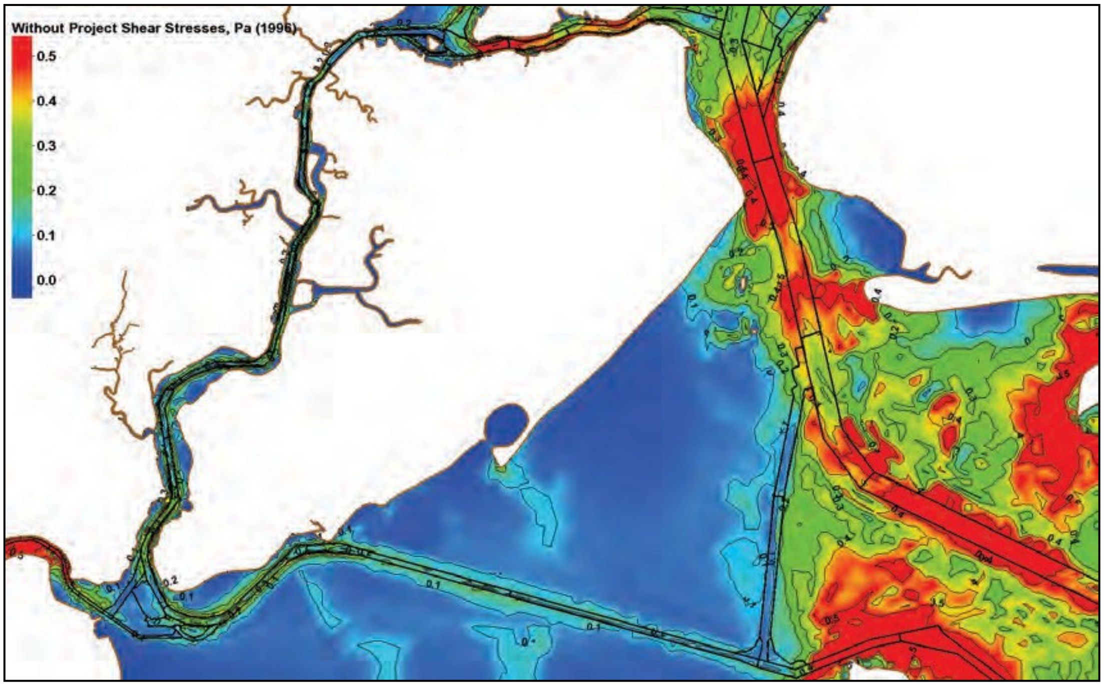


Table 32. Dredge volumes in Newark Bay, Kill van Kull, and Upper Bay (1996).

Depositional Volumes in Newark Bay, Kill van Kull, and Upper Bay, cy (1996)			
Reach	Without Project	With Project	With/Without Dredge Percentage
Newark Bay			
Newark Bay Reach A	136,294	145,056	106
Newark Bay Reach B	99,412	116,990	118
Newark Bay Reach B1	3,050	3,097	102
Newark Bay Reach C	3,410	3,688	108
Newark Bay Reach D	18,907	21,526	114
Newark Bay Reach E	33,334	39,977	120
Newark Bay Reach E1	4,863	6,329	130
Newark Bay Reach F	4,276	4,929	115
Newark Bay Reach G	92,711	80,746	87
Newark Bay Reach I	3,253	7,382	227
Newark Bay Reach I1	2,792	3,744	134
Kill van Kull			
NY&NJ Channels Reach A	65,632	74,980	114
NY&NJ Channels Reach B	333	25	8
NY&NJ Channels Reach C	28,266	36,447	129
Upper Bay			
Anchorage Channel Reach A	67,492	60,638	90
Anchorage Channel Reach A1	32,334	28,965	90
Anchorage Reach C1	8,384	8,288	99
Bay Ridge & Red Hook Reach A	15,468	14,493	94
Bay Ridge & Red Hook Reach B	165,306	166,247	101
Bay Ridge & Red Hook Reach C	62,815	55,605	89
Bay Ridge & Red Hook Reach D	71,013	68,688	97
Red Hook Flats Anch. Reach A	21,331	18,616	87
Red Hook Flats Anch. Reach B	45,732	39,074	85
Red Hook Flats Anch. Reach C	67,751	64,100	95
Red Hook Flats Anch. Reach D	138,264	131,511	95
Port Jersey Reach A	60,549	53,491	88
NJ Pierhead Ch. Reach A	12,760	13,741	108
NJ Pierhead Ch. Reach B	9,137	10,999	120
NJ Pierhead Reach C	10,930	10,886	100
Liberty Reach A	8,227	6,908	99

Arthur Kill and Raritan Bay results

Figure 299. Without-project (top) and with-project (bottom) average shear stresses, Pa (1996).



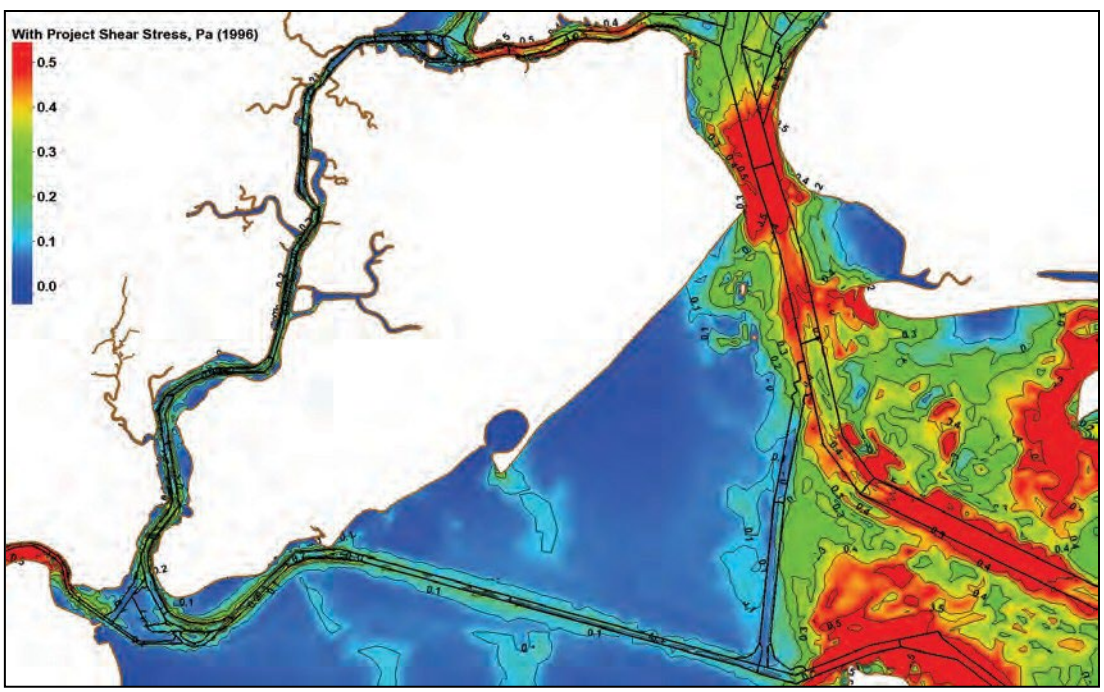
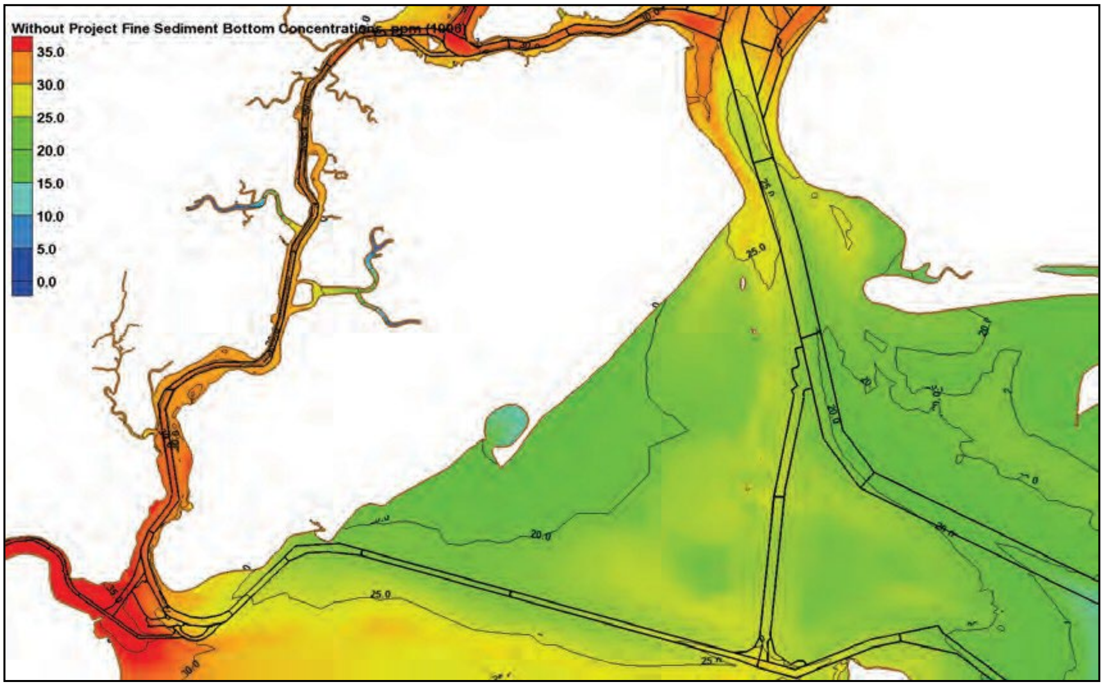


Figure 300. Without-project (top) and with-project (bottom) average bottom salinity, ppt (1996).

Figure 301. Without-project (top) and with-project (bottom) average fine sediment bottom concentrations, ppm (1996).



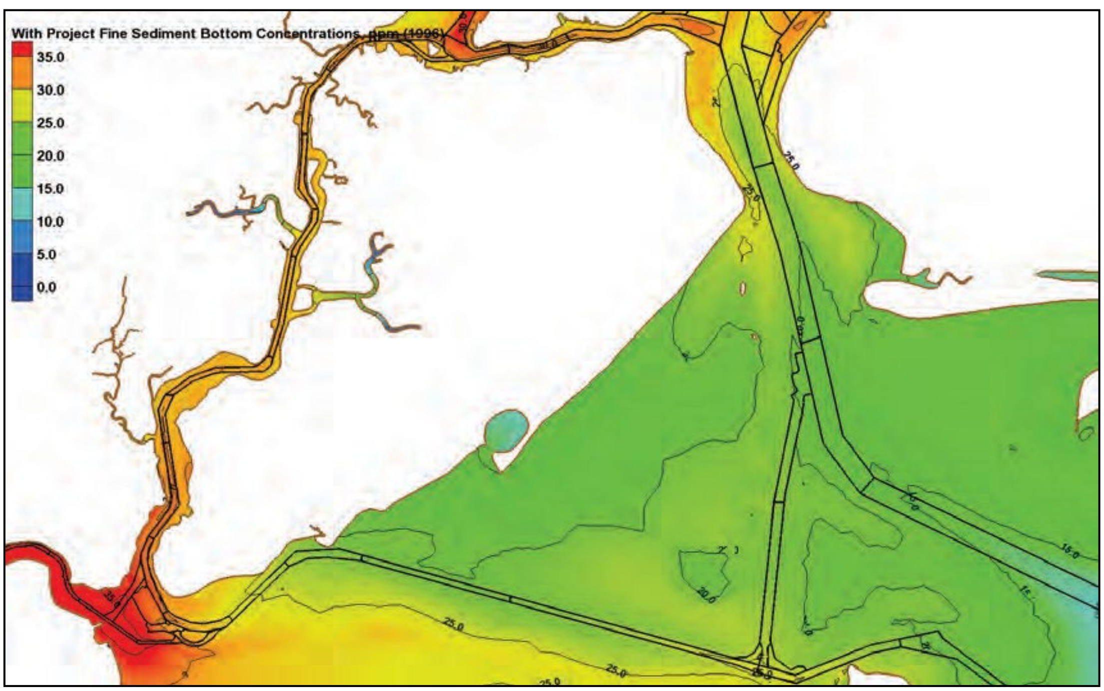


Figure 302. Without-project (top) and with-project (bottom) average sand bottom concentrations, ppm (1996).

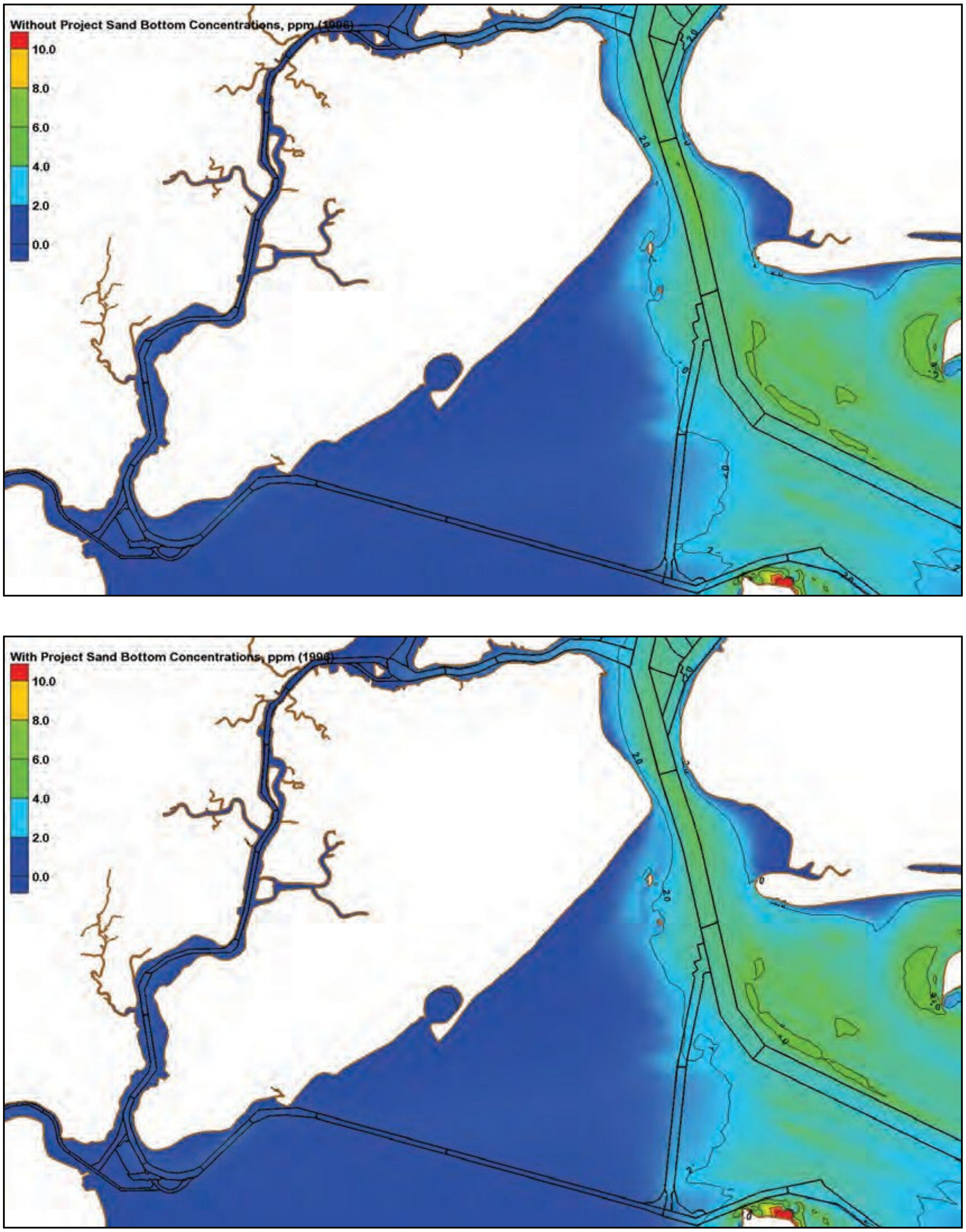
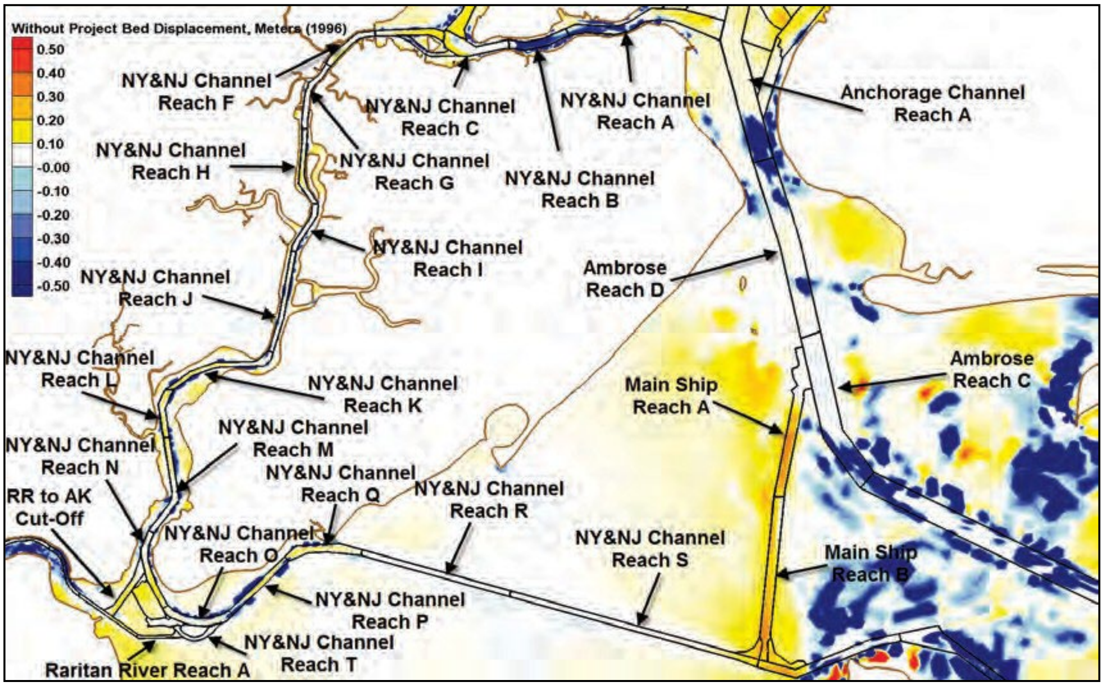


Figure 303. Without-project (top) and with-project (bottom) bed displacement, m (1996).



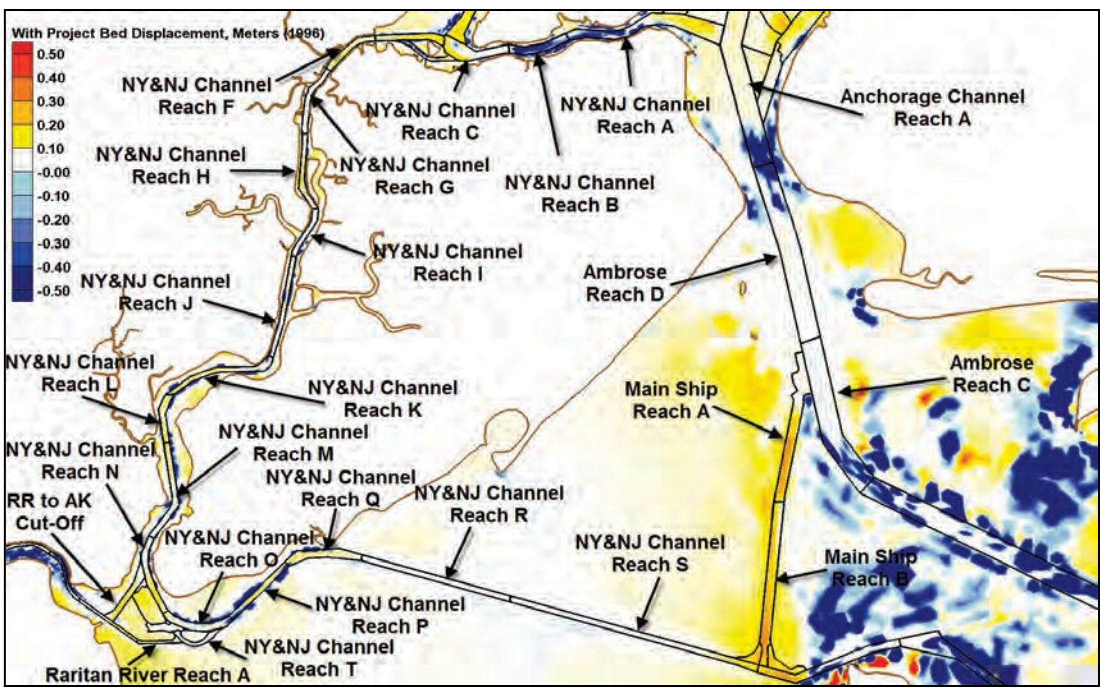
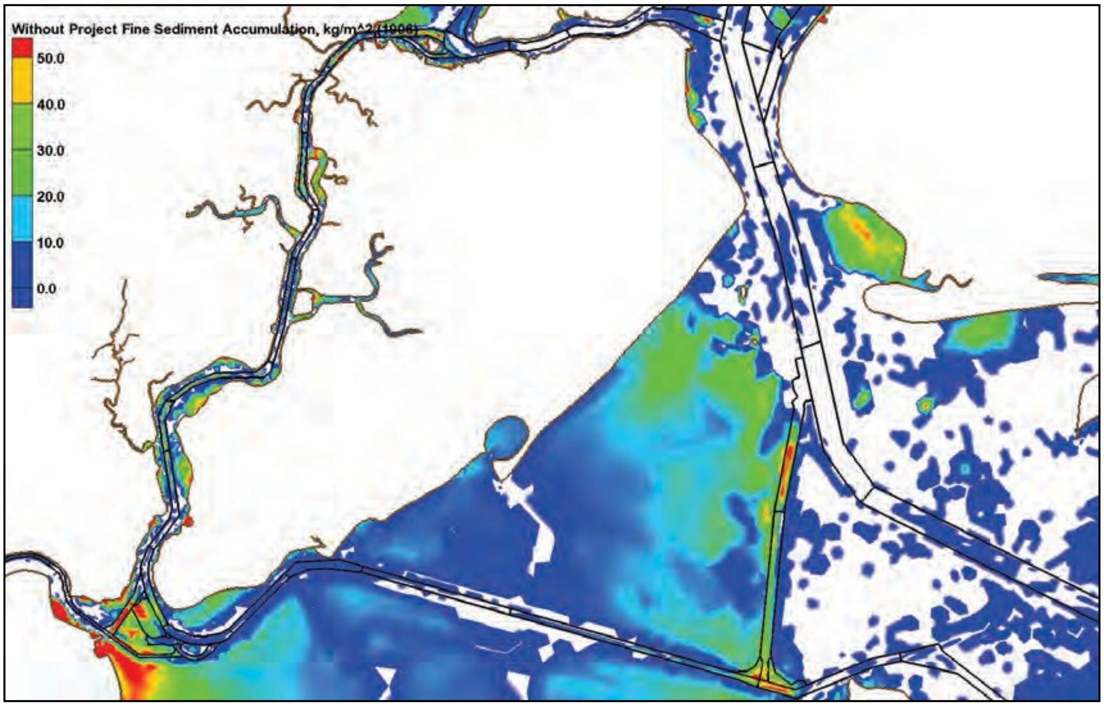


Figure 304. Without-project (top) and with-project (bottom) fine sediment accumulation, kg/m² (1996).



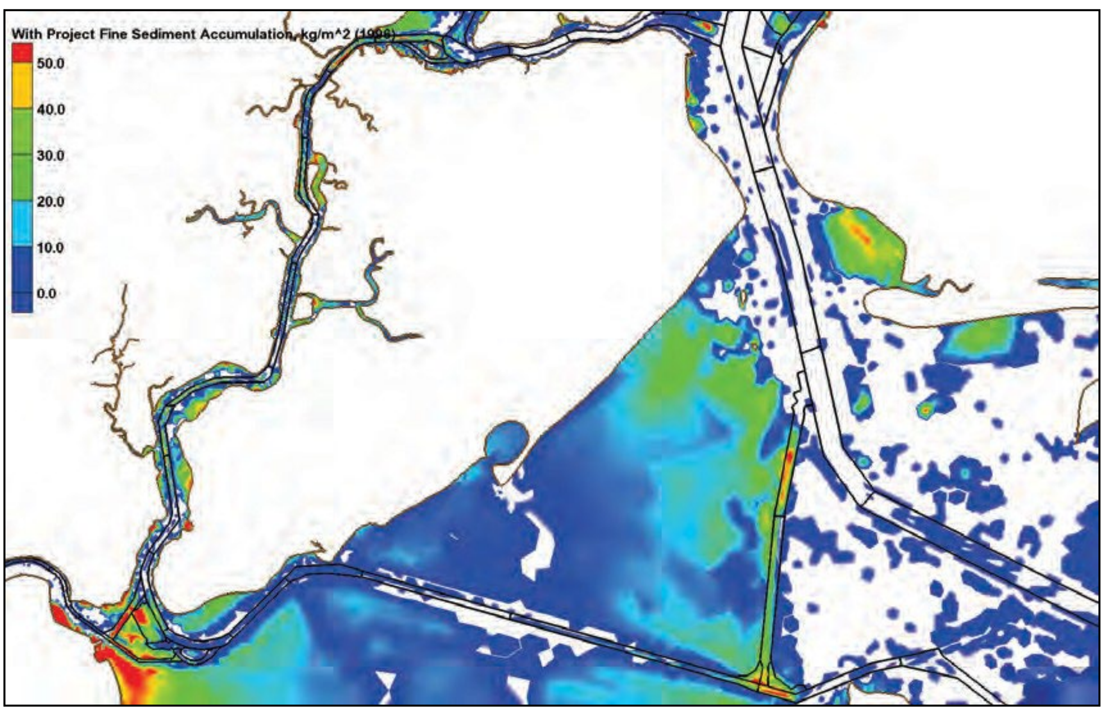
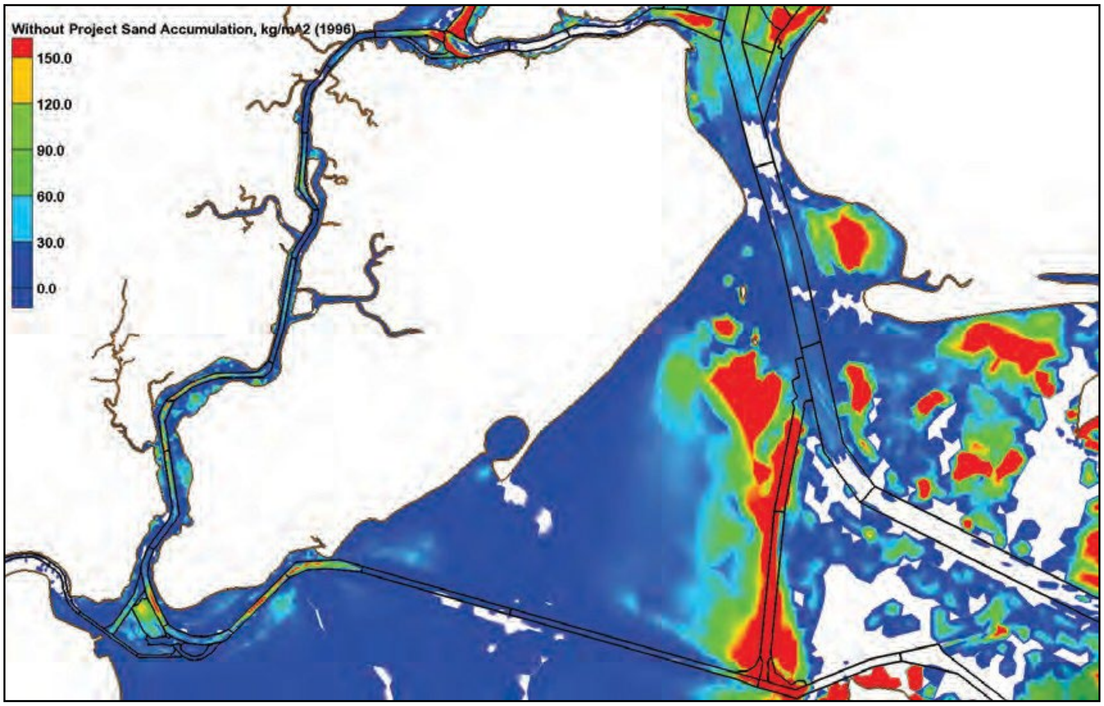


Figure 305. Without-project (top) and with-project (bottom) sand Accumulation, kg/m^2 (1996).



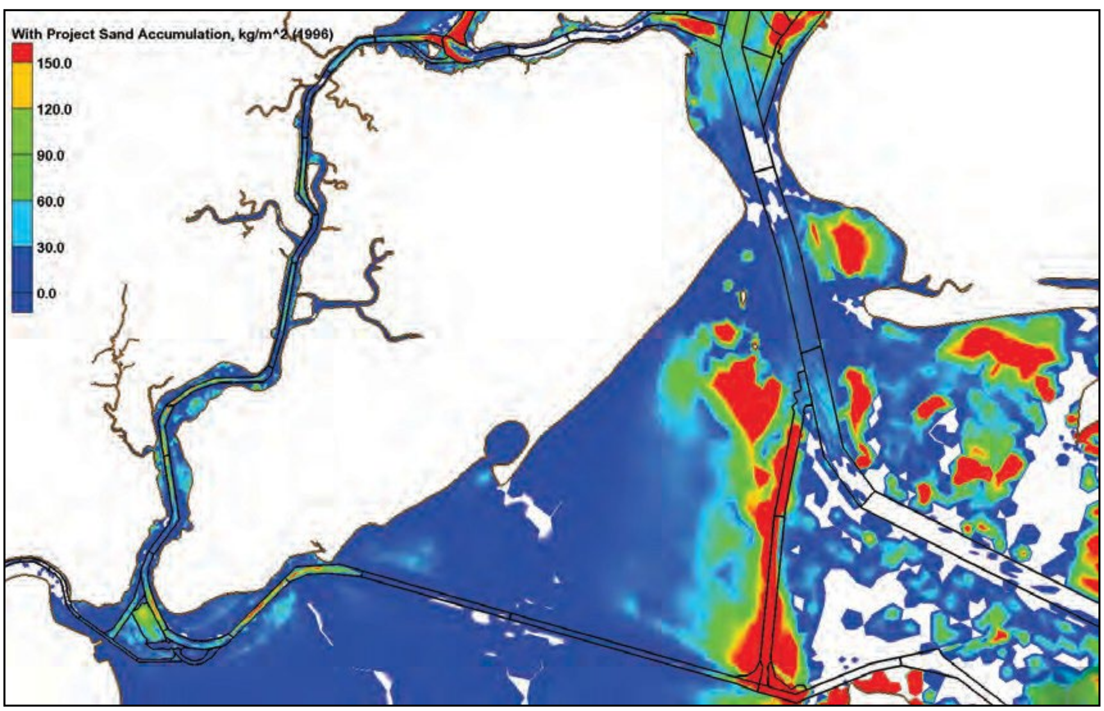


Figure 306. Dredge with-project/without-project percent differences (1996).

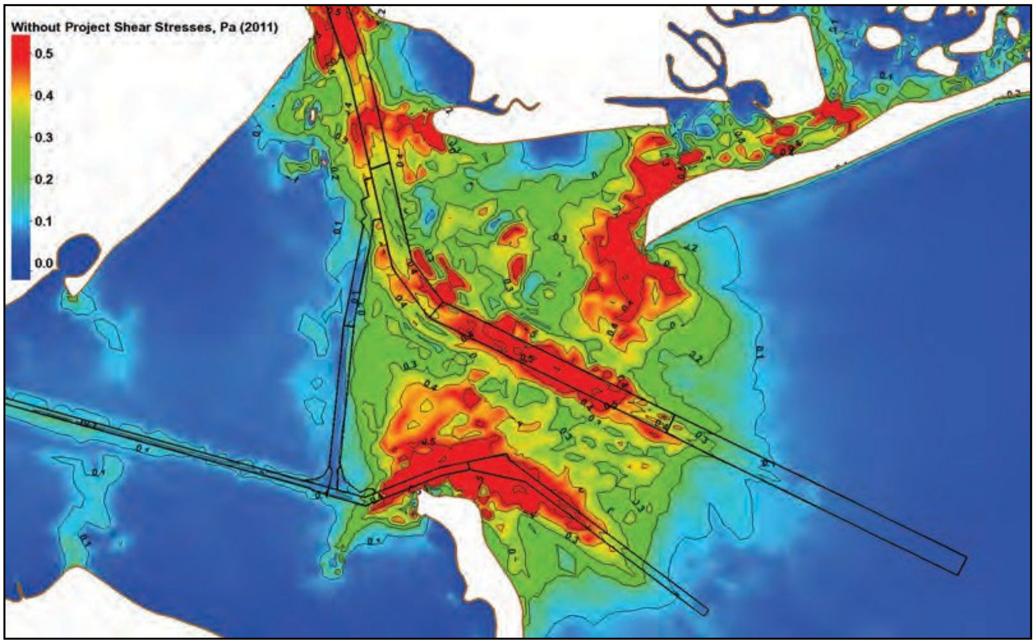
Table 33. Dredge volumes for Arthur Kill and Raritan Bay (1996).

Depositional Volumes in Arthur Kill and Raritan Bay, cy (1996)			
Reach	Without Project	With Project	With/Without Dredge Percentage
Arthur Kill			
NY&NJ Channels Reach D	29,861	31,464	105
NY&NJ Channels Reach E	4,849	5,254	108
NY&NJ Channels Reach F	6,318	10,796	171
NY&NJ Channels Reach G	1,233	1,822	148
NY&NJ Channels Reach H	7,968	9,236	116
NY&NJ Channels Reach I	654	932	143
NY&NJ Channels Reach J	4,340	5,390	124
NY&NJ Channels Reach K	17,380	17,483	101
NY&NJ Channels Reach L	13,453	13,539	101
NY&NJ Channels Reach M	11,776	12,305	104
NY&NJ Channels Reach N	20,672	18,124	88
Raritan Bay			
NY&NJ Channels Reach O	7,308	8,214	112
NY&NJ Channels Reach P	20,621	19,739	96
NY&NJ Channels Reach Q	22,607	20,663	91
NY&NJ Channels Reach R	392	392	100
NY&NJ Channels Reach T	1,452	1,618	111
RR to AK Cut-Off Reach A	19,628	20,478	104
Raritan River Reach A	4,206	4,525	108
Raritan River Reach B	7,098	7,184	101
Raritan River Reach C	617	511	83
Raritan River Reach D	105	82	78

Appendix F: Results for 2011

Lower Bay results

Figure 307. Without-project (top) and with-project (bottom) average shear stresses, Pa (2011).



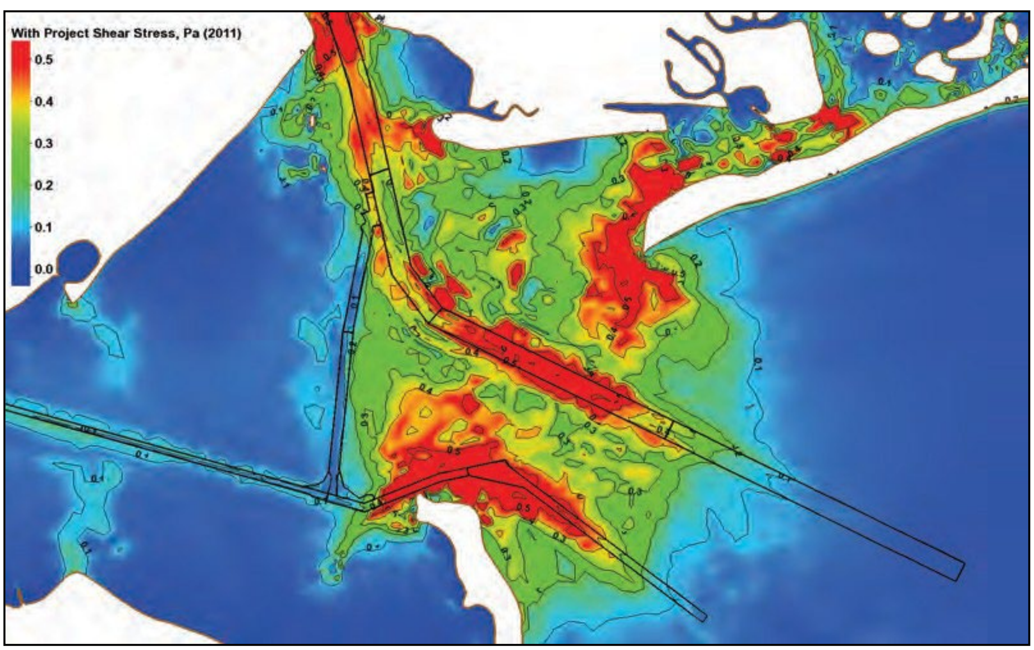
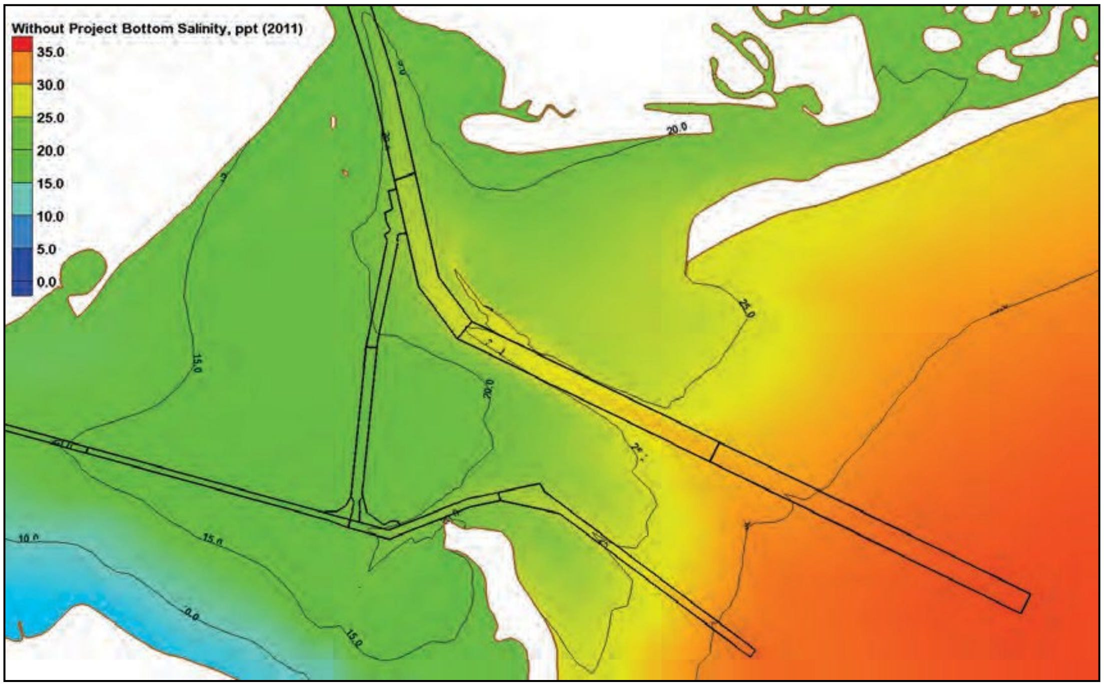


Figure 308. Without-project (top) and with-project (bottom) average bottom salinity, ppt (2011).



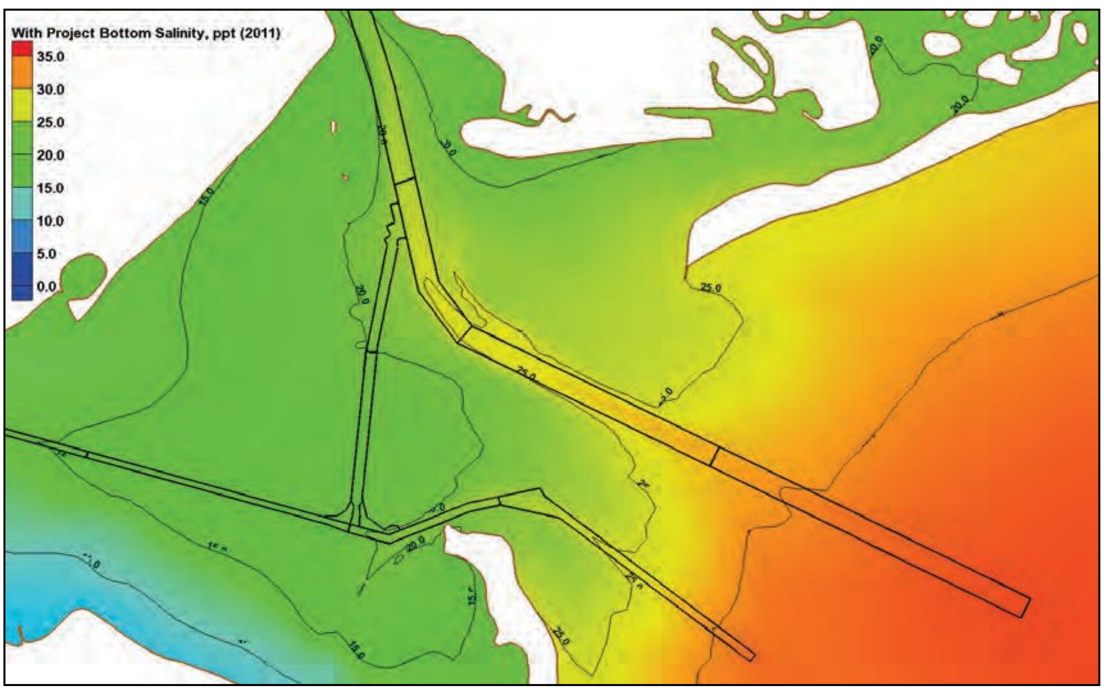


Figure 309. Without-project (top) and with-project (bottom) average fine sediment bottom concentrations, ppm (2011).

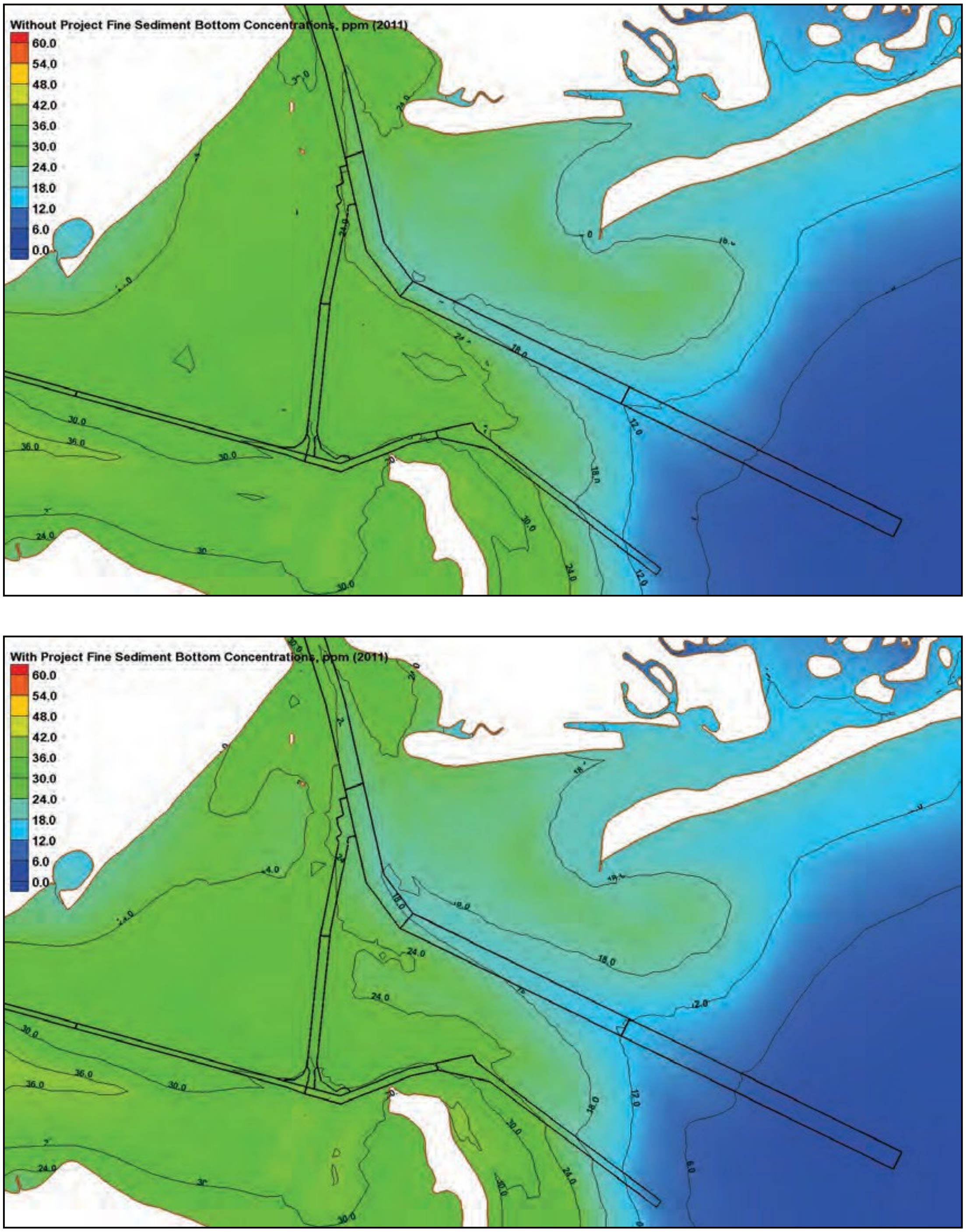
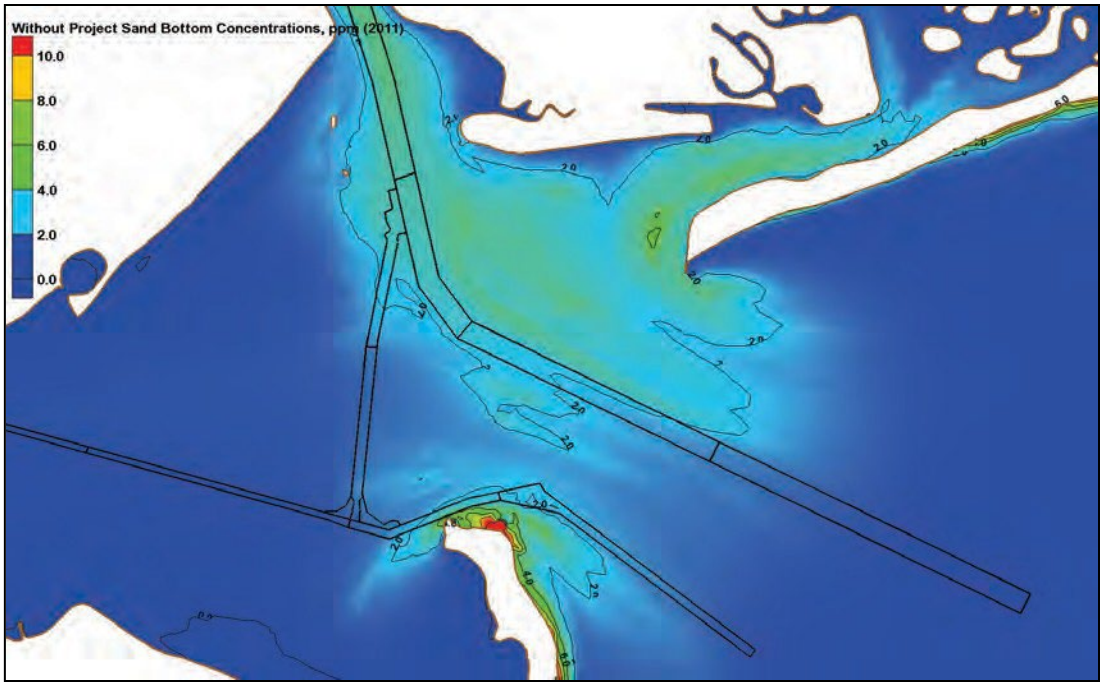


Figure 310. Without-project (top) and with-project (bottom) average sand bottom concentrations, ppm (2011).



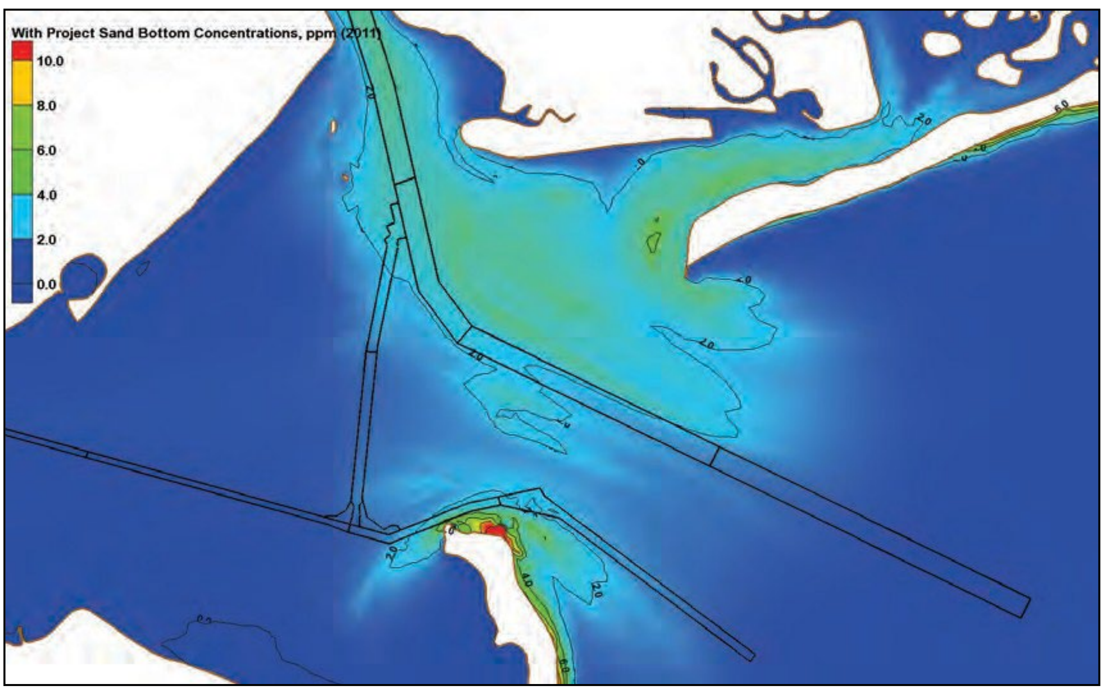
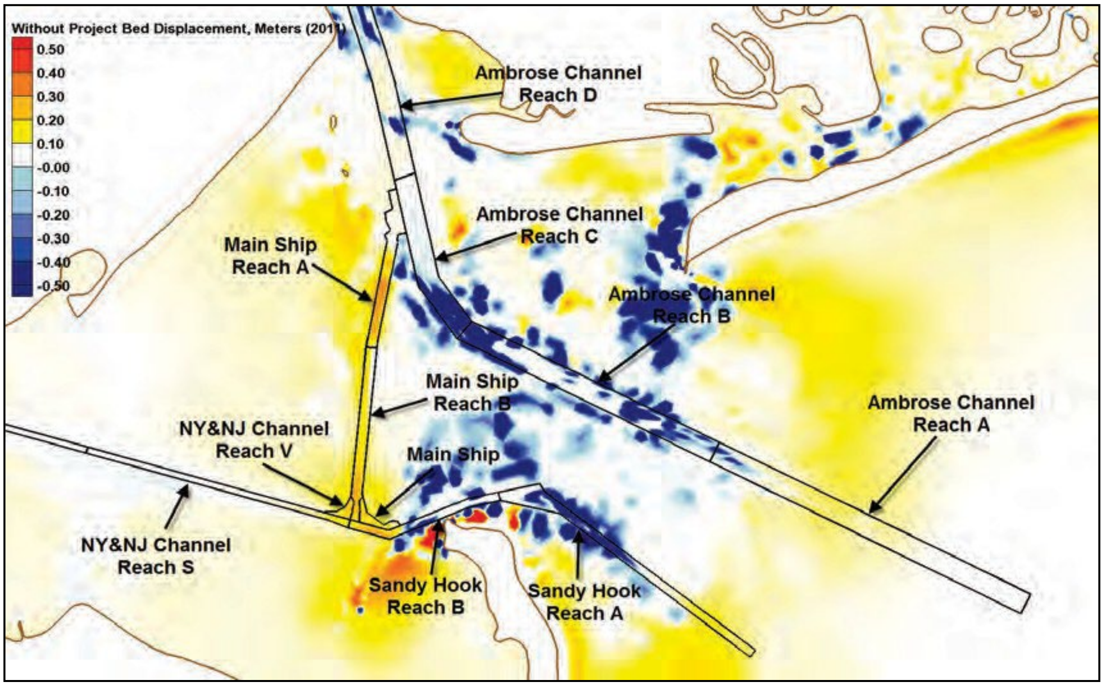


Figure 311. Without-project (top) and with-project (bottom) bed displacement, m (2011).



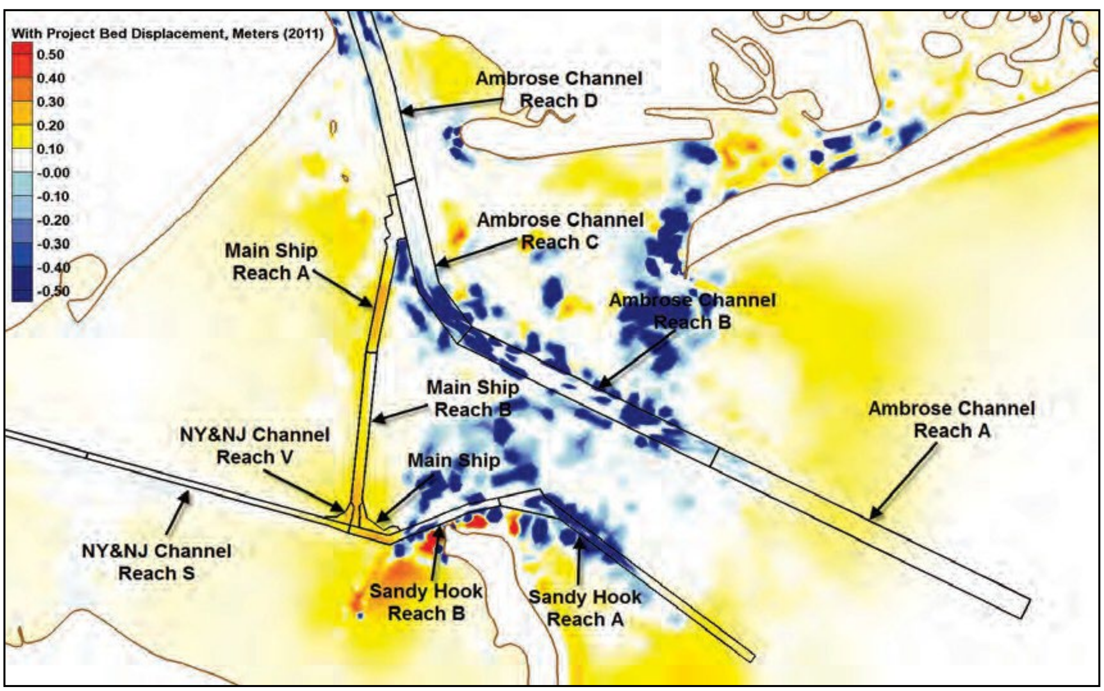
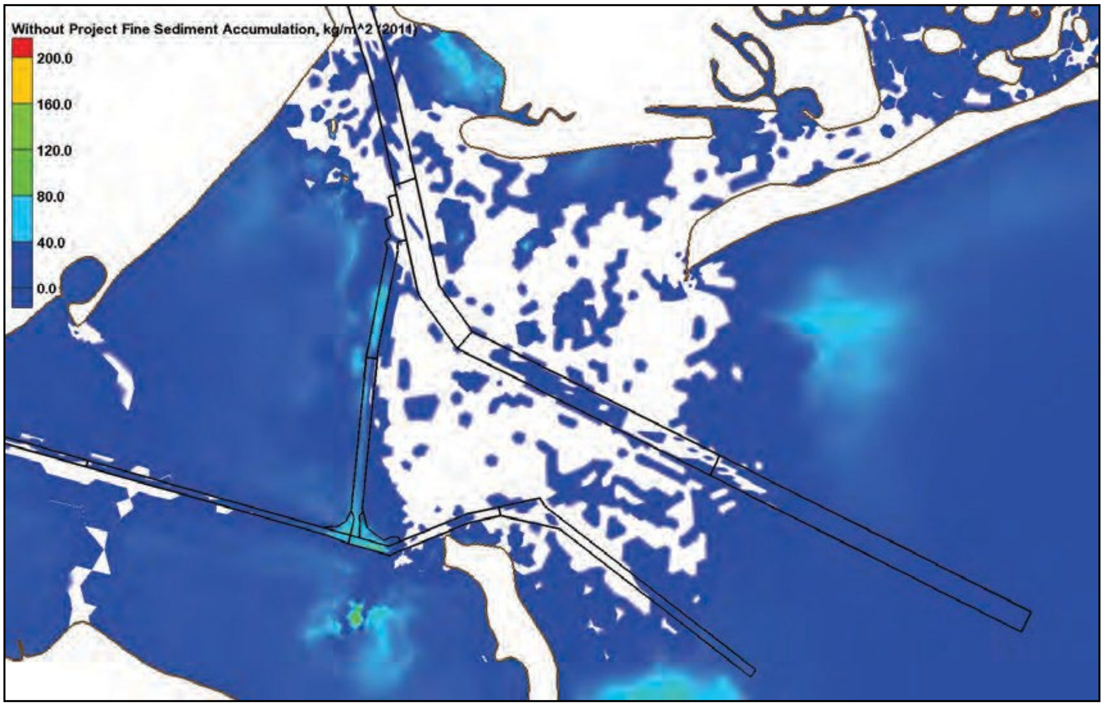


Figure 312. Without-project (top) and with-project (bottom) fine sediment accumulation, kg/m² (2011).



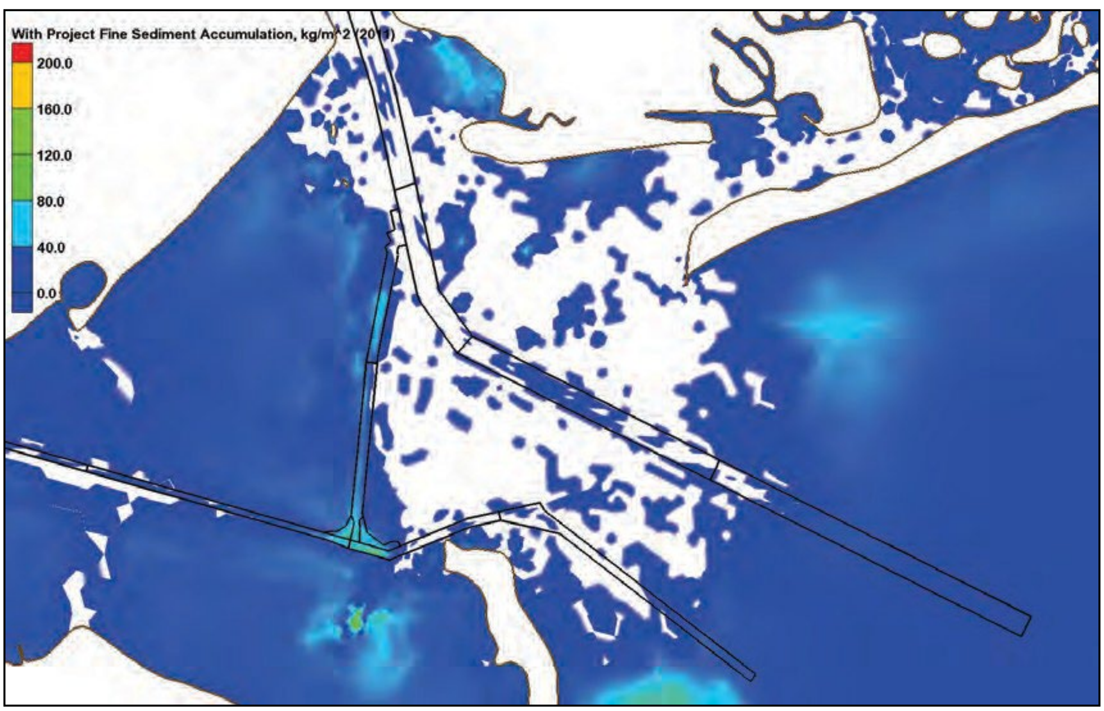
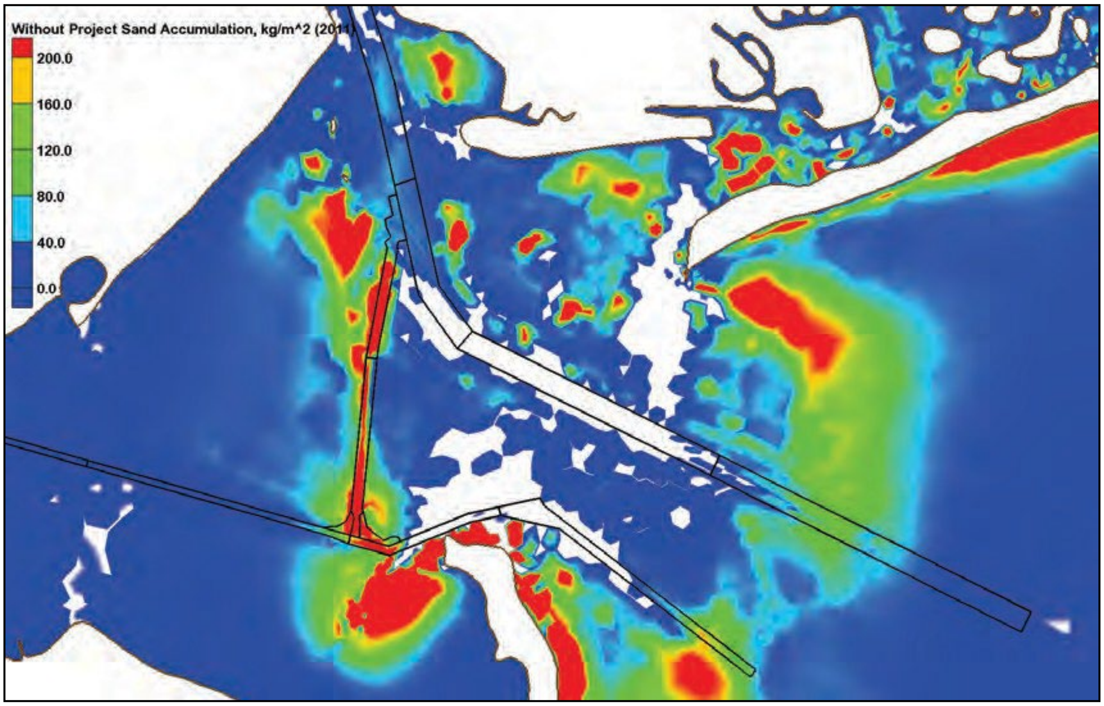


Figure 313. Without-project (top) and with-project (bottom) sand accumulation, kg/m^2 (2011).



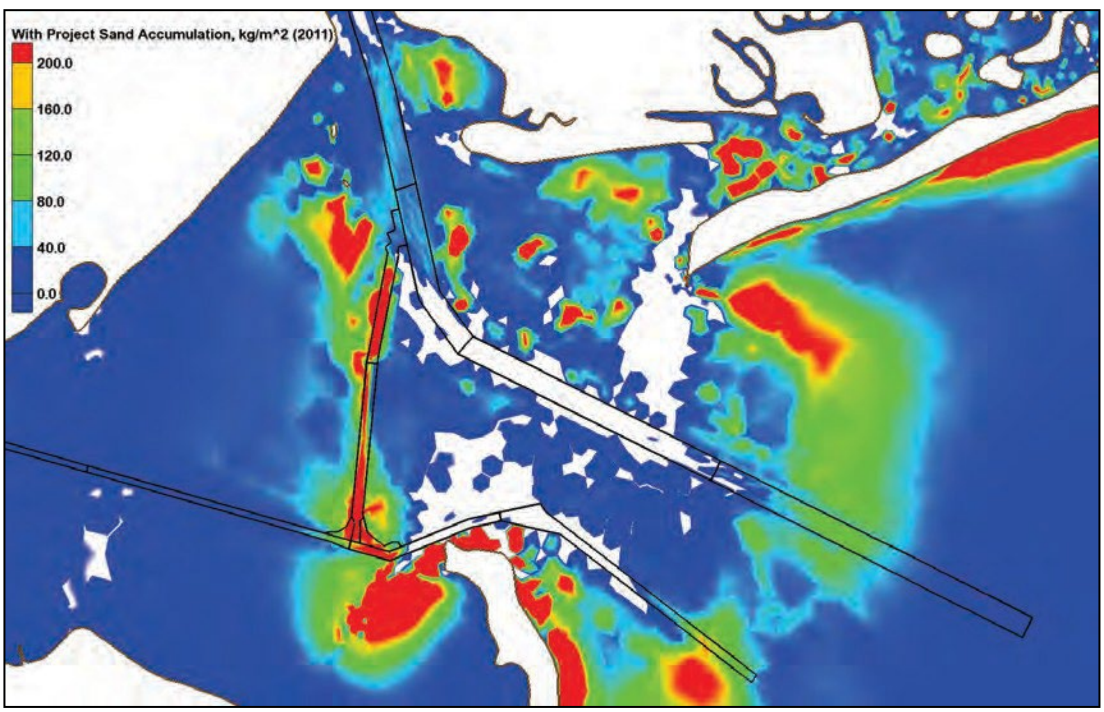


Figure 314. Dredge with-project/without-project percent differences (2011).

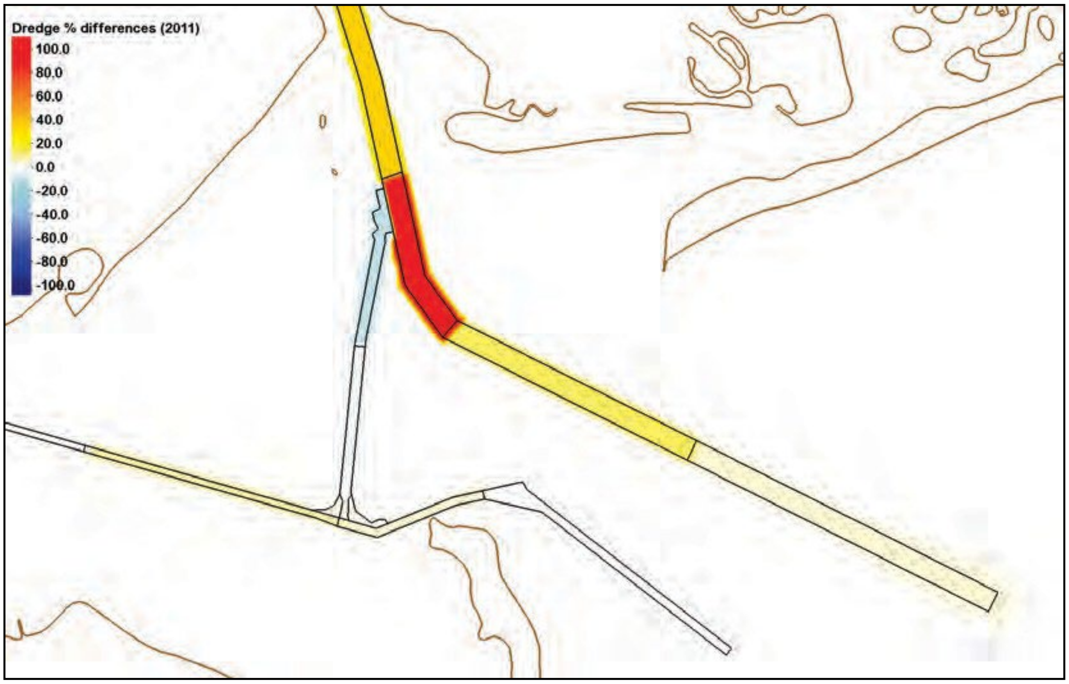
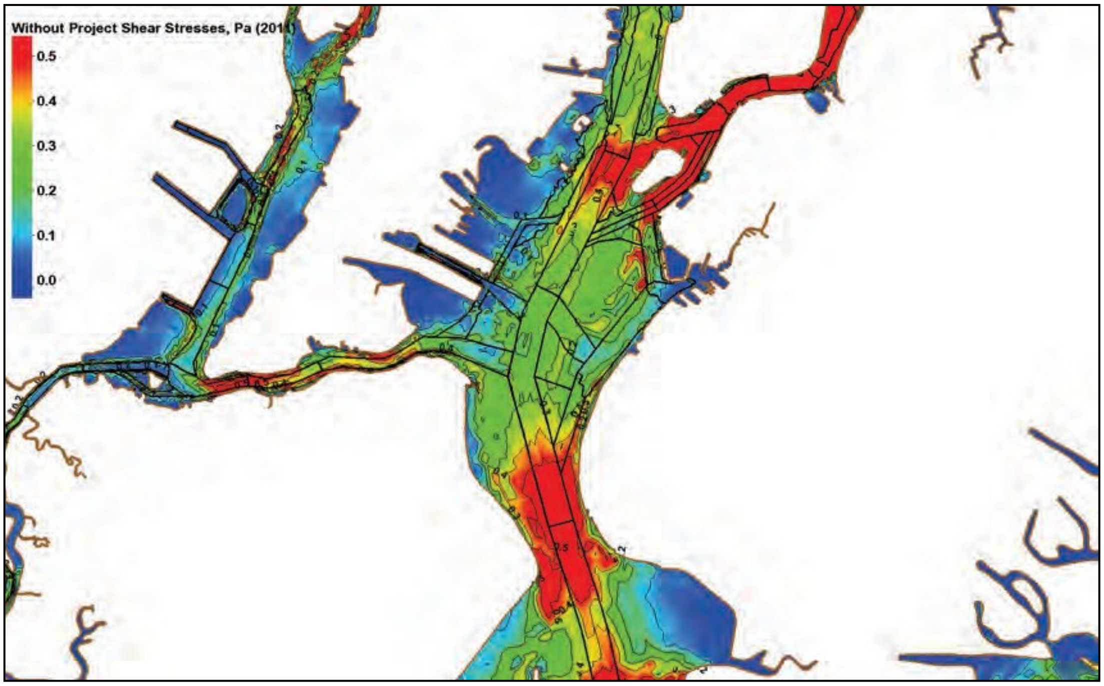


Table 34. Dredge volumes for Lower Bay (2011).

Depositional Volumes in Lower Bay, cy (2011)			
Reach	Without Project	With Project	With/Without Dredge Percentage
Ambrose Channel Reach A	152,305	157,665	104
Ambrose Channel Reach B	1,001	1,127	113
Ambrose Channel Reach C	3,931	8,697	221
Ambrose Channel Reach D	31,994	42,913	134
Main Ship	48,581	49,581	102
Main Ship Reach A	190,973	165,876	87
Main Ship Reach B	214,019	208,308	97
Sandy Hook Reach A	64,444	64,138	100
Sandy Hook Reach B	71,399	74,062	104
NY&NJ Channels Reach S	33,129	35,503	107
NY&NJ Channels Reach V	33,479	34,242	102

Newark Bay, Kill van Kull, and Upper Bay results

Figure 315. Without-project (top) and with-project (bottom) average shear stresses, Pa (2011).



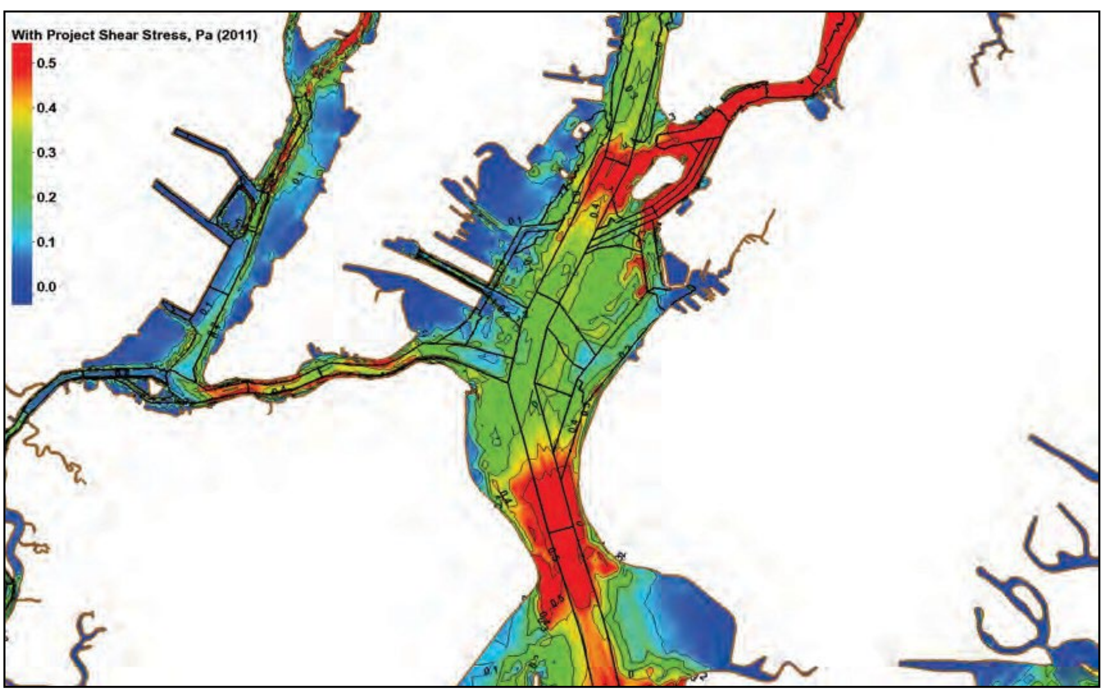
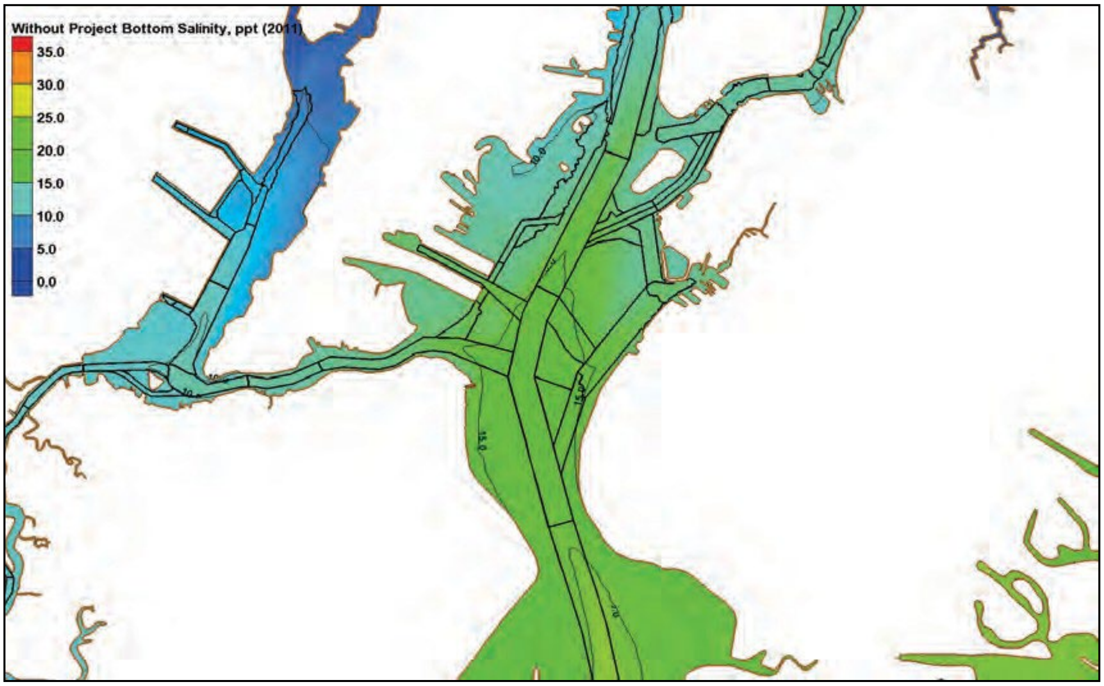


Figure 316. Without-project (top) and with-project (bottom) average bottom salinity, ppt (2011).



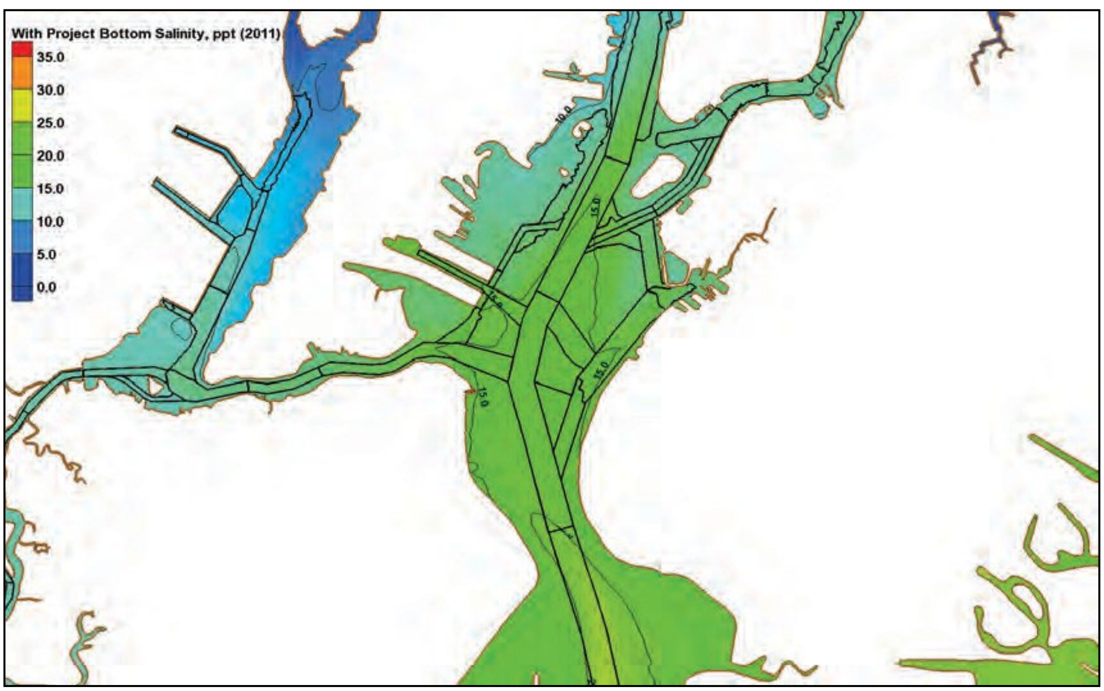


Figure 317. Without-project (top) and with-project (bottom) average fine sediment bottom concentrations, ppm (2011).

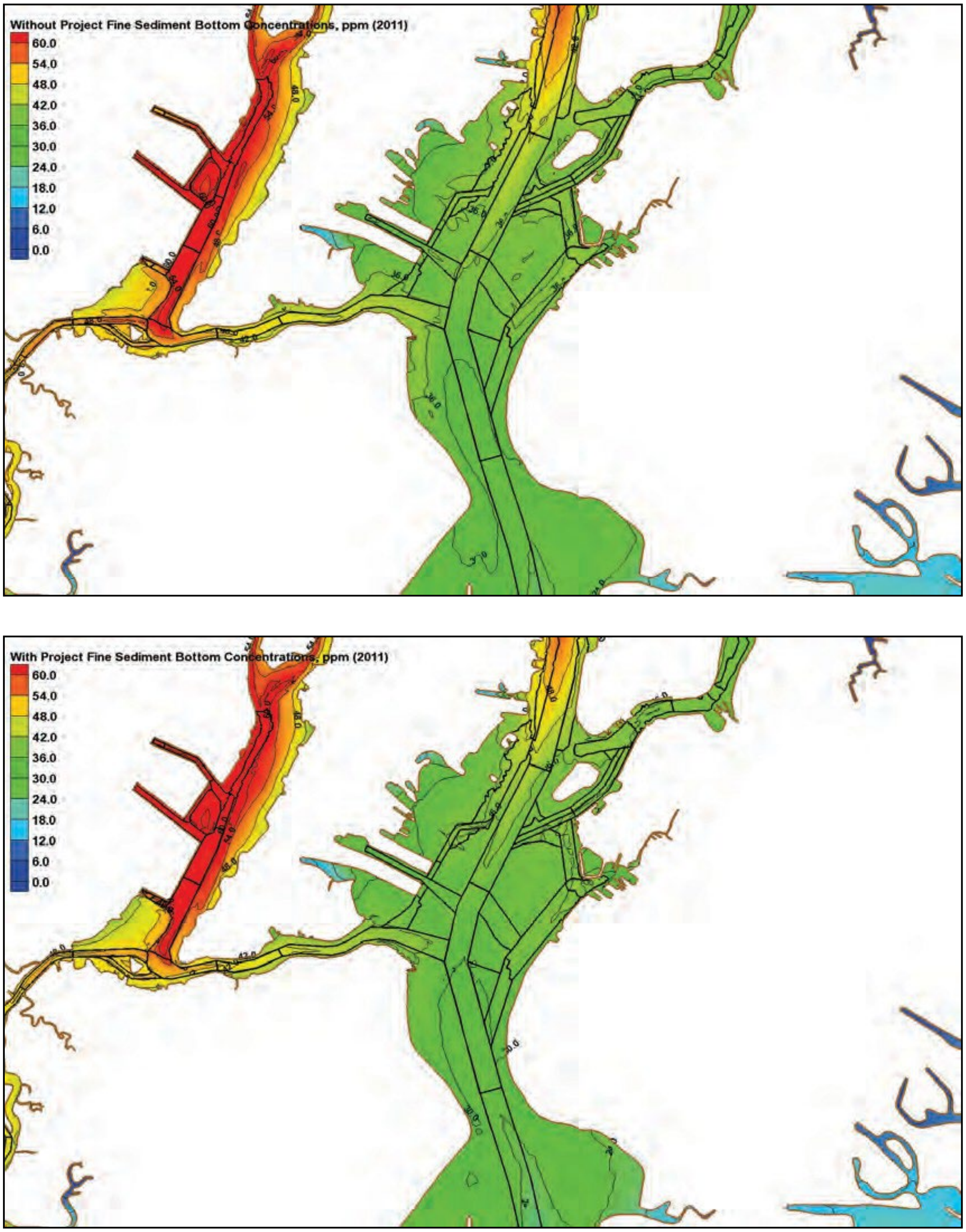


Figure 318. Without-project (top) and with-project (bottom) average sand bottom concentrations, ppm (2011).

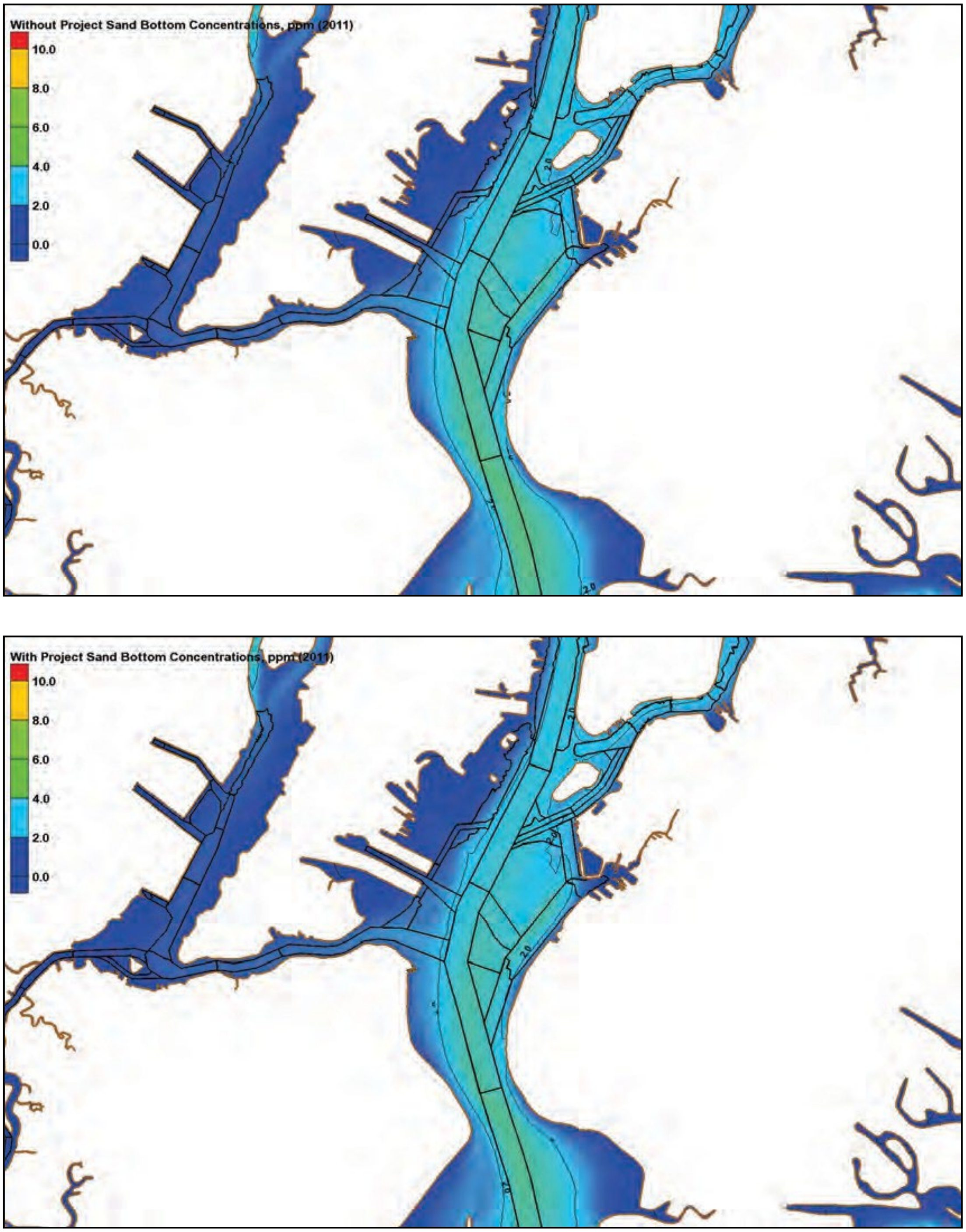
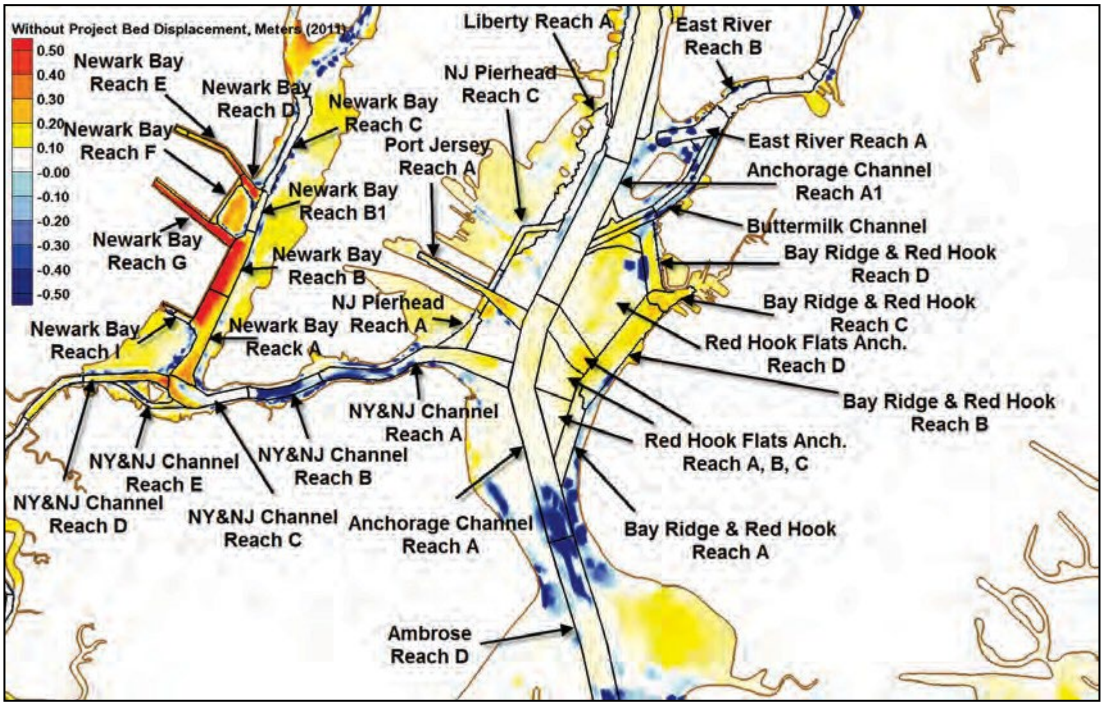


Figure 319. Without-project (top) and with-project (bottom) bed displacement, m (2011).



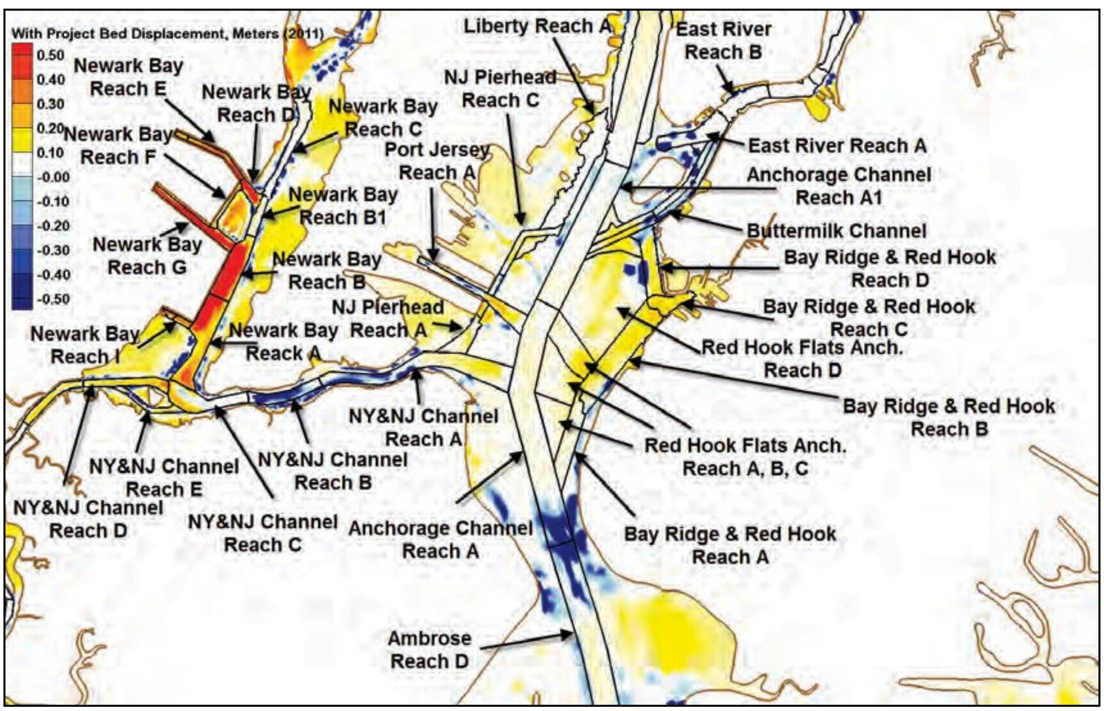


Figure 320. Without-project (top) and with-project (bottom) fine sediment accumulation, kg/m² (2011).

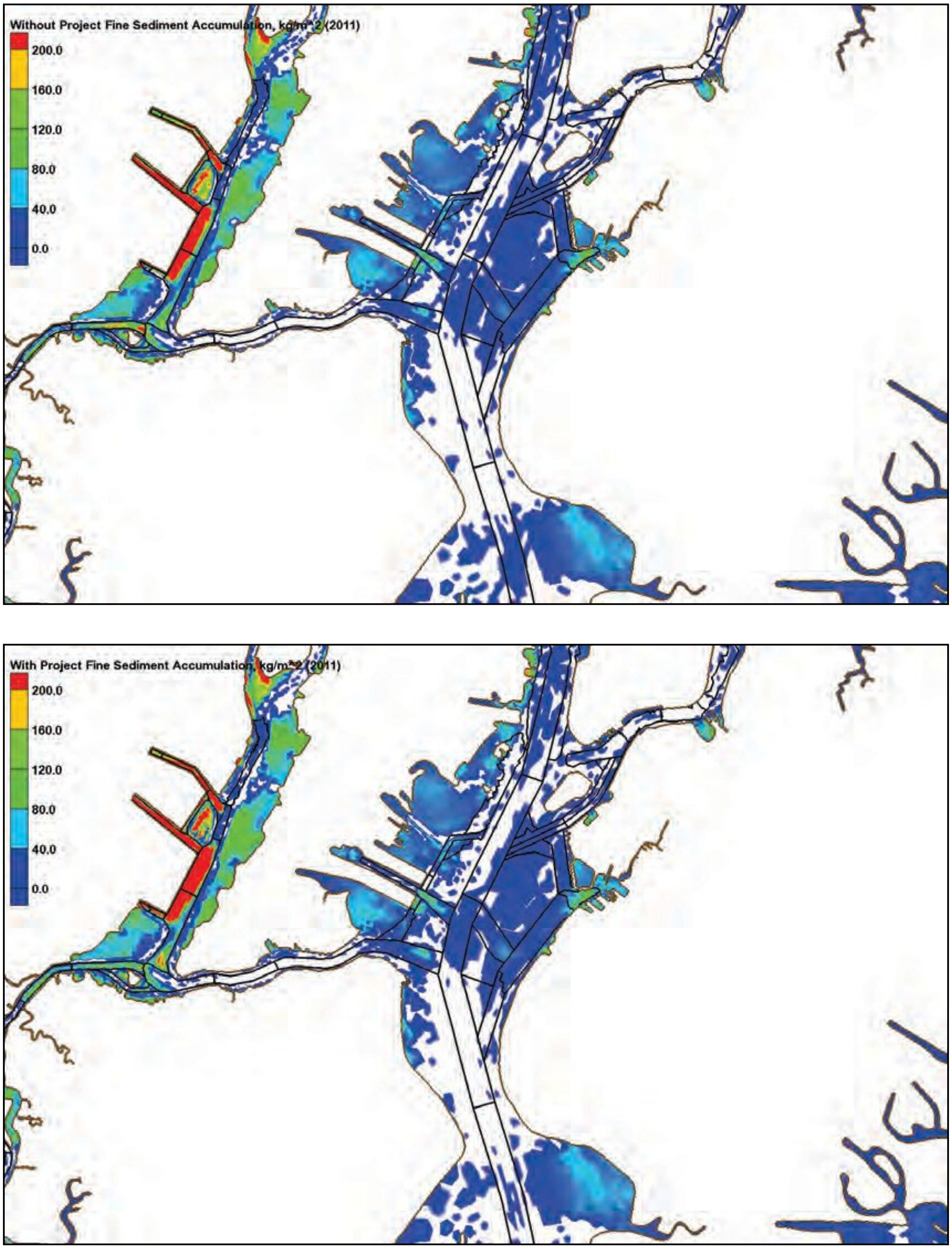
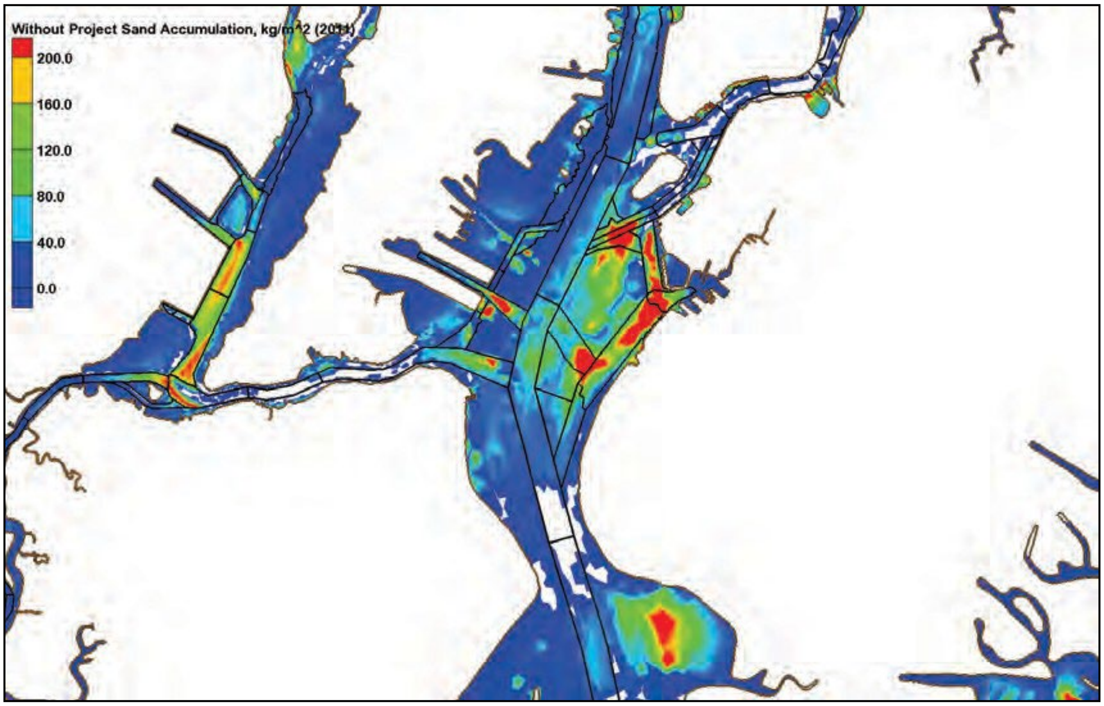


Figure 321. Without-project (top) and with-project (bottom) sand accumulation, kg/m² (2011).



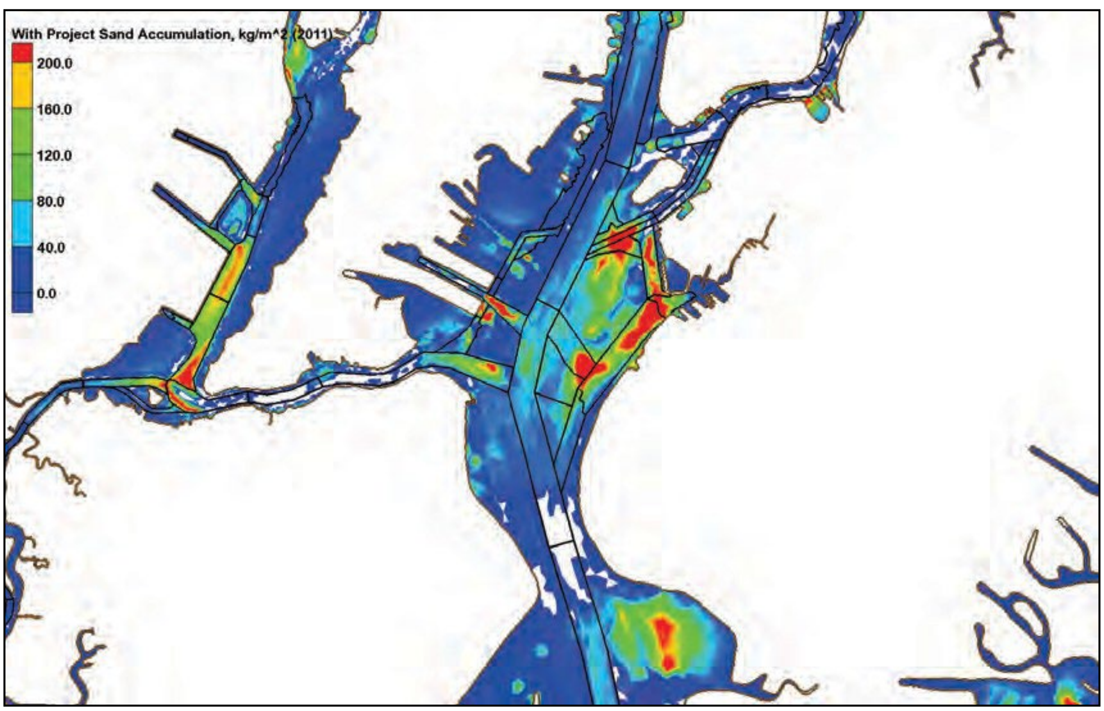


Figure 322. Dredge with-project/without-project percent differences (2011).

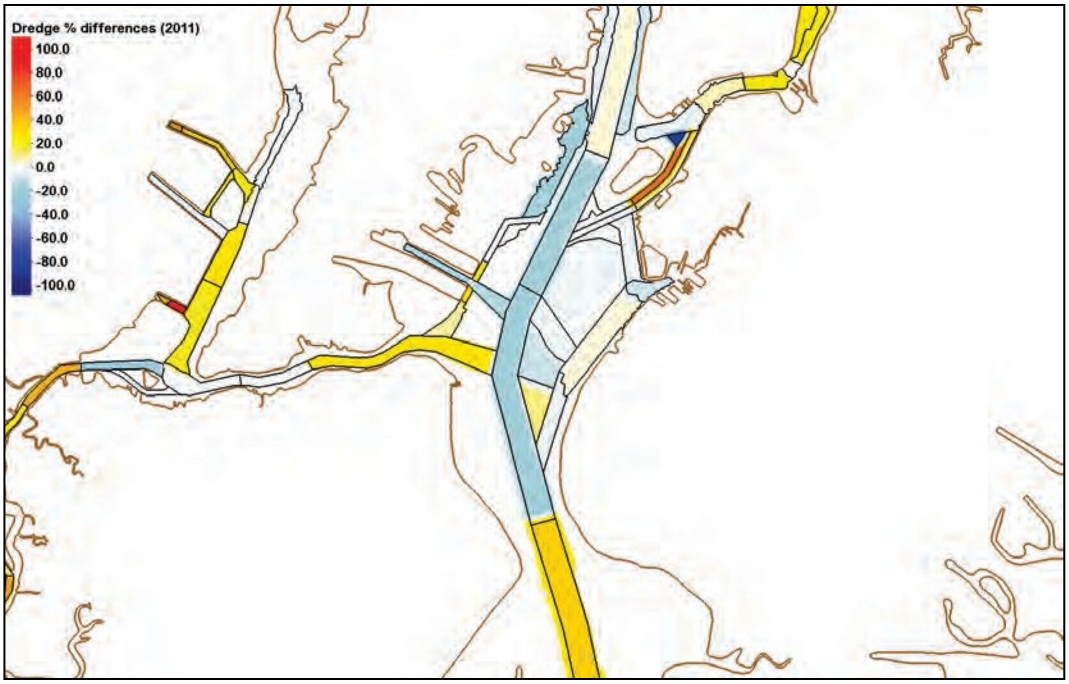
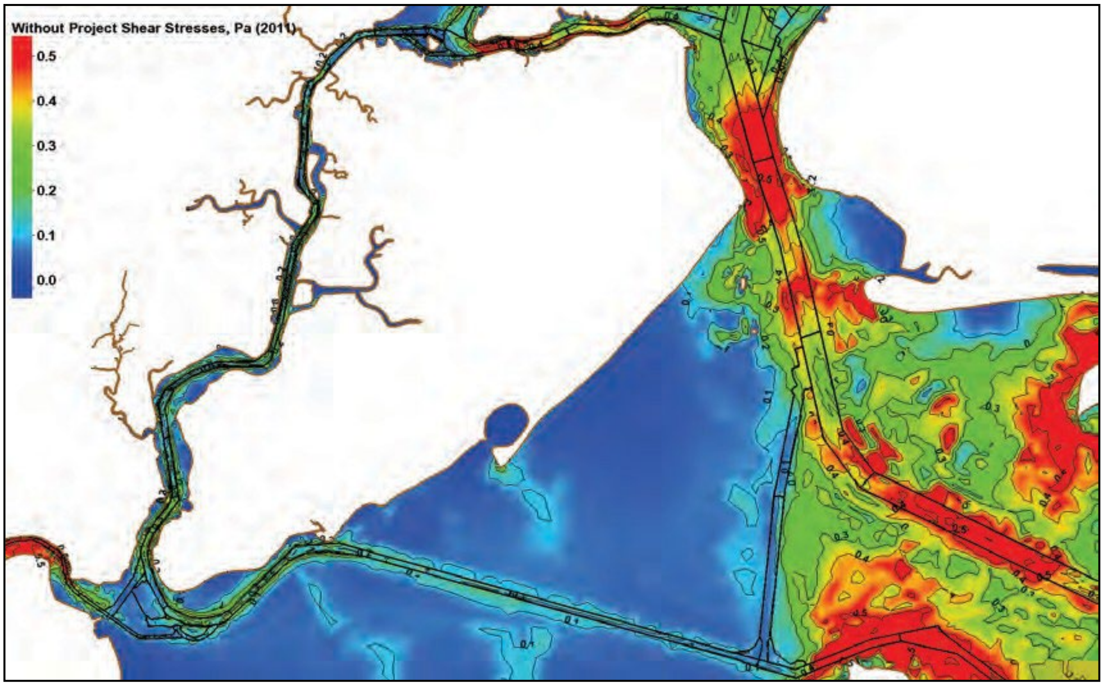


Table 35. Dredge volumes for Newark Bay, Kill van Kull, and Upper Bay (2011).

Depositional Volumes in Newark Bay, Kill van Kull, and Upper Bay, cy (2011)			
Reach	Without Project	With Project	With/Without Dredge Percentage
Newark Bay			
Newark Bay Reach A	317,327	372,027	117
Newark Bay Reach B	321,599	411,907	128
Newark Bay Reach B1	5,279	5,391	102
Newark Bay Reach C	4,471	4,376	98
Newark Bay Reach D	65,904	79,366	120
Newark Bay Reach E	61,929	82,445	133
Newark Bay Reach E1	7,150	10,801	151
Newark Bay Reach F	25,474	30,355	119
Newark Bay Reach G	280,325	270,799	97
Newark Bay Reach I	7,229	18,029	249
Newark Bay Reach I1	7,480	10,813	145
Kill van Kull			
NY&NJ Channels Reach A	43,736	56,159	128
NY&NJ Channels Reach B	601	593	99
NY&NJ Channels Reach C	61,398	60,702	99
Upper Bay			
Anchorage Channel Reach A	56,696	45,424	80
Anchorage Channel Reach A1	21,793	17,564	81
Anchorage Reach C1	8,752	8,652	99
Bay Ridge & Red Hook Reach A	16,723	15,909	95
Bay Ridge & Red Hook Reach B	158,204	162,998	103
Bay Ridge & Red Hook Reach C	58,923	52,727	89
Bay Ridge & Red Hook Reach D	57,356	55,795	97
Red Hook Flats Anch. Reach A	13,116	14,446	110
Red Hook Flats Anch. Reach B	34,266	30,210	88
Red Hook Flats Anch. Reach C	61,788	59,765	97
Red Hook Flats Anch. Reach D	150,840	146,815	97
Port Jersey Reach A	51,303	42,639	83
NJ Pierhead Ch. Reach A	11,058	11,882	107
NJ Pierhead Ch. Reach B	8,190	9,669	118
NJ Pierhead Reach C	12,430	12,257	99
Liberty Reach A	8,764	7,058	81

Arthur Kill and Raritan Bay results

Figure 323. Without-project (top) and with-project (bottom) average shear stresses, Pa (2011).



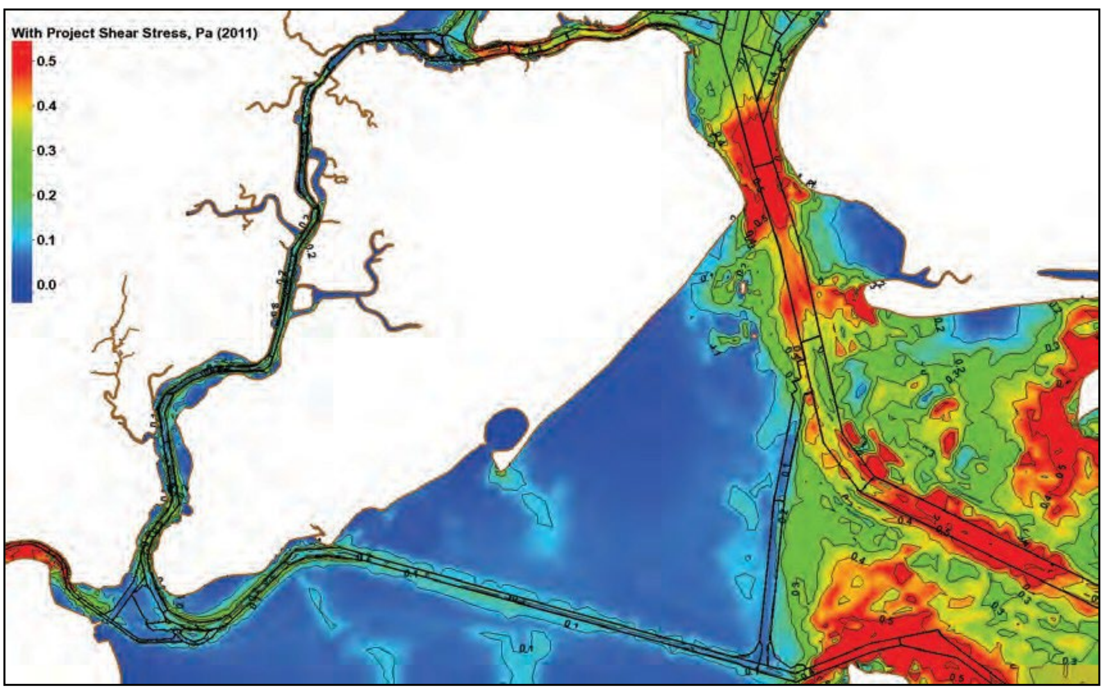


Figure 324. Without-project (top) and with-project (bottom) average bottom salinity, ppt (2011).

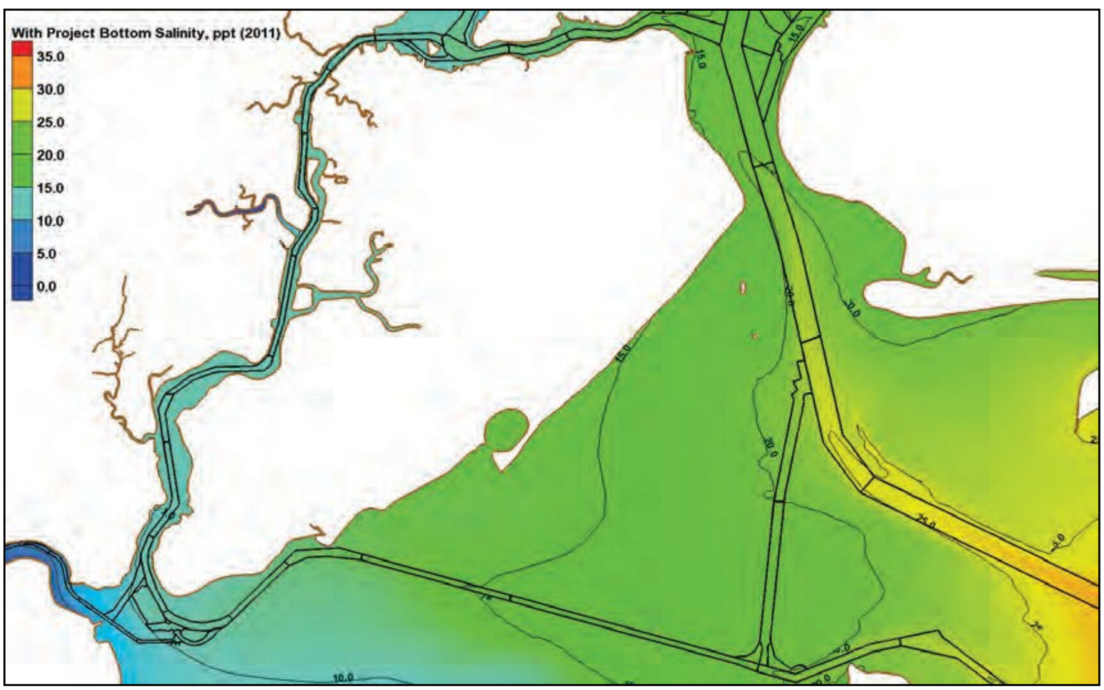


Figure 325. Without-project (top) and with-project (bottom) average fine sediment bottom concentrations, ppm (2011).

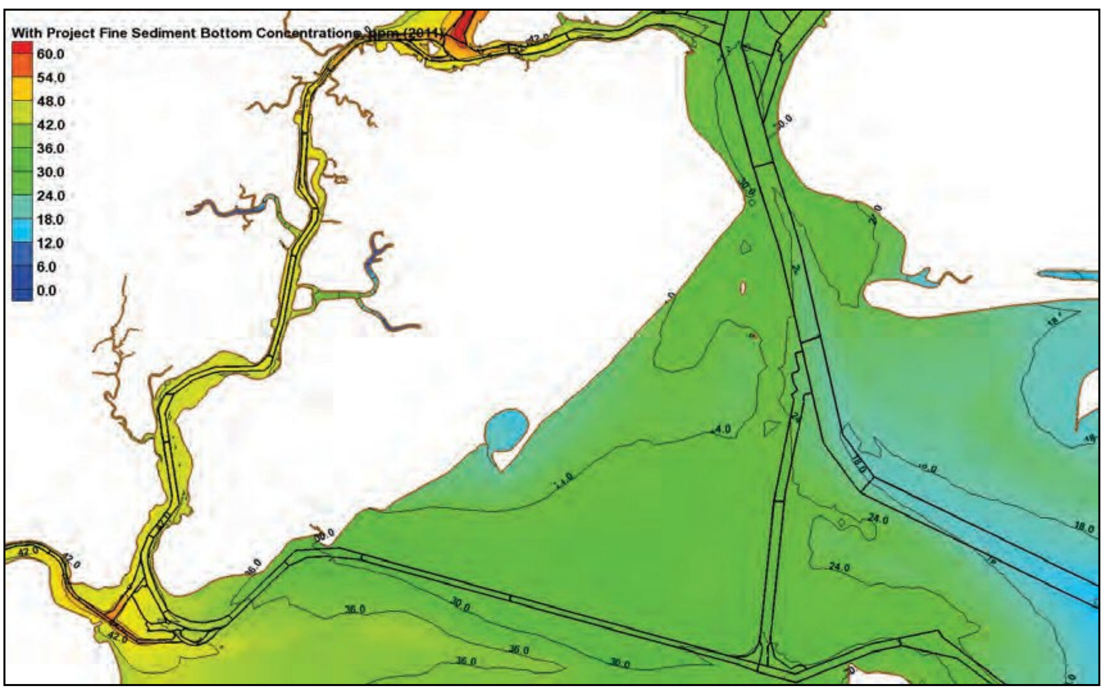
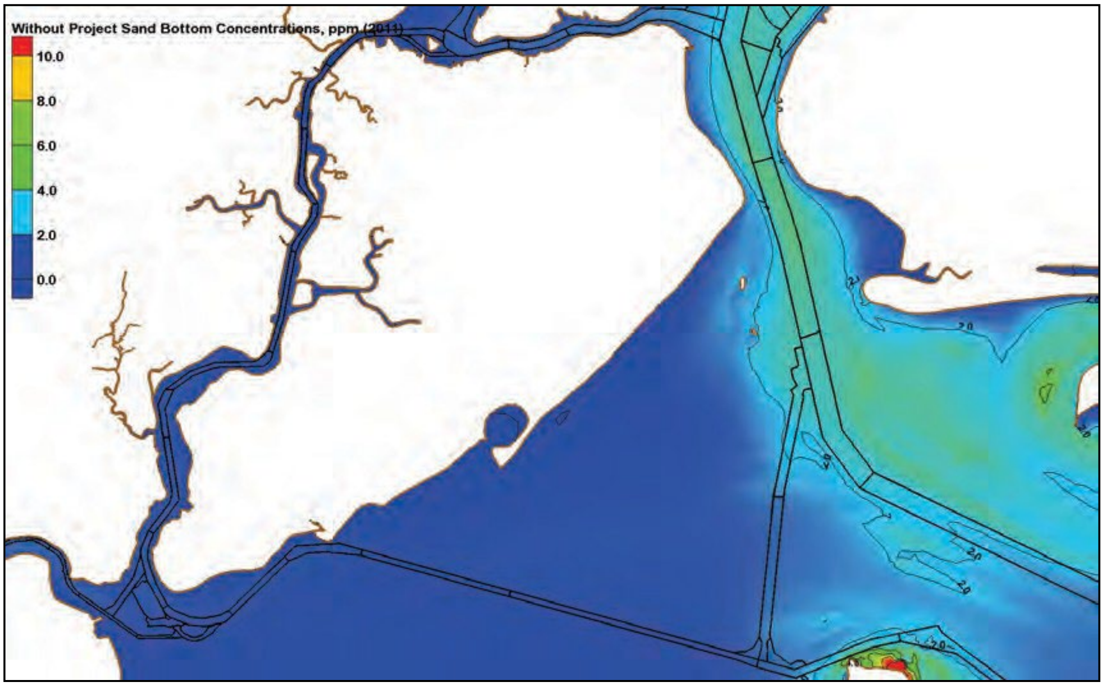


Figure 326. Without-project (top) and with-project (bottom) average sand bottom concentrations, ppm (2011).



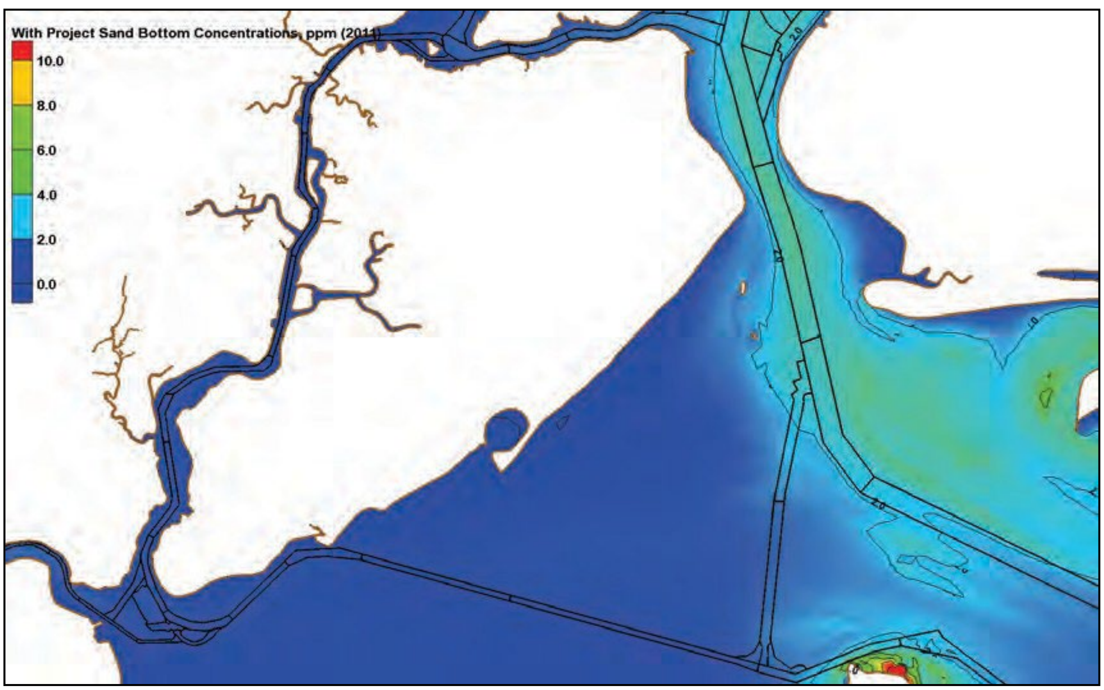


Figure 327. Without-project (top) and with-project (bottom) bed displacement, m (2011).

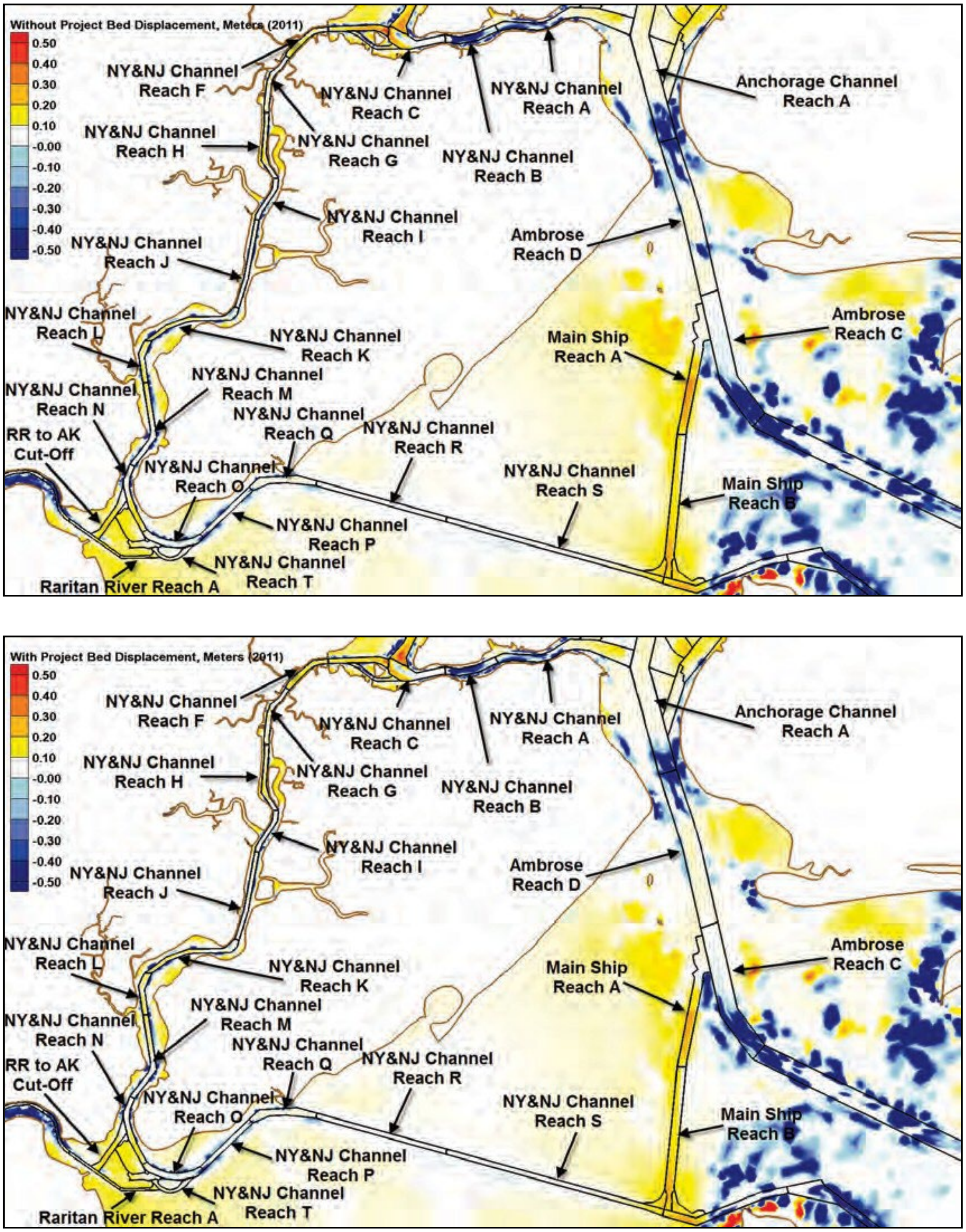
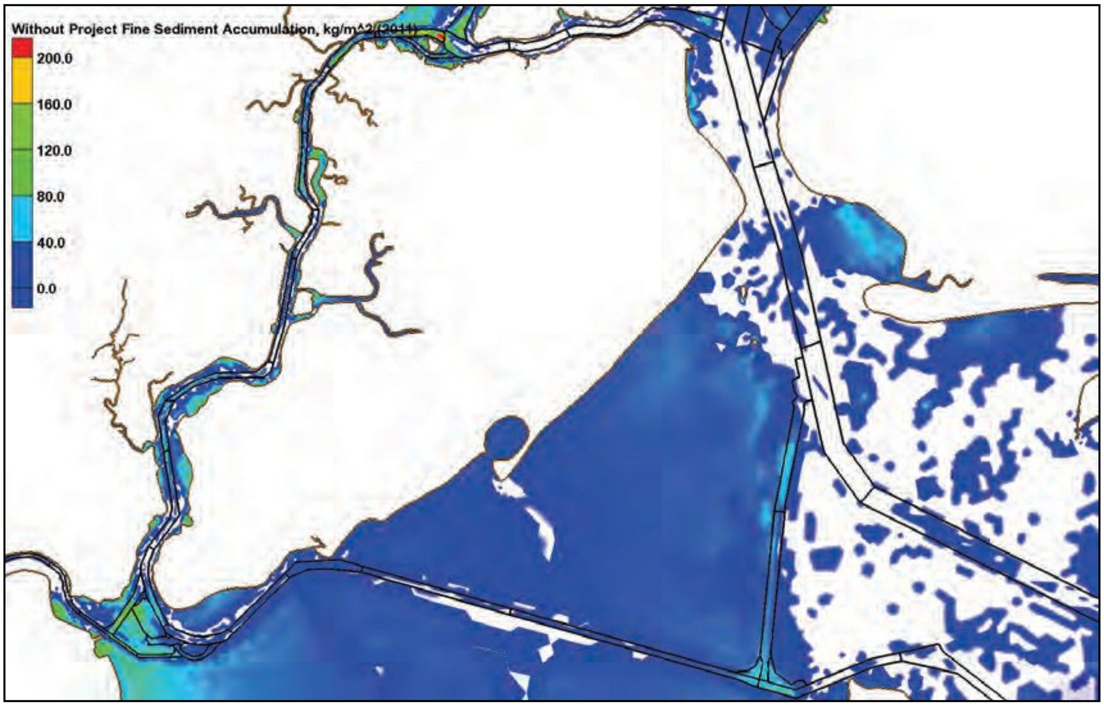


Figure 328. . Without-project (top) and with-project (bottom) fine sediment accumulation, kg/m² (2011).



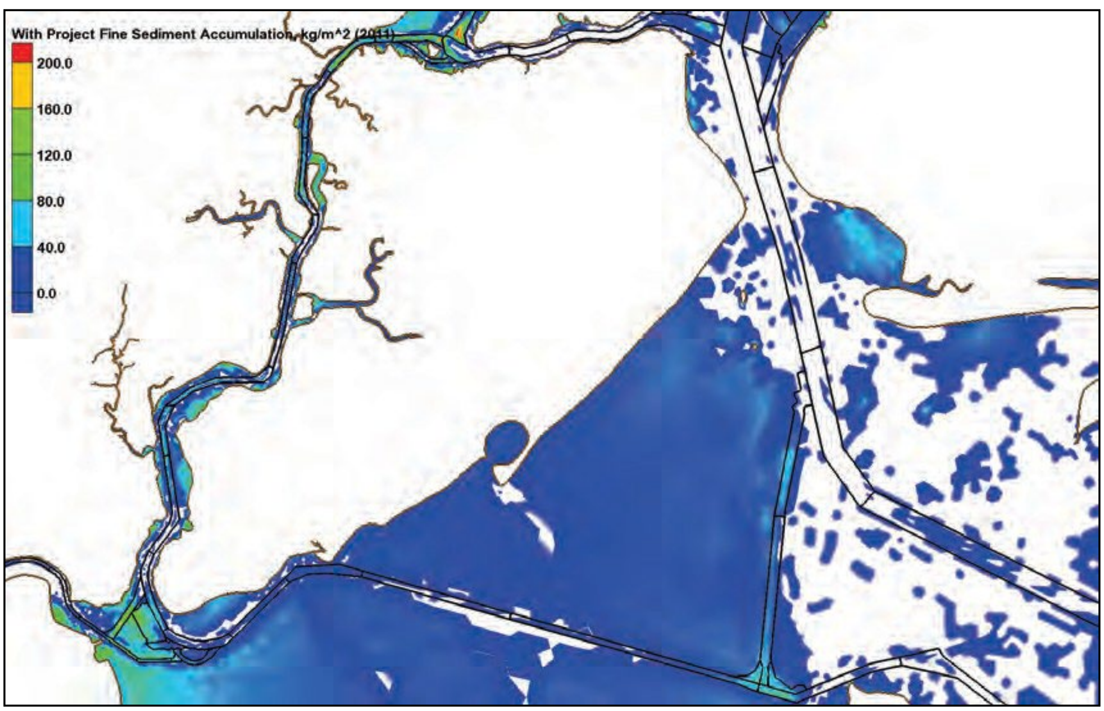
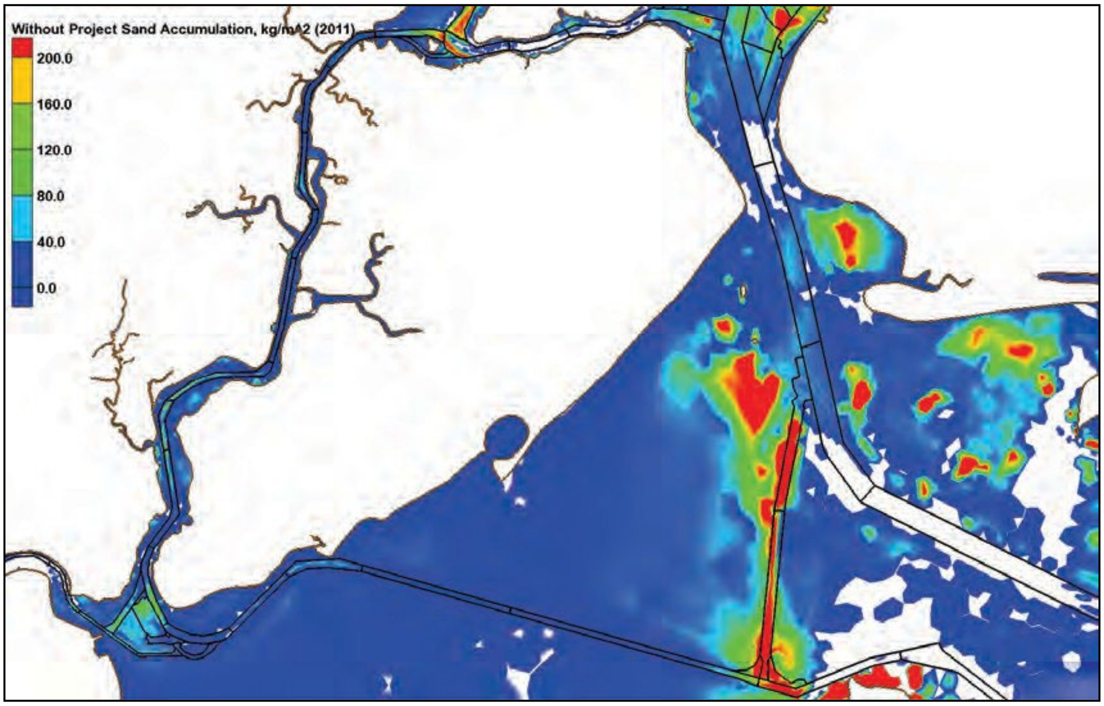


Figure 329. Without-project (top) and with-project (bottom) sand accumulation, kg/m² (2011).



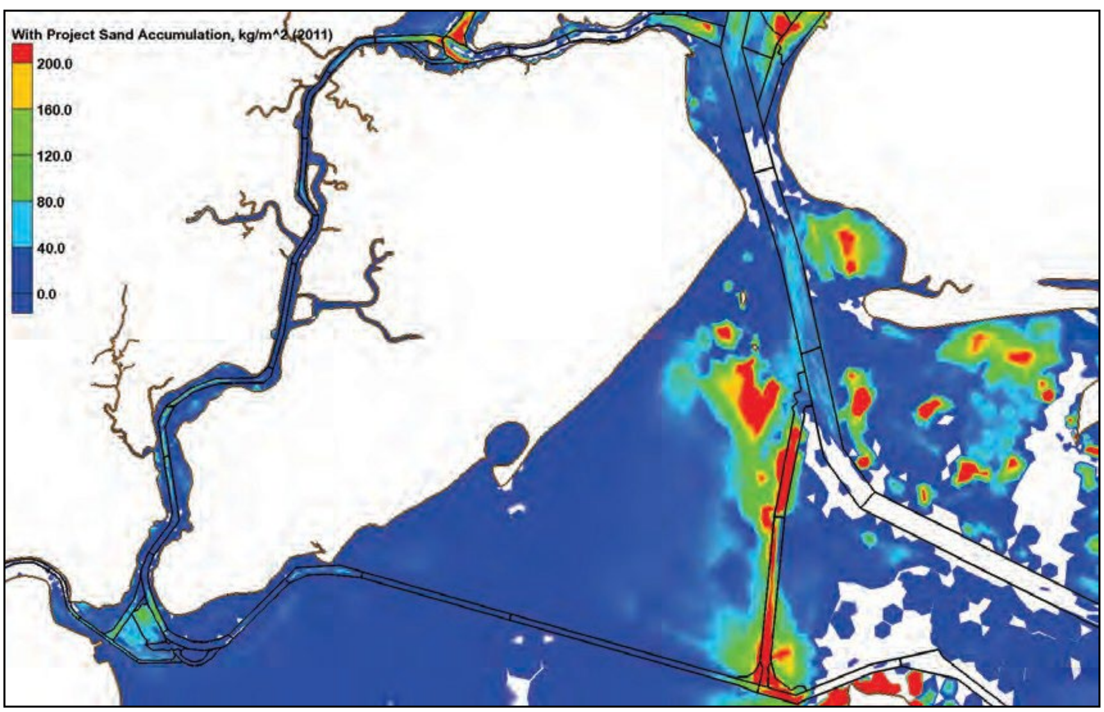


Figure 330. Dredge With-project/without-project percent differences (2011).

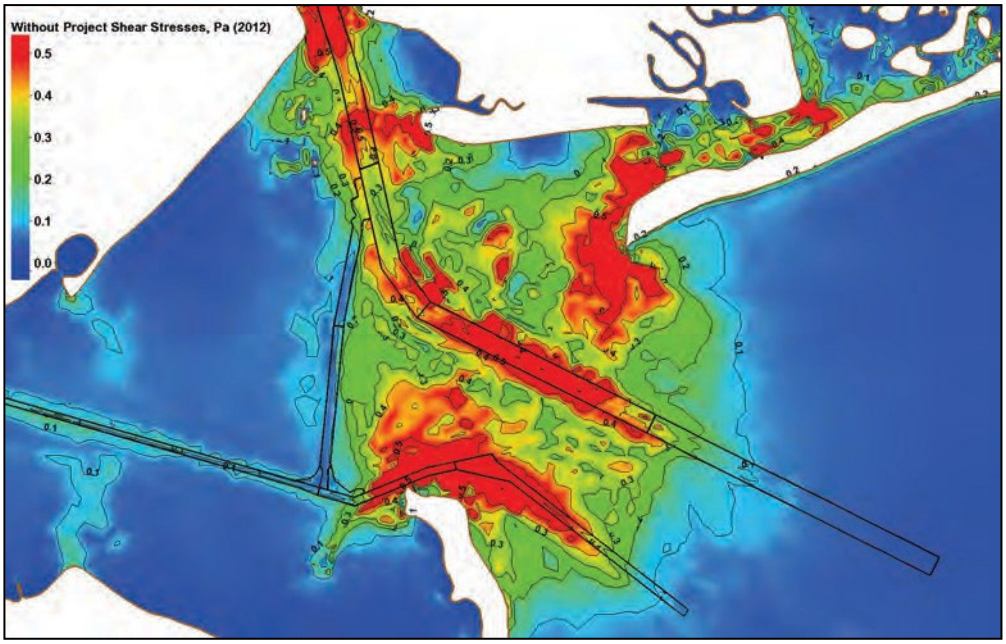
Table 36. Dredge volumes for Arthur Kill and Raritan Bay (2011).

Depositional Volumes in Arthur Kill and Raritan Bay, cy (2011)			
Reach	Without Project	With Project	With/Without Dredge Percentage
Arthur Kill			
NY&NJ Channels Reach D	72,937	55,311	76
NY&NJ Channels Reach E	11,094	11,005	99
NY&NJ Channels Reach F	18,510	26,534	143
NY&NJ Channels Reach G	4,449	5,488	123
NY&NJ Channels Reach H	11,359	12,523	110
NY&NJ Channels Reach I	739	1,101	149
NY&NJ Channels Reach J	2,526	3,532	140
NY&NJ Channels Reach K	15,998	16,462	103
NY&NJ Channels Reach L	13,819	13,219	96
NY&NJ Channels Reach M	10,957	11,026	101
NY&NJ Channels Reach N	21,943	19,196	87
Raritan Bay			
NY&NJ Channels Reach O	3,307	3,890	118
NY&NJ Channels Reach P	2,812	2,077	74
NY&NJ Channels Reach Q	6,151	6,075	99
NY&NJ Channels Reach R	423	418	99
NY&NJ Channels Reach T	5,401	5,756	107
RR to AK Cut-Off Reach A	35,173	36,563	104
Raritan River Reach A	10,663	10,985	103
Raritan River Reach B	12,104	12,623	104
Raritan River Reach C	2,009	2,018	100
Raritan River Reach D	86	54	63

Appendix G: Results for 2012

Lower Bay results

Figure 331. Without-project (top) and with-project (bottom) average shear stresses, Pa (2012).



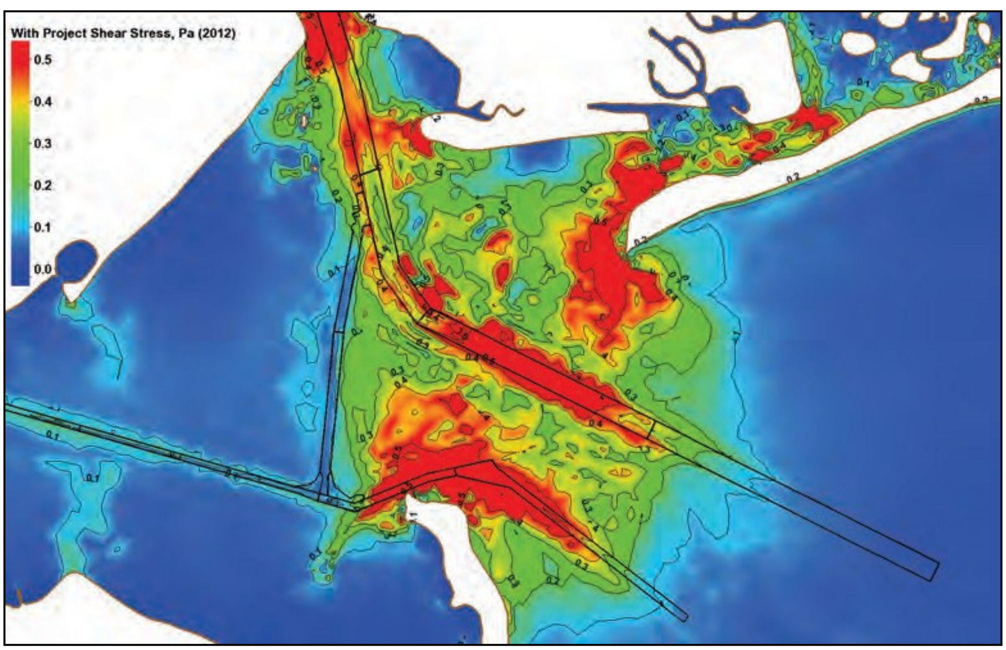
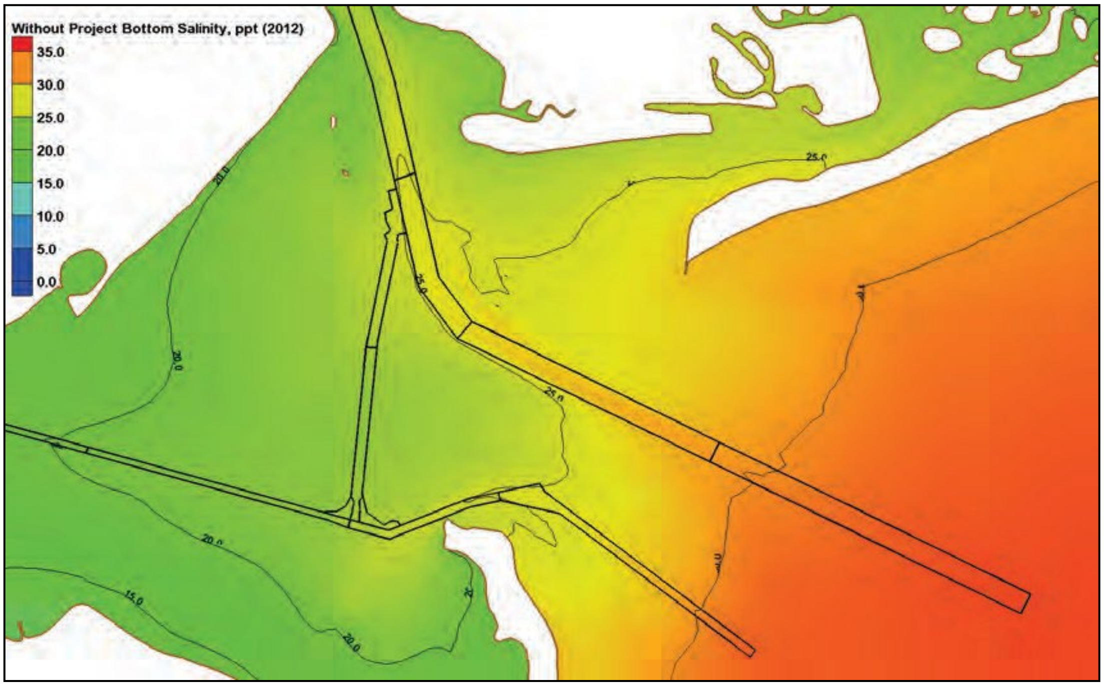


Figure 332. Without-project (top) and with-project (bottom) average bottom salinity, ppt (2012).



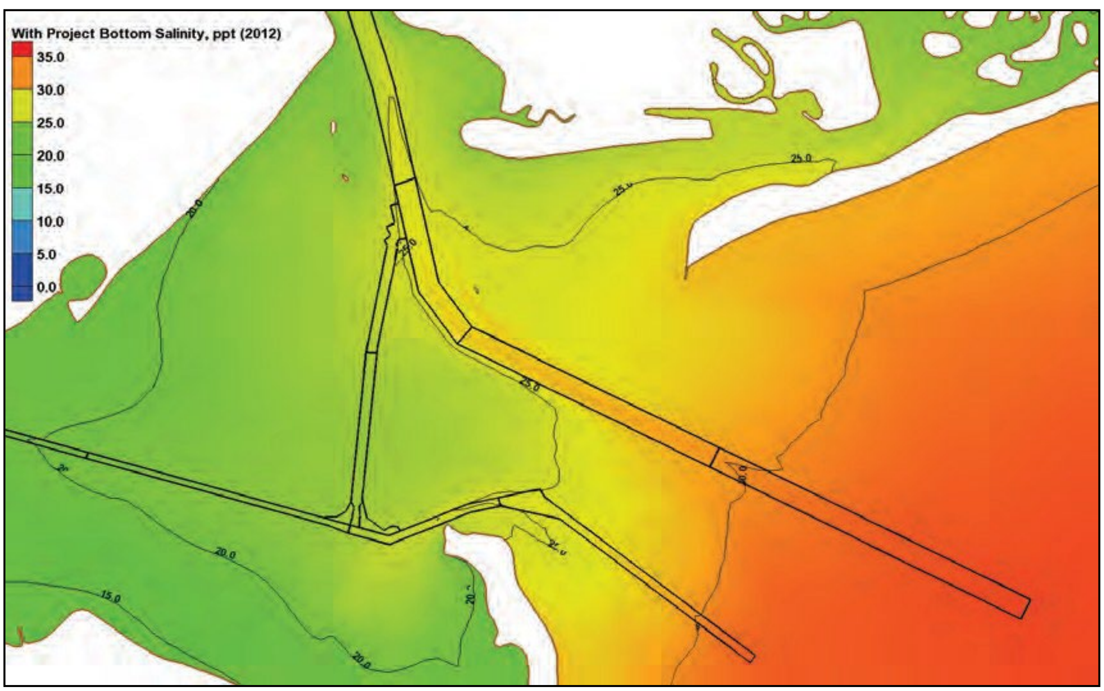
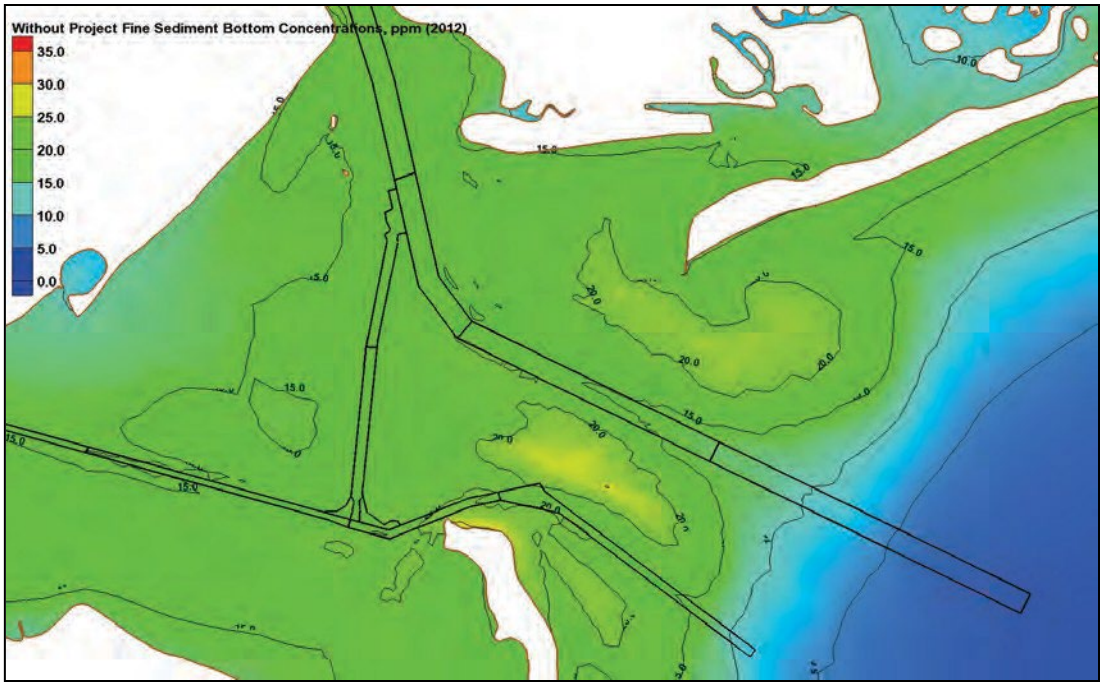


Figure 333. Without-project (top) and with-project (bottom) average fine sediment bottom concentrations, ppm (2012),



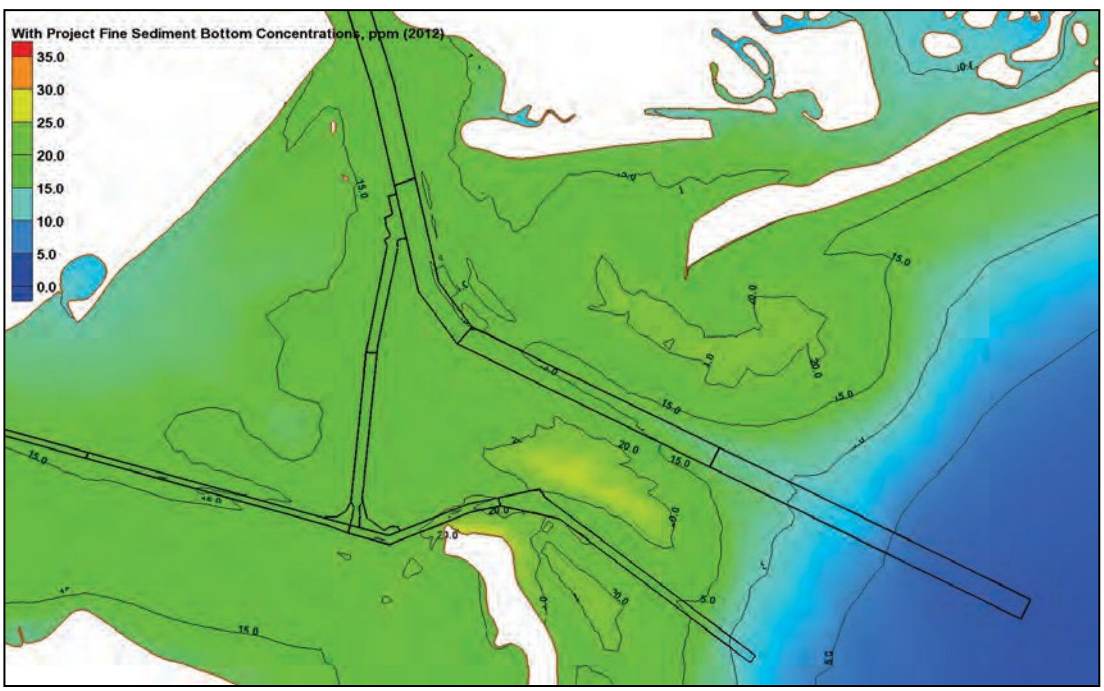
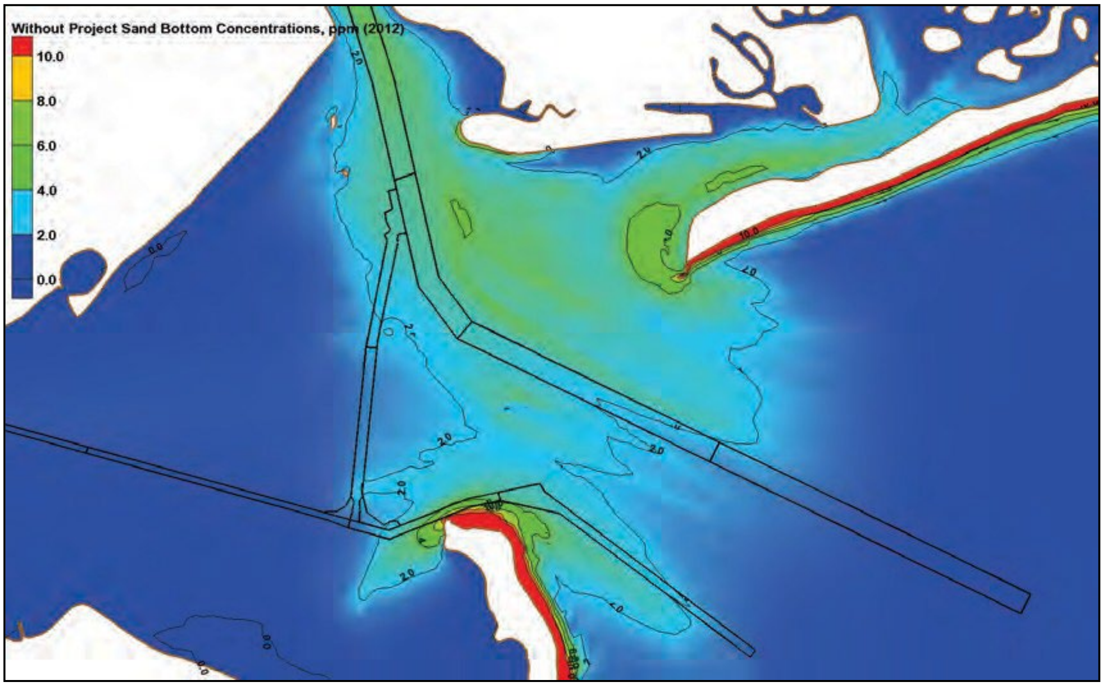


Figure 334. Without-project (top) and with-project (bottom) average sand bottom concentrations, ppm (2012).



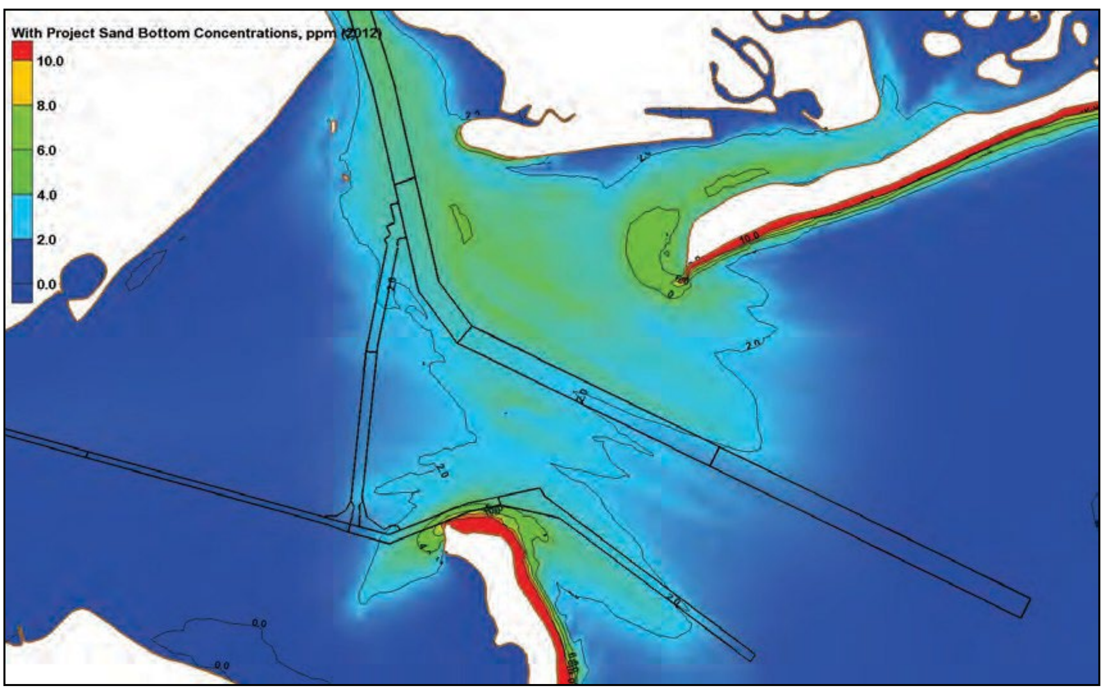


Figure 335. Without-project (top) and with-project (bottom) bed displacement, m (2012).

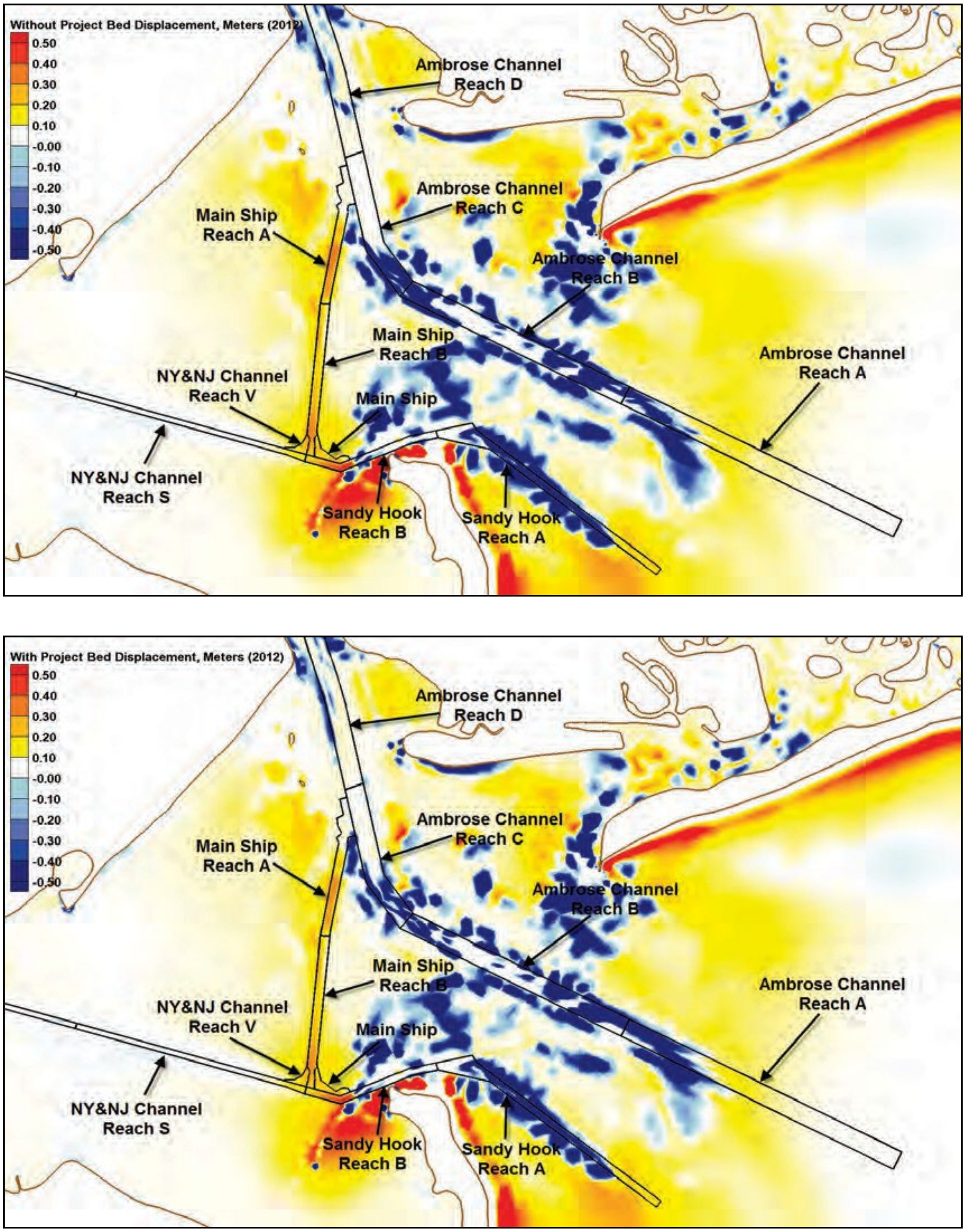
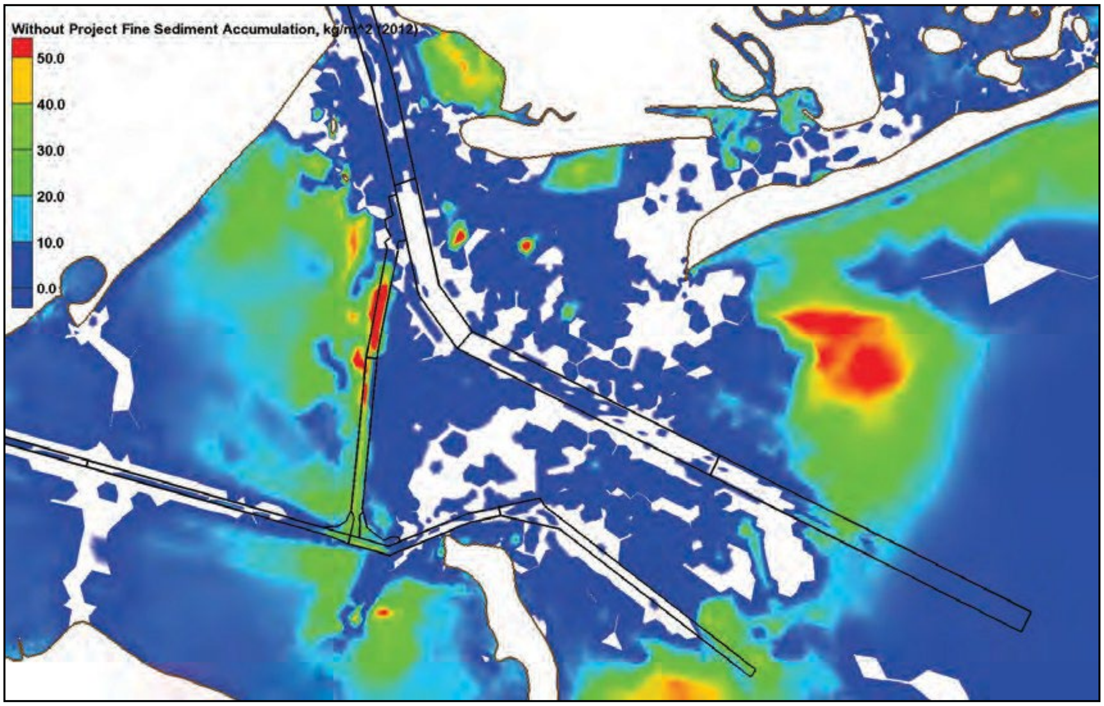


Figure 336. Without-project (top) and with-project (bottom) fine sediment accumulation, kg/m² (2012).



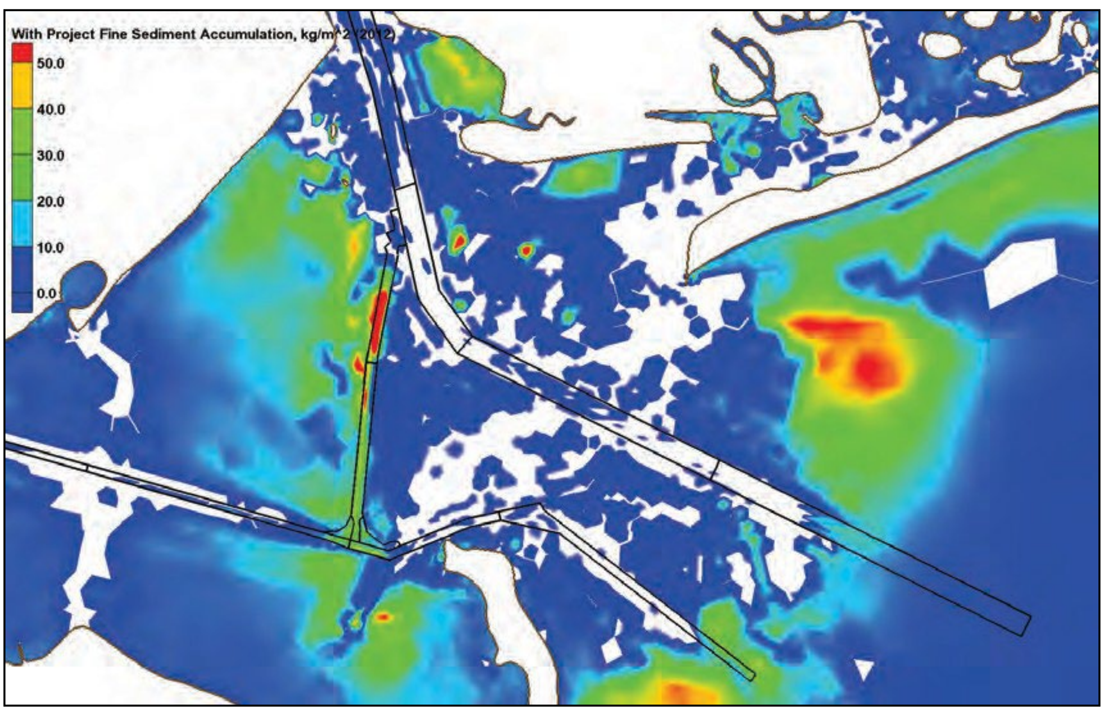
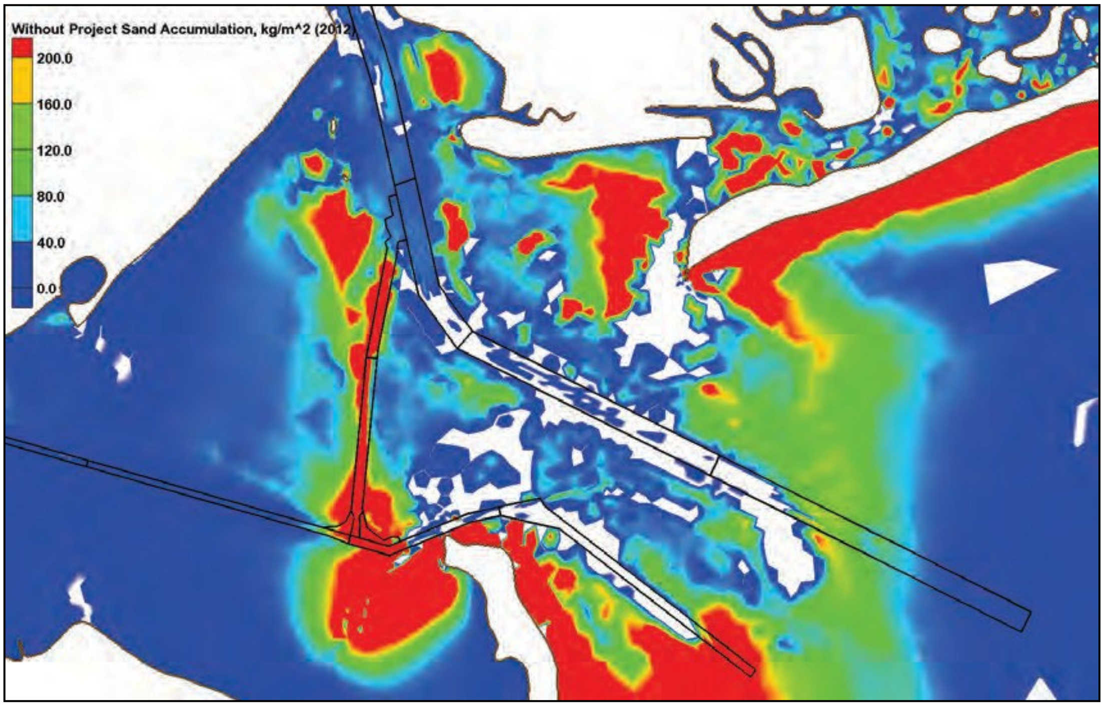


Figure 337. Without-project (top) and with-project (bottom) sand accumulation, kg/m² (2012).



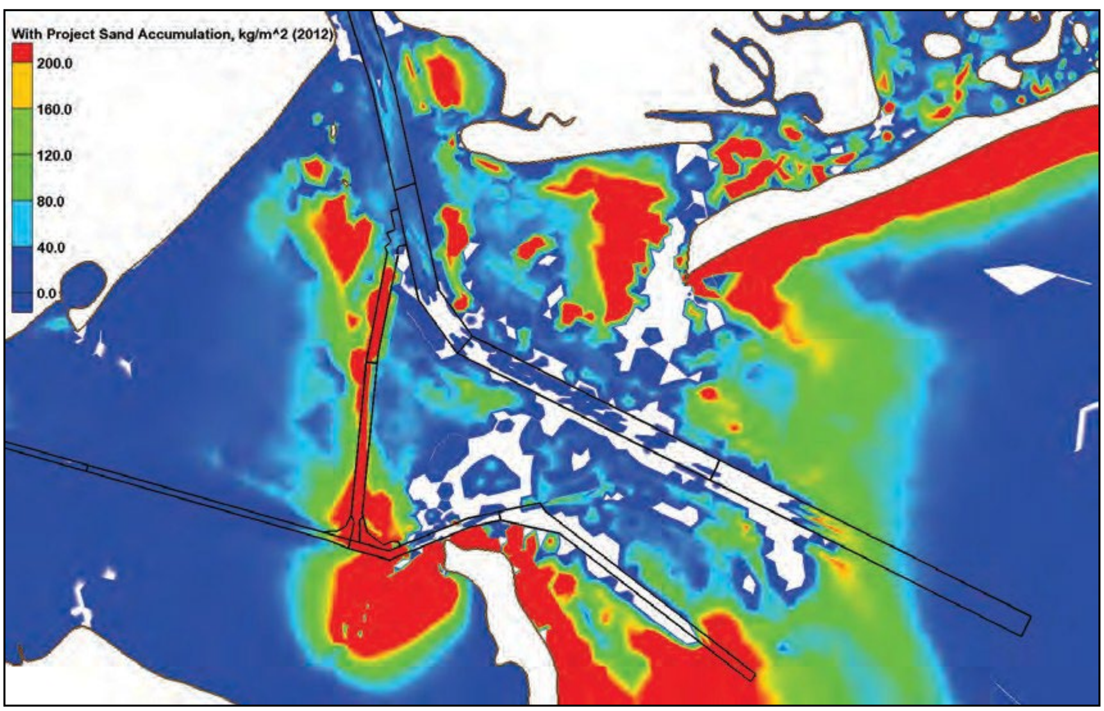


Figure 338. Dredge with-project/without-project percent differences (2012).

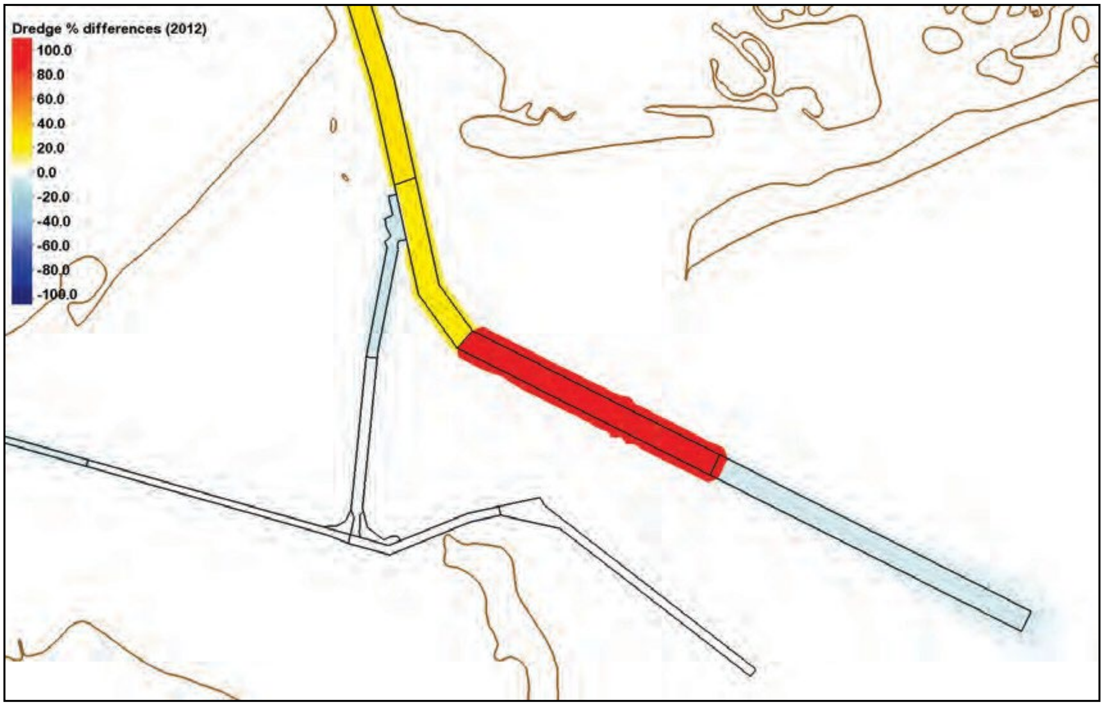
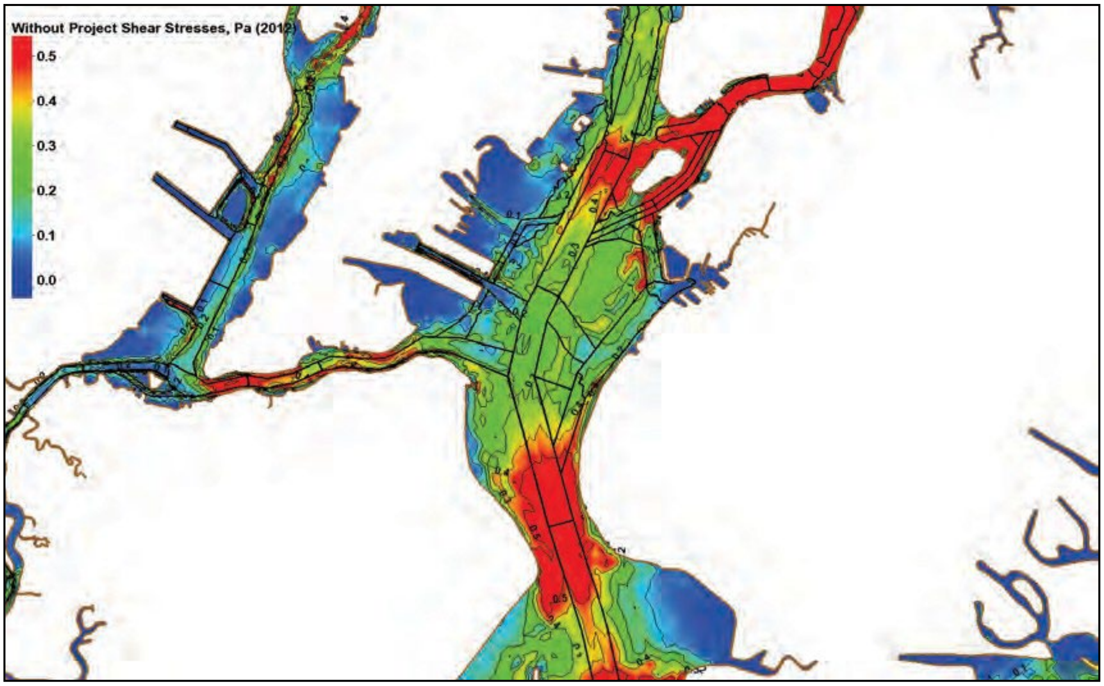


Table 37. Dredge volumes in Lower Bay (2012).

Depositional Volumes in Lower Bay, cy (2012)			
Reach	Without Project	With Project	With/Without Dredge Percentage
Ambrose Channel Reach A	191,714	173,980	91
Ambrose Channel Reach B	0	55	N/A
Ambrose Channel Reach C	12,088	15,297	127
Ambrose Channel Reach D	39,248	50,605	129
Main Ship	64,042	62,307	97
Main Ship Reach A	225,162	200,474	89
Main Ship Reach B	293,451	284,928	97
Sandy Hook Reach A	89,848	89,724	100
Sandy Hook Reach B	134,060	132,788	99
NY&NJ Channels Reach S	28,982	28,225	97
NY&NJ Channels Reach V	38,676	37,442	97

Newark Bay, Kill van Kull, and Upper Bay results

Figure 339. Without-project (top) and with-project (bottom) average shear stresses, Pa (2012).



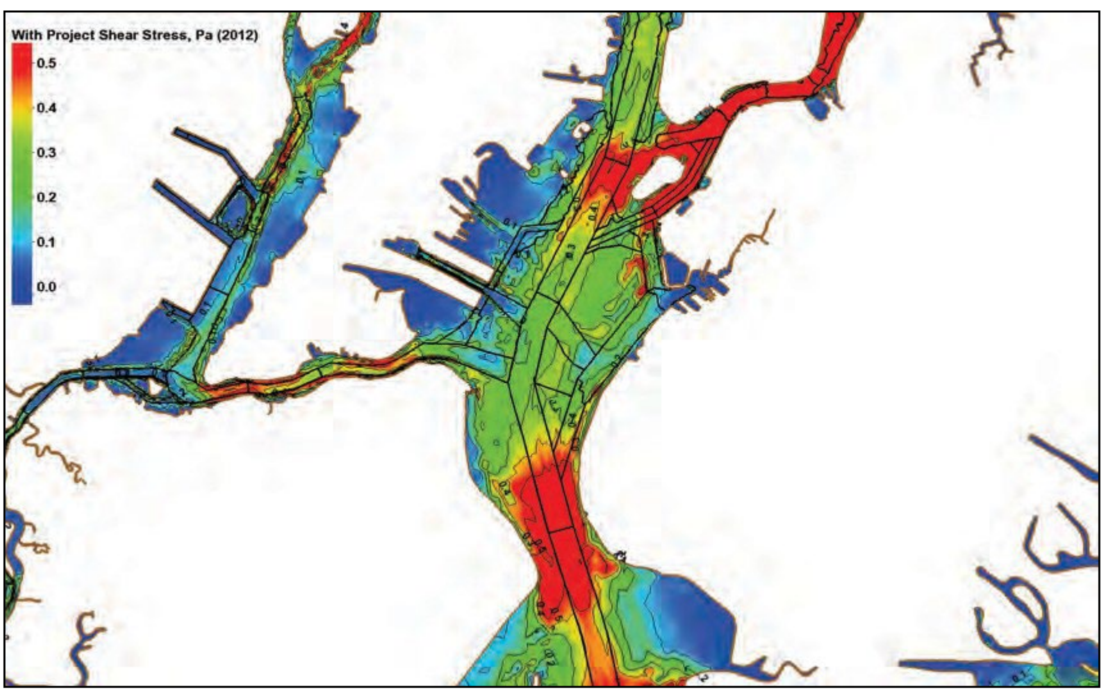


Figure 340. Without-project (top) and with-project (bottom) average bottom salinity, ppt (2012).

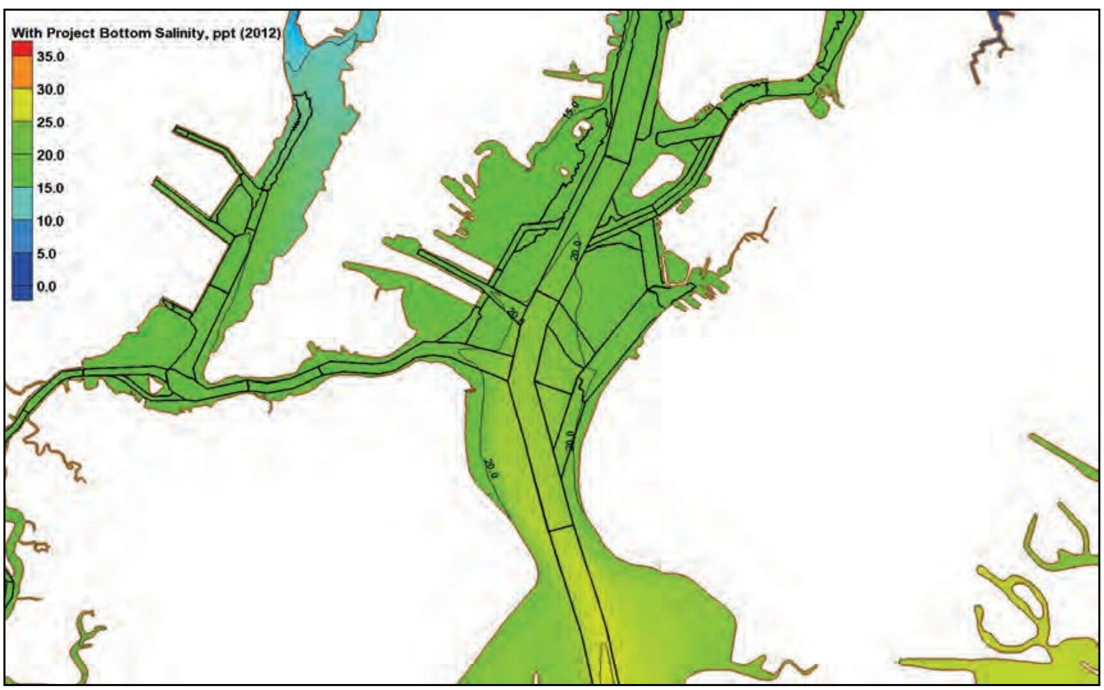
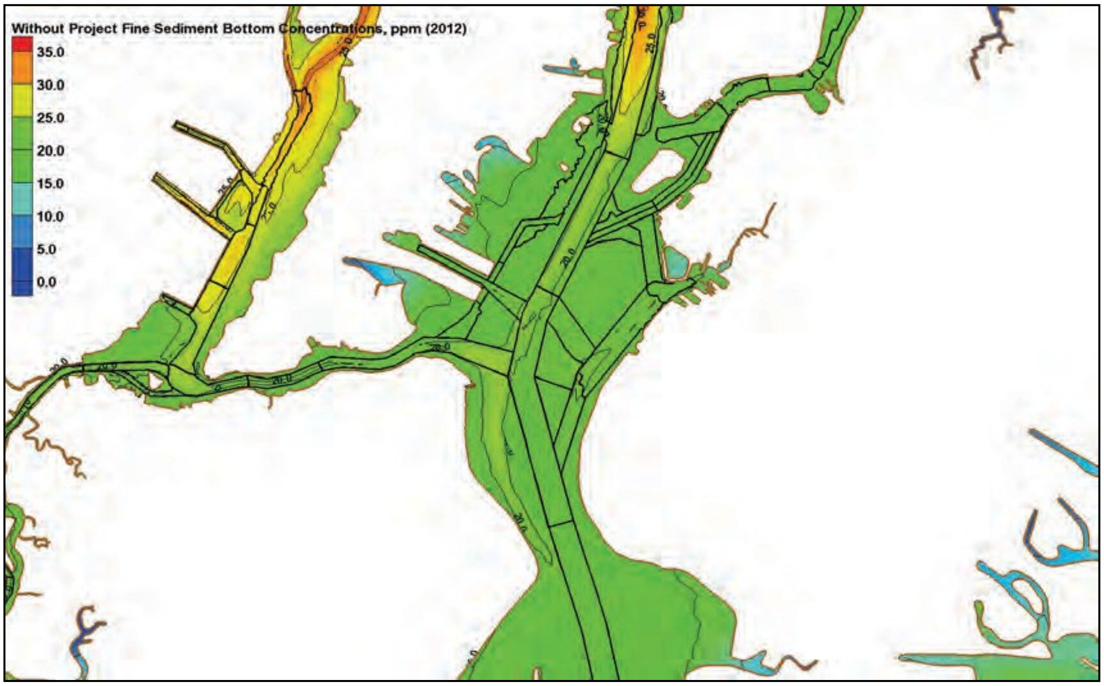


Figure 341. Without-project (top) and with-project (bottom) average fine sediment bottom concentrations, ppm (2012).



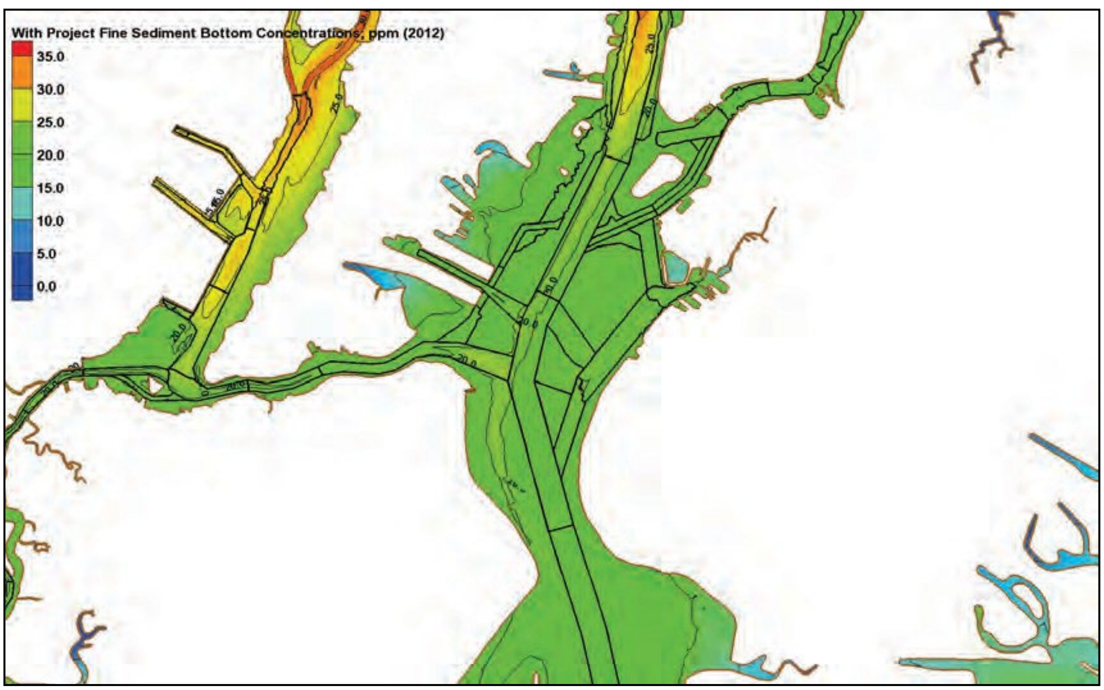
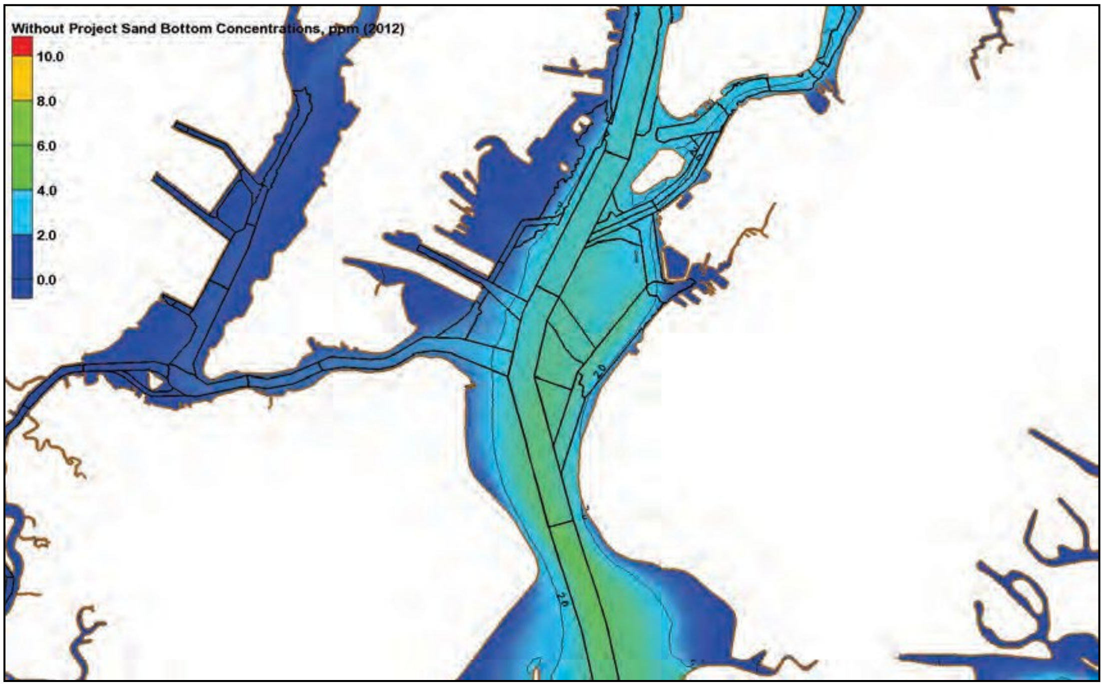


Figure 342. Without-project (top) and with-project (bottom) average sand bottom concentrations, ppm (2012).



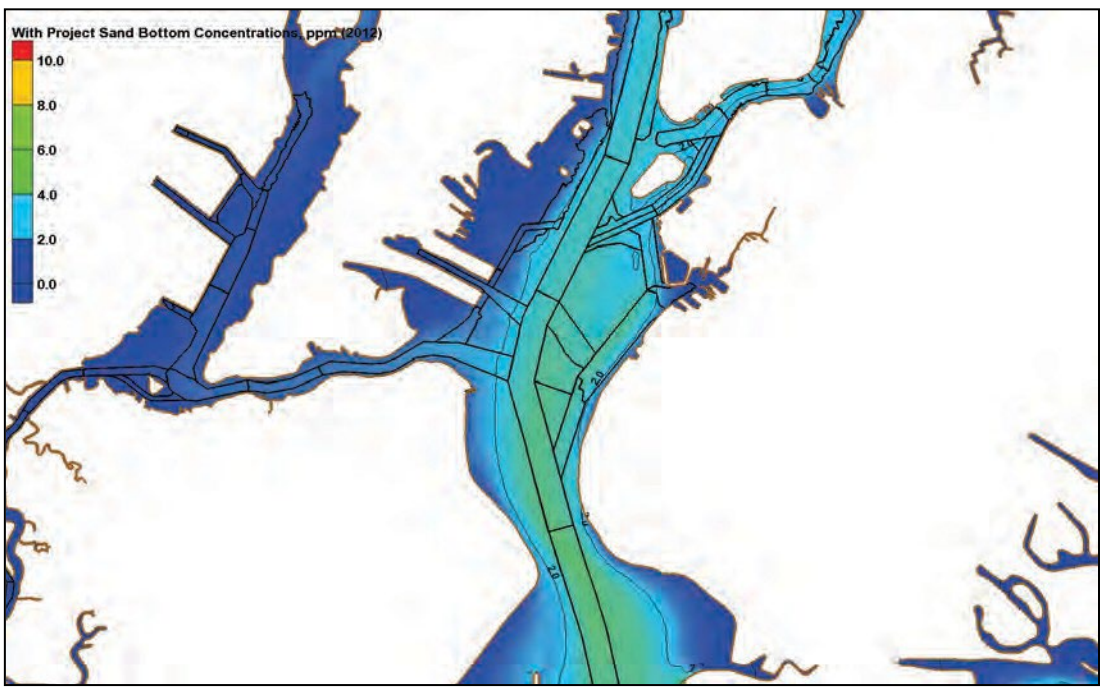
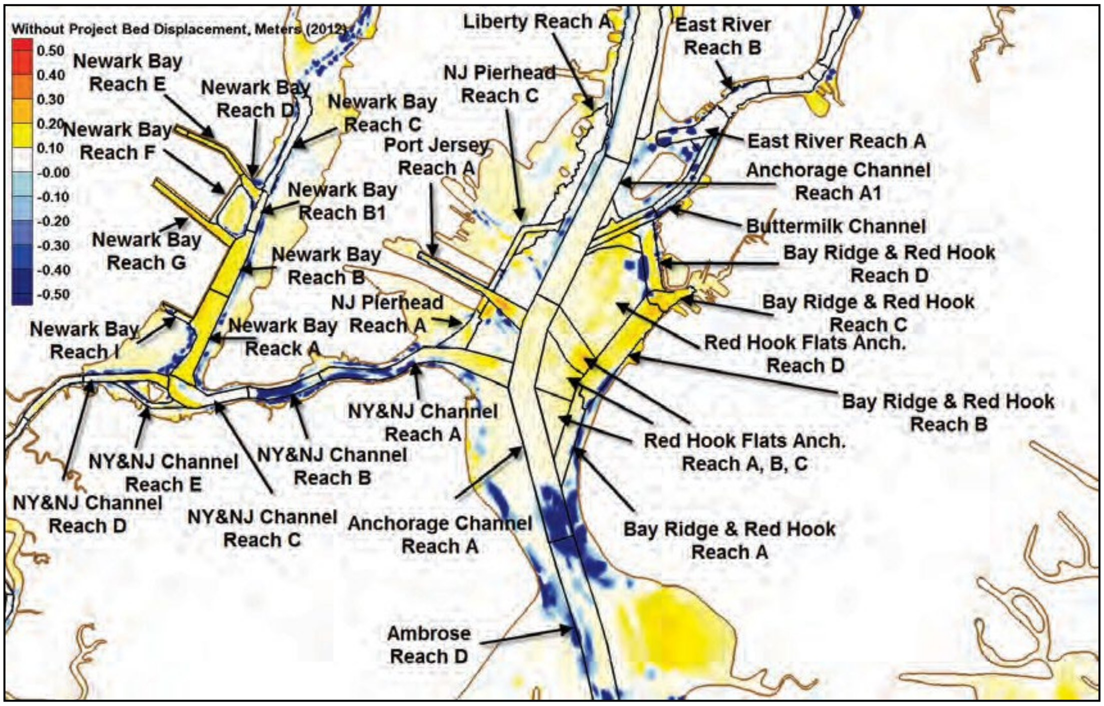


Figure 343. Without-project (top) and with-project (bottom) bed displacement, m (2012).



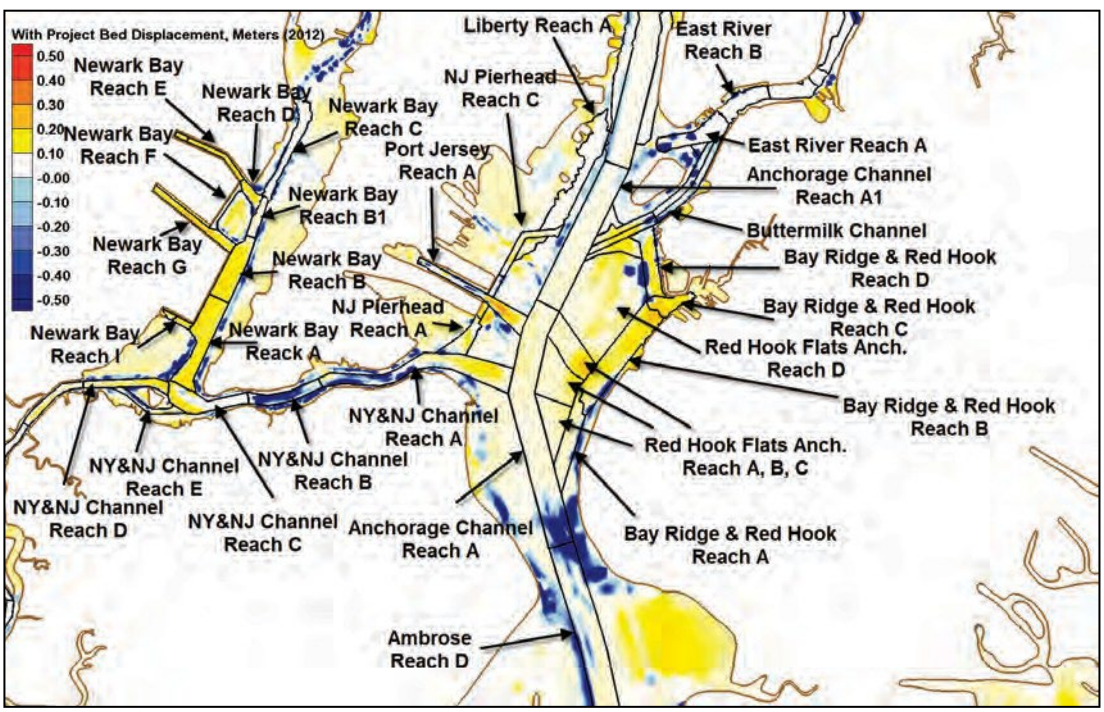


Figure 344. Without-project (top) and with-project (bottom) fine sediment accumulation, kg/m² (2012).

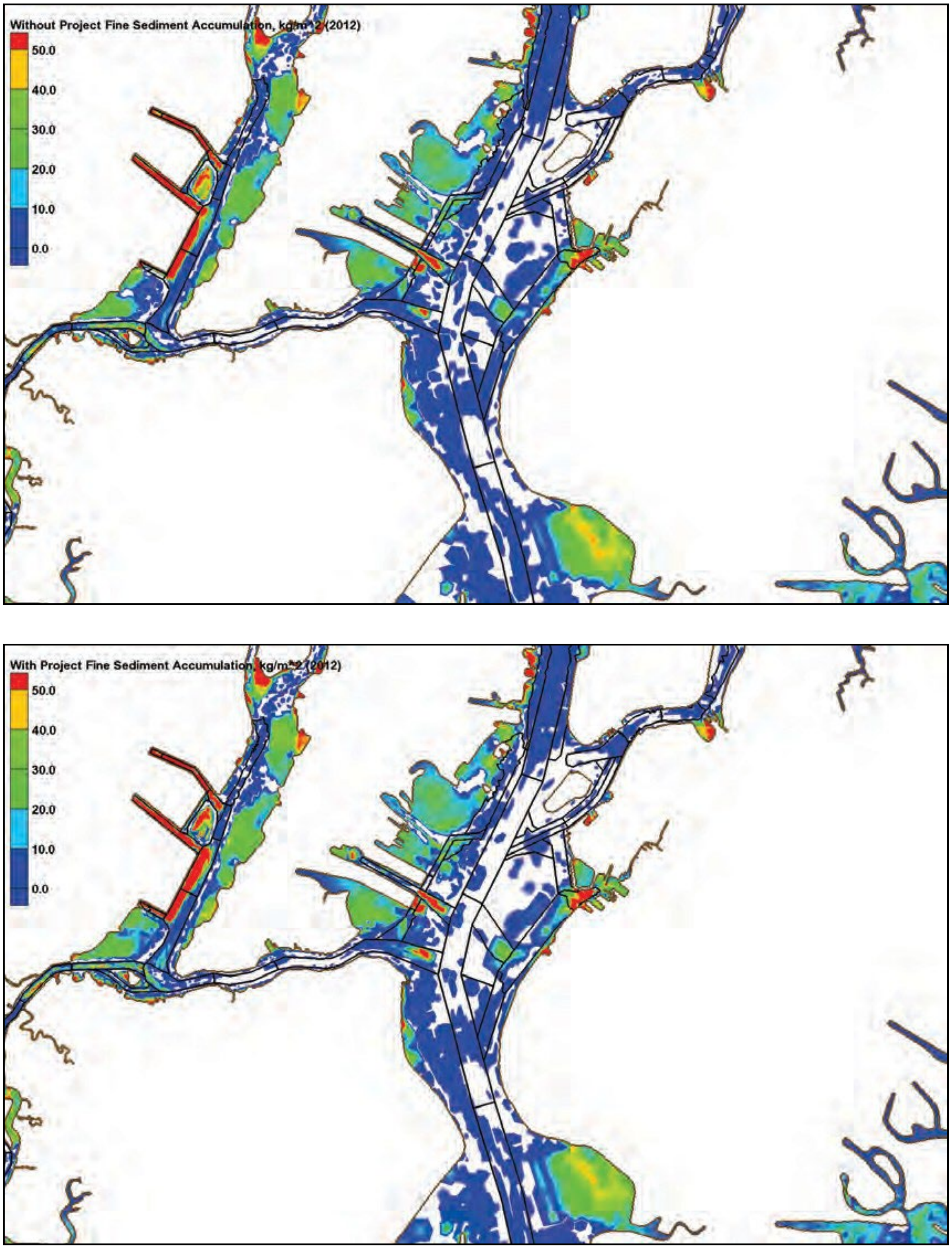
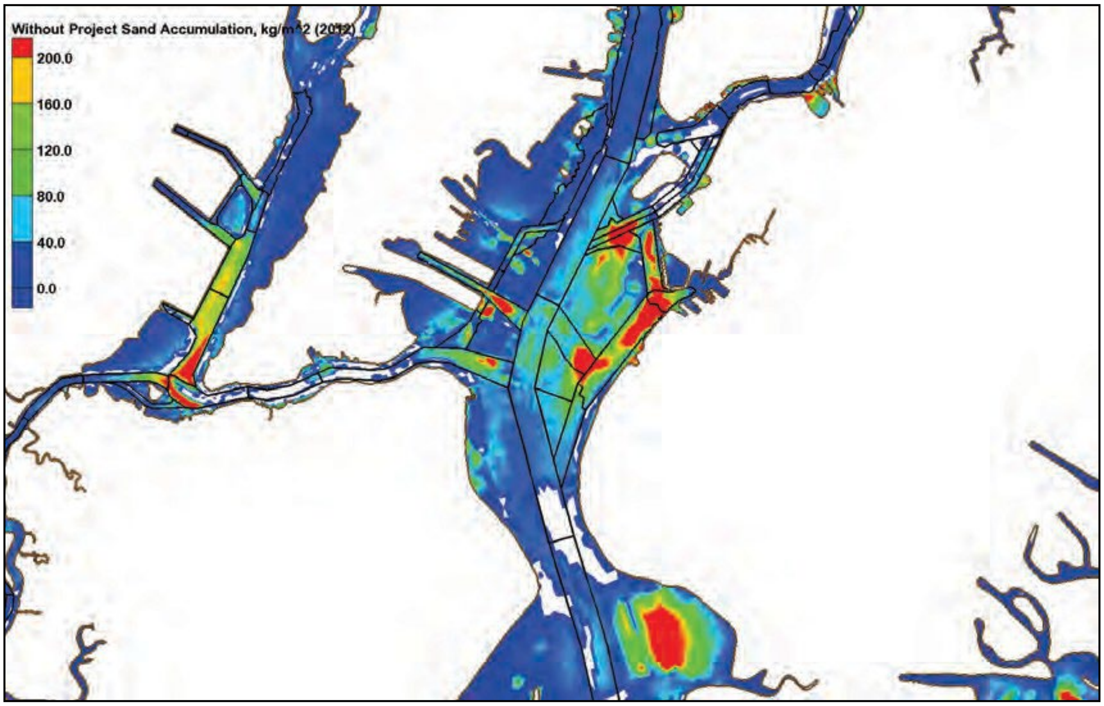


Figure 345. Without-project (top) and with-project (bottom) sand accumulation, kg/m² (2012).



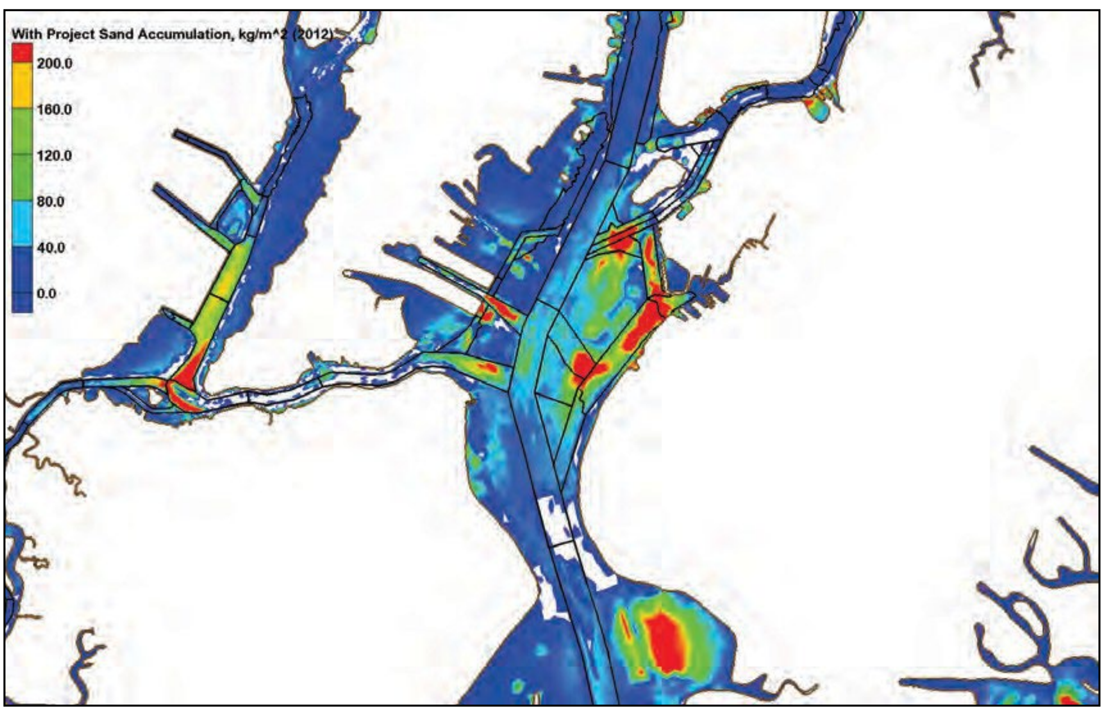


Figure 346. Dredge with-project/without-project percent differences (2012).

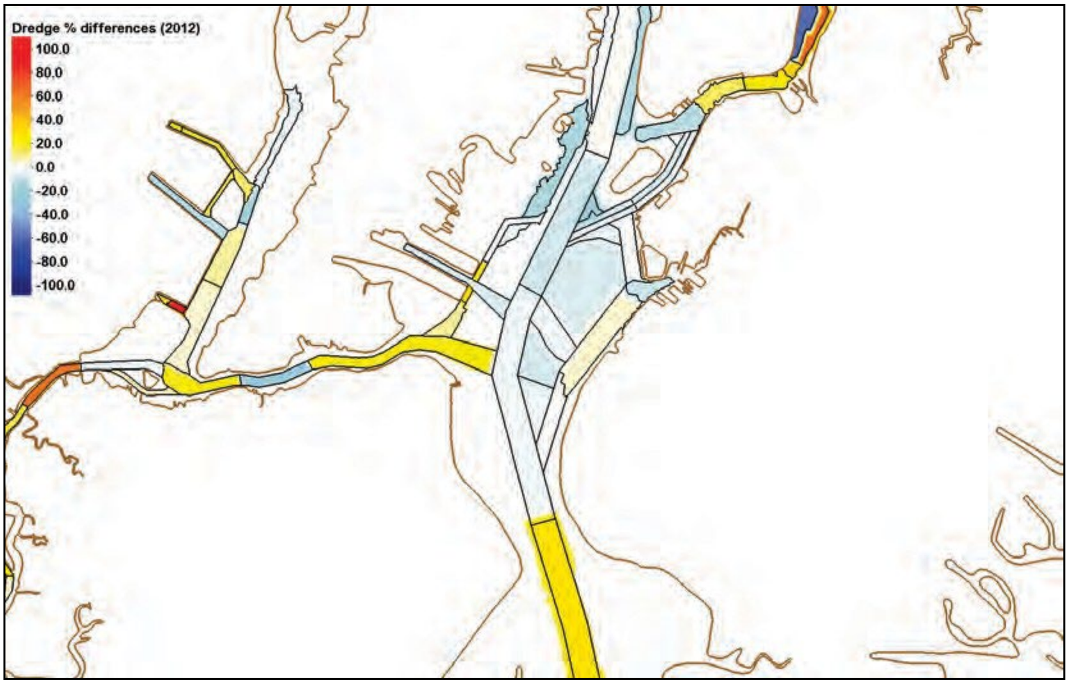


Table 38. Dredge volumes in Newark Bay, Kill van Kull, and Upper Bay (2012).

Depositional Volumes in Newark Bay, Kill van Kull, and Upper Bay, cy (2012)			
Reach	Without Project	With Project	With/Without Dredge Percentage
Newark Bay			
Newark Bay Reach A	132,574	137,619	104
Newark Bay Reach B	87,238	93,803	108
Newark Bay Reach B1	3,839	3,088	80
Newark Bay Reach C	2,131	2,034	95
Newark Bay Reach D	14,445	16,109	112
Newark Bay Reach E	22,738	26,199	115
Newark Bay Reach E1	3,310	3,875	117
Newark Bay Reach F	3,453	3,904	113
Newark Bay Reach G	67,863	57,735	85
Newark Bay Reach I	2,821	6,395	227
Newark Bay Reach I1	2,262	3,006	102
Kill van Kull			
NY&NJ Channels Reach A	57,649	68,101	118
NY&NJ Channels Reach B	1,513	1,136	75
NY&NJ Channels Reach C	37,967	44,703	118
Upper Bay			
Anchorage Channel Reach A	68,389	66,433	97
Anchorage Channel Reach A1	37,139	33,485	90
Anchorage Reach C1	8,295	7,970	96
Bay Ridge & Red Hook Reach A	21,676	21,668	100
Bay Ridge & Red Hook Reach B	166,141	172,801	104
Bay Ridge & Red Hook Reach C	56,922	50,402	89
Bay Ridge & Red Hook Reach D	55,422	55,717	101
Red Hook Flats Anch. Reach A	22,465	21,700	97
Red Hook Flats Anch. Reach B	48,265	44,034	91
Red Hook Flats Anch. Reach C	70,280	68,015	97
Red Hook Flats Anch. Reach D	146,744	135,065	92
Port Jersey Reach A	57,080	52,435	92
NJ Pierhead Ch. Reach A	12,135	13,100	108
NJ Pierhead Ch. Reach B	8,371	10,139	121
NJ Pierhead Reach C	10,827	10,746	99
Liberty Reach A	10,687	8,821	83

Arthur Kill and Raritan Bay results

Figure 347. Without-project (top) and with-project (bottom) average shear stresses, Pa (2012).

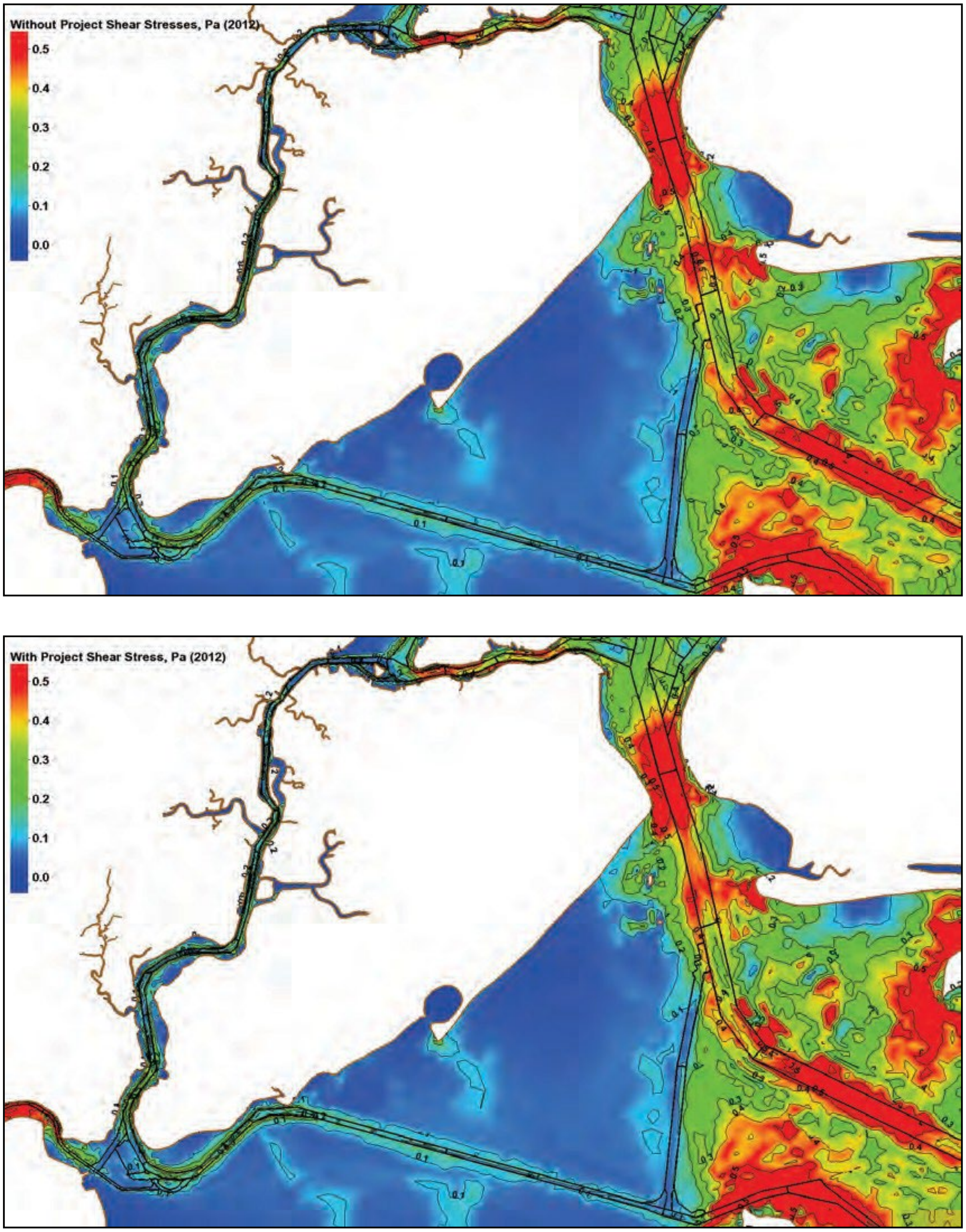


Figure 348. Without-project (top) and with-project (bottom) average bottom salinity, ppt (2012).

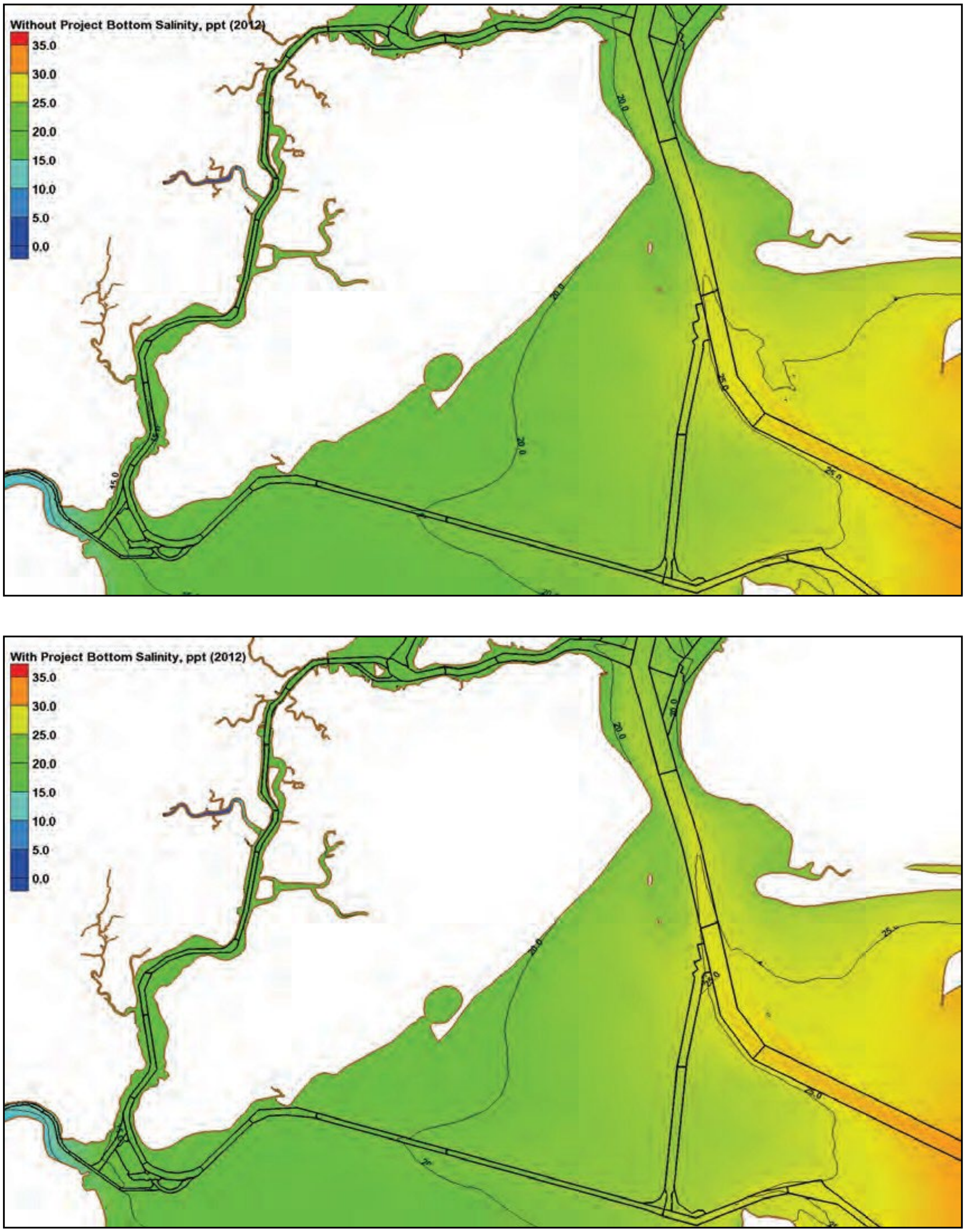
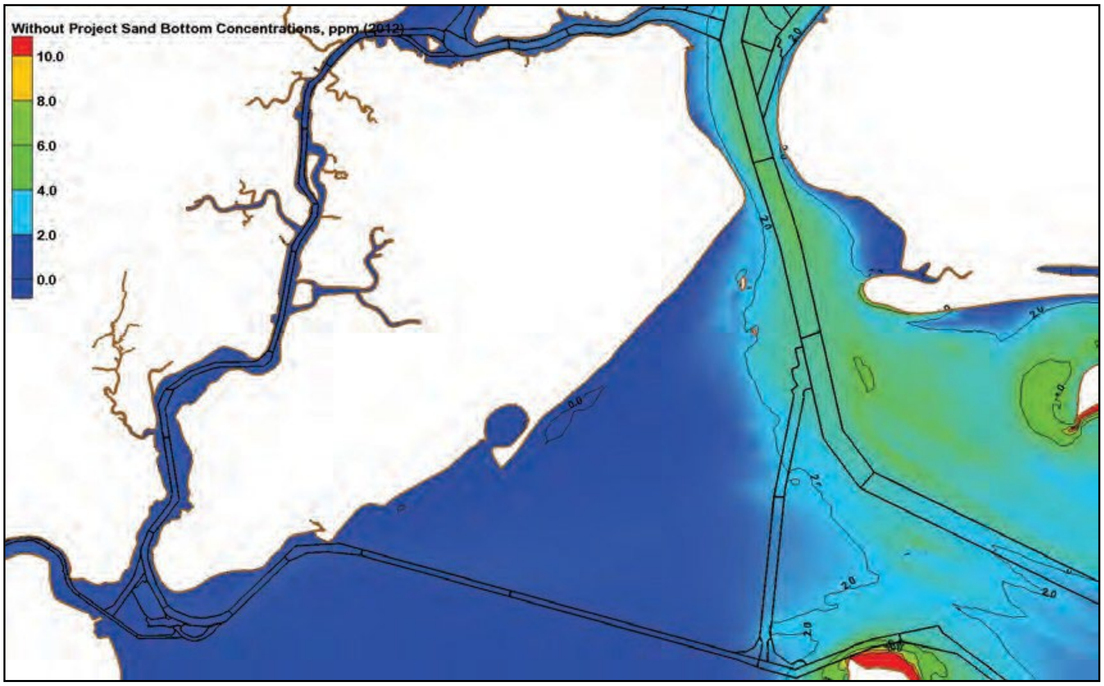


Figure 349. Without-project (top) and with-project (bottom) average fine sediment bottom concentrations, ppm (2012).

Figure 350. Without-project (top) and with-project (bottom) average sand bottom concentrations, ppm (2012).



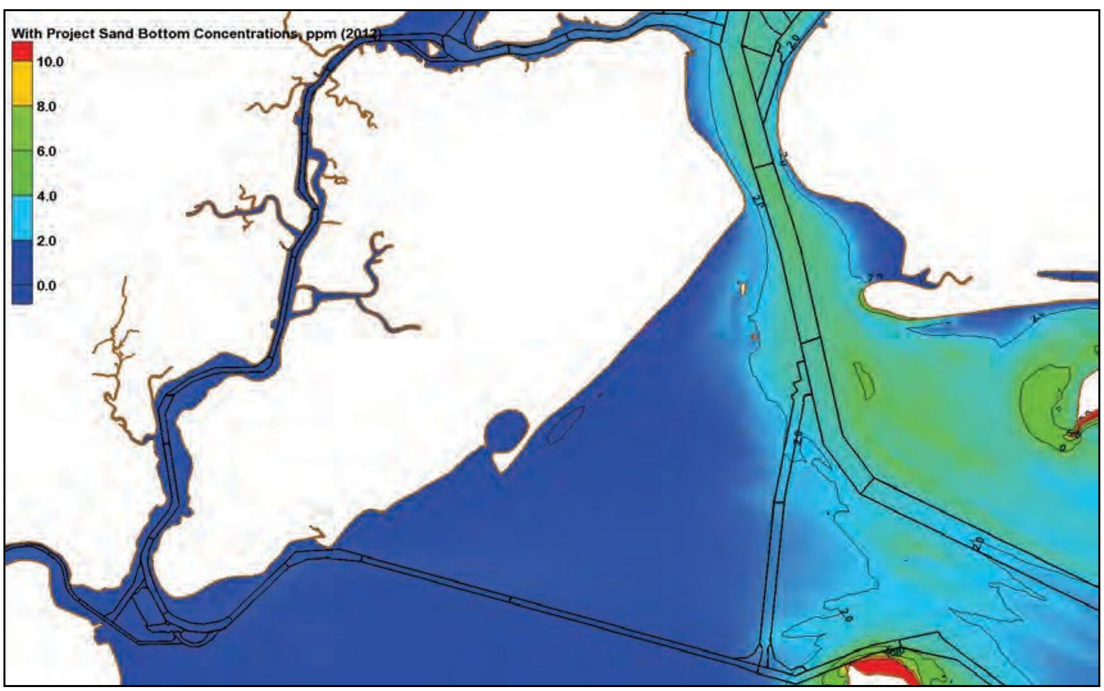


Figure 351. Without-project (top) and with-project (bottom) bed displacement, m (2012).

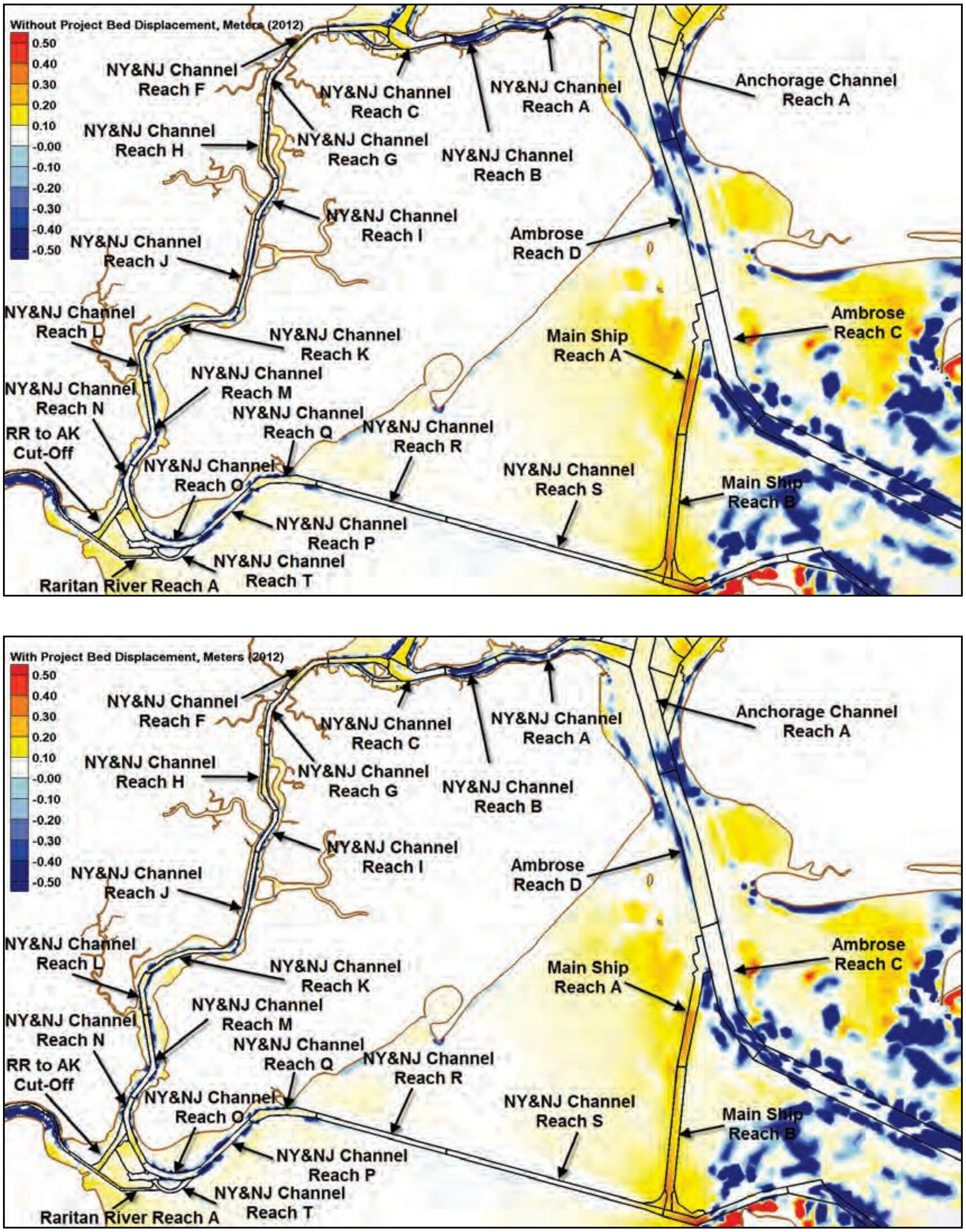
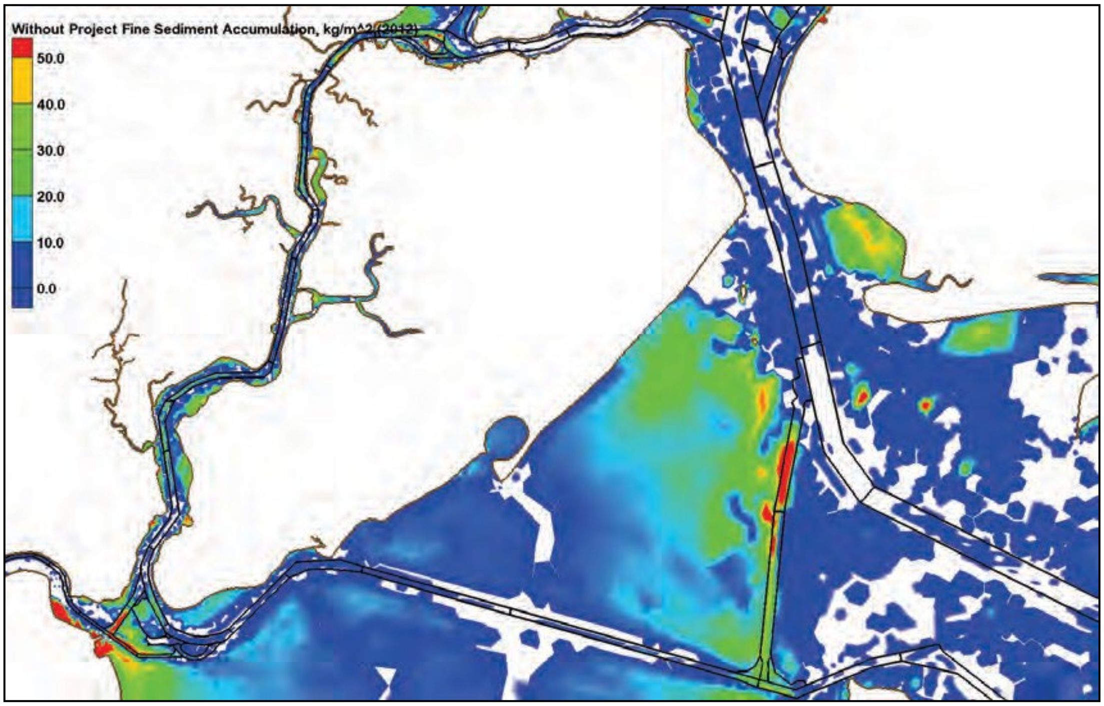


Figure 352. Without-project (top) and with-project (bottom) fine sediment accumulation, kg/m² (2012).



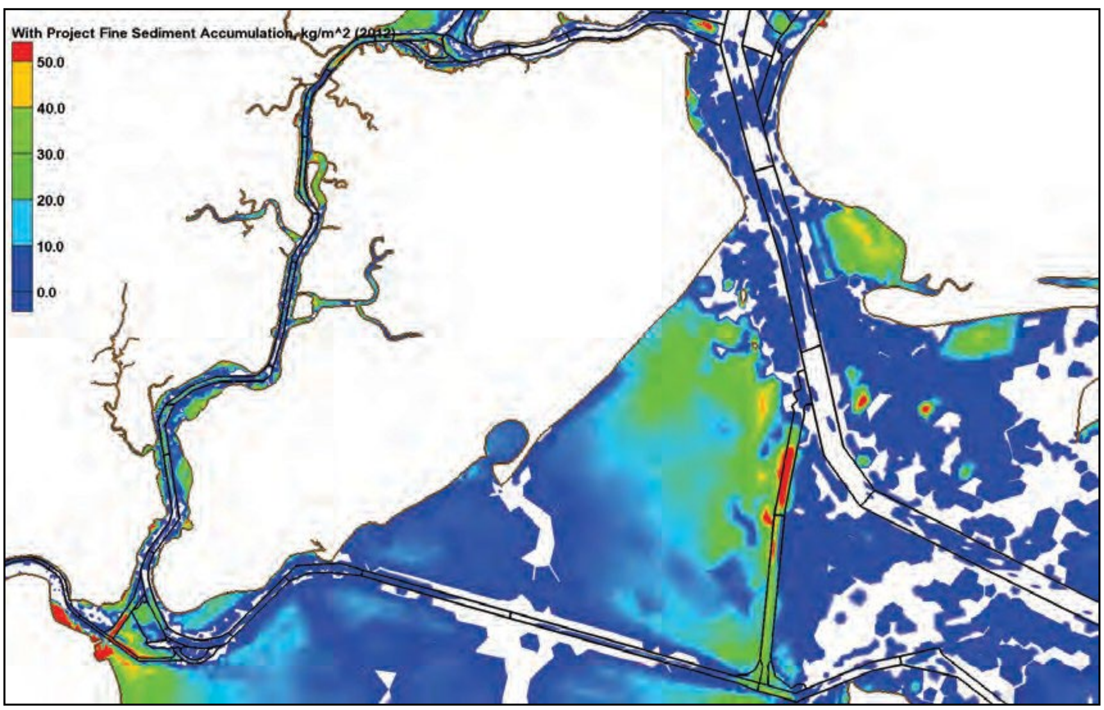
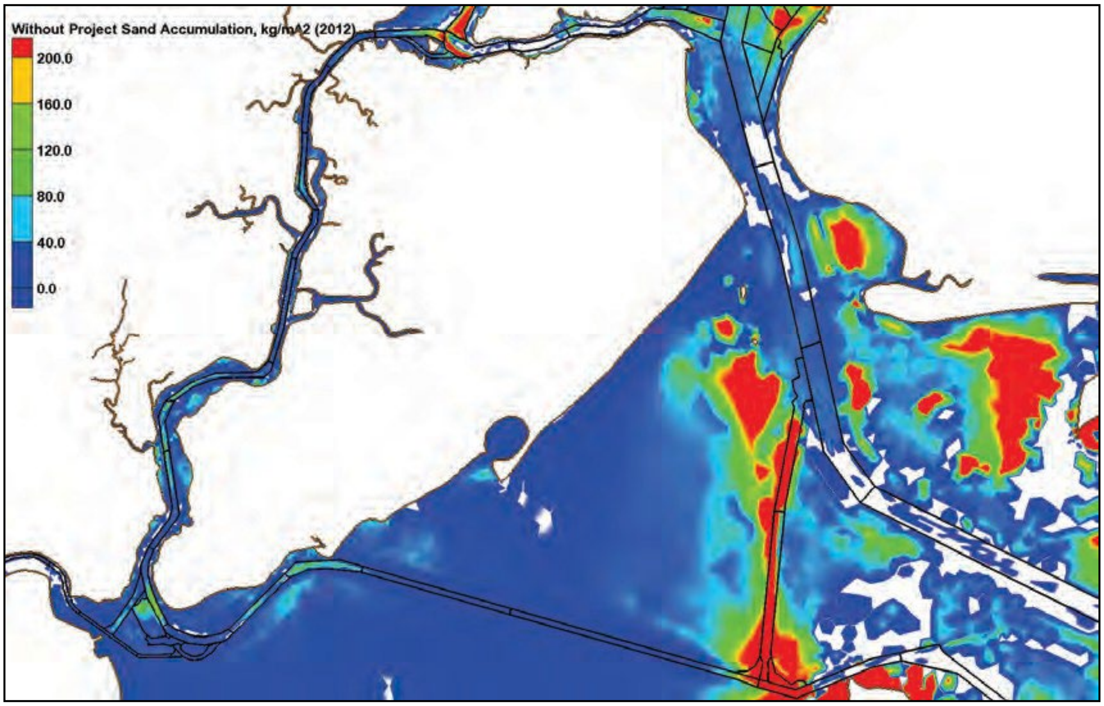


Figure 353. Without-project (top) and with-project (bottom) sand accumulation, kg/m² (2012).



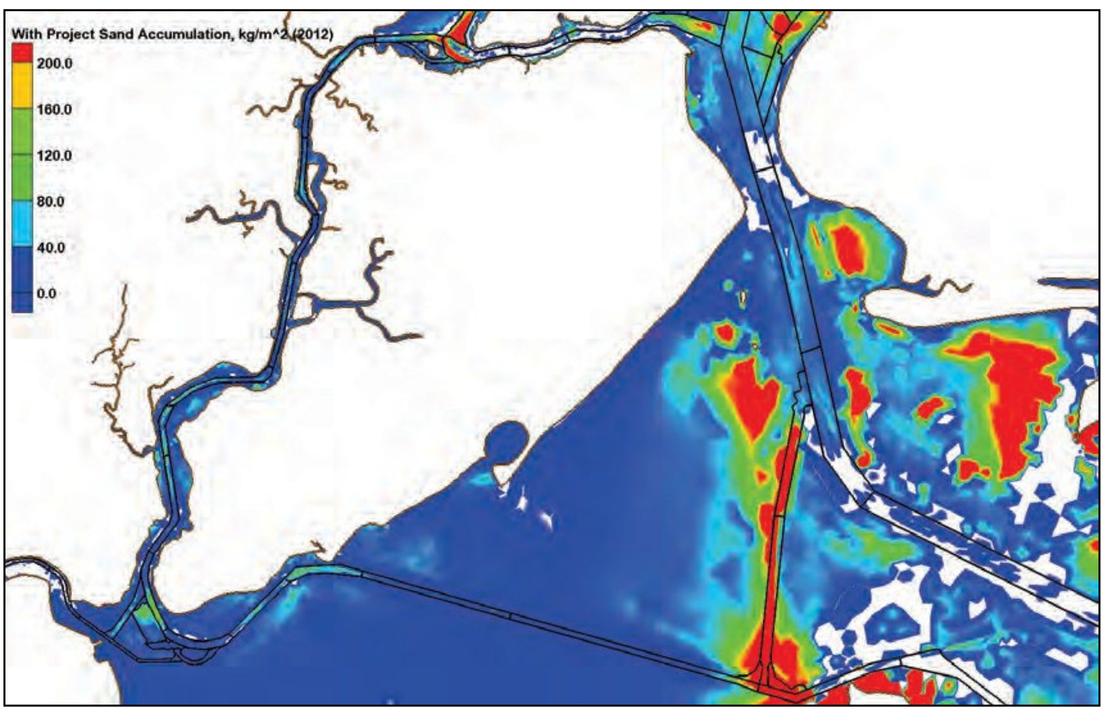


Figure 354. Dredge with-project/without-project percent differences (2012).

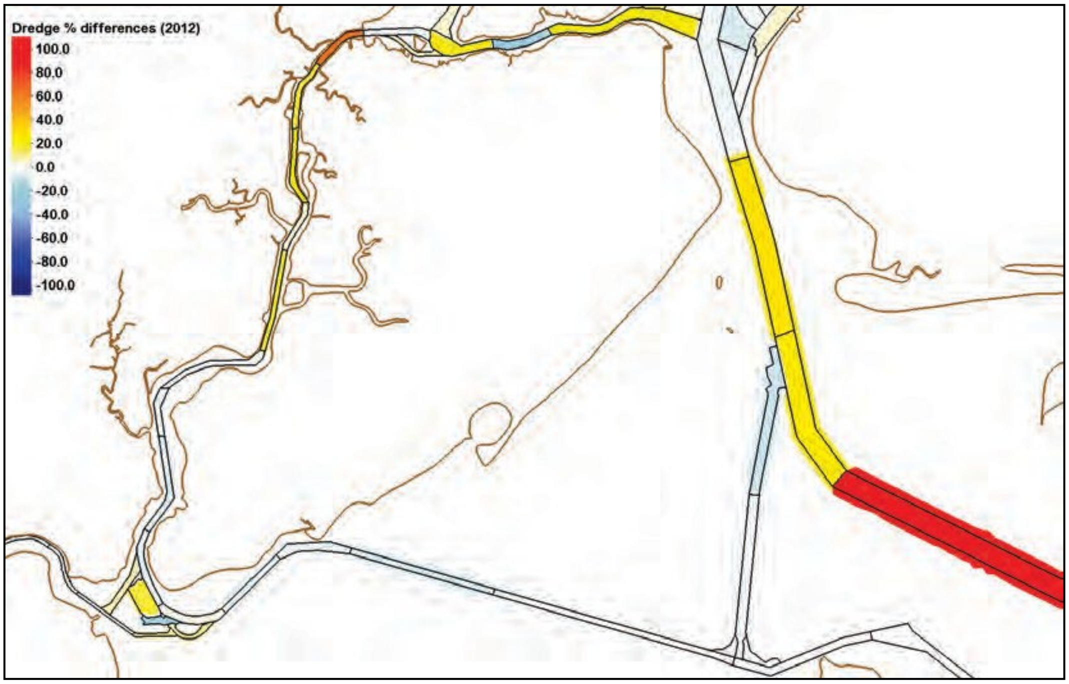


Table 39. Dredge volumes for Arthur Kill and Raritan Bay (2012).

Depositional Volumes in Arthur Kill and Raritan Bay, cy (2012)			
Reach	Without Project	With Project	With/Without Dredge Percentage
Arthur Kill			
NY&NJ Channels Reach D	27,935	26,814	96
NY&NJ Channels Reach E	4,892	5,162	106
NY&NJ Channels Reach F	6,126	9,889	161
NY&NJ Channels Reach G	1,902	2,179	115
NY&NJ Channels Reach H	5,886	7,066	120
NY&NJ Channels Reach I	1,131	1,174	104
NY&NJ Channels Reach J	3,778	4,357	115
NY&NJ Channels Reach K	10,650	10,322	97
NY&NJ Channels Reach L	9,412	9,038	96
NY&NJ Channels Reach M	9,150	8,577	94
NY&NJ Channels Reach N	17,080	16,097	94
Raritan Bay			
NY&NJ Channels Reach O	2,621	2,675	102
NY&NJ Channels Reach P	6,085	5,653	93
NY&NJ Channels Reach Q	15,060	14,467	96
NY&NJ Channels Reach R	2,078	1,889	91
NY&NJ Channels Reach T	862	938	109
RR to AK Cut-Off Reach A	14,758	15,646	106
Raritan River Reach A	3,210	3,464	108
Raritan River Reach B	8,301	8,423	101
Raritan River Reach C	369	375	102
Raritan River Reach D	220	209	95

Appendix H: Difference Plots for the With- and Without-Project Bed Shears, Bottom Layer Salinity, Bottom Layer Fine Sediment Concentrations, and Bottom Layer Sand Concentrations

Lower Bay results

Figure 355. With-minus without-project average bed shear stresses (N/m^2) for 1985.

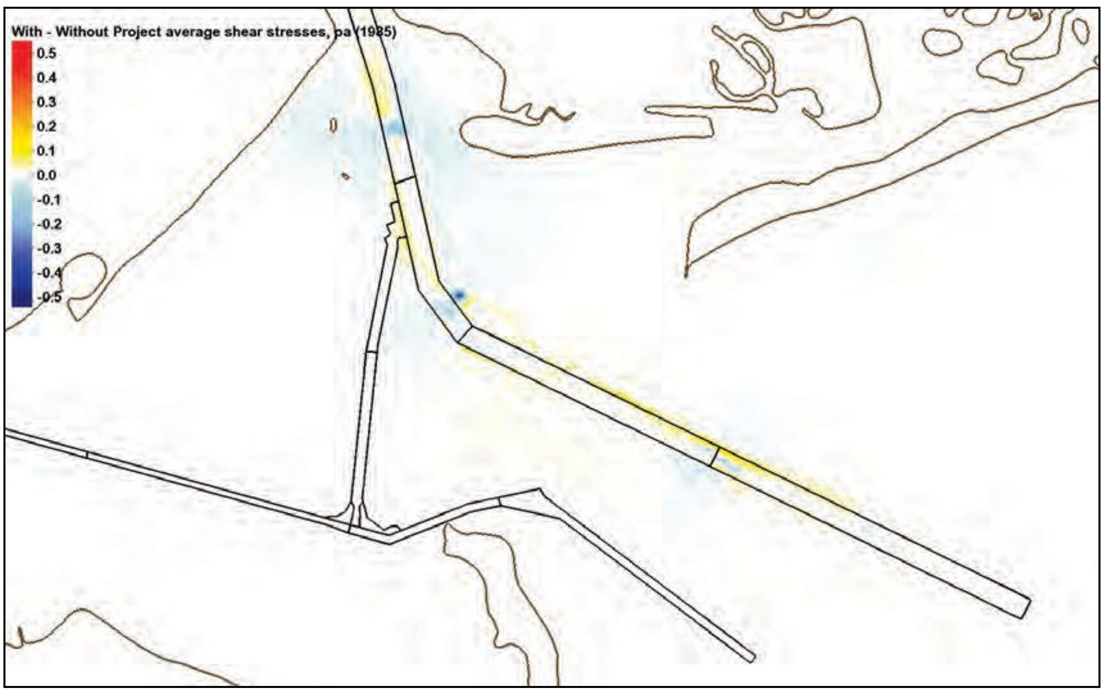


Figure 356. With- minus without-project average bed shear stresses (N/m²) for 1995.

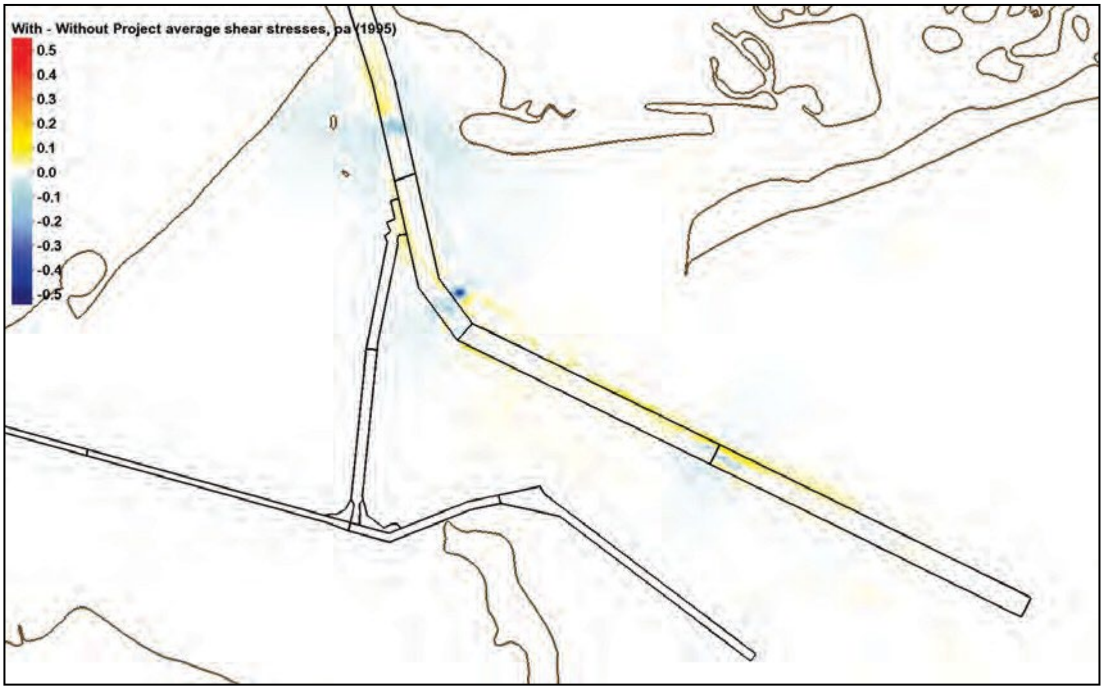


Figure 357. With- minus without-project average bed shear stresses (N/m²) for 1996.

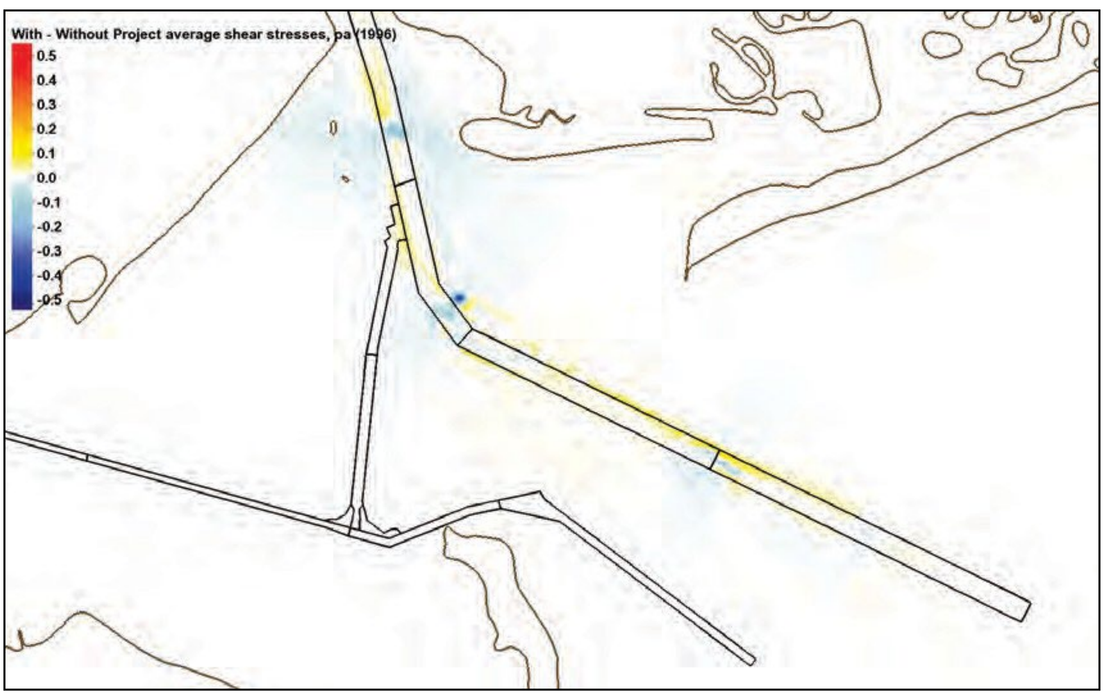


Figure 358. With- minus without-project average bed shear stresses (N/m2) for 2011.

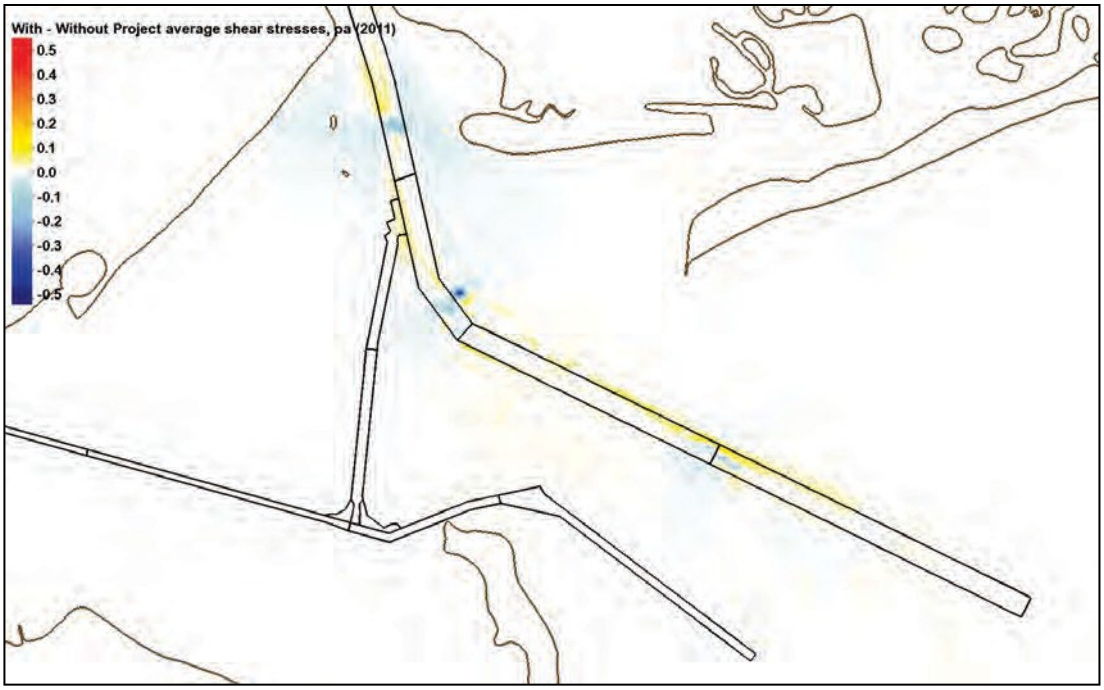


Figure 359. With- minus without-project average bed shear stresses (N/m2) for 2012.

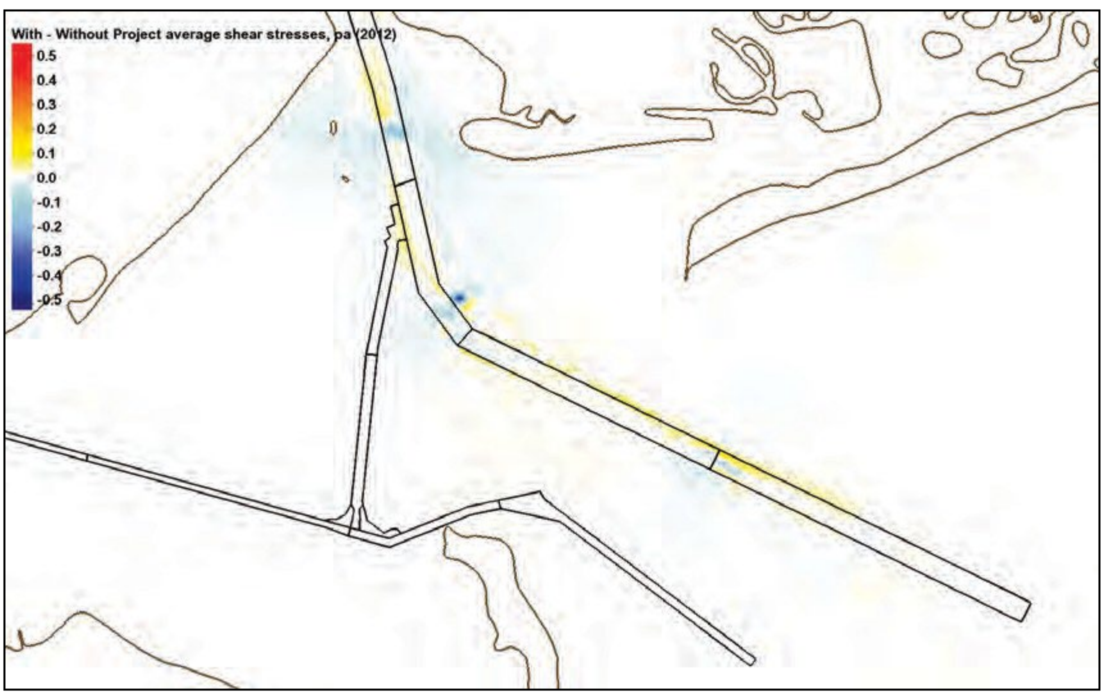


Figure 360. With- minus without-project average bottom layer salinity values (ppt) for 1985.

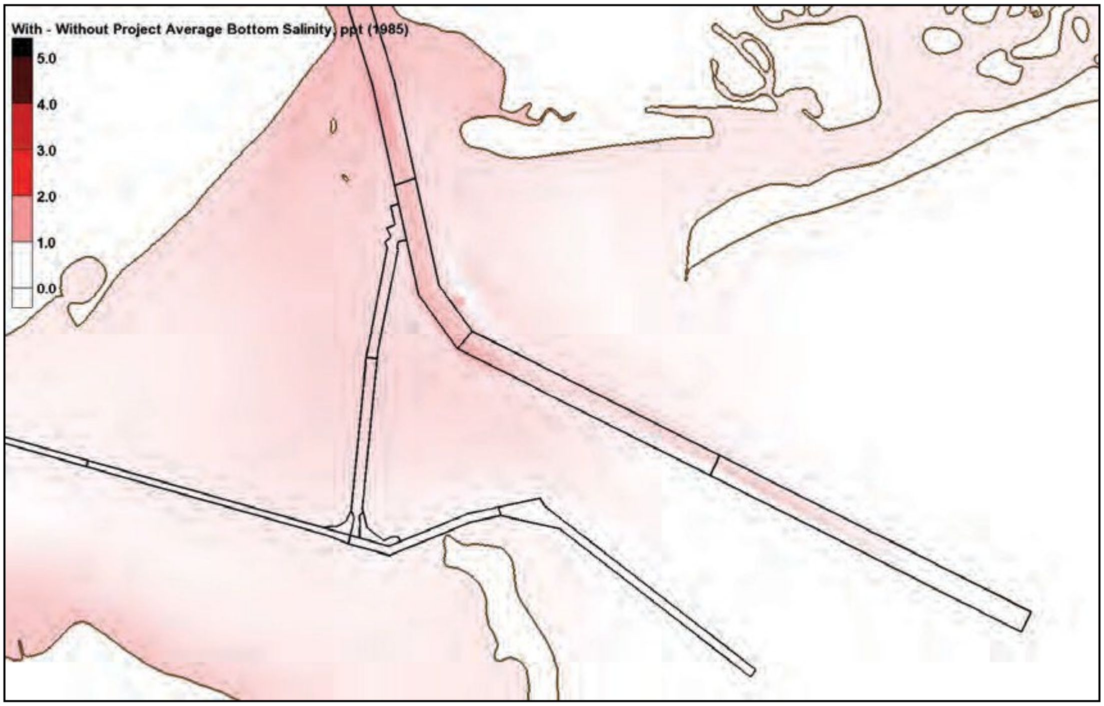


Figure 361. With- minus without-project average bottom layer salinity values (ppt) for 1995.

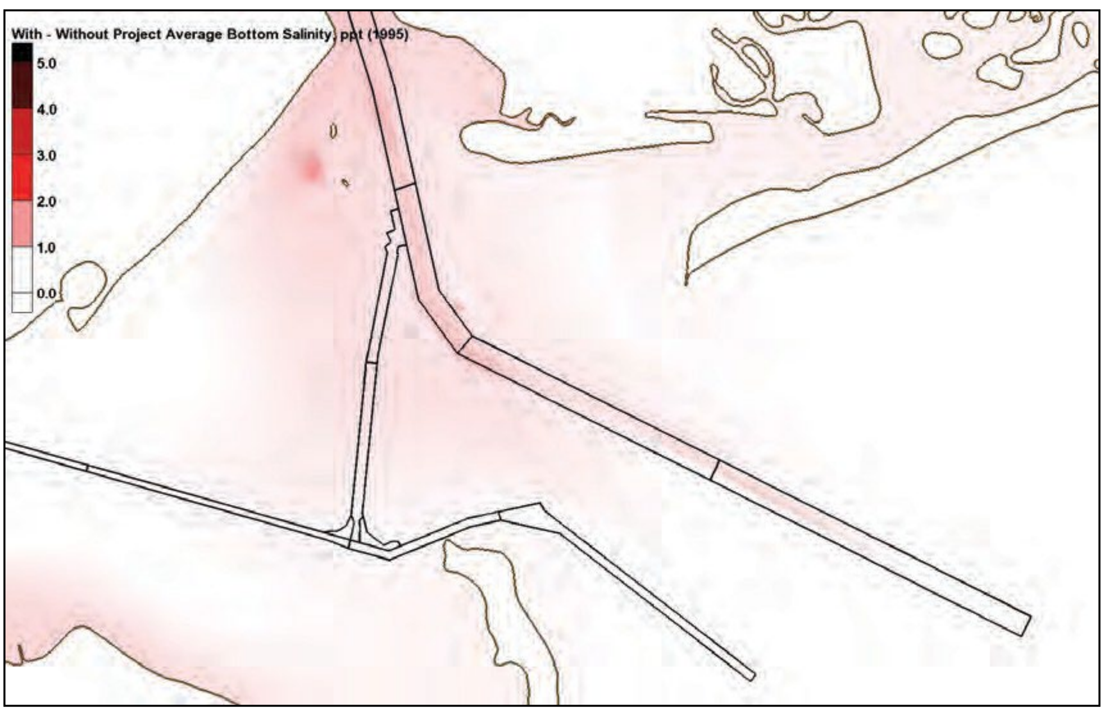


Figure 362. With- minus without-project average bottom layer salinity values (ppt) for 1996.

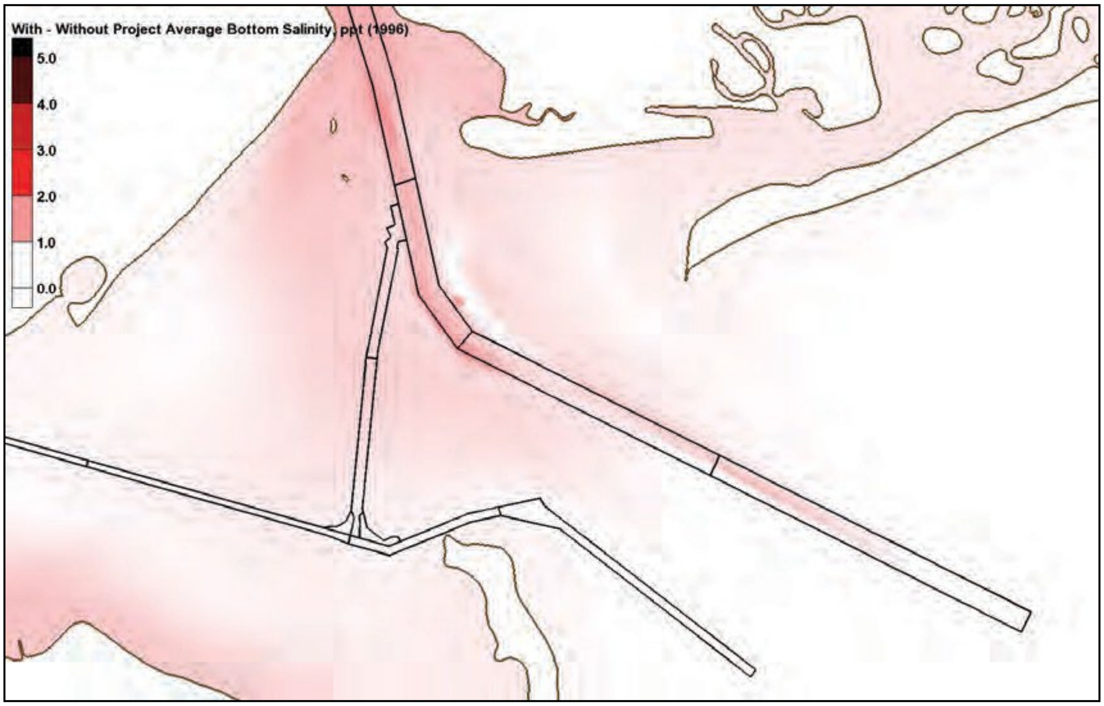


Figure 363. With- minus without-project average bottom layer salinity values (ppt) for 2011.

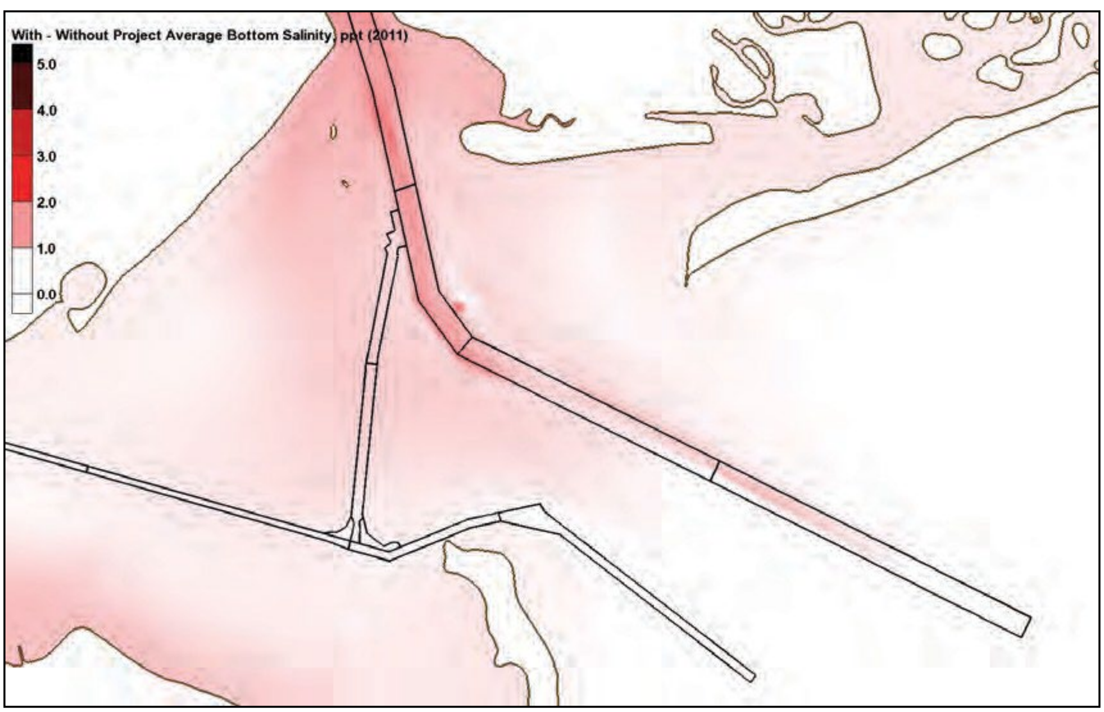


Figure 364. With- minus without-project average bottom layer salinity values (ppt) for 2012.

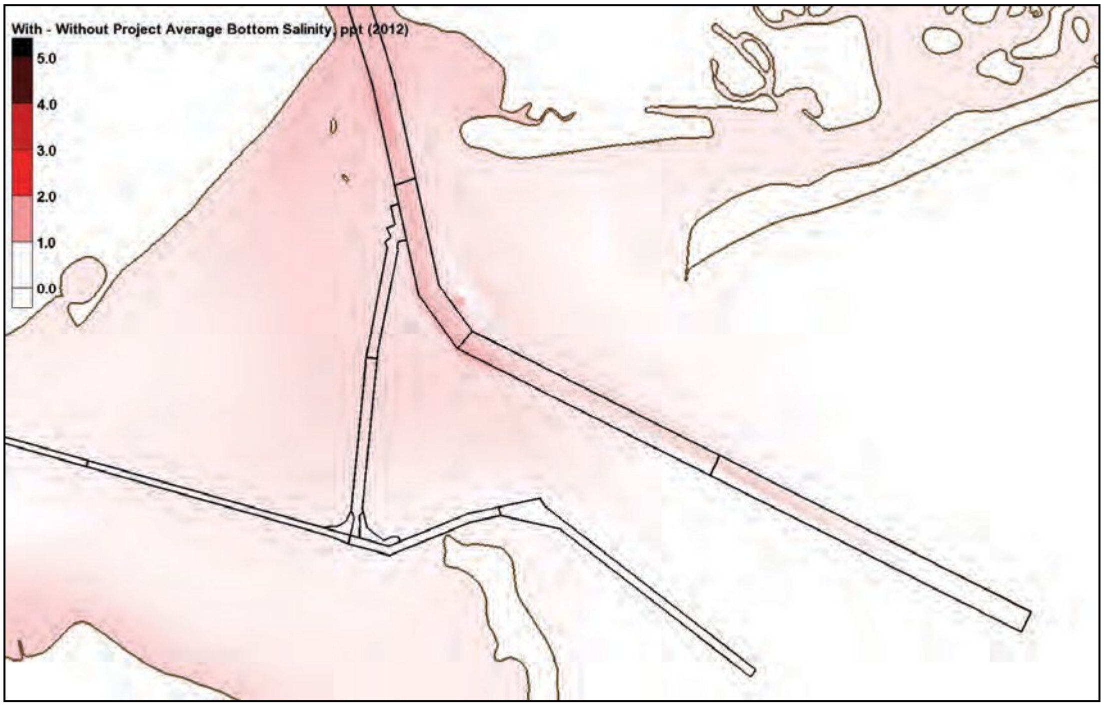


Figure 365. With- minus without-project average bottom layer fine sediment concentrations (ppm) for 1985.

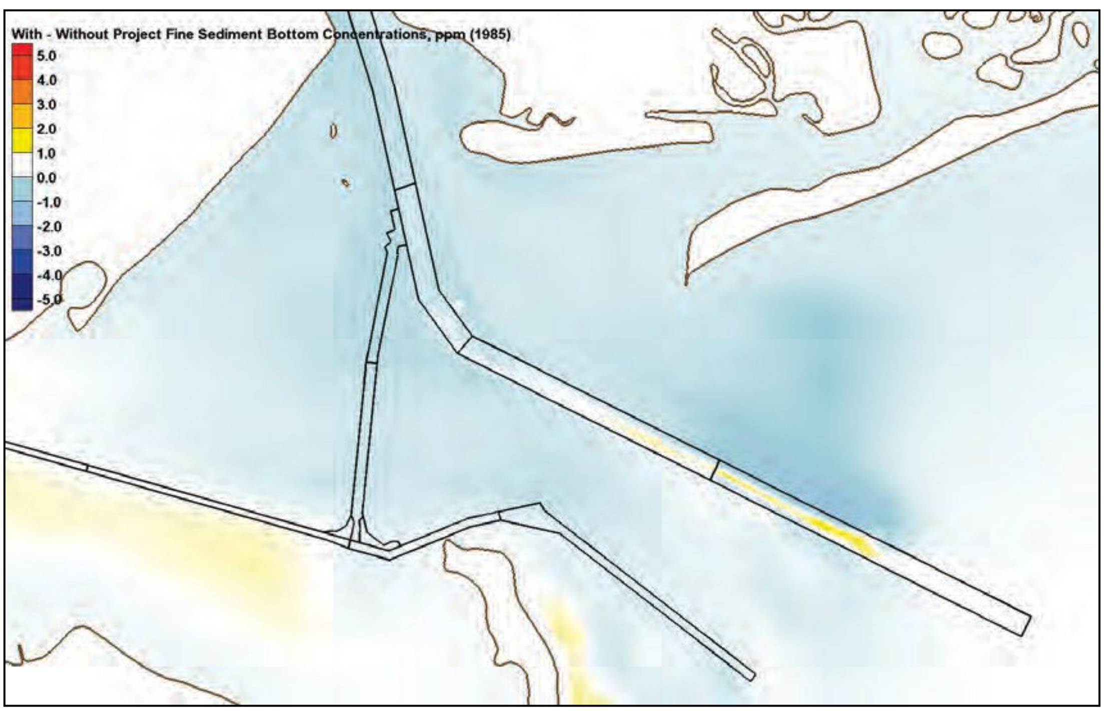


Figure 366. With- minus without-project average bottom layer fine sediment concentrations (ppm) for 1995.

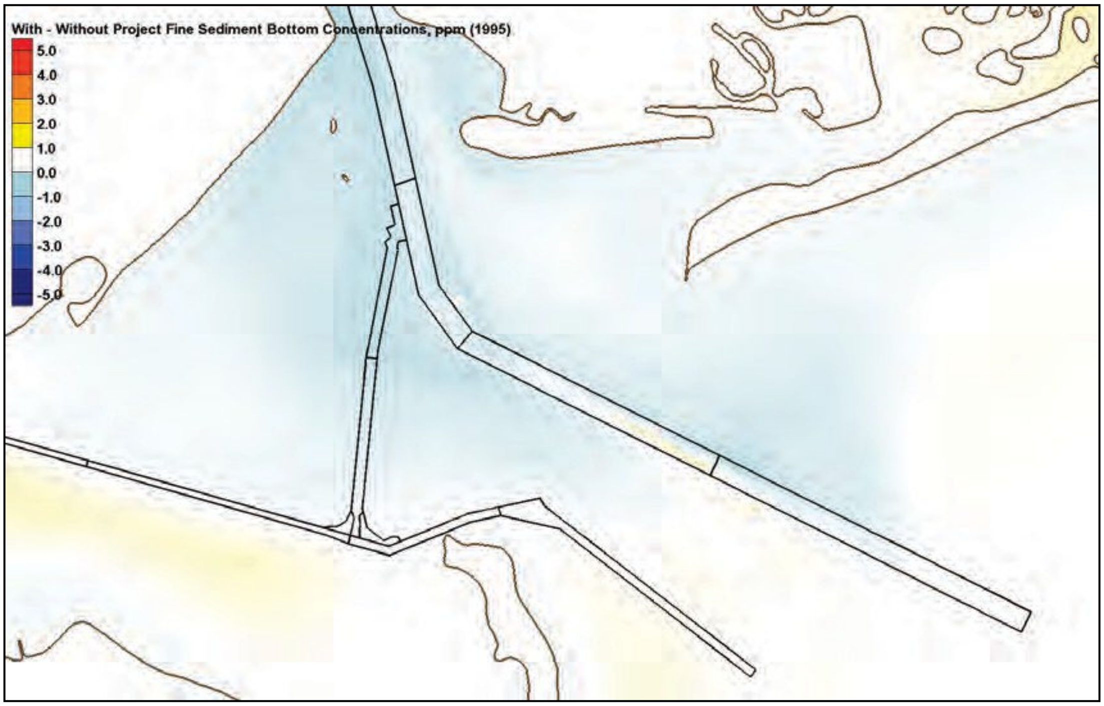


Figure 367. With- minus without-project average bottom layer fine sediment concentrations (ppm) for 1996.

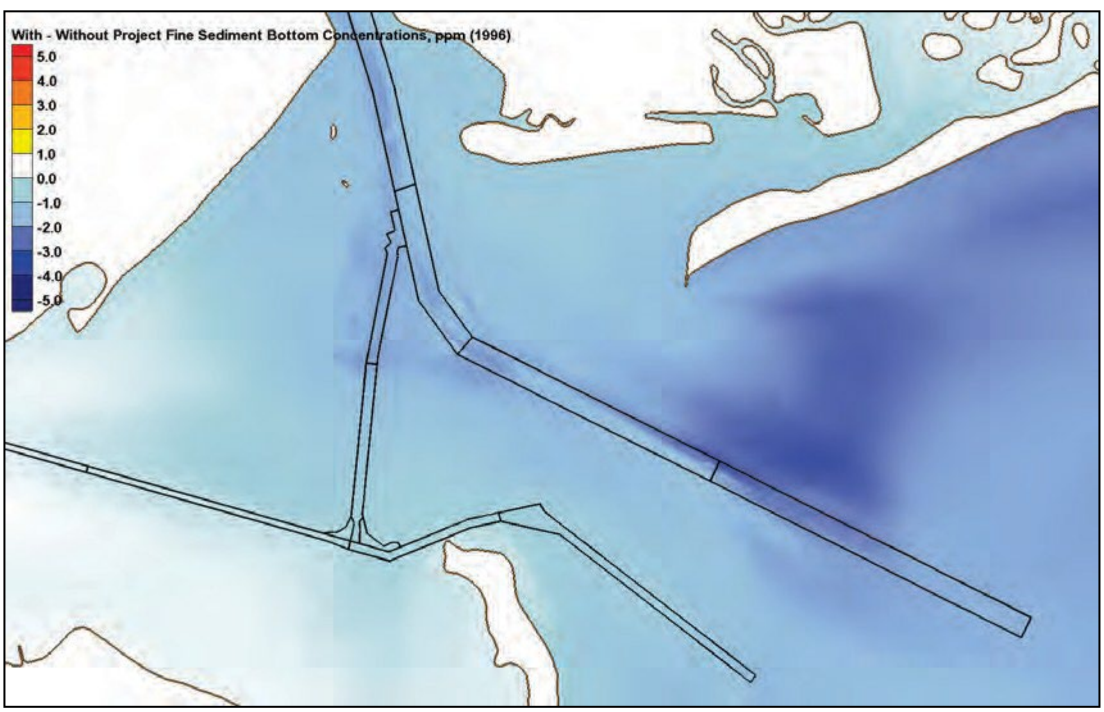


Figure 368. With- minus without-project average bottom layer fine sediment concentrations (ppm) for 2011.

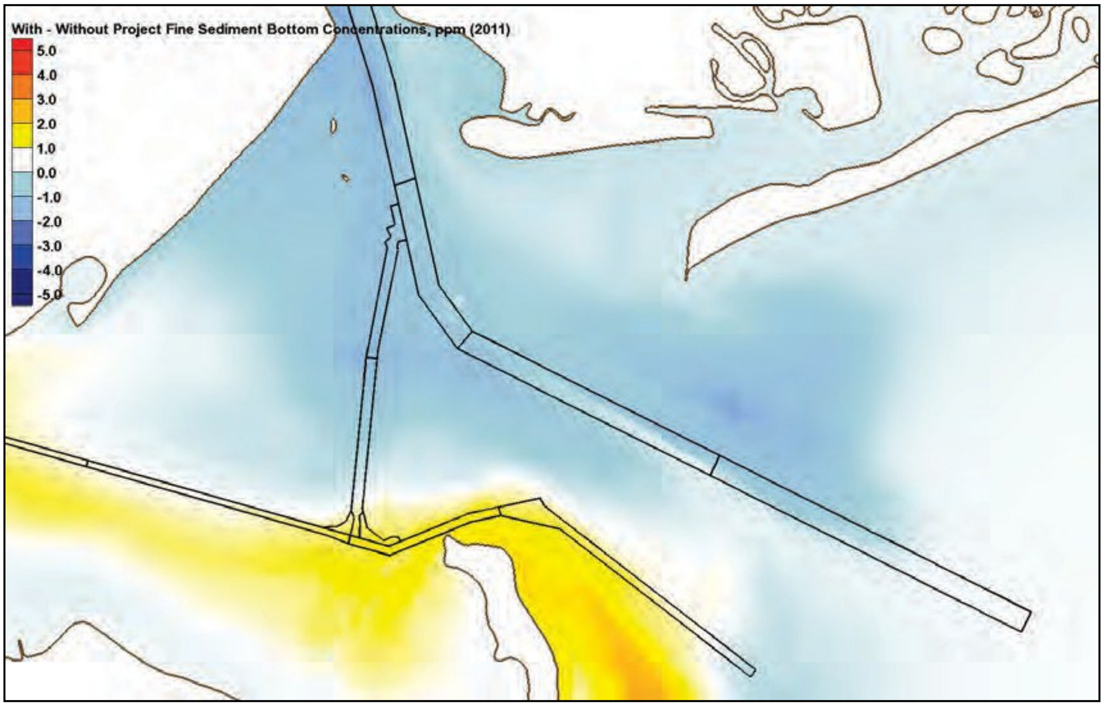


Figure 369. With- minus without-project average bottom layer fine sediment concentrations (ppm) for 2012.

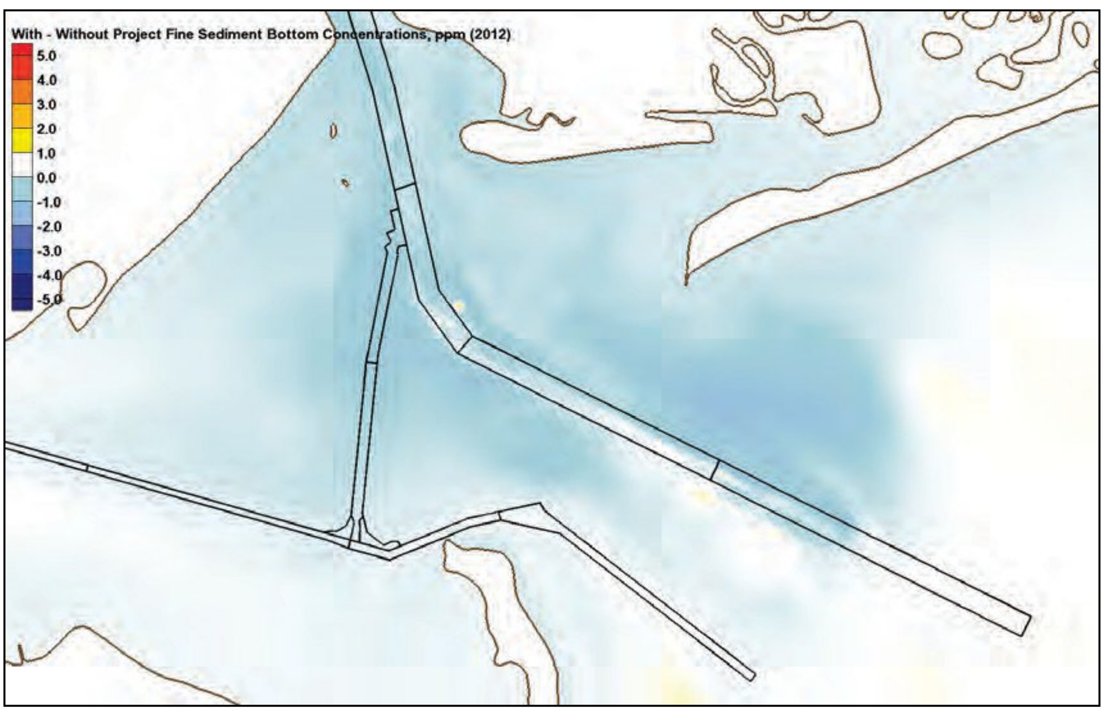


Figure 370. With- minus without-project average bottom layer sand concentrations (ppm) for 1985.

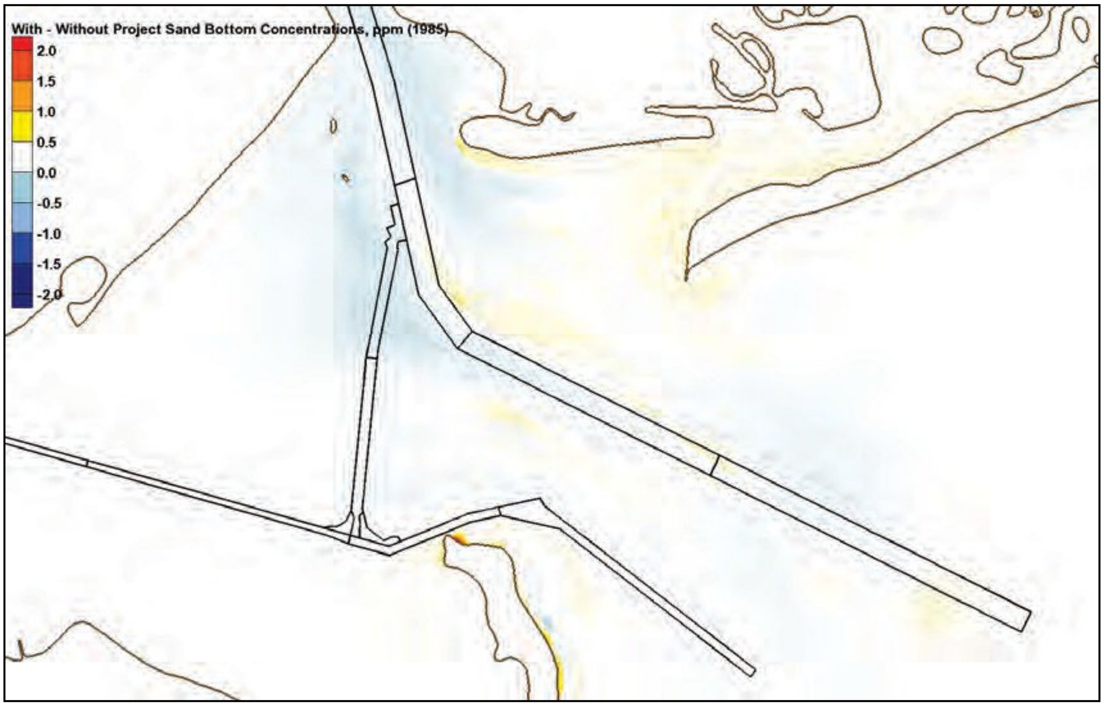


Figure 371. With- minus without-project average bottom layer sand concentrations (ppm) for 1995.

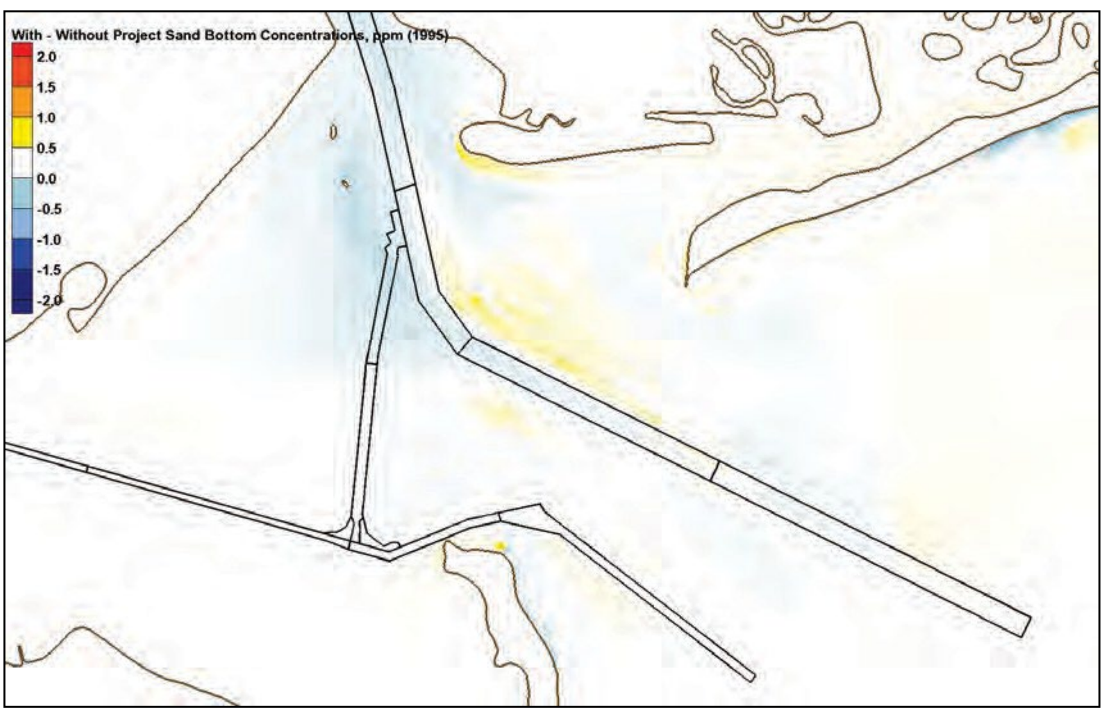


Figure 372. With- minus without-project average bottom layer sand concentrations (ppm) for 1996.

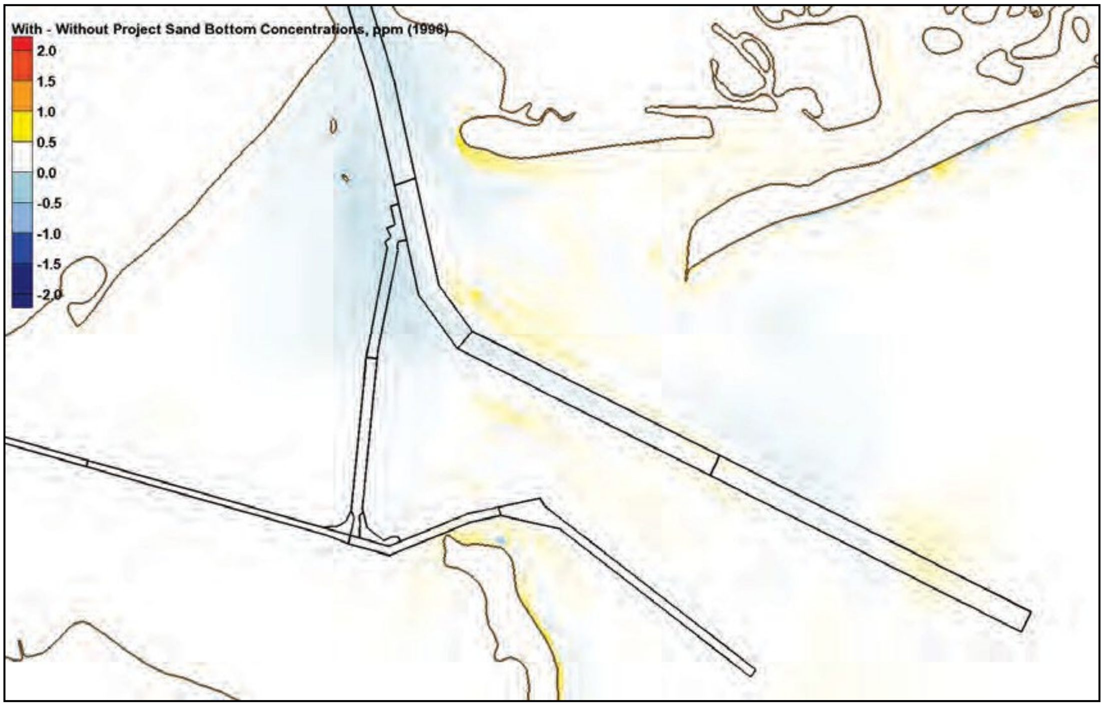


Figure 373. With- minus without-project average bottom layer sand concentrations (ppm) for 2011.

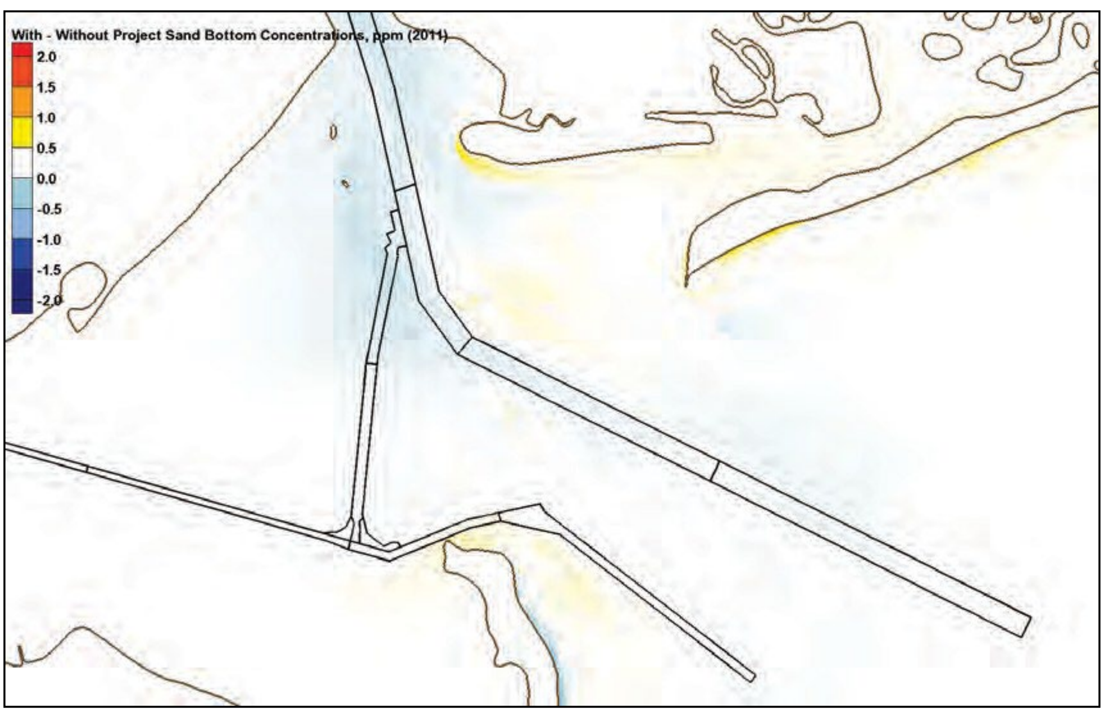


Figure 374. With- minus without-project average bottom layer sand concentrations (ppm) for 2012.

Newark Bay, Kill van Kull, and Upper Bay

Figure 375. With- minus without-project average bed shear stresses (N/m^2) for 1985.

Figure 376. With- minus without-project average bed shear stresses (N/m^2) for 1995.

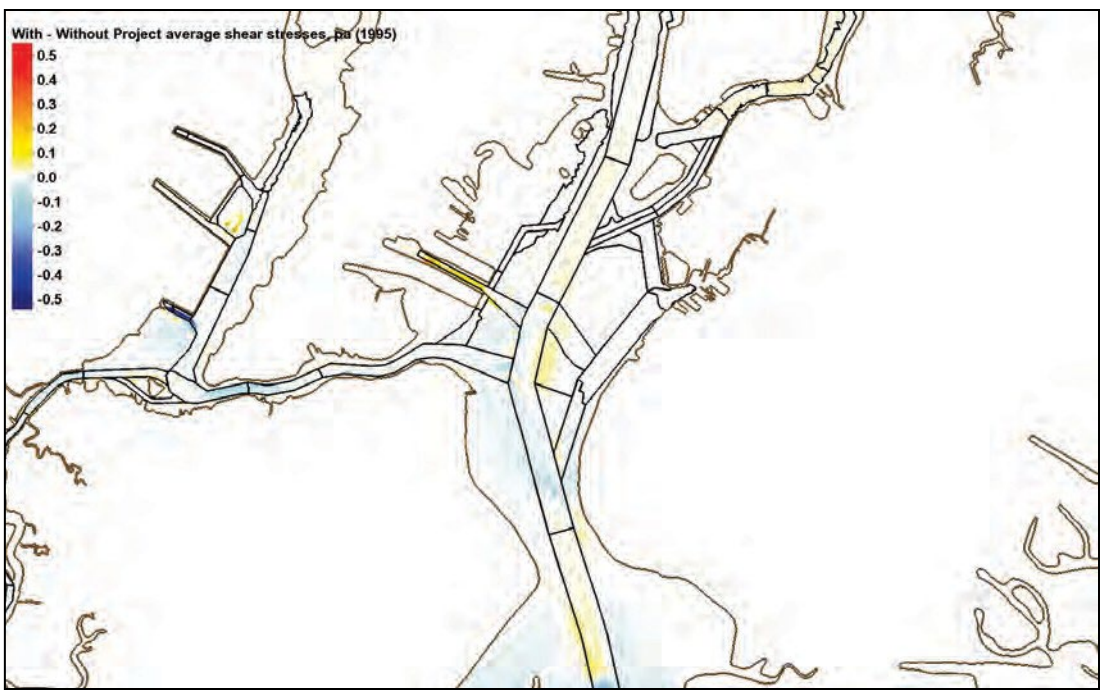


Figure 377. With- minus without-project average bed shear stresses (N/m²) for 1996.

Figure 378. With- minus without-project average bed shear stresses (N/m²) for 2011.

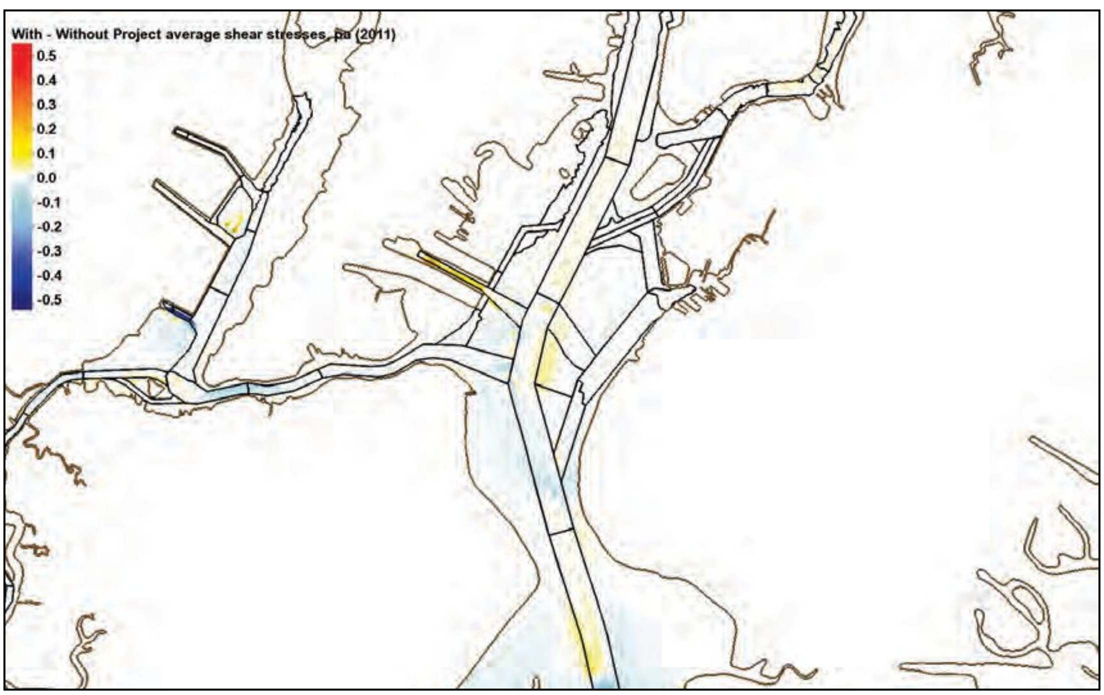


Figure 379. With- minus without-project average bed shear stresses (N/m²) for 2012.

Figure 380. With- minus without-project average bottom layer salinity values (ppt) for 1985.

Figure 381. With- minus without-project average bottom layer salinity values (ppt) for 1995.

Figure 382. With- minus without-project average bottom layer salinity values (ppt) for 1996.

Figure 383. With- minus without-project average bottom layer salinity values (ppt) for 2011.

Figure 384. With- minus without-project average bottom layer salinity values (ppt) for 2012.

Figure 385. With- minus without-project average bottom layer fine sediment concentrations (ppm) for 1985.

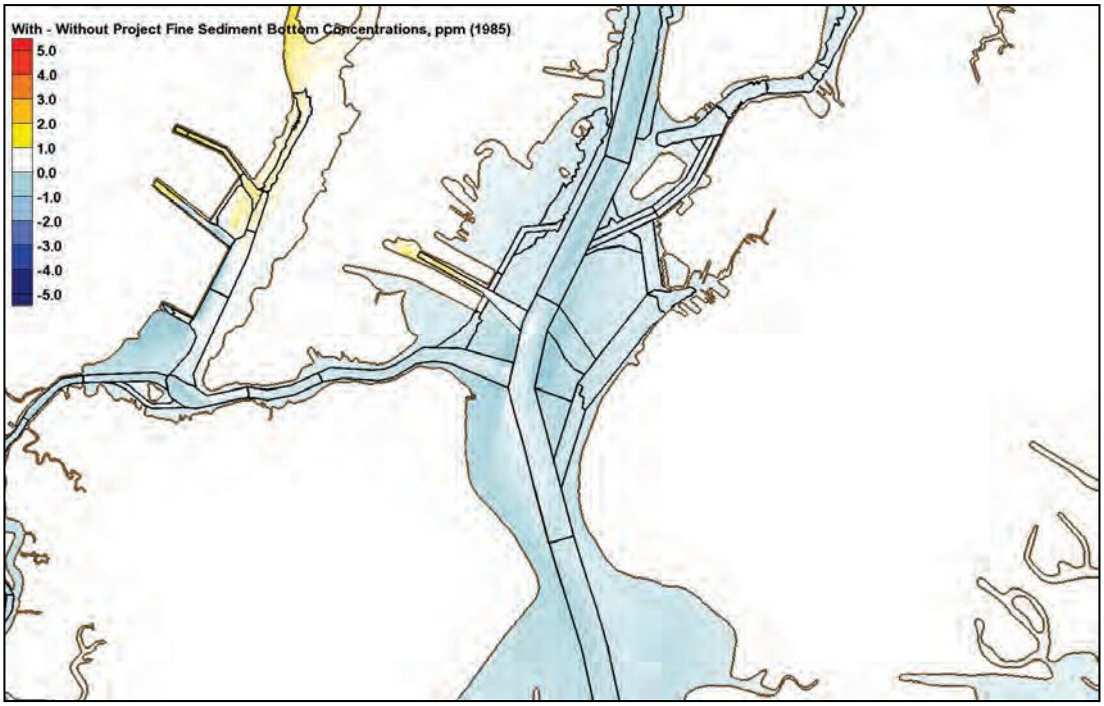


Figure 386. With- minus without-project average bottom layer fine sediment concentrations (ppm) for 1995.

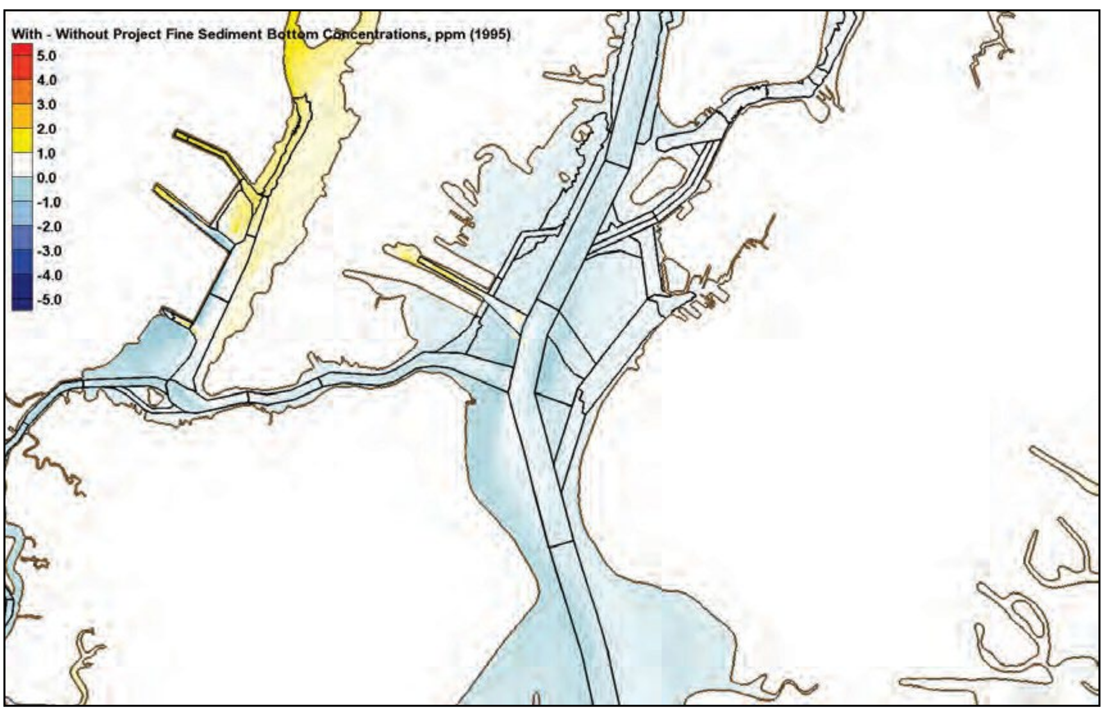


Figure 387. With- minus without-project average bottom layer fine sediment concentrations (ppm) for 1996.

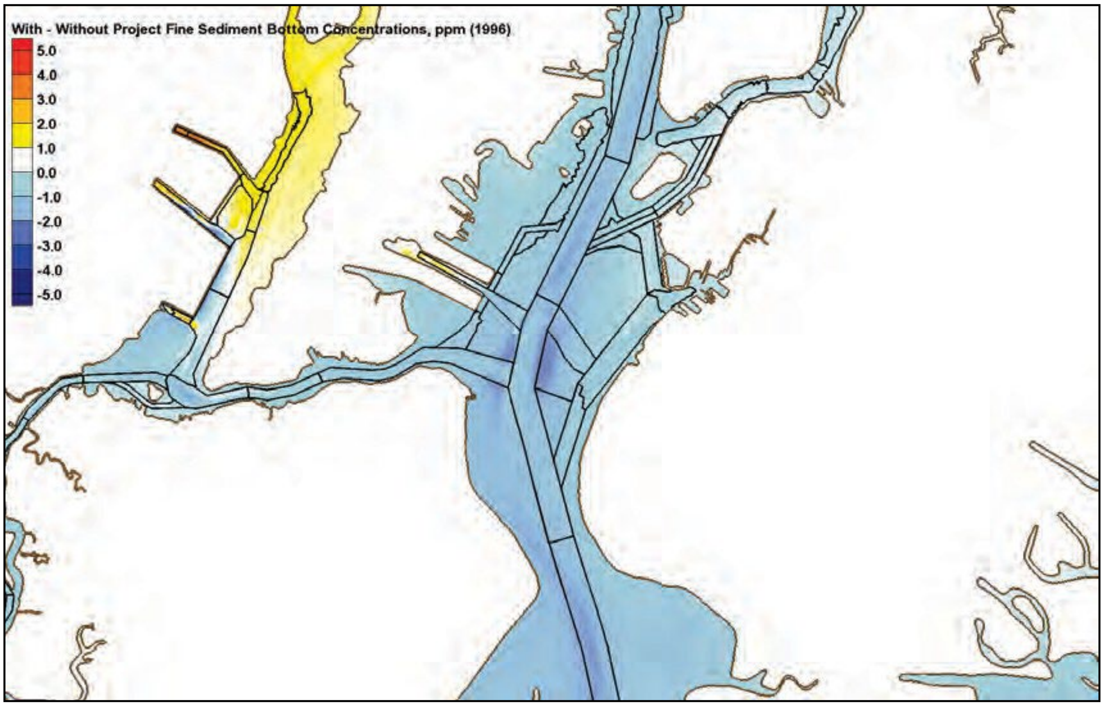


Figure 388. With- minus without-project average bottom layer fine sediment concentrations (ppm) for 2011.

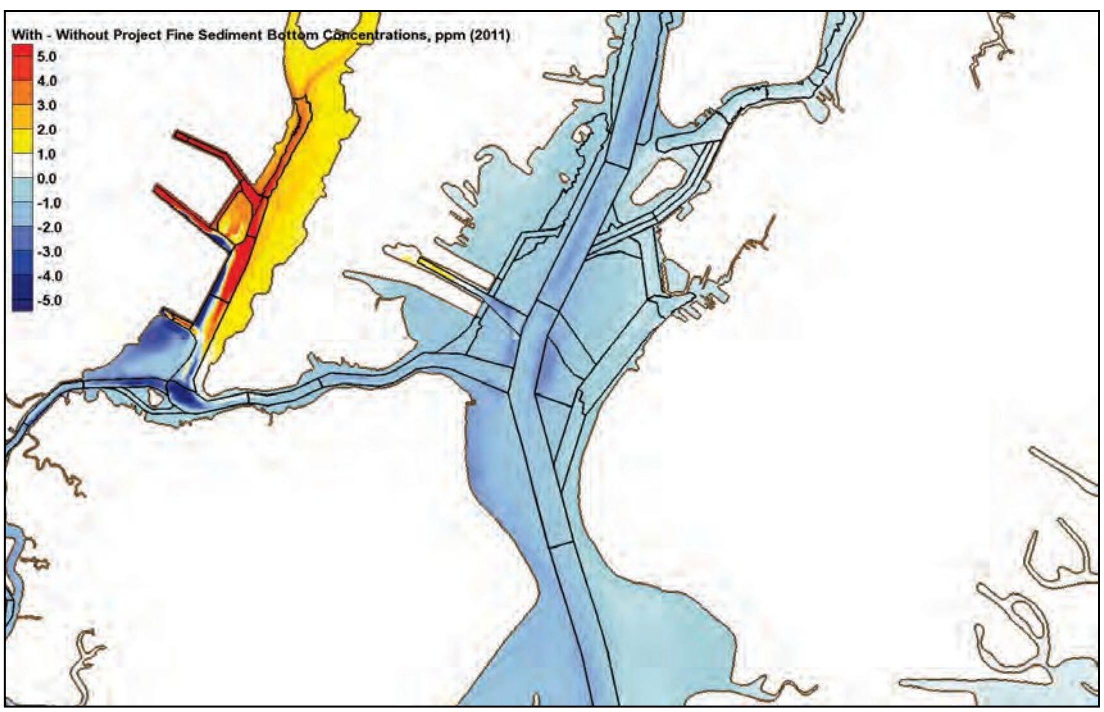


Figure 389. With- minus without-project average bottom layer fine sediment concentrations (ppm) for 2012.

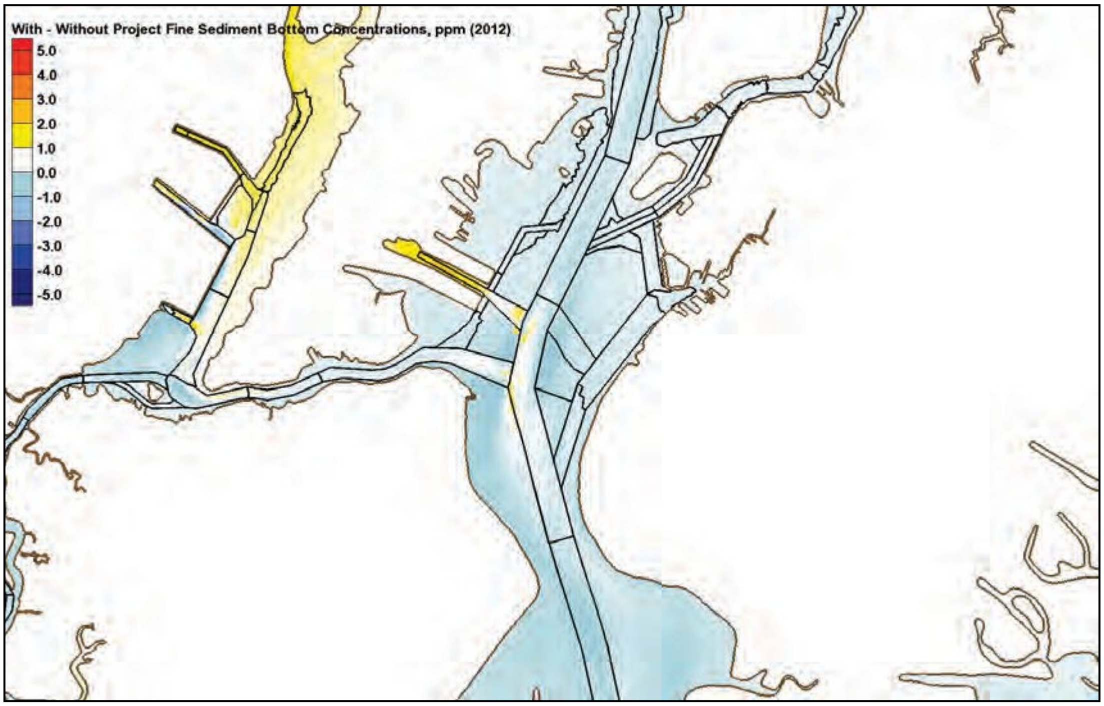


Figure 390. With- minus without-project average bottom layer sand concentrations (ppm) for 1985.

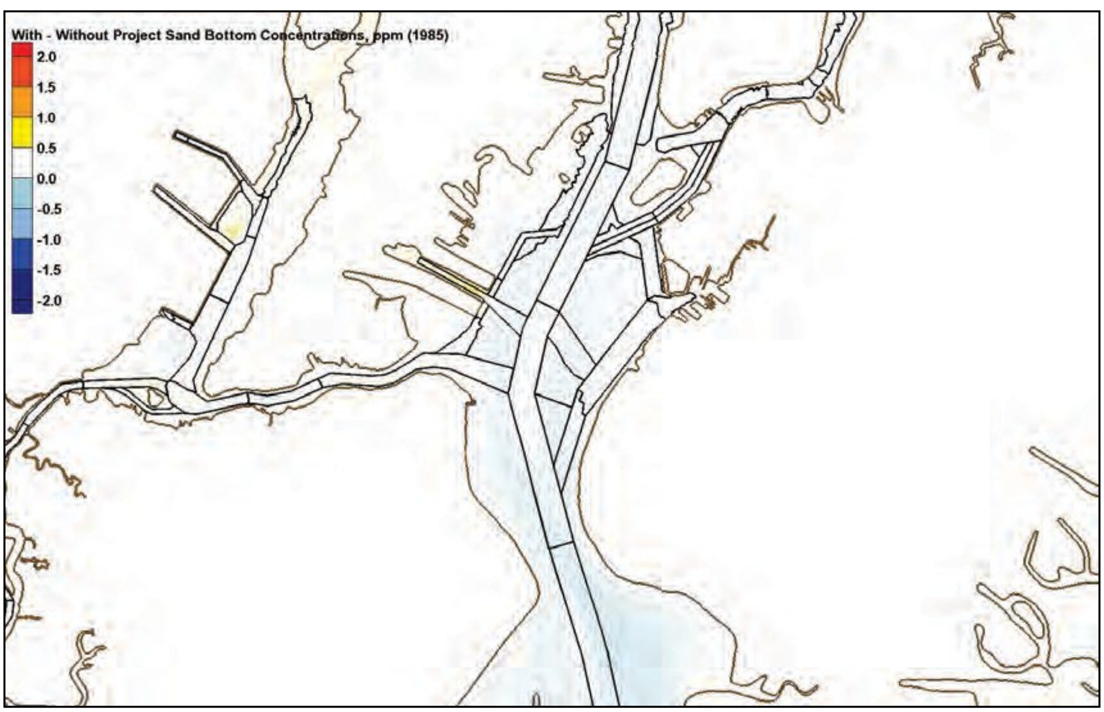


Figure 391. With- minus without-project average bottom layer sand concentrations (ppm) for 1995.

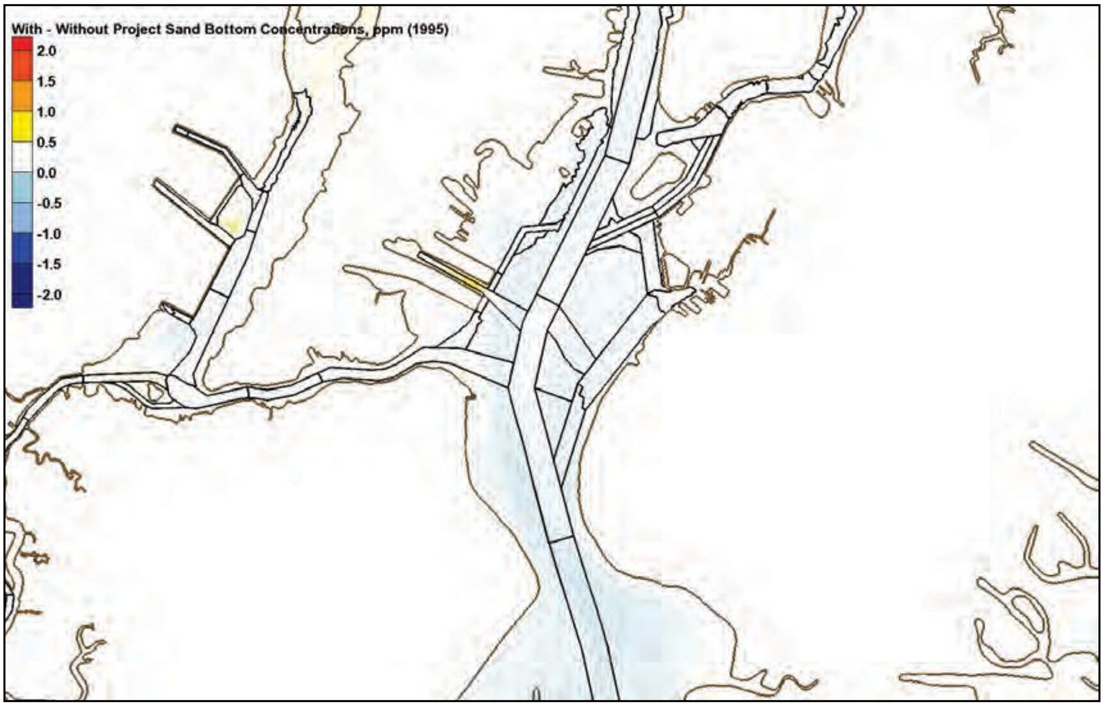


Figure 392. With- minus without-project average bottom layer sand concentrations (ppm) for 1996.

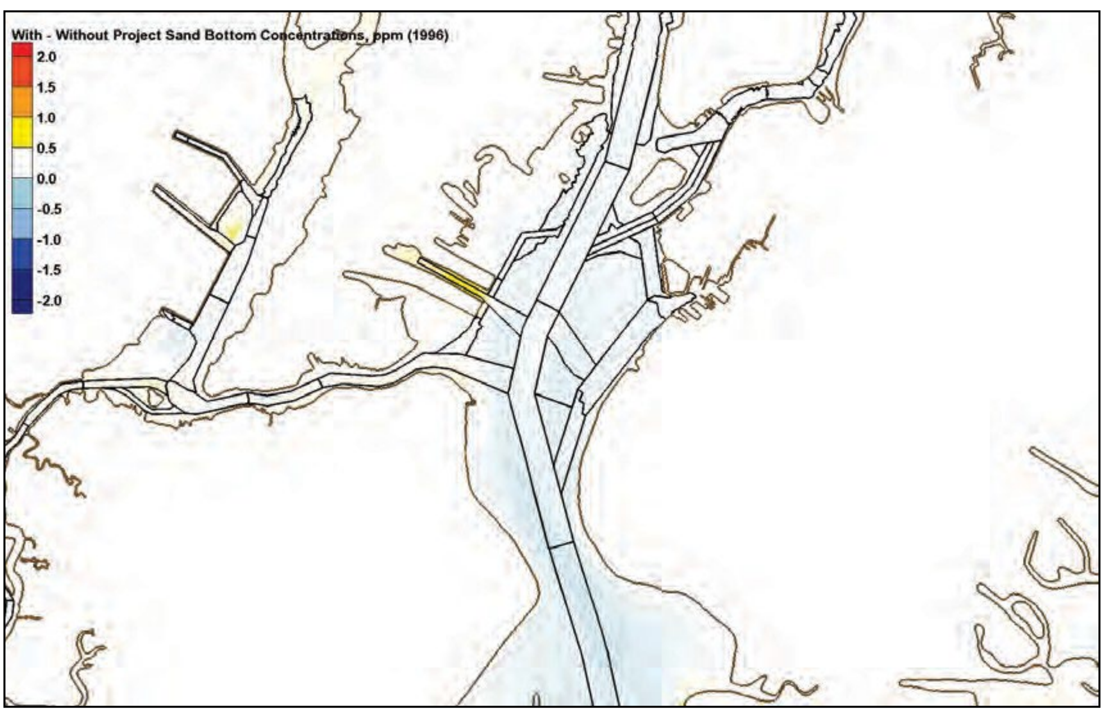


Figure 393. With- minus without-project average bottom layer sand concentrations (ppm) for 2011.

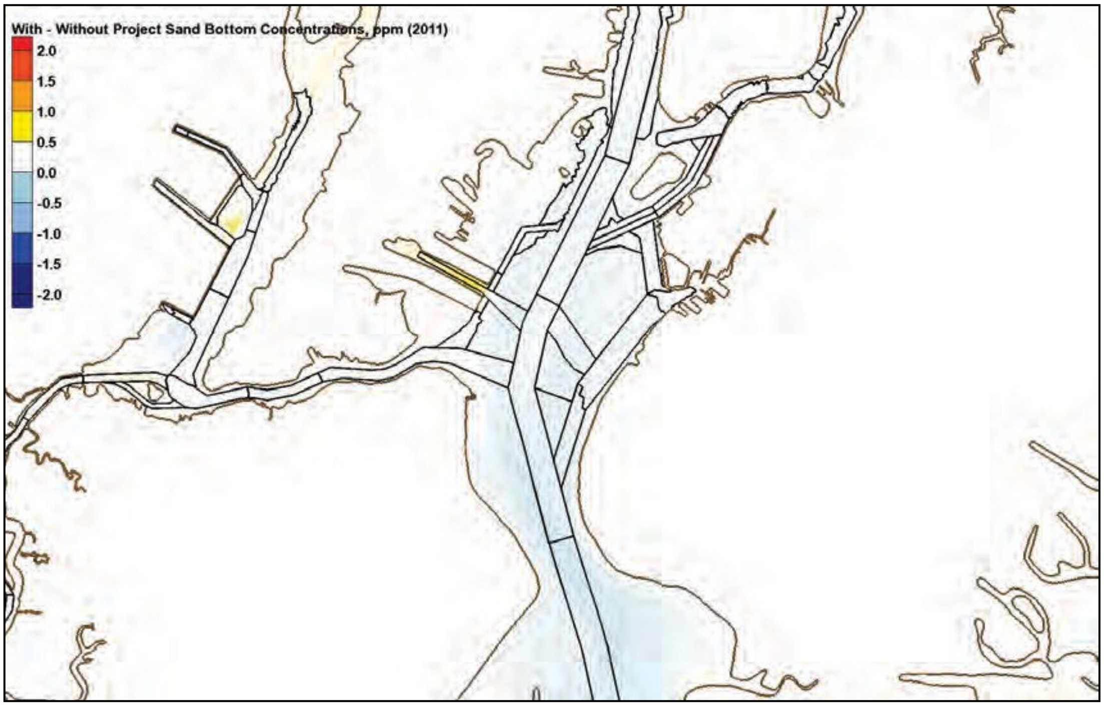
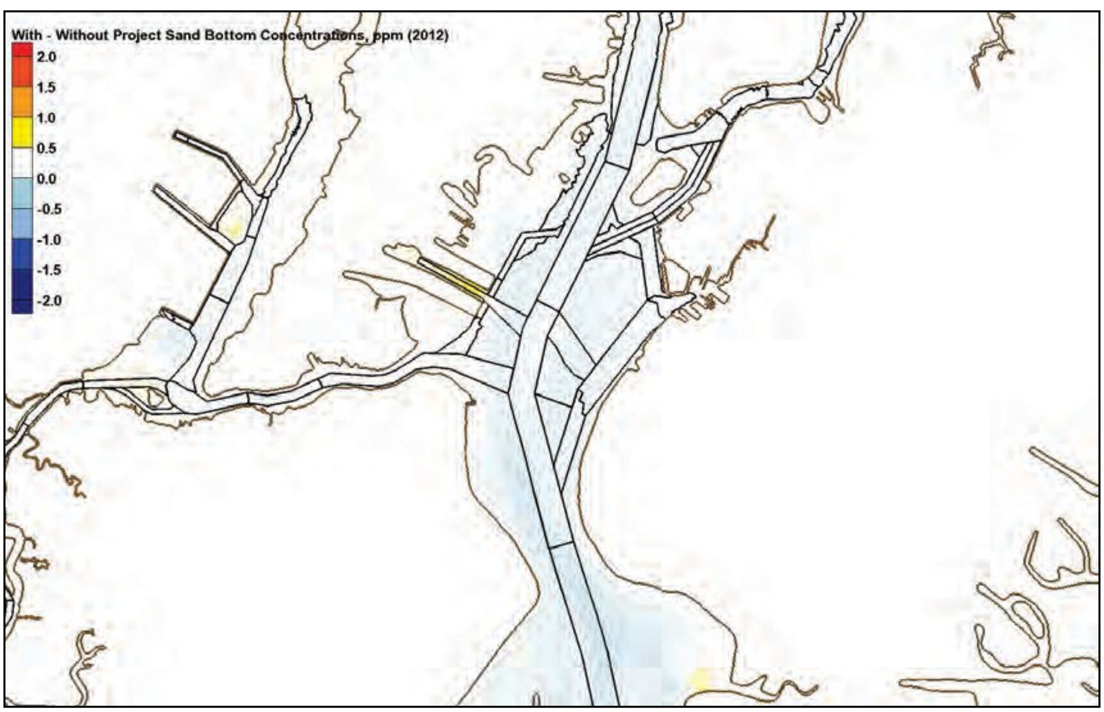


Figure 394. With- minus without-project average bottom layer sand concentrations (ppm) for 2012.



Arthur Kill and Raritan Bay results

Figure 395. With- minus without-project average bed shear stresses (N/m²) for 1985.

Figure 396. With- minus without-project average bed shear stresses (N/m²) for 1995.

Figure 397. With- minus without-project average bed shear stresses (N/m2) for 1996.

Figure 398. With- minus without-project average bed shear stresses (N/m2) for 2011.

Figure 399. With- minus without-project average bed shear stresses (N/m²) for 2012.

Figure 400. With- minus without-project average bottom layer salinity values (ppt) for 1985.

Figure 401. With- minus without-project average bottom layer salinity values (ppt) for 1995.

Figure 402. With- minus without-project average bottom layer salinity values (ppt) for 1996.

Figure 403. With- minus without-project average bottom layer salinity values (ppt) for 2011.

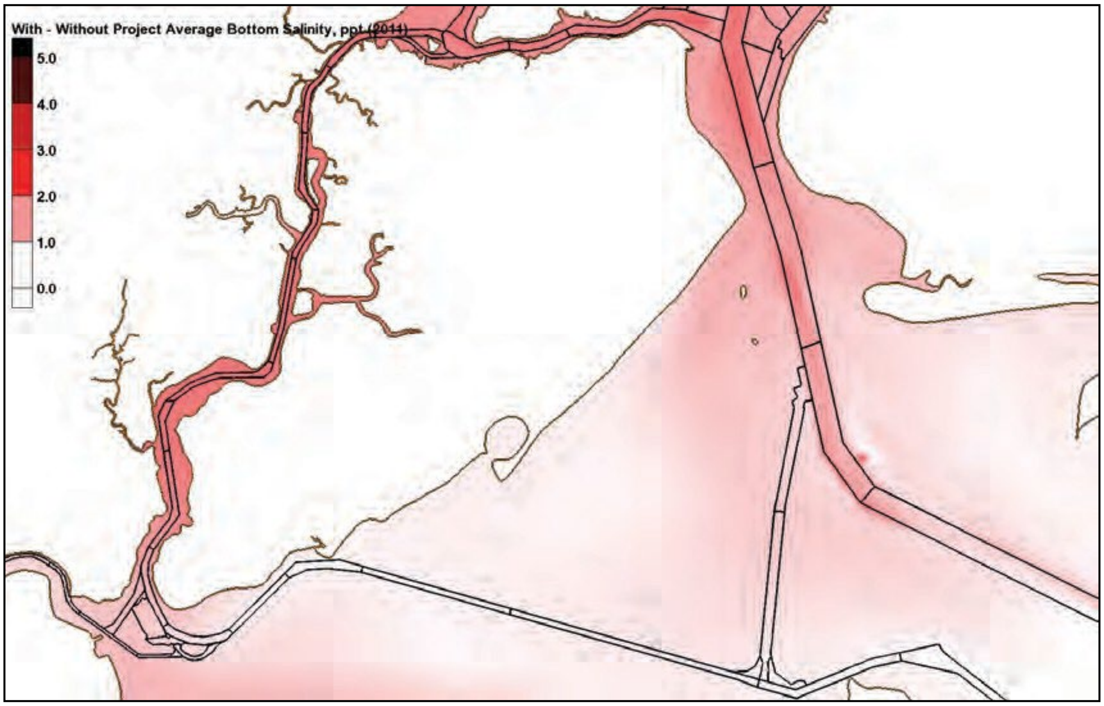


Figure 404. With- minus without-project average bottom layer salinity values (ppt) for 2012.

Figure 405. With- minus without-project average bottom layer fine sediment concentrations (ppm) for 1985.

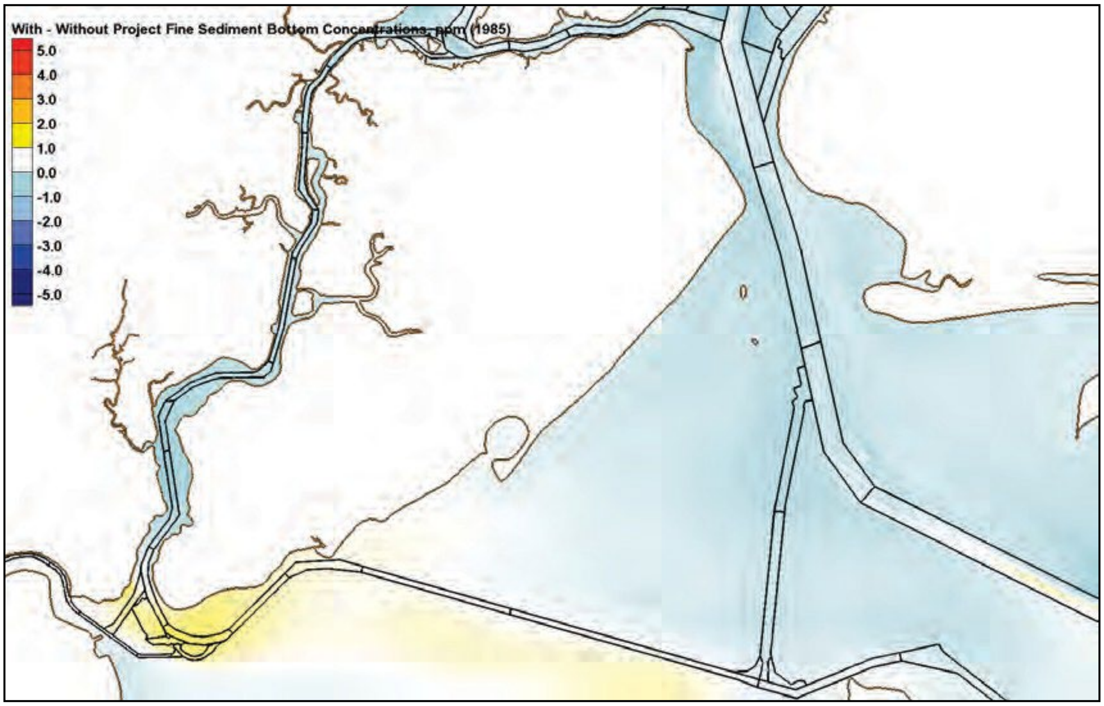


Figure 406. With- minus without-project average bottom layer fine sediment concentrations (ppm) for 1995.

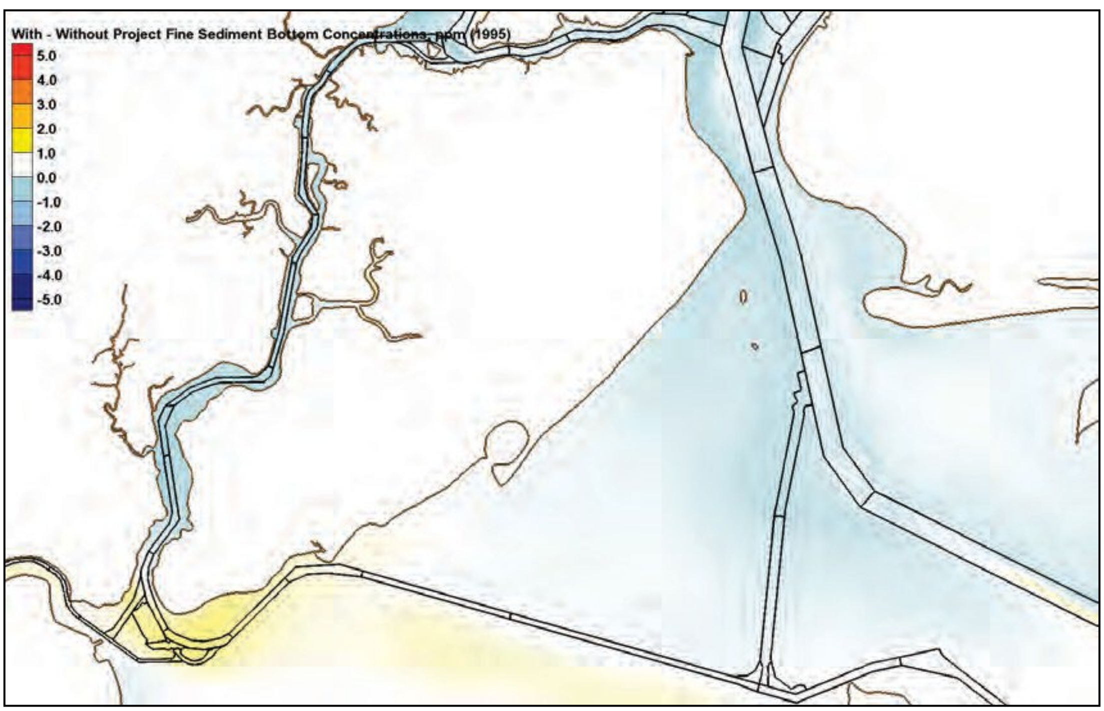


Figure 407. With- minus without-project average bottom layer fine sediment concentrations (ppm) for 1996.

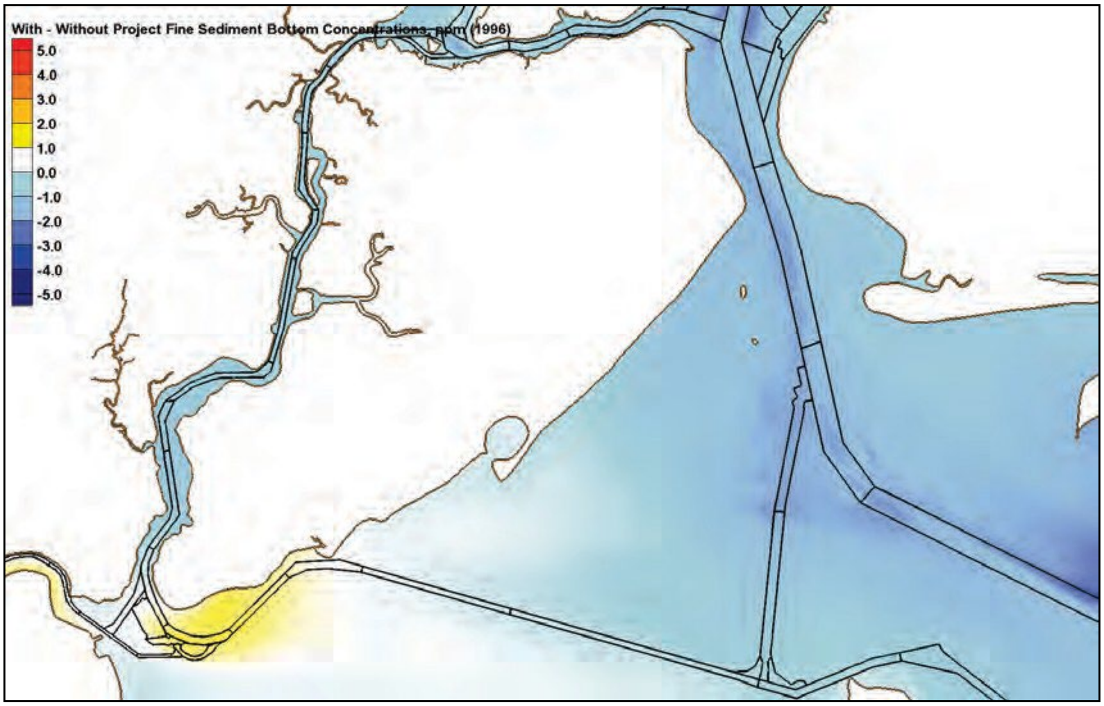


Figure 408. With- minus without-project average bottom layer fine sediment concentrations (ppm) for 2011.

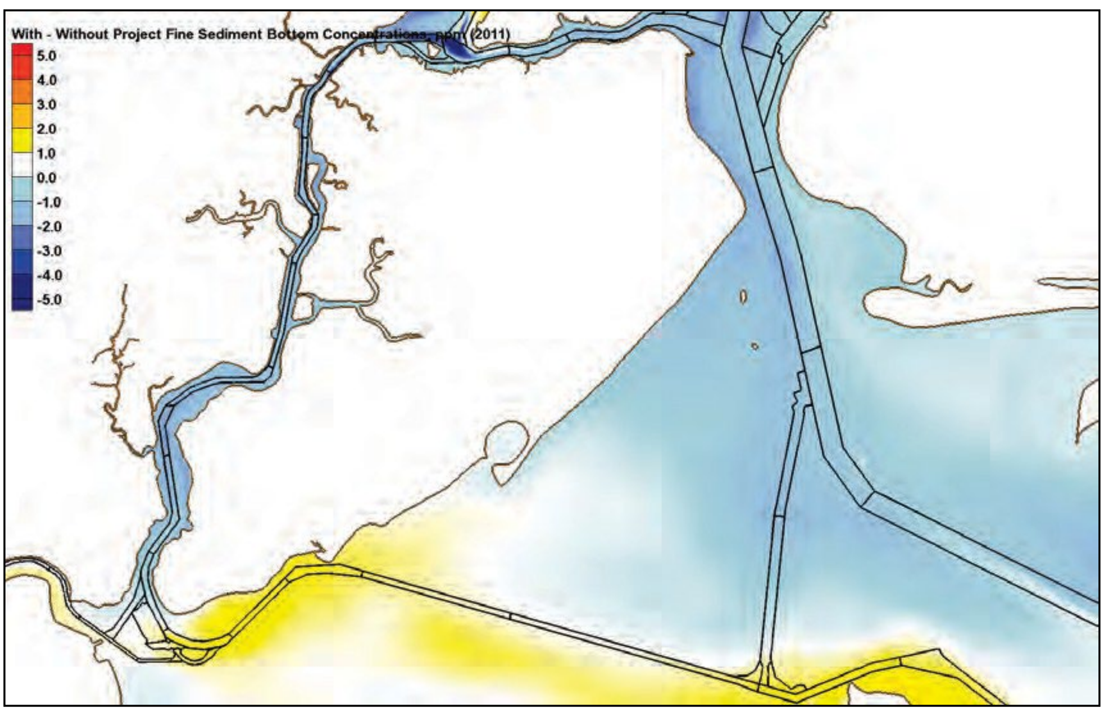


Figure 409. With- minus without-project average bottom layer fine sediment concentrations (ppm) for 2012.

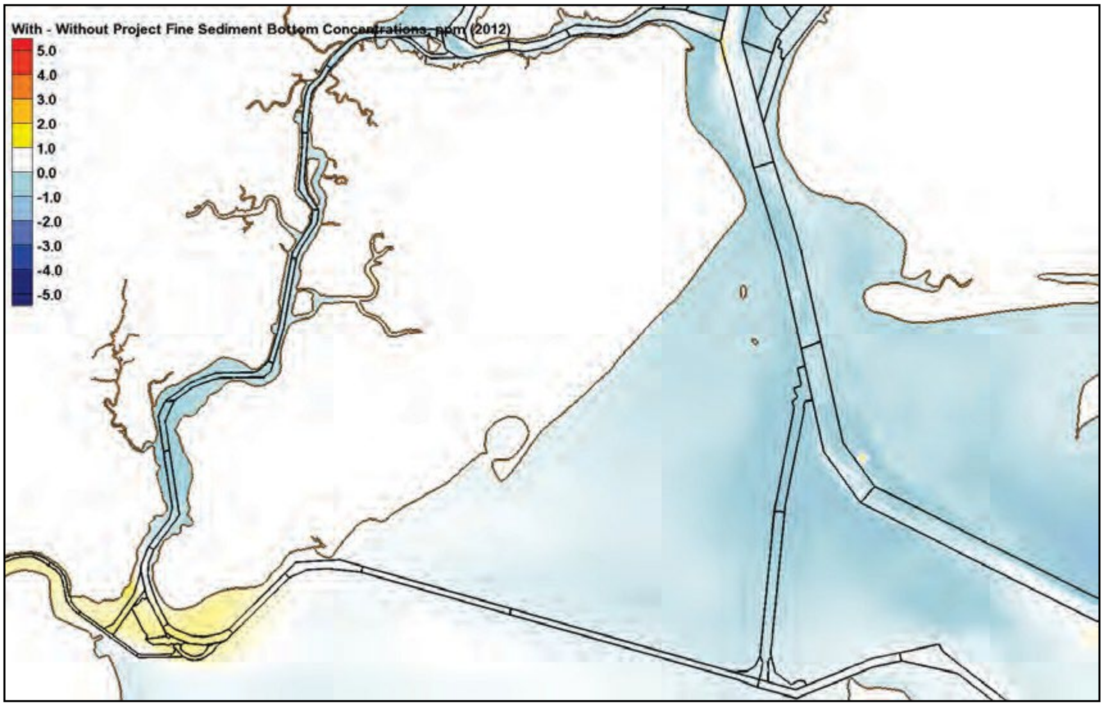


Figure 410. With- minus without-project average bottom layer sand concentrations (ppm) for 1985.

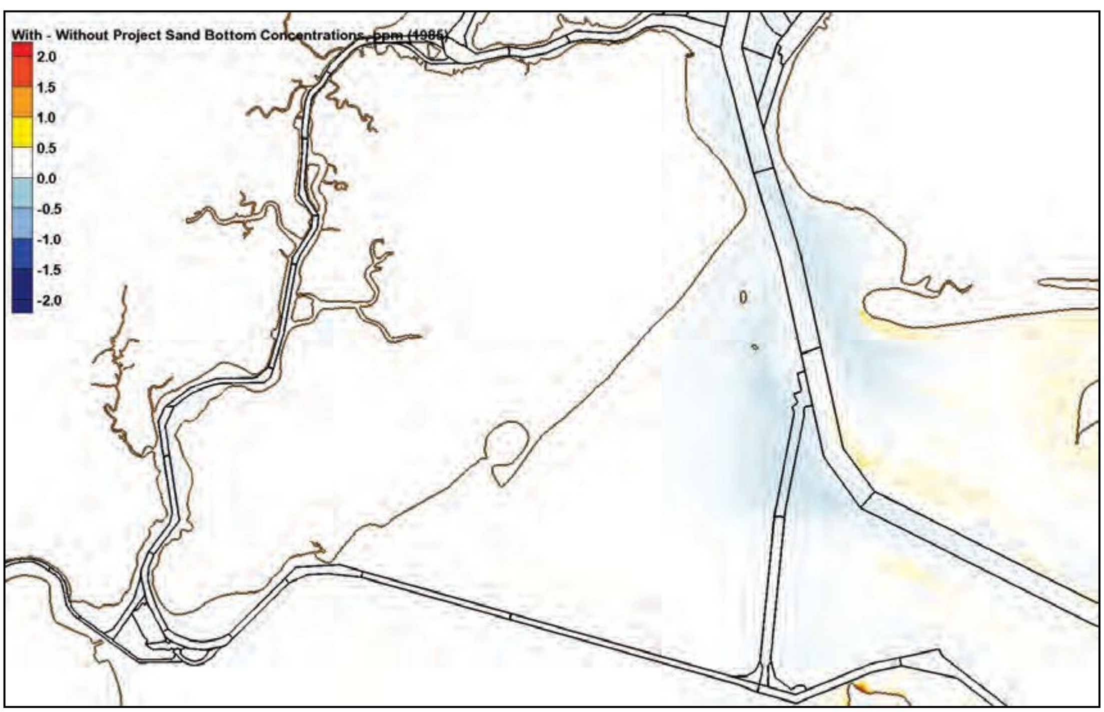


Figure 411. With- minus without-project average bottom layer sand concentrations (ppm) for 1995.

Figure 412. With- minus without-project average bottom layer sand concentrations (ppm) for 1996.

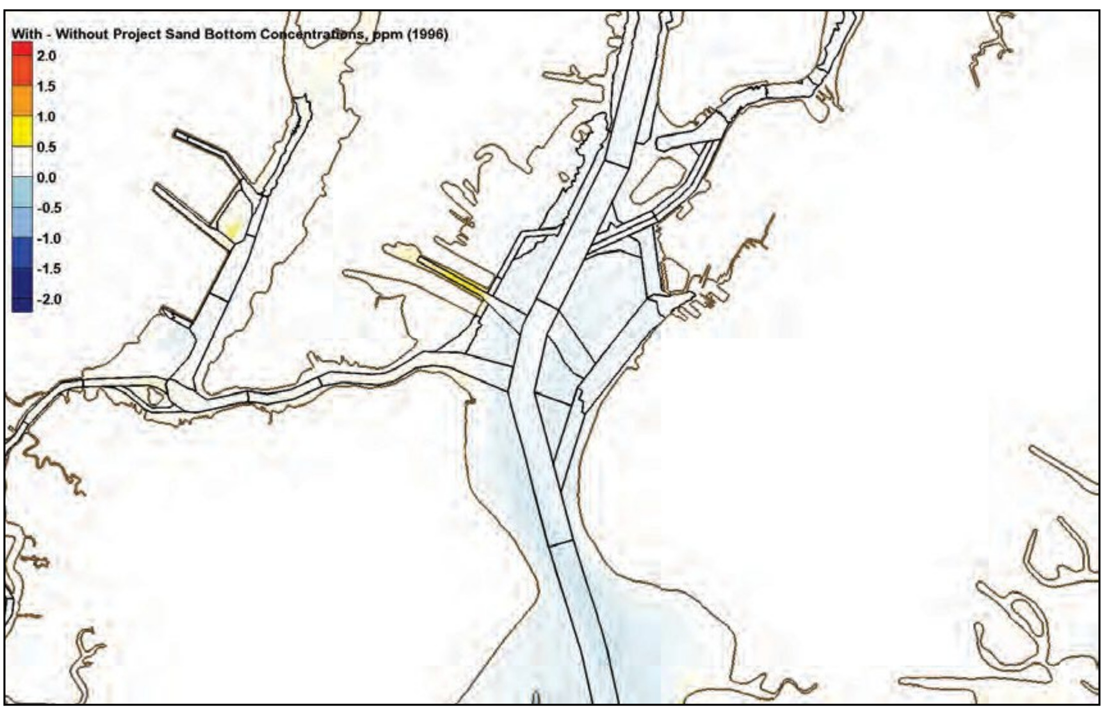


Figure 413. With- minus without-project average bottom layer sand concentrations (ppm) for 2011.

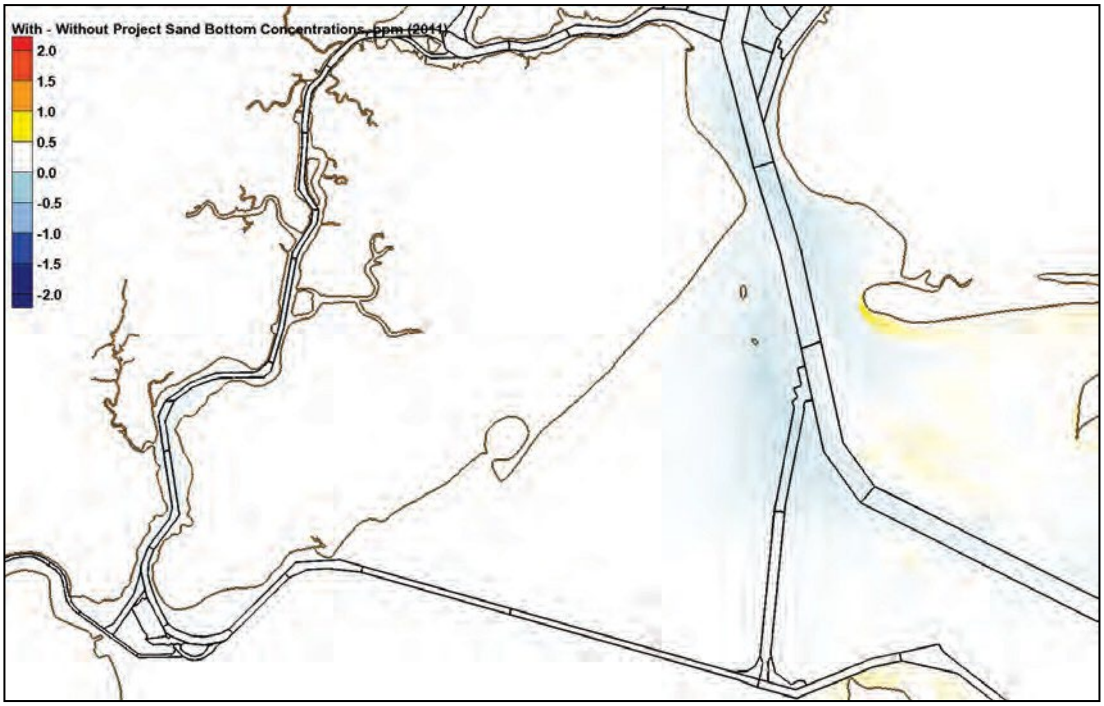


Figure 414. With- minus without-project average bottom layer sand concentrations (ppm) for 2012.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
angstroms	0.1	nanometers
atmosphere (standard)	101.325	kilopascals
bars	100	kilopascals
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
foot-pounds force	1.355818	joules
inches	0.0254	meters
knots	0.5144444	meters per second
microns	1.0 E-06	meters
miles (nautical)	1,852	meters
miles (US statute)	1,609.347	meters
miles per hour	0.44704	meters per second
pounds (force)	4.448222	newtons
pounds (force) per square foot	47.88026	pascals
pounds (mass)	0.45359237	kilograms
quarts (US liquid)	9.463529 E-04	cubic meters
slugs	14.59390	kilograms
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
tons (2,000 pounds, mass)	907.1847	kilograms
tons (2,000 pounds, mass) per square foot	9,764.856	kilograms per square meter
yards	0.9144	meters

Acronyms and Abbreviations

2D	two-dimensional
3D	three-dimensional
AdH	Adaptive Hydraulics
CENAN	US Army Corps of Engineers, New York District
ECSTDB	East Coast Sediment Texture Database
ERDC	US Army Engineer Research and Development Center
ETM	Estuarine Turbidity Maximum
HARS	Historic Area Remediation Site
LISSDB	Long Island Sound Sediment Database
MLLW	mean lower low water
MSL	mean sea level
MWTF	Municipal Wastewater Treatment Facilitie
NACCS	North Atlantic Coast Comprehensive Study
NDBC	National Data Buoy Center
NOAA	National Oceanic and Atmospheric Administration
NYNJH	New York/New Jersey Harbor
RMSE	root-mean-square error
SEDLIB	Sediment transport library
SI	Scatter Index
SSC	suspended sediment concentrations
STWAVE	Steady-State spectral WAVE
SW	Shallow Water
USGS	US Geological Survey
WIS	Wave Information Study

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
August 2020	Final Report	

4. TITLE AND SUBTITLE
New York/New Jersey Harbor Sedimentation Study:
Numerical Modeling of Hydrodynamics and Sediment Transport

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Tate O. McAlpin, Joseph V. Letter, Jr., Mary Bryant, Anthony G. Emiren, Gary L. Brown, Gaurav Savant, Bryce W. Wisemiller, Jamal A. Sulayman, and Corey J. Trahan

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) (see reverse)

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC TR-20-15

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers, New York District
New York, NY 10278

10. SPONSOR/MONITOR'S ACRONYM(S)
USACE NAN

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Work Item Code 1J186F, "ERDC Sedimentation Modeling"

14. ABSTRACT
The New York/New Jersey Harbor (NYNJH) is a vital economic resource for both the local economy and the entire US economy due to the vast quantity of imports and exports handled by the numerous ports in this waterway. As with most ports, there is a significant, recurring expense associated with dredging the navigation channels to the authorized depths. In an effort to determine the impact of channel enlargements ("the project") on dredging volumes, a numerical model study was performed. The advantage of a numerical model study is the ability to isolate individual system modifications and associated impacts in terms of dredging volumes. Five years (1985, 1995, 1996, 2011, and 2012) were simulated for both the with- and without-project conditions to determine the impact of the channel deepening on the dredging requirements for a wide range of meteorological conditions including storm events. The numerical model results were analyzed to provide insight into which locations will experience increased/decreased deposition and quantify the amount of increase/decrease for a given channel reach. The model results indicate a relatively minor increase in the total dredge volumes for the NYNJH with the increase being insignificant in comparison to the natural variability in dredge volumes across years.

15. SUBJECT TERMS
Channels (Hydraulic engineering), Dredging, Hydrodynamics, New York Harbor (N.Y. and N.J.), Numerical analysis, Salinity, Sedimentation and deposition, Sediment transport

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Tate O. McAlpin
Unclassified	Unclassified	Unclassified	SAR	448	**19b. TELEPHONE NUMBER** *(Include area code)* 601-634-3249

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) (continued)

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Knoxville, TN 37919

US Army Corps of Engineers
New York District
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New York, NY 10278

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ATTACHMENT 5

MITAGS STUDY

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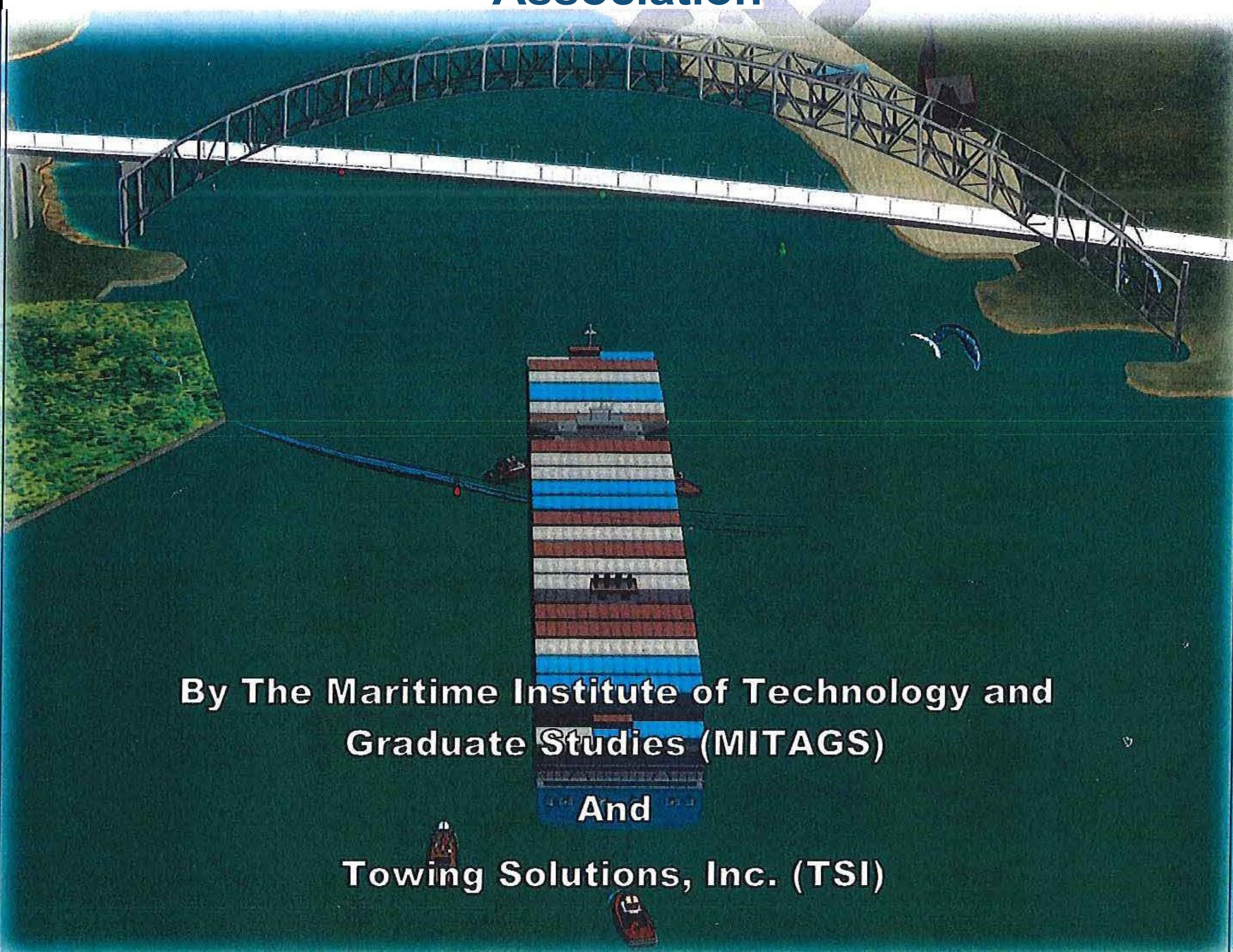
MARITIME INSTITUTE OF TECHNOLOGY & GRADUATE STUDIES
PACIFIC MARITIME INSTITUTE

THE LEADER IN NjARITIME TRAINING

Prellmlnary 18,000 TEU Full Mission Ship Slmulatlon Study Report For The Port of New York / New Jersey Shipping Association



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MITAGS is internationally certified as a Maritime Simulation & Training Center by Det Norske Veritas

Study Name	Preliminary 18,000 TEU ULCV Full-Mission Ship Simulation Study for the Port of NY/NJ
Note	*The companion report is14,000 TEU ULCV Study.*
Project Location	Port of New York and New Jersey
Purpose	q v.elopment of best practices for the navigational transits of 18,000 TEU Ultra Large Containerships (ULCV) in the Port of NY/NJ
Customer	Port of New York/ New Jersey Shipping Association
Bidder Legal Name and Location	The MMP MATES Program, DBA the Maritime Institute ofTechnology & Graduate Studies, and the Pacific Maritime Institute (MITAGS-PMI). 692 Maritime Boulevard Linthicum Heights, MD 21090-1952 Tel: 410-859-5700 Fax: 410-859-8416 Email: **exdir@mitags.org** Web: httu:LLwww.mitags-umi.org
Bidder Description	The MM&P Mates Program is a 501(c)9 VEBA Non-profit Trusteeship. The "MATES Program" was founded by the International Organizations of Masters, Mates and Pilots and the leading U.S. Flag ship operators in 1968. Its mission is to enhance professionalism through the development and presentation of internationally recognized programs in leadership, education, training and safety for the maritime industry. MITAGS and PMI are the primary training and simulation centers for the MMP professional deck officers and pilots. Tax ID Number: 13-2577386. MD Tax Exemption Number: 31000665 Dun and Bradstreet Number: 010094977
Draft Release Date	
Project Leader	Mr. Glen Paine, Executive Director, MMP MATES Program
Authorized Signature	

MITAGS-PMI accepts no liability for the use of the findings, conclusions and recommendations provided by the conning pilots in this simulation study. Additionally, MITAGS-PMI cannot be held responsible for errors in the data provided by the client and other third parties used for the programming of the simulator hydrodynamic ship/ tugmodels, and databases.

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Table 1: Table of Abbreviations

A	Aft	p	Port
CL	Center Lead	Q	Quarter
COG	Course of ground	S	Starboard
DM	Docking Master	SH	Shoulder
F	Forward	SOG	Speed over the ground
KVK	Kill Van Kull Waterway	STW	Speed through the water
NBD	Newark Bay Draw		

1. BACI<GROUND AND PURPOSE

The Port of New York and New Jersey has completed a major navigational channel deepening and improvement project. The controlling depths of the channels have been increased to 50 feet at mean low, lower, water. Additionally, the project includes raising the Bayonne Bridge to allow passage of higher ultra large container vessel (ULCV} air drafts. The bridge project is expected to be completed in 2017.

The Port of NY/NJ, through the Deep Draft Working Group of the Harbor Operations Committee, desired to conduct a full-mission ship simulation study to develop the "best practices" for ULCV transits to the major container terminals within the area. This includes APM / Maher Terminals in Port Elizabeth, Port Newark Container Terminal, GCT New York LP Terminal (Howland Hook}, and GCT Bayonne LP Terminal {Global Marine}.

The Maritime Institute of Technology and Graduate Studies (MITAGS} provided this service in two Parts.

Part A, Phase I evaluated 14,000 TEU ULCV MSC Kalina Class {max LOA 366 *x* beam 51 meters}. Phase I used full-mission ship simulation (FMSS} to assist in the development of "best practices" for handling ULCV. (Phase II sessions will occur at later dates to familiarize the other pilots and tug masters on the what was learned in Part A, Phase I.} *The results of these tests are contained in a separate report.*

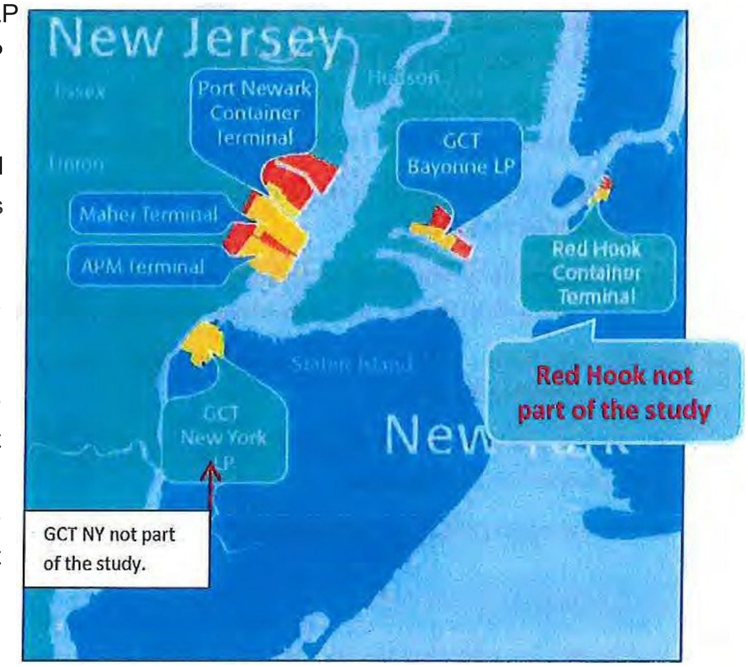

Figure 1: Layout of NJ/NV Terminal Area

Part B, Phase I evaluation was similar, but used the 18,000 TEU Maersk Triple E ULCV Class (max LOA 399 *x* beam 59 meters} instead of the Kalina Class. The goal was to determine the feasibility and challenges to address for this vessel class. **This report contains the results of Triple E Tests.**

The MITAGS simulators are capable of providing the most realistic presentation in the world. The theater projection area is over twenty-four meters wide and twelve meters in height. This provides unsurpassed depth perception and visual accuracy. The FMSS simulator, operated by the Sandy Hook and docking pilot(s}, was integrated with one assist-tug simulator operated by an experienced tug master. Additional tugs were operated from the console.

Figure 2: Port Elizabeth/ Newark, NJ

For more infor·mation on MITAGS, please visit **www.mitags-pmi.org**, and our YouTube® site for video excerpts of previous simulation projects: **http://www.youtube.com/user/MaritimeInstitute**.

1.1 SIMULATION STUDY OBJECTIVES

The 18,000 TEU ULCV Simulation Study provides *preliminary* findings, conclusions, recommendations for the following objectives:

1. Recommendations on "best practices" for ULCV inbound / outbound transits and berthing evolutions to / from APM/Maher/PNCT (Port Elizabeth/Port Newark) with similar sized ULCVs berthed on both sides of the channel.
2. ~~RecommeRdatioRs oR "best practices" for ULCV iRbouRd / outbouRd traRsits and berthiRg evolutioRs to / from GCT Ne'ʄ\' York LP (HowlaRd Hook)~~. Note: In the interest of time, the pilots' removed this objective since the Terminal does not have cranes capable of handling the larger ULCVs and no Immediate plans for replacements.
3. Recommendations on "best practices" for ULCV inbound / outbound transits and berthing evolutions to GCT Bayonne LP (Bayonne Marine Terminal/ Port Jersey).
4. Identification of environmental operational limits for wind directions / speed, and water current velocities/ directions.
5. Assessment of limitations of the existing assist tug capabilities (number, type, and power) needed for safe handling of ULCV Class under various environmental conditions.
6. Feasibility of ULCV meeting Panamax Class size vessels at selected channel reaches in order to expedite traffic flow.
7. Recommendations on "best practices" for responding to propulsion, rudder, and/ or tugfailures at selected channel reaches.
8. Recommendations for future pilot/ tugmaster familiarization training.

1.2 SCOPE OF WORK

Part B, Phase I modeled the 18,000 TEU ULCV Class entering and departing Port Elizabeth/ Port Newark, and Bayonne Terminals to/ from the Verrazano Bridge. The environmental conditions evaluated started from slack water up to maximum flood/ ebb, and wind conditions from calm up to 20 knots.

Deliverables - Parts A & B Phase I Studies

The following services were provided to meet the study's objectives:

- Updated the existing MITAGS visual New York Harbor database to include the heightened Bayonne Bridge and changes to Port Elizabeth, Port Newark, Howland Hook, and Global Marine Container Terminal Berths capable of handling the ULCVs.
- Updated the depth contours based on the ACOE soundings. This enhanced the simulation of the "bank effect" experienced by a deep-draft vessel transiting in a restricted channel.
- Modified USACOE water current data to be uploaded into the simulator for exercises. Waterway Simulation Technology (WST) programmed 48 different water current models that covered two different Hudson River flow conditions, and multiple times. Each model is a single point in time.
- Modified the MITAGS library's hydrodynamic ship model of the *Maersk Triple E* Class to drafts of 42'-00" and 49'-00." The models were even keel. The models represented·ULCV with maximum LOA ofl,308' x 193.5' beam.

- Provided the MITAGS library's ASD "Edward J. Moran" tug model.
- Proviped MITAGS library Transas Conventional #4 tug model to represent the class of conventional tugs that are currently used for post panamax vessels.
- Programmed the "Brian McAllister" ASD model.
- Assisted in the development of the test matrix with client.
- Pre-validated database and models with Sandy Hook Pilots and Docking Masters on May 3 - 6, 2016. Also contracted with a United Kingdom pilot to assist in the model validation process.
- Provided pilot plug interface for the pilots' portable navigation system.
- Provided one FMSS and one tug bridge for one-way traffic simulation tests, and two, FMSS and one_ tug bridges for two-way traffic tests.
- Conducted simulation tests with appropriate support staff of shiphanding expert, simulator operator, and engineering support.
- Contracted with Towing Solutions, Inc. to observe tests and make recommendations related to the use of assist tugs.
- Provided report of simulation tests with findings, conclusions, recommendations, and supporting data.
- Contracted with Waterway Simulation Technology (WST) to complete a surge study to calculate the approximate forces and moments a 9,000 TEU Containership, and Aframax tanker, moving at speeds from 4 to 8 knots, would exert on a tanker moored 'parallel to the ship channel in still water at select distances off the moored vessel. This was compared against the forces and moments generated by models of the *MSC Kalina Class* and *Maersk Triple E* transiting at the same speeds and distances. *(A separate report.)*

1.3 ASSUMPTIONS

MITAGS used the following assumptions in developing this study:

1. The Port Authority provided accurate data of the areas not depicted on existing NOAA for programming the terminals. This included location of berths, bulkheads, dimensions of container cranes, and depth soundings alongside.
2. The Port Authority provided accurate electronic pictures of the facilities.
3. The Pilots provided the climatological data on the environmental conditions simulated and included in the test matrix. This included prevailing wind directions/ strengths.
4. The Port Authority provided accurate illumination guides for terminal lights for night visuals.
5. MITAGS test matrix assumed one-way traffic for most exercises. Select meeting situations in the Kill Van I<ull were conducted using two bridges integrated together. This allowed pilots to conn both bridges.
6. Made four tugs available for each exercise. The assist tugs included two, 46-ton BP conventional, and two, ASDs with bollard pull between 80 to 85 tons.
7. The Pilots provid_ed information on the size of target vessels placed alongside the berths at Sc-IMTT, Buckeye Bayonne, Gordon's Terminal, Pier A-IMTT.

1,4 ASSUMPTIONS AND LIMITATIONS

Inherent in any simulation is the accuracy of the data programmed into the simulator. MITAGS simulation exercises are based on the information provided by the client. The accuracy of this data will have a major impact on the validity of the test results.

The hydrodynamic models used in the simulation were vetted by experienced pilots, MITAGS staff, and company representatives. The model behaviors are based on the pilot card, windage, general arrangement plans, squat table, and other data provided by client or other sources. The model behaviors, as calculated by the simulator, are adjusted based on the consensus opinion of the MITAGS staff and the pilots. Since the adjustments are "subjective," the recommended model adjustments may vary depending on the collective experience of the testing captains and pilots at each session. The models were a good approximation of the particular classes of vessels. Specific vessels in "real-world" situations may handle significantly different from those programmed into the simulator.

The MITAGS simulator provides a close approximation of vessel squat in shallow water. However, an adequate safety margin needs to be used in order to account for changes in squat due to vessel speeds, displacements, channel shoaling, and tidal actions. In this study, squat was generally not a significant factor due to the water depths and slow speeds.

Due to the underwater volume of these vessels, substantial surge forces may occur in confined waters even at low speeds. *Port Elizabeth Reach* and *Port Jersey* warrant special attention due to restricted configurations. This analysis is beyond the capabilities of full-mission ship simulation.

Model behavior is highly dependent on the accuracy of depth contours (shape), the current and wind flows. In "real world" situations, such forces could vary significantly over the operating area. In addition, the models used in these tests were representative of "vessel classes" similar in size and displacement. Vessels of the same class may have significant differences in handling characteristics in real-word conditions.

Water currents were based on U.S. Army Corps. Engineers' models. However, at the time of simulation, there were no field measurements available at Bergen Point for validation purposes. (Additional current meters are being installed at Bergen Point and other areas. Once installed the simulated current models should be compared.)

The "auto-tug" feature of the simulator provides a more realistic simulation of the assist tug than vector forces, but is not as accurate as having a tug bridge integrated with the full-mission simulator. Auto-tugs and one integrated tug bridge was used in these tests.

The test recommendations assume experienced pilots and tug masters operating vessels with the current technology. Operational limits should take into account the real-world tug capabilities, and the need for all local pilots and tug masters to gain experience. Limitations can be gradually reduced as the pilots and tug masters gain experience.

1.S PROJECT TEAM AND SIMULATION FACILITIES

Project team members are listed below. The team members are highly experienced in channel design/ modeling, simulation and shiphandling. The full-mission shiphandling simulator meets or exceeds the Det Norske Veritas (DNV) standards. MITAGS-PMI is DNV certified as a "Maritime Training and

Simulation Center." *Please refer to the MITAGS-PMI Simulation Capability* & *Facilities Guide for further details on team member qualifications and simulation capabilities.*

Table 2: 18,000 TEU (Part B, Phase I) Support Team for August 23-26, 2016 Tests	
MITAGS Team Member	**Position and Duties**
Mr. Glen Paine Executive Director	Responsible for overall coordination with client representatives and ensured the necessary resources were allocated to the project.
Mr. Hao Cheong **Ship Modeler**	**Responsible for the overall simulation technical support of project. Assisted** in collecting the data for modeling the terminals and vessels. Served as liaison with MITAGS Simulation Engineering Staff.
Mr. Robert Weiner, Naval Architect Ship Modeler	Responsible for the programming of the ship models, databases, and underwater depth contours. Also provides support for simulator projection system and maintenance during tests.
Captain Curtis Fitzgerald SHS Consultant	Responsible for validating the ship model with Capt. Michael.
Captain Larry Bergin Shiphandling Consultant Project Leader	Responsible for providing on-bridge support to pilots conning the simulated vessels, and expertise in the handling of large deep-draft vessels in pilotage waters.
Captain Greg Brooks, TSI Assist Tug Consultant	Provided comments and suggestions on the use of assist tugs during transits and berthing evolutions. Co-author of Final Report.
Capt. Ken Kujala Simulator Operator	Responsible for the overall operation of the simulator during the tests. Reports·to MITAGS SHS Project Leader.
Sandy Hook, Docking Masters, and Tug Captains	
Captain R.J. Schoenlank	Senior Pilot and President, Sandy Hook Pilots
Captain John J. DeCruz	Sandy Hook and President, Sandy Hook Pilots
Captain Robert J. Blake	Sandy Hook Conning Pilot
Captain John Oldmixon	Sandy Hook Conning Pilot
Capt. Jack Olthuis	Executive Director, Sandy Hook Pilots
Capt. Bobby Flannery	Moran Docking Master and Conning Pilot
Capt. Robert Ellis	McAllister Docking Master and Conning Pilot.
Capt. Nathan Oliveira (6/29 to 7/1)	Moran Tug Master and operator of tug bridge
Observers	
Captain Michael Day	Captain of the Port - New York. United States Coast Guard (24th)
Mr. Gregory Hitchen	Director, Vessel Traffic Service. United States Coast Guard. (24th)
Ms. Bethann Rooney	Assistant Director, Port Development, The Port Authority of NY & NJ.

1.6 TIME LINE AND TEST LOCATION

The Study took place at the Linthicum Heights, Maryland Campus of the Maritime Institute of Technology and Graduate Studies. This campus is located nea.rthe Baltimore / Washington

International Airport (BWI) and has easy access to the AMTRAK® BWI Baltimore Station as well as Interstate 1-95. Hotel accommodations were made available on the 40-acre campus.

Part B, Phase I (18,000 TEU ULCV) took four days to complete (Tuesday, August 23, 2016 to Friday, August 26, 2016). Monday, August 22, 2016 was used for pre-validation re iew.

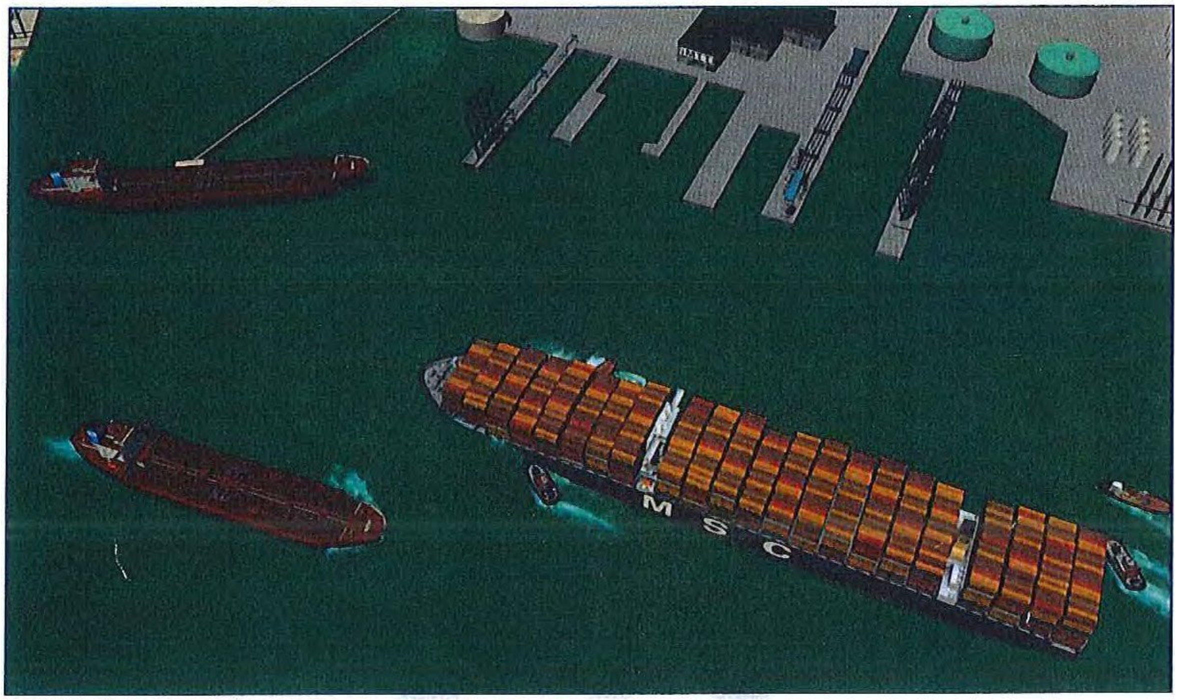

Figure 3: Kalina Meeting In KVK

2. HYDRODYNAMIC SHIP MODELING

The ship models, used in the study included two load conditions. Each hydrodynamic model was pre-validated by the MITAGS-PMI shiphandling experts comparing to sea trial data, tank tests (if available), pilot/ captain reports, and vessels of similar class and size. The models were also validated by pilots that had experience handling these vessel classes. The models used data provided by MSC and Maersk Lines. Please refer to Appendices for more detailed information on the handling characteristics of each model.

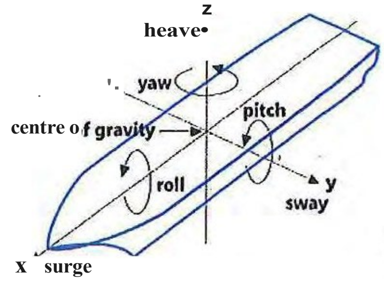

Figure 4: Model Motion

Panamax
old | new

Table 3: Ship Models Used in the Study

Ship Models	**Parts A & B** 14,000 TEU ULCV MSC Kalina Class	**Part B** 18,000 TEU Maersk Triple E	Assist Tug Transas Conventional #4	Assist Tug* Brian A. McAllister	Assist Tug* Edward J. Moran
Bridge location	Forward	Forward	n/a	**n/a**	n/a
Maximum Container Load	14,000TEU	18,000	n/a	n/a	n/a
Displacement at 42' Draft	**172,769**	206,397	**n/a**	n/a	**n/a**
Displacement at 49' Draft	198,160	240,905	n/a	n/a	n/a
Wind Area with Max Deck load in **load & Ballasted (sq. meters)**	14526mA2 at **42' draft 14,000mA2 at 49'draft**	15,633m"2 at **42' draft 16,555MA2 at 49'draft**	**n/a**	**n/a**	**n/a**
Length (meters)	**366 (1,201')**	**399 (1,308')**	126 feet	99.1 feet	100feet
Beam	**51.2 {168')**	**59 (193.5')**	**34 feet**	**40 feet**	**37.1'**
Trim	**even**	**even**	even	**even**	**even**
load Draft	**14.9 (49')**	**14.9 {49')**	**12'-06"**	**18.9 feet**	**16 feet**
Mid Load Draft	**12.8 (42')**	**12.8 (42')**	**n/a**	n/a	n/a
Engine kW and Propeller	**Low Speed Diesel, Single Screw FPP**	**Low Speed Diesel, Twin ScrewFPP**	**Conventional twin screw**	**6,770 BHP**	**6,000 BHP**
Rudder Type	**1,Semi suspended**	2, **Semi suspended**		**ASD**	**ASD**
Bow Thrusters	**2, at 1,700kW**	**2 at 2,500kW each**	**n/a**	**n/a**	**n/a**
Stern Thrusters	**n/a**	n/a	**n/a**	**n/a**	n/a
Chock and Bltt SWL/Bollard Pulls	**75 metric tons**	**75/ 150**	**46 metric tons**	**85 metric tons+**	**83 tons**
Chock and Bltt Locations	**Fwd./** Aft	**Fwd./ Aft**	n/a	n/a	n/a
Tug Location Restrictions	**TBD**	**TBD**	**n/a**	**n/a**	**n/a**

6448
81,488?
K-class extended 1138
~~348.2m(1,141)~~
2.8m(140.2)
~~14.02(46)~~
18'

289.56m 950'
32.31m 106'
12.04m 39.5'
366m 1201'
49m 161'
15.2m 50'

*The model *Edward J. Moran* was programmed for the Savannah River Pilots ULCVTests. It should have similar horsepower and bollard pull as the Moran boats being built at Washburn & Doughty. The *Brian McAllister* was programmed using design parameters since the vessel is still under construction.

The test matrix used assessed the impact of the following forces on the handling of these simulated vessels:

- Prevalent local environmental conditions (waves, wind, currents, and tides).
- Forces created by tugs.
- The reduction in under keel clearance due to squat and interaction.
- Bank effects depending on the channel conditions and ship operating speed.
- Drift angles created by wind forces from various directions.
- Acceleration and deceleration of model.
- Rudder/ propulsion forces needed to maintain track line.

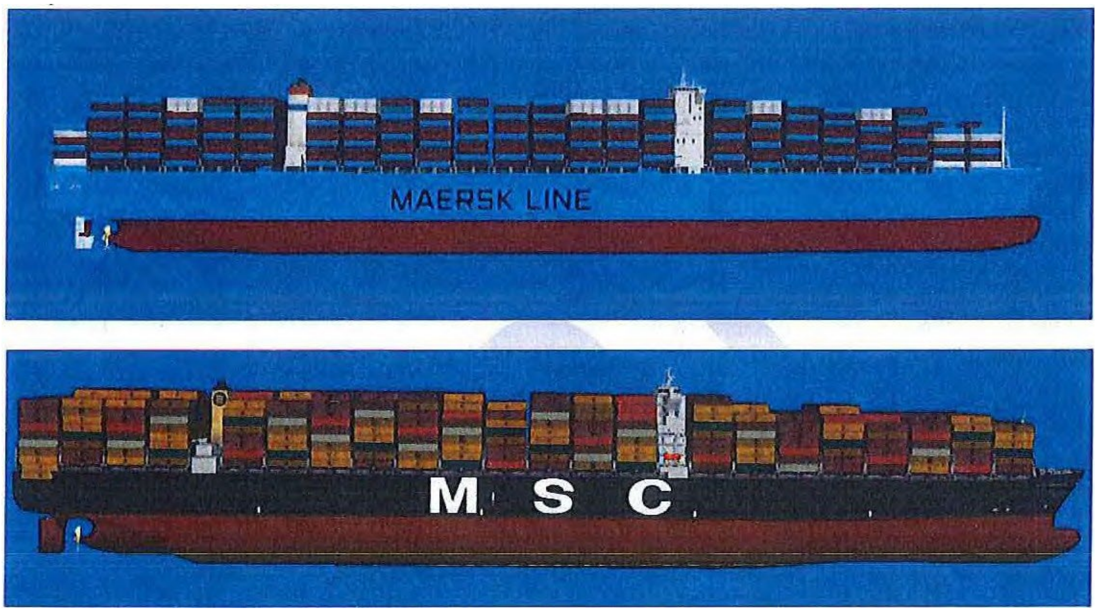

Figure 5: Profile Views of the Triple E and Kalina Models

3. DATABASES' DEVELOPMENT

The MITAGS Simulation Engineering Department used proprietary Transas®database modeling software to import the electronic chart display information system (ECDIS) data. This software automatically transferred the information from ECDIS into simulator database elements, and links the visual and radar databases. The ECDIS data included:

- Hydrographic: depth points, depth lines, depth contours, drying areas, three dimensional (3D) channel bottom.
- Landmass: 3D terrain, DEM data, coastlines, islands, pier structures, etc.
- Navigation Aids: buoys, ranges, and lighthouses.
- Navigation Signals: color, light timing, light sector, etc.

The database was then overlaid with the terminal design(s), approach channels, and any other navigationally significant feature that was available. The database included ECDIS and RADAR displays.

Figure 6:Sample Visual Graphics[1]

[1] The visual depicts the existing Bayonne Bridge raised in height for the purposes of the simulation study. It does not reflect the image bridge after construction. The pilots did not evaluate placement for maximum air draft for maneuvering at Bergen Point. The bridge visuals can be updated at a later date for future training requirements.

Table 4: Electronic Chart Data Used for Developing Visual Databases			
New York F Database Information			
Database version: 6.40.000.24062.55			
Build data: 7/1/2016			
Exercise area size: 47.9 x 43.0 nautical miles			
Number of lighthouses: 75			
Number of buoys: 384			
Database purposes			
New York F exercise area is designed for the purposes of navigational training.			
Database bounds			
New York F exercise area exists within the rectangle with following coordinates:			
SW corner: 40°09.00N 74°13.99W			
NE corner: 40°51.99N 73°11.oow			
List of used electronic nautical charts			
NM	Number	Scale	Date of last correction
1	u12339	10000	08.04.2004
2	u12334	10000	03.03.2004
3	u12335	10000	08.04 2004
4	u12333	15000	08.04.2004
5	u12401	15000	08.04.2004
6	u12402	15000	08.04.2004
7	u12366	20000	08.04.2004
8	u12326	80000	08.04.2004
Created by			
6/29/2016			
The following updates have been added in the database.			
1. Updated all of the navigational aids to NOAA ENC charts dated March 2016) US4NY1AM) USSNJ11M) US5NJ13M) US5NJ14M) US5NY1BM) US5NY1CM) USSNY1DM) US5NY11M) USSNY12M) US5NY19M			
2. Imported the depth survey of 2015 from the Army Corp			
3. Imported the depth survey of 2014 and 2016 from NOAA			
4. Added more visual details around Port Elizabeth, Global Marine Terminal, Howland Hook Terminal and also along the coastline.			
5. Raised the Bayonne Bridge to meet the specified clearance			

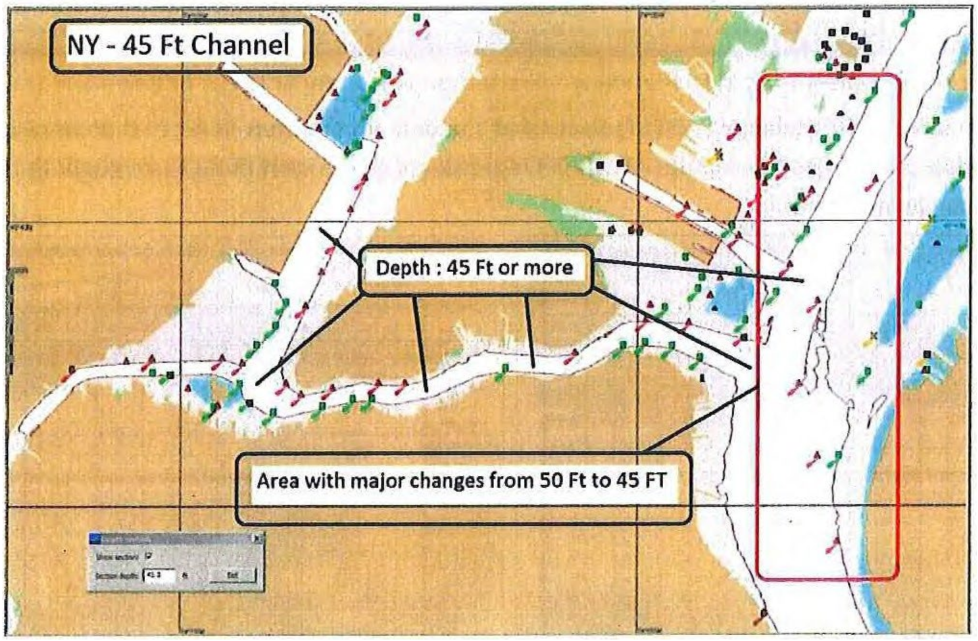

Figure 7: Depth Areas of 45 feet or More at MLLW

3.1 UNDERWATER CONTOURS

The first stage of the programming used the underwater contours based on the NOAA electronic chart for that area from the Transas® World Library. It was then enhanced with bathymetric data provided by the Army Corps of Engineers for the navigation channel, and NOAA for deep water adjacent to the channels. This created more realistic bank slopes and contours. The bathymetric data coordinates were in latitude and longitude and referenced to WGS-84 datum. Coordinate format was degrees and decimal degrees to six places. Isolated shallow spots were removed from the channels, and alongside the berths at Global Marine Terminal, Port Elizabeth, and Howland Hook.

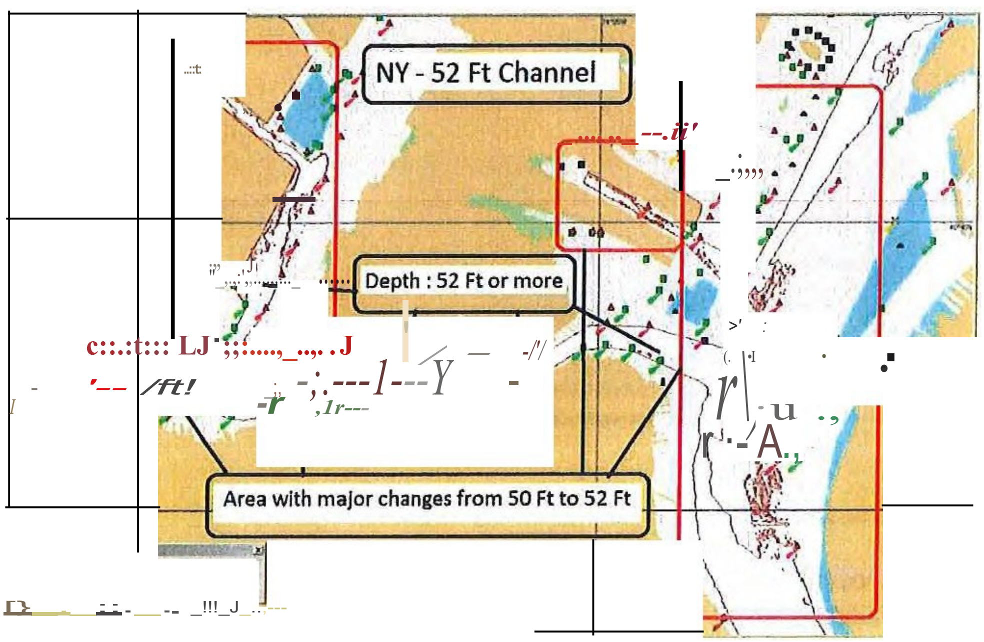

Figure 8: Depth Areas of 52 Feet or More at MLLW

3.2 WATER CURRENTS

The water current models used in the Study were based on U.S. Army Corps of Engineers {ACOE) data. Waterway Simulation Technology (WST) formatted the data in 48 different files[2] that were capable of being loaded into the Transas Simulator. Each file represented the current flows throughout the testing area at asingle point in time.

May10, 2012-After Spring Tide-51,300cfs on Hudson River (MagnitudeInKnots)							
lii,	Go,On!sl!ri&g	BergtnPL	Port Eiubeth	Conmij HookRif'€	Portltrsey	Verrmno Bri<fi,N	Verrmno 8/i6i1S
trt-3120	0.31	121	0.19	O.IO	0.08	0.50	0.29
tlY-Jm	016	U4	039	0.10	039	U&	0.91
UY-3m	O.S4	LI7	050	O.,S	0.11	1.71	Ul
l/Y-31L3	1.01	1.36	0,49	0.16	LOI	1.91	Lil
IIY-31!4	Ill	O.IO	0.31	021	Q91	1.61	Ll6
111-3125	0.74	0.54	Ml	0.43	0.51	0.61	0.60
IIY•3126	0.12	LOI	058	070	0.00	0.70	0.21
NY•III 1.25	0.15	1.19	0.73	0.88	0.00	0.88	0.16
IIY-3127	0.60	0.7&	O.!O	0.10	0.64	1.45	0.81
IIY-3118	0.8)	O.IS	0.62	0.12	0.91	1.77	1.14
IIY-3129	0.9S	0.10	0.4)	0.27	0.99	1.78	1.20
IIY·3L;o	0.89	O.l)l	031	0.1,	0.93	1.19	1.0!
IIY·IIII	0.81	0.12	0.IS	0.116	0.74	1.16	0.83
IIY·III2	0.68	0.37	0.08	0.1!	0.50	0.64	0.49
IIY-31II	0.47	0.76	0.10	0.41	0.14	0.23	0.16
IIY-3134	0.12	L67	037	o.al	0.0	L46	LO!
l/Y-IIJS	0.49	LOI	0.61	LOS	0.89	1.00	Lil
IIY·121 1.25	0.61	2.55	0.78	1.31	I.II	2.50	2.01
IIY-III LI	0.74	3.80	0.93	1.60	1.34	3.00	2.42
IIY-III6	LII	Lil	O.S4	0.6&	0.97	LIO	W
IIY-3137	I.I!	0.37	Ml	0. S	0.61	0.70	0.76
IIY-3138	0.31	LO!	0.70	0.1!	0.12	0.31	0.21
IIY-3139	0.74	0.50	0.74	0.41	0.29	0.9S	0.14
IIY-3140	0.72	0.16	0.37	0.11	0.64	1.09	0.6&
IIY-3141	0.72	0.06	o.Jl	O.ll	Ml	L63	Lil
IIY-3142	0.91	0.16	0.0	o.37	o.91	1.71	L16
IIY-3141	1.01	al,	0.49	O.IS	0.76	1.28	0.a,
	fioodTl<ie						
	EltTl<ie						

April 8, 2012 -SpringTide-7,062.cfs on Hudson River(Magnitudein Knots)							
	G«:t.t-.ab:llritl'g	9t nFt.	'' '' ' Eir • b. .lh	Cor.51.abl;i: Hot-ltR;u•-£	F"ortJ:ri;.v	Vtnu no Bn1j N	V;;rr.Jur.o Btf S
NY-1352	ll91	1.n	0.62	o.95	1.0)	2.19	1.77
ii'/.ffs3'	1.40	:LU	052	0.62	1.14	Ul	1.63
1{i-2JS3(1.5l	Z,10	1.77	0.83	0.93	1.71	3.32	2.45
NY-2354	1.24	IU1	0.29	0.10	0.9S	1.51	1.16
NY-ms	051	0.70	0.,14	ML	MS	0.27	0.45
N'l-iisi;			0 n		o.u	101	0.)9
IN-2357	o'.'u···	-.:so ·	"O:ff	o5 a	O.Bl	1.61	1.01
N>'-2357(1.15	0.&5	1.00	1.04	0.98	1.04	2.01	1.26
1{f-2357(1.!l	1.22	1.44	1.49	1.75	1.50	2.!)0	1.82
NY•2J5S	0.93	0.4)	0.66	0.52	1.01	1.00	1.34
NY-1.359	5	O.Jl	0:54	0.33	l.W	l:9!	1.!6
h'f-Ill9iJ.5j	1.43	0.47	0.81	0.50	1.64	2.97	2.04
h'f•LJSS9.JI	2.19	0.71	1.25	0.76	2.50	4.55	3.12
NY•W.O	0.91	O.ZJ	0.50	0.31	0.97	1.69	J.16
NY·Il61	0.17	0.10	0.J5	0.12	0.74	1.09	O.li
NY•Il62	0.74	o.n	0.04	0.49	0.)7-	o.u	0.14
NY-2161	U.31	1.16	U.JJ	o.91	O.lJ	U4	U.99
N'/·2!64	(us	2.15	o.ro	1.05	o.ao	1.94	1.55
Nfll	Ul	1.71	0.60	0.13	1.01	2.08	1.6!
NY•2lU.	1.26	ClcO	O.l5	O.M	G.91	1.53	1.28
NY-71_67	o.52	U.4!	U.17	0.49	0.51	U.JU	U.7U
NY·216S	O.ll	0.tO	0.52	0.59	0.17	0.19	0.17
NY•l369	0.43	0.50	O.H	0.47	0.43	U6	0.47
N'i-2170	0.72	0.43	O.SO	0.54_	o.89	HJ	LIi
FA'•2171	Ul	U,45	U56	U.51	1.01	2.U2	1.38
NY•Il72	0.19	0.41	0.60	G.41	0.S9	1.77	J.2.4
NY•Il7l	1.01	1119	1137	IUO	0.70	o.91	0.64
NY-2174	U.'4	1.21	0.12	0.10	O.ll	0.19	0.14
NY-1.31S	Ohl	1.63	O.J9	0.74	0.16	1.09	0.81
	Fbt-dTie"						
	Etbl'c<						

Figure 9: WST Water Current File Names

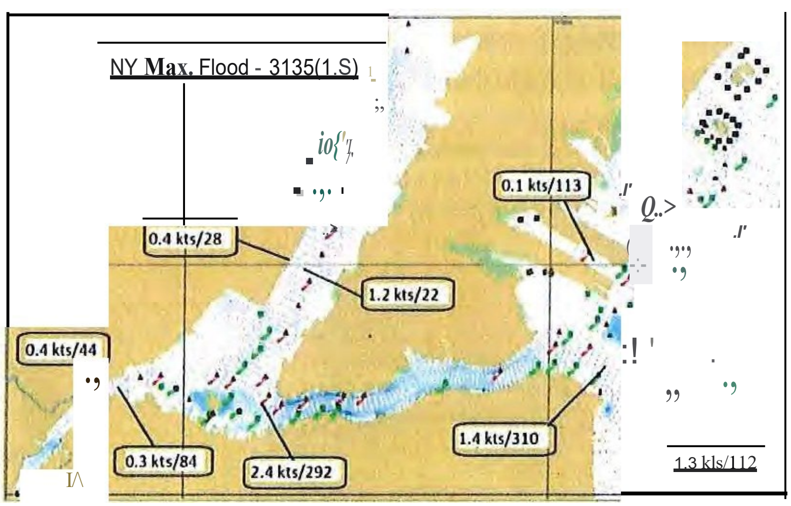

Figure 10: Sample Flood Current Data Points

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2 Please refer to the Appendices for a more detailed explanation of how the water current models were developed and programmed.

During the pre-validation exercises, the pilots noted that the directions of flows were accurate, but the velocities were less than they expect to experience in real-world situations in the Bergen Point area. WST increased the velocities of each data point by a certain percentage (see file names highlighted in yellow in thetable above). After the changes, the pilots felt the ship model reaction was more realistic. However, it did raise some concern about the accuracy of the velocities and the model responses to the current forces.

Transiting through Bergen Point (inbound / outbound) was determined to be the controlling factor of the transit. The ULCVs would have to time their transits to make the turn at Bergen Point when the tidal currents velocities were low. This meant determining time "windows" on either side of slack water-high, and slack water-low that the velocities would be low enough for safe transits. Theoretically, there would be four different time windows per twenty-four hour tidal cycles (two highs, two lows). However, the Triple E at 49' draft would be limited to the periods before/ after slack water-high in order to have enough under keel clearance.

To determine which current model files to use, the pilots analyzed the NOAA predicted current tables for the Bayonne Bridge KVK location (the closest reference to Bergen Point). They were able to determine that, on average, the change in current velocity on either side of slack waters over time can be roughly calculated as a percentage of the max current velocity during a particular tide cycle. The relationship determined was as follows:

Flood to High Water Slack (High Water) -

- 1.5 hours before the end of the flood-high water, the current strength was approximately 60% of the predicted max flood current.
- 1 hour before the end of flood-high water, the current strength was approximately 43% of the predicted max flood current.

High Water Slack Ebb Begins

- 1 hour into the ebb, the current strength was approximately 40% of the predicted max flood current
- 1.5 hours into the ebb, the current strength was approximately 54% of the predicted max flood current.

Ebb to Slack Low Water

- 1.5 hours before the end of ebb-low water, the current strength was approximately 60% of the predicted max flood.
- 1 hour before the end of the ebb-low water, the current strength was approximately 40% of the predicted max flood.

Slack Flood Begins (Low Water)

- 0.5 hour (30 minutes) into the flood, the current strength was approximately 30% of the predicted max flood.
- 1 hour into the flood, the current strength was approximately 60% of the predicted max flood.
- 1.5 hours into the flood, the current strength was approximately 85% of the predicted max flood.

Assuming 2.55 knots as the average maximum flood current at Bergen Point, the following current velocities were calculated based on percentages:

Flood to High Water Slack (High Water)

- 1.5 hours before the end of flood-high water, 60% of 2.55 knots: 1.53 knots flood
- 1 hour before the end of flood-high-water, 43% of 2.55 knots: 1.09 knots flood

High Water Slack Ebb Begins

- 1 hour into the ebb, after high water, 40% of 2.55 knots: 1.02 knots ebb
- 1.5 hours into the ebb, after high water, 54% of 2.55 knots: 1.38 knots ebb

Ebb to Slack Lo Water

- 1.5 hours before end of ebb-low water, 60% of 2.55 knots: 1.53 knots ebb
- 1 hour before the end of ebb-low water, 40% of 2.55 knots: 1.02 knots ebb

Slack Flood Begins (Low Water)

- 0.5 hour into the flood after low water, 30% of 2.55 knots: 0.77 knots flood
- 1 hour into the flood after low water, 60% of 2.55 knots: 1.53 knots flood
- 1.5 hours into the flood after low water 80% of 2.55 knots: 2.1 knots flood

From this information, the pilots went back to the WST current model files and selected models where the maximum currents at Bergen Point were the closest to the following values:

1. .02 knots to represent 40% of ebb.
2. 1.53 knots to represent 60% of ebb.
3. 1.09 knots to represent 43% of flood.
4. 1.53 knots to represent 60% of flood.

Approximate Bergen Point Transit Time Windows

Based on above, the ULCV should have the following time windows where, on average, the maximum predicated current at Bergen point would be the following percentage less than max current:

- 60% or less: 1.5 before to 2.0 hours after high-water slack; 1.5 hours before to 1.0 after low-water slack.
- 40% or less: 1.0 before either side of high-water slack; 1.0 hour before to 45 minutes after low-water slack.

Again, note that the ULCV at 49' draft can only use the time windows around slack high water to ensure enough under keel clearance.

3.3 WIND DIRECTIONS AND SPEEDS

Wind directions and speeds were controlled from the operator_console. The directions, and speeds (including gusts), were provided by the local pilots. In most cases, the wind directions and velocities selected were the most challenging. Maximum wind speed tested was 30 knots.

3.4 VISIBILITY; DAY NIGHT SCENES

Tests were conducted with clear visibility during daylight hours. However, the simulator operator was capable of simulating rain squalls, fog, low-altitude clouds, and night visuals.

4. WATERWAY SIMULATION TECHNOLOGY (WST) SUPPORT STUDIES

WST generated a separate *"Memo for the Record of Passing Effects on Moored Vessels in Kill Van Ku/16-4-16."* The Study placed a target vessel **in** the approximate position of the Hess (Buckeye) - Bayonne Terminal berths. It then calculated the theoretical forces each vessel class would generate on the berth when transiting along the centerline of the channel at various speeds. The *Kalina,* at 5 knots, generated the same forces as the *AMaersk* {9,000 TEU} at 6 knots. The *Triple E,* at 4 knots, generated the same forces as 9,000 TEU at 6 knots. The pilots used this as guidance for the maximum speed to transit in the KVK where the theoretical forces would be no greater than currently produced by current vessel transits. Note that the forces' calculations were based on maintaining position on the center line of the channel. Forces rapidly increase as distance between the transiting ship and berth decreases.

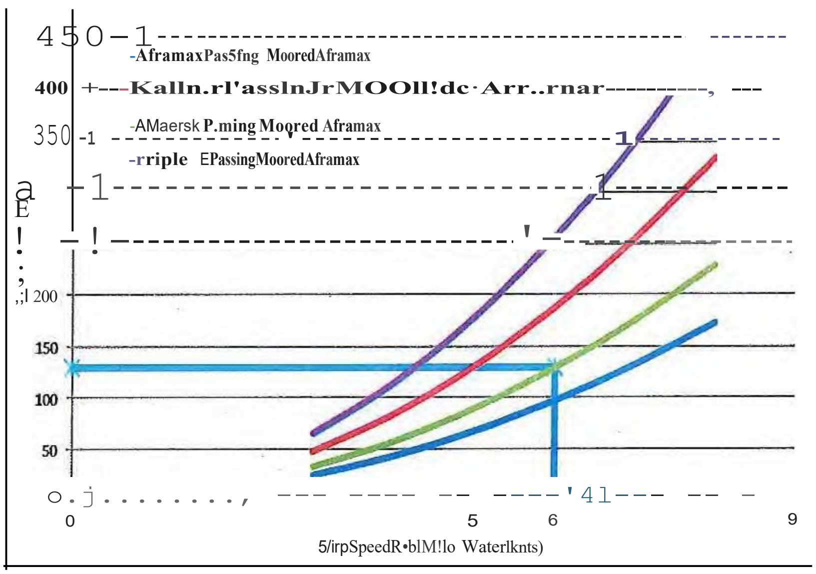


Figure **6: Moored** AframaxForward surgeForces

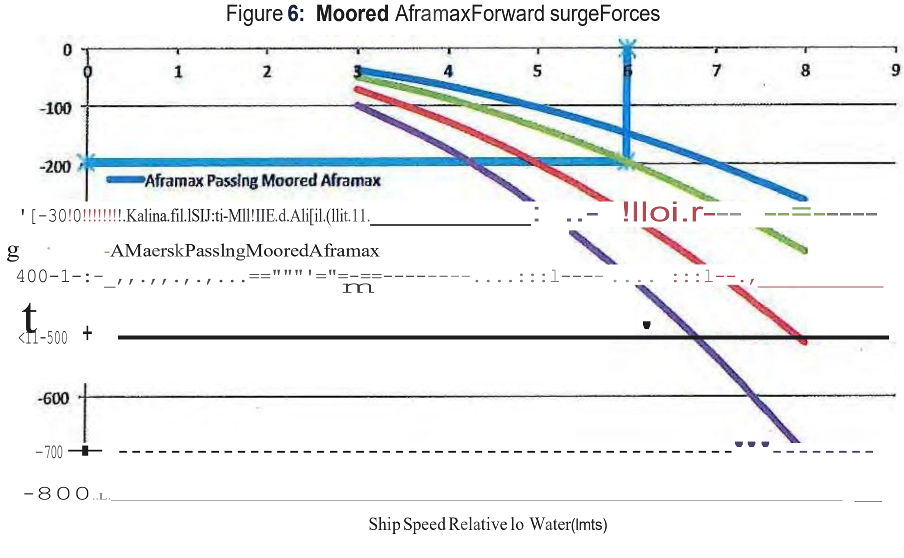


Figure 7: Moored Aframax Aft Surge Forces

Figure 11: Excerpt of Surge Forces vs. Speed by Vessel Class in the KVK from the WST Report.

5. MANEUVERING STUDY METHODOLOGY

MITAGS programmed the deepened navigation channels, turning basin, and container berths. MITAGS modified the *Maersk Triple E Class* hydrodynamic ship models to the requested drafts {42' and 49'). The tide was set at mean lower, low water (MLLW) unless otherwise specified by the conning pilot. All models used the maximum deck load profile for windage area.

The test matrix was developed by the pilots to formulate the "best practices for handling 18,000 ULCVs to the specific container terminals, suggested environmental limits (wind, current, tide, and visibility), and assist tug requirements. The exercises used the *Triple E* Class Models at the 42' and 49' drafts. Target ships were place on the container berths to better simulate the expected restrictions. All simulation exercises were run in "real time." This meant that it took close to the same amount of time in the simulator as in the real world. To maximize the simulator time, the exercises were stopped when the objectives were achieved. In order to make better use of the simulator time, the pilots decided not to evaluate Howland Hook, Staten Island Terminal since these berths are not equipped to handle the 14,000 TEU Class of containership ships. In four days, the pilots completed twenty-seven runs.

5.1 EXERCISE SCENARIOS

After each run, the coning pilot and tug operator were debriefed and requested to fill out a run questionnaire. At the end of the simulation, final evaluations were requested from all participants and a consensus on the parameters needed to handle this class of ship on a routine basis.

Figure 12: Triple E entering Port Elizabeth Branch Reach

6. TOWINGS SOLUTIONS OBSERVATIONS - 18,000 TEU

Towing Solutions, Inc., is a recognized expert in the use of assist tugs. MITAGS contracted with TSI to observe the simulation and provide suggestions on ways maximize the efficiencies of the assist tugs, and comments on the feasibility of handling Ultra Large Container Vessels (ULCVs) in the Port of New York/New Jersey.

This Study was a preliminary review of the feasibility of handling 18,000 TEU ULCVs. It was a follow-up to the 14,000 TEU Study conducted in June 27 - July 1, 2016). Both classes of vessels are in service, and are significantly larger than the current ULCVs calling on the Port of NY/ NJ. The Study completed 27 research simulation runs of various lengths to develop procedures, if possible, to safely and consistently bring these large ships into both Port Elizabeth and Global Terminal in Port Jersey. To facilitate the review, the runs are categorized as follows:

1. Full (or near full) runs inbound or outbound from Stapleton Anchorage to Port Elizabeth.
2. Rounding Bergen Point inbound from Bergen Point East Reach to Buoy 3 in Newark Bay.
3. Rounding Bergen Point Outbound from Buoy 3 in Newark Bay to Bergen Point East Reach.
4. Inbound from Buoy 10 Newark Bay to Port Elizabeth.
5. Outbound from Port Elizabeth to Buoy 10 Newark Bay.
6. Inbound from Upper Bay Buoy 30 to Global Terminal.
7. Outbound from Global Terminal to Upper Bay Buoy 30.
8. Emergency Turns above and below the Verrazano Narrows Bridge.

The Feasibility Evaluation Team met with the MITAGS staff on the afternoon of Monday, August 22, 2016, to review the data that they had gathered and aeveloped on the Maersk "Triple E" 18,000 TEU ULCV. Additionally, time was allotted to run additional exercises with the *Kalina model* meeting a smaller tanker (600'xl0'z41') in the Kill Van Kull.

With the exception of the meeting runs previously mentioned and some demonstration runs, The Maersk "Triple E" class model was used at 42' and 49' drafts. The tug packages consisted of a mix of up to four tugs. The newly modeled *Brian McAllister* was used to model a 6,000 hp. ASD with a bollard pull rating of approximately 85 (metric) tons. This *Edward J. Moran* model was also used (an 82 ton, 6,000 hp. ASD). In addition to the two tractors, the Docking Masters (DMs) had the option of adding up to two, 4,000 Hp. 46 ton bollard pull conventional boats *(Brendan McAllister* and *McAllister Sisters).* During these sessions, one of the ASDs was operated by Captain Nathan Oliveira of Moran. The other boats were controlled by the simulator operator with advice provided by Captain Brooks if there was a question as to the DM's order(s).

6.1 FULL LENGTH RUNS - IN OR OUTBOUND - CON HOOK TO PORT ELIZABETH

Run 1 *Kalina* Meeting a Tanker (600'x 105' x 41') in KVK

Pilot: Robert Flannery — Kalina, 49' Draft

Pilot: Robert Blake — 600'x 106' CPP Tanker

Wind/Current: 40% Flood, S 20

Start: Con Hook Reach — Finish: Con Hook & Bergen Point Reaches

Tugs: *Kenny* Port Bow, *Brian* Starboard Bow, *Edward* C/L aft, *Miriam* port bow

Description:

Initially the Docking Master (DM) used the *Edward* at half astern to slow the *Kalina,* and then increased the *Edward's* power to ¾. The DM then used the *Edward* at a port 45° to slow his swing into the KVK. The ship was making 4.0 knots passing Hess, Bayonne, with th.e *Edward* stopped. The *Edward* was then used at a 45° angle to port at half power to slow the ship and induce a starboard turn on the ship. Several of the tugs were used to turn to starboard and then arrest the turn as the ship was still making only 4.0 knots as the ship passed the red lighted buoy. The ships met by design just before the intersection of Con Hook Reach and the Bergen Point East Reach. The ships safely passed each other with a separation of 354' (the *Kalina* was making 4.5 knots). However, as is usual with the *Kalina,* her stern swung wide in the turn and the stern was close.r to the tanker berth on the north side of the channel.

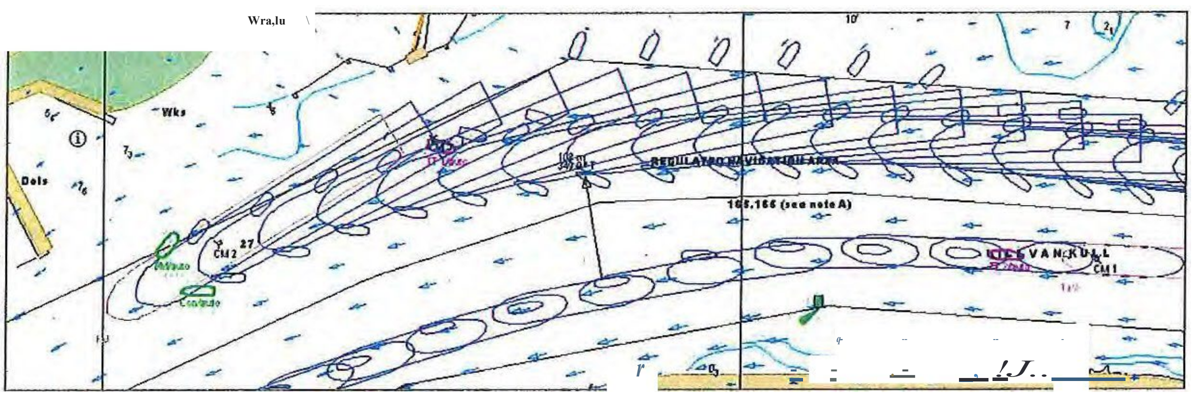


Figure 13: Run 1- Kalina Meeting in Kill Van Kull

Run 2 Kalina Meeting Tanker in the KVK

Pilot: Robert Flannery — *Kalina*;-[lnbou — Wind/Current: 40% Flood, S 20

Pilot: John Oldmixon — *Memphis,* [outbou d]

Start: Buoy 26 — Finish: Intersection of Con Hook and Bergen Point East Reaches

Tugs: Kenny Port Bow, Brian Starboard Bow, Edward C/L aft, Miriam Free

Description:

The OM was not satisfied with the results of Run 1, and asked to repeat it. The *Kalina* started on the Con Hook Reach making 7.4 knots. The pilot used the *Edward* in the direct pull mode at a starboard 45°, at¾ power to slow the ship and to begin his turn to port off the range. The pilot also used the bow tugs backing alongside the ship's hull at half astern to further assist slowing the ship. The ship was making 3.8 knots off Hess, Bayonne. The OM continued to use the tugs to maintain a modest speed on the ship as it proceeded up the KVK. The *Kalina* passed the other ship at the intersection of the Con Hook Reach and the Bergen Point East Reach at 4.7 knots, and cleared the ship at Pier A. Unfortunately, in order for the *Kalina* to make this turn she needs to be turned hard and this makes the stern swing in a very wide swath. Because of this the OM felt that he ended up "too close to the ship at Pier A" and "could have sucked the berth ship off the dock". Another issue with this large turn is getting the required swing rate off of the ship, so that she can then begin the turn to starboard towards the Bayonne Bridge.

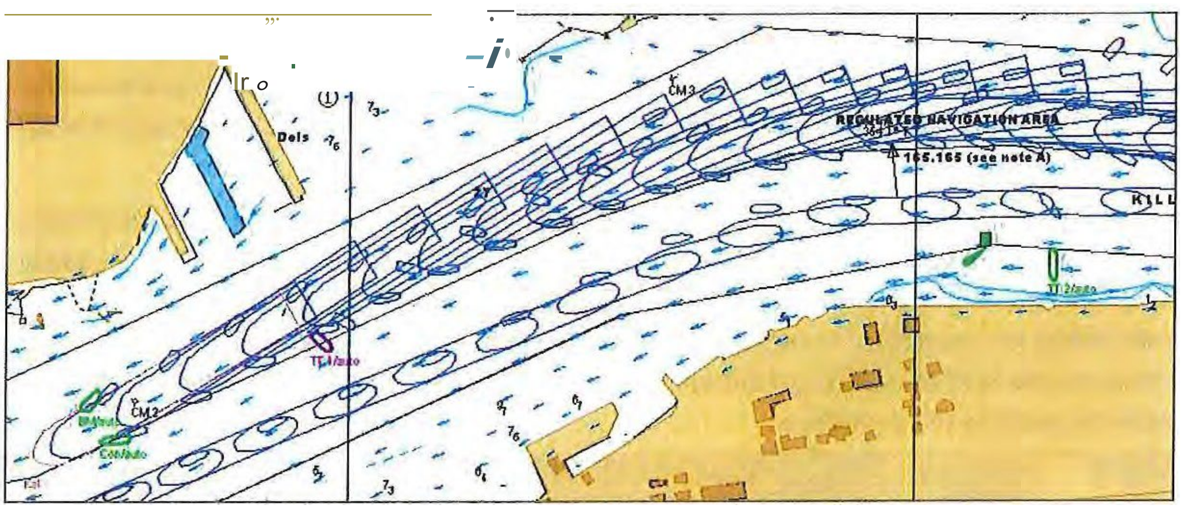


Figure 14: Run 2 - Kalina - Meeting in Kill Van Kull

Alternate Meeting Solution

The pilots and docking master were concerned about their ability to safely maneuver this class of vessel, and meet a small vessel in the KVK. <u>If they were unable to resolve this issue, the KVK would have to</u> be <u>closed to all traffic duri :14,000 TEU ULCV transits to Port Elizabeth</u>. In Runs #1 and #2, and the runs made in the initial 14,000 TEU Study, the *Kalina* was operated on her side of the channel and met the opposing traffic port to port. This is the norm, but requires the *Kalina* to negotiate some very sharp turns. In discussing this, the pilots and docking masters noted that if instead of passing port to port, if they were to pass starboard to starboard they could minimize these large turns as seen above. Further, if the *Kalina* class were to enter the KVK favoring the southern side of the channel, they would be creating a maximum clearance to all of the tankers berthed in this waterway, as all of the berths are located on the north side of the channel. *Because of the importance of keeping the KVK open to smaller traffic, this starboard to starboard passing should be explored in more depth.*

Run 3 Inbound Run through KVK to South Reach

Pilot: Robert Flannery *Triple E,* Draft 42'

Current/Wind: Slack, N-5

Start: Stapleton Finish: Newark Bay Draw (NBD)

Tugs: C/L aft *Edward,* Starboard bow *Brian,* Port bow *Miriam,* Light Boat *McAllister Sisters*

Description:

The DM used the *Edward* indirect to starboard at full power, then reduced quickly to half power, as the ship responded well to the tug forces. The ship developed an 11°/m turn rate to port and the pilot stopped the *Edward.* Passing the St. George Ferry Term(nal, the ship was just slightly to port of the Con Hook range making 5.6 knots (SOG) with a 4°/m turn rate to port (using 10° port rudder). The DM used the *Edward in transverse arrest slow to ease the ship's speed down (the DM changed to in/ine slow on the* Edward at 4.8 knots, then went up to half power in the tug). At 4.6 knots the rudder was placed hard to port and the *Miriam* ordered to pull full alongside. With the ship off buoy 5 making 4.5 knots and headed 270° the *Edward* and *Miriam* were stopped. From this position to buoy 8 the DM ordered the *Edward* indirect to port (initially the tug produced only 28t but Captain Oliveira eventually was able to work the boat up to the mid S0'st). The ship made the turn at buoy 8 very nicely at 4.5 knots.

Off of Cadell's Shipyard, the DM used the tugs to slow the ship as its speed had increased to 5.4 knots. Turning on to the west end of the East Bayonne Reach, the DM used the stern tug in the indirect mode to create a 6°/m turn rate to starboard. The speed was reduced to 3.5 knots. Both-bow tugs were used to retard the ship on half bells, then up to full.

When the ship's bow reached Bergen Point buoy 16, the *Edward* was used in the powered indirect mode, full to port, then down to half, as the DM used the tug at various speeds to maintain the DM's desired turn rate. The ship was making 3.9 knots with the stern moving sideways to port at 2.8 knots and the bow to starboard at 0.7 knots. Halfway around the turn the pilot stopped the tug but had to use the boat again to keep the ship's turn rate up. The DM did a very good job keeping this *Triple E* model safely in the center of the channel.

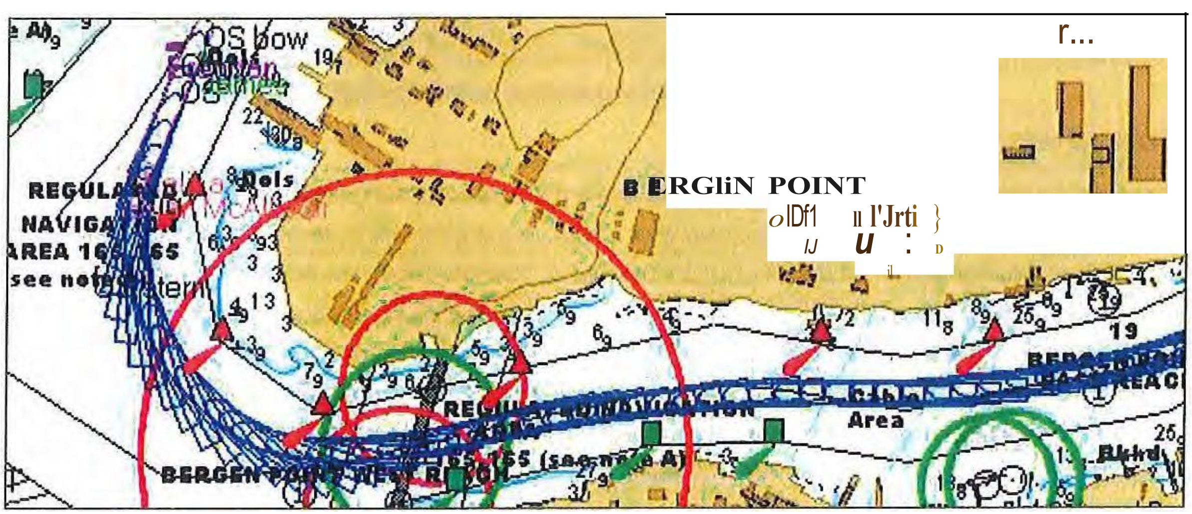


Figure 15: Run 3-Triple E - Approach & Turn at Bergen Pt.

Run 15 Kalina Meeting Traffic in KVK

Pilot: Robert Flannery — *Kalina,* Inbound

Pilot: John DeCruz — *Memphis,* Outbound

Wind/Current: S 20, 1.5 Flood

Start: Con Hook Range — Finish: After passing

Tugs: C/LA *Brian,* Starboard Bow *Miriam,* Port bow *Edward,* Free - *Sisters*

Description:

At the start of the exercise the *Kalina* was being set to the north as it entered the Con Hook Reach by the flood current and wind. Once the set had been controlled by getting the *Kalina* fully into the current flooding into the Kills, the ship passes up the channel in the middle of the channel. As the *Kalina* was passing Buoy 8 in the Kills, the *Brian* was ordered into the powered indirect maneuver, full to port. Unfortunately, this maneuver.was conducted late and the *Kalina* finished its turn back to starboard when the ship was fully on the port side o(the channel. This missed turn required another hard turn to starboard in order to miss the oncoming *Memphis* which was accomplished. However, the model was heading for the tanker moored at Berth A. Another hard turn to port was required to miss the moored tanker. The two models passed safely with a 152' of clearance. The next turn was successfully executed and the *Kalina* cleared the moored tanker by 171'. While this run was successful, it is one that we would not want to repeat. It should also be noted that this run took place at the end of a busy day.

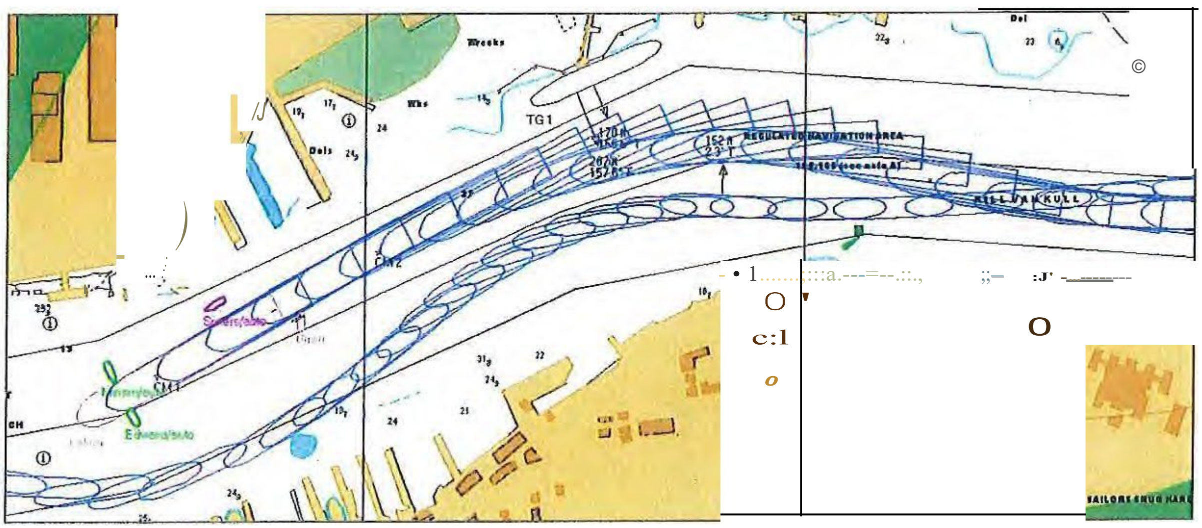


Figure 16: Run 15 - Kalina meeting Tanker Memphis

Run 16 Triple E Inbound KVK

Pilot: Robert Ellis — *Triple E,* Draft: 49'

Wind/Current: S 20, 1.5 Flood — +3' Tide

Start: Con Hook Range — Finish: Grounded

Tugs: CLA *Brian,* Starboard Bow *Sisters,* Port Bow *Edward,* Free: *Miriam*

Description:

The OM was late turning the ship onto the Constable Hook Reach and the ship grounded on the north side of the channel into the KVK. Captain Ellis felt the 3.3 knot northerly current was not representative of real-world conditions.

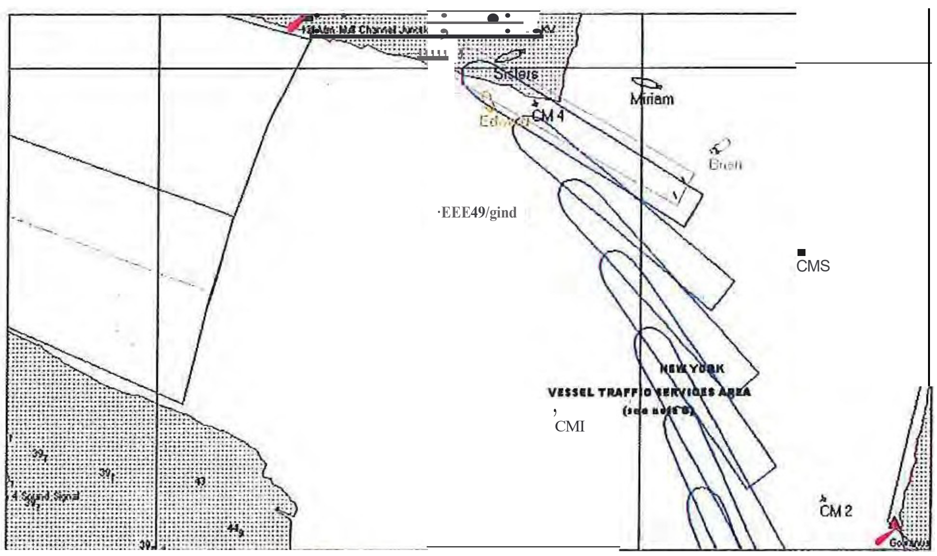


Figure 17: Run 16- *Triple E* grounding as it entered Con Hook Reach

Run 17 Triple E Inbound to KVK

Pilot: Robert Flannery — *Triple E,* Draft 49'

Wind/Current: S 20, 1.25 Flood — +3' Tide

Start: Stapleton Anchorage — Finish: KVK

Tugs: CLA *Brian,* Starboard bow, *Miriam,* Port Bow Edward, Free *Sisters*

Description:

As the model passed Stapleton Anchorage, it had the two bow tugs and the tug C/L aft backing to slow the ship down. Reaching 4.5 knots (SOG) the DM slowed the three boats to slow bells. Passing the St. George Ferry Terminal, the DM had the model lined up on the Con Hook Range with a 16° drift angle on the ship. Later, the DM ordered the two bow tugs to pull at half astern alongside of the ship.

When the bow of the model was abeam of buoy 5, the speed had been reduced to 4.1 knots and the DM stopped the *Edward* and asked the *Miriam* to back alongside at full power to reduce the ship's turn to port. Passing Buoy 7, the OM asked the *Brian* to perform a powered indirect to port, easy. In order to keep the speed of the ship moderate as it passed a series of tankers moored on the Bayonne shore, the *Brian* was eased up to half. The ship passed the second ship at Hess Bayonne making 4.1 knots (STW). Passing buoy 8 the model was making 4.3 knots (STW). A nice run with complete control.

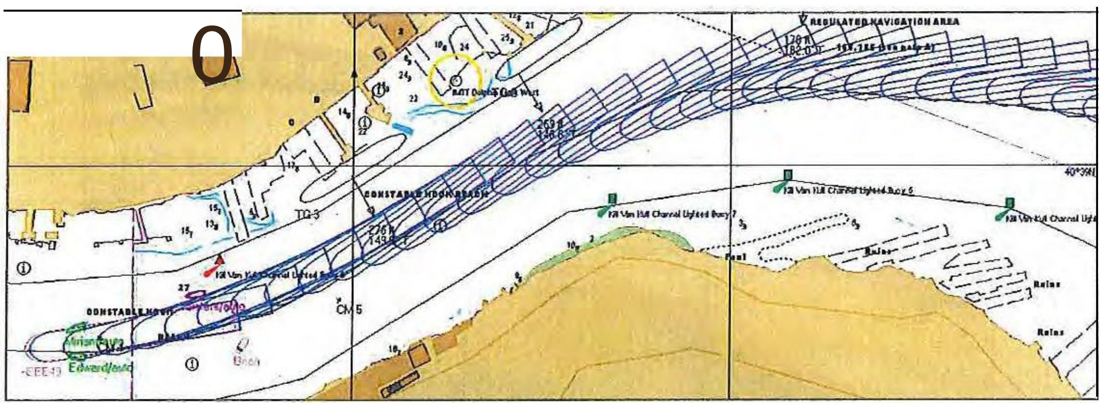


Figure 18: Run 17-Triple E Entering & Transiting Con Hook Reach - Ebb

Figure 19: Run 17 Screen Shot

Run 18 Triple E Inbound to KVK

Pilot: Robert Ellis — *Triple E,* Draft 49'

Start: Stapleton — Finish Bergen Pt. E Reach — Current/Wind: S 20, 1 knot flood

Tugs: C/L Aft *Brian,* Starboard B_ow *Miriam,* Port bow *Edward,* Free *Sisters*

Description:

This a repeat of Run 17 but with the wind and current reversed. The DM turned into the Con Hook Reach a bit late but was able to establish the model on the port side of the channel rounding the green buoys north of the Staten Island Ferry Terminal. With the bow of the ship passing Buoy 3, the model was making 4.7 knots (STW). The *Brian* was used to create the turn to port using the powered indirect maneuver to starboard with the ship making 15°/m rate of turn. The *Triple E* passed the second ship moored on the Bayonne waterfront at 3.1 knots (STW),- and safely made the turn at the red Lashing buoy 8.

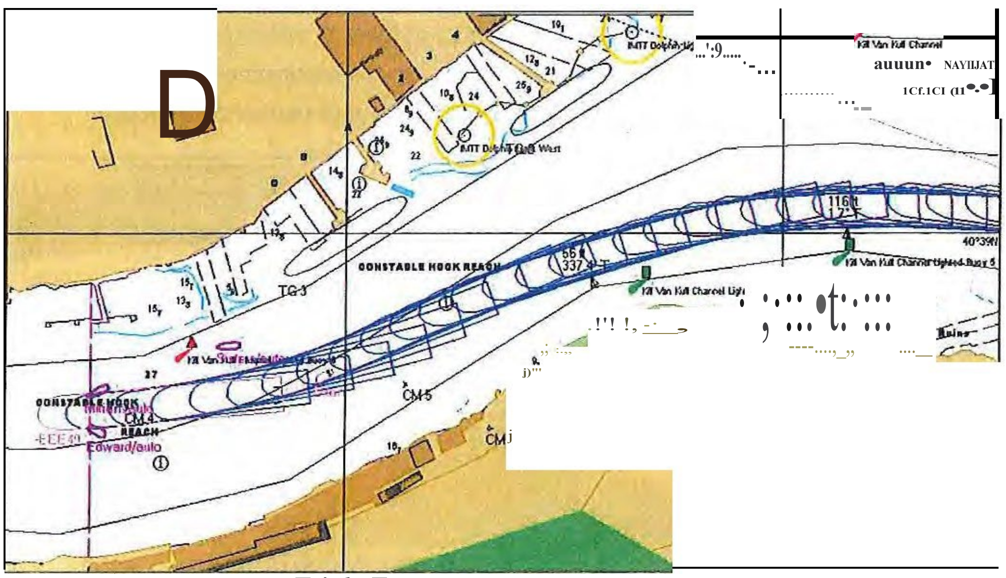


Figure 20: Run 18 -*Triple E* Entering & Transiting Con Hook Reach - Flood

6.2 ROUNDING BERGEN POINT INBOUND BERGEN POINT EAST REACH TO BUOY 3

The following runs focused on the sharp turn at Bergen Point into South Reach, Port Elizabeth

Run 4 Bergen Point Turn Inbound

Pilot: Robert Ellis — *Triple E,* Draft 49'

Current/Wind: 40% Ebb, NE-20 — +3' Tide

Start: Bayonne City Dock — Finish: NBD

Tugs: C/L aft *Edward,* Starboard Bow *Brian,* Port bow *Miriam,* Light Boat *Sisters*

Description:

At the start of the exercise the model was making 3.7 knots (STW). Passing Buoy 12 the DM asked the Tug *Sisters* to come up and lay on the starboard quarter. Passing under the bridge the DM ordered the *Edward* to direct pull mode at 45° full; the *Sisters* push full; and *Brian* back easy alongside. The *Edward,* in the direct pull could only get to about a 45° angle on his towline and the pilot DM stopped him as he was headed to the green buoy. *Edward,* 45° to port full (indirect - 75t). *Sisters* push half and then full. *Brian* backed half at a 45. Using the assist tugs, the DM made a very nice turn round Bergen Point. The *Triple E* model handled quite well.

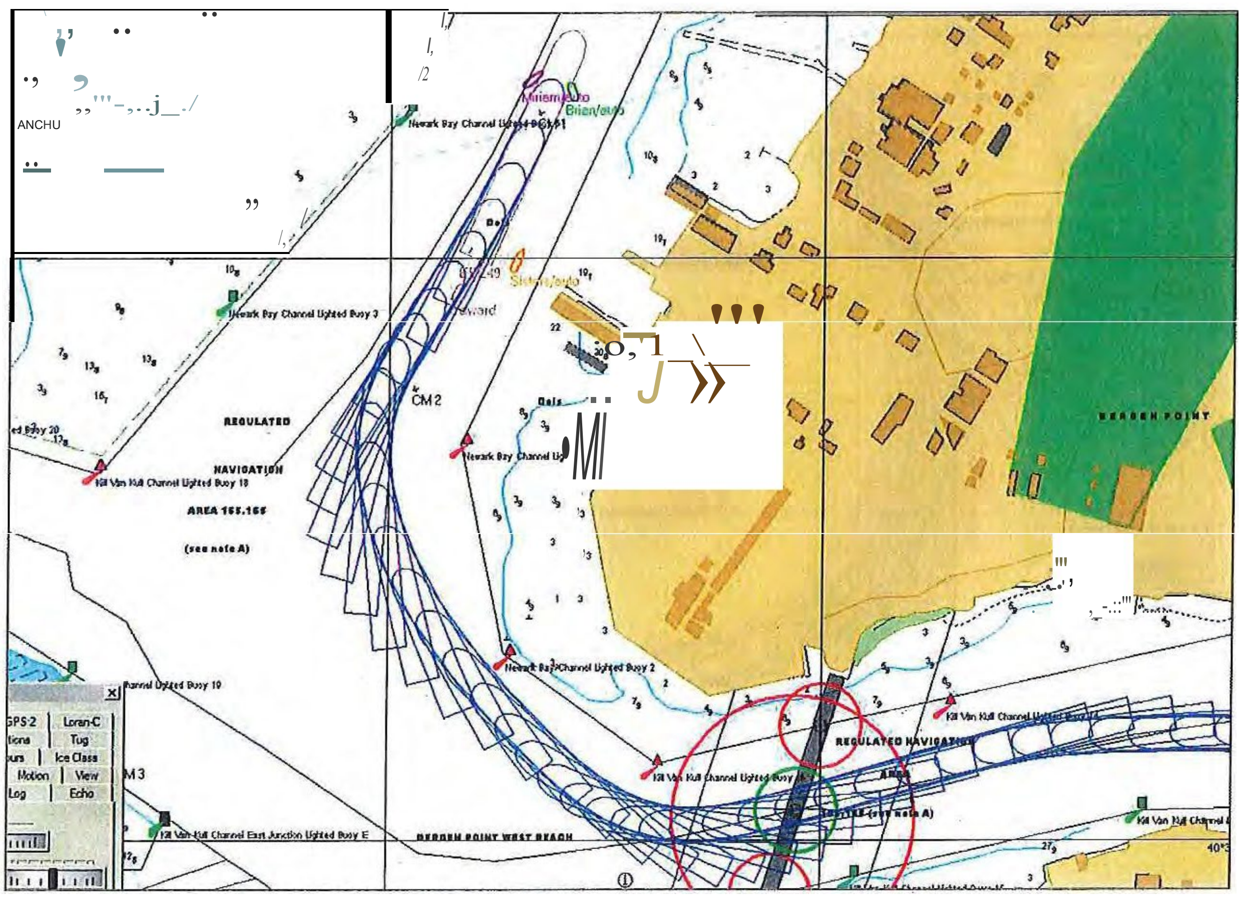


Figure 21: Run 4 - Triple E @ 49'

Run 5 Triple E Inbound Bergen Point

Pilot: Robert Flannery *Triple E,* Draft - 49' +3' Tide

Current/Wind: 1.8 knots Flood, NE - 20

Start: Stapleton Finish: Buoy South Reach, Buoy 5

Tugs: C/L aft *Edward,* Starboard Bow *Brian,* Port bow *Miriam,* Light Boat *Sisters*

Description:

The DM used the tugs to minimize the ship's speed in the Kills which allowed him to make controlled turns as the channel weaved its way to Bergen Point. With the flood current, the DM passed under the Bayonne Bridge on the north side of the channel. Passing buoy 16, the DM placed the rudder hard to starboard and ordered the *Edward* to conduct the powered indirect maneuver to port at half power and then ordered the *Edward* up to¾ power. The DM made a very controlled turn around Bergen Point and nded up exactly on the centerline of the channel heading north to Port Elizabeth.

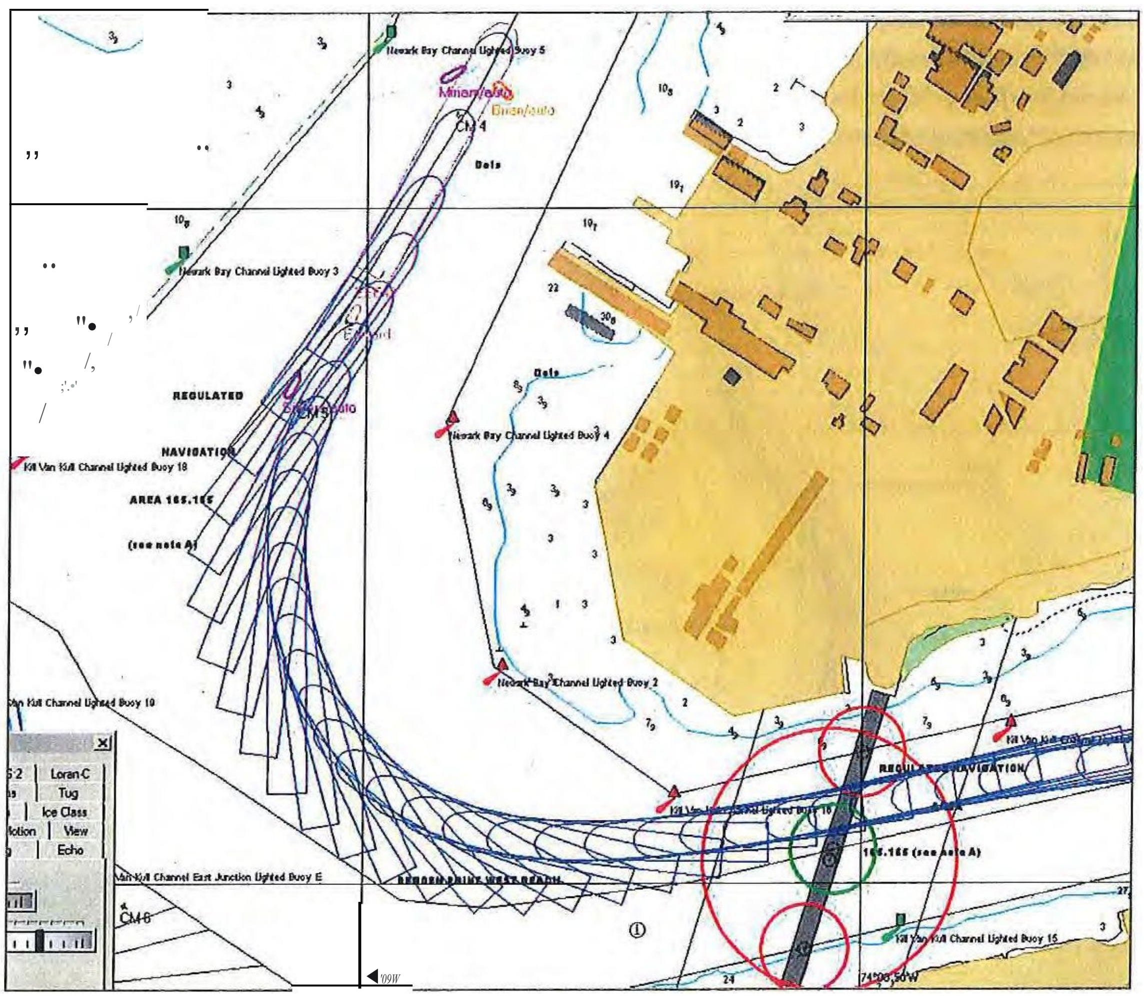


Figure 22: Run 5 - *Triple* E - Inbound at Bergen Point

6.3 BERGEN POINT OUTBOUND BUOY 3 TO BERGEN POINT EAST REACH.

The following exercises focused on the outbound turn at Bergen Point.

Run 6 Outbound Bergen Point

Pilot: Robert Ellis — *Triple E,* Draft 49'

Current/Wind: 40% Flood, NW - 20 — + 3' Tide

Start: NBD — Finish: Bergen Point East Reach

Tugs: C/L aft *Edward,* Starboard Bow *Miriam,* Port bow *Brian,* Light Boat *Sisters*

Description:

The model approached the Bergen Point turn at 3.9 Knots (STW). Prior to starting his turn, the OM ordered the *Sisters* red to the port quarter. Once the DM wanted to begin his turn, he ordered the *Sisters* to push easy, the *Brian* was ordered to conduct a direct pull at port 45° easy. Finally, the *Edward* was ordered into the powered indirect at¾ power and then up to full. Later, the *Brian* was ordered up to¾ and then to full power. Of note, during this maneuver, the *Edward* lost 15 tons of towline force by jackknifing to the direct pull too soon. The DM maintained a 12°/m turn rate throughout the turn and passed under the Bayonne Bridge slightly to the north side of the channel. A very pretty run!

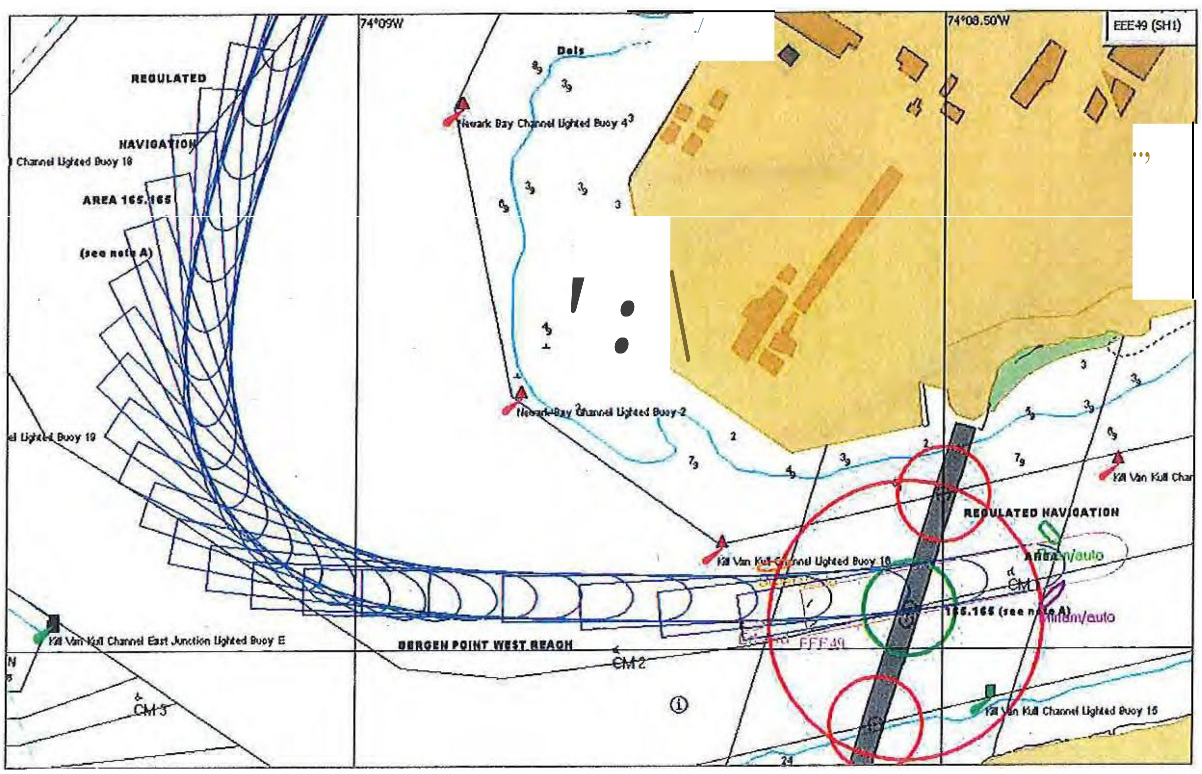


Figure 23: Run 6 - Triple E Southbound to Bayonne Bridge

Run 7 Outbound Bergen Point

Pilot: Robert Flannery | *Triple E,* Draft 49'

Current/Wind: 40% Ebb, NW· 20 | +3' Tide

Start: NBD | Finish: Off Moran's Yard

Tugs: C/L aft *Edward,* Starboard Bow *Miriam,* ort bow *Brian,* Light Boat *Sisters*

Description:

At the start of the exercise the model was making 7.4 knots (STW). The docking master ordered the Edward to pull direct inline half, and then increased this order to¾ power. The *Brian* was backing at half alongside and then the DM increased him to¾ power. Approaching the turn to the bridge, the *Edward* was ordered to conduct a direct pill to starboard at full power. The *Brian* was also ordered to pull at full power. At the start of this turn the ship was making 5.0 knots (STW). The DM established a 15°/m turn rate and used the tugs to mai_ntain this turn rate. On completing the turn, the ship was to the south of the bridge's centerline (eventually the ship's main deck aft came to within 43' of the edge of the channel) and the DM ordered both bow boats to drag at half power. The bow boats were stopped and the *Edward* ordered to perform a direct pull to port half power. Very quickly the DM had the ship back on the centerline of the channel.

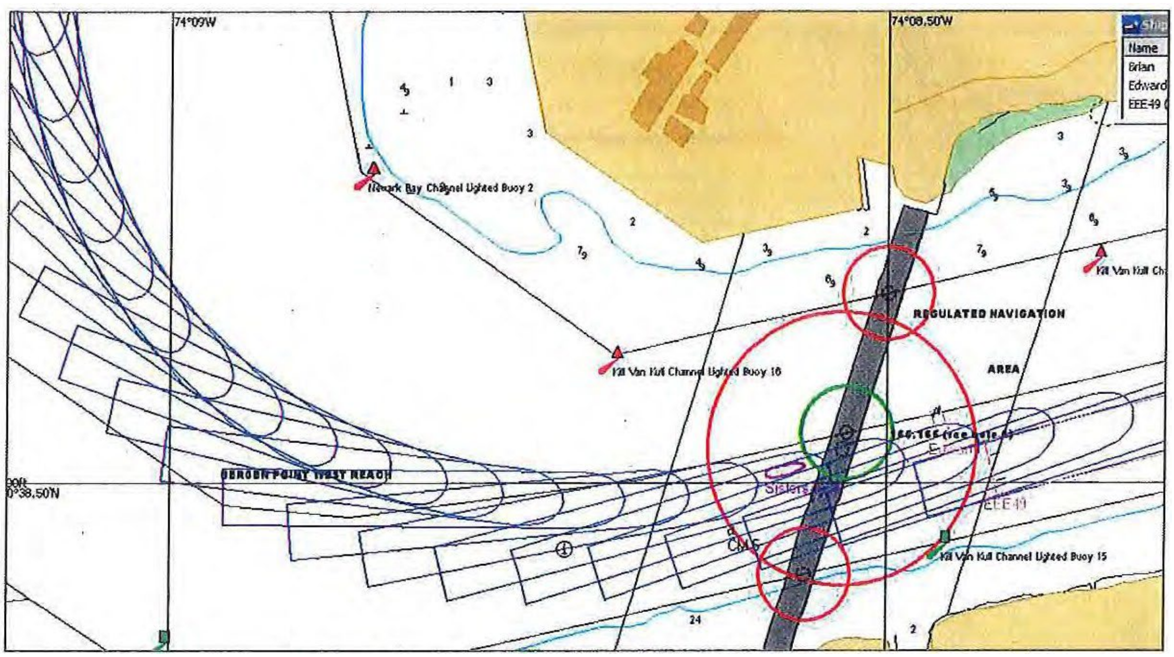


Figure 24: Run 7 - *Triple E* Close to the Chal'.Inel Edge

6.4 INBOUND FROM BUOY 10 NEWARK BAY TO PORT ELIZABETH

The following runs focused on the transit into the berth areas of Port Elizabeth.

Run 8 Inbound to Port Elizabeth Branch Reach

Pilot: Robert Ellis	*Triple E,* Draft 49'
Current/Wind: 1.5 Kt. Ebb, N - 20	+ 3' Tide
Start: Bayonne City Dock	Finish: Port Elizabeth

Tugs: C/L Aft *Brian McAllister,* Starboard Bow *Miriam,* Port bow *Edward,* Light Boat *Sisters*

Description:

The model started at 5.1 knots (STW). Approaching the bridge, the DM ordered the *Sisters* to lay on the starboard quarter ready to push. As the ship passed under the bridge the DM ordered the Sisters to push at full power. The *Brian* was ordered to pull in a direct pull at a port "90" (Due to the speed of the ship at this time, while the *Brian* was pulling at ninety degrees to the ship, the towline however was leading directly astern - applying a breaking force to the ship but not the steering force that the pilot desired. At the higher speed through the water the tug would have performed better in the powered indirect mode). Eventually, the DM ordered the *Brian* to the indirect position at 90° at half power. Using the tugs, the pilot was able to neatly make the turn at Bergen Point and start north to Port Elizabeth. Approaching the turn into the Port Elizabeth Channel, the DM by his own critique noted that with the North wind and ebb current he turned into the PE Channel a bit too early.

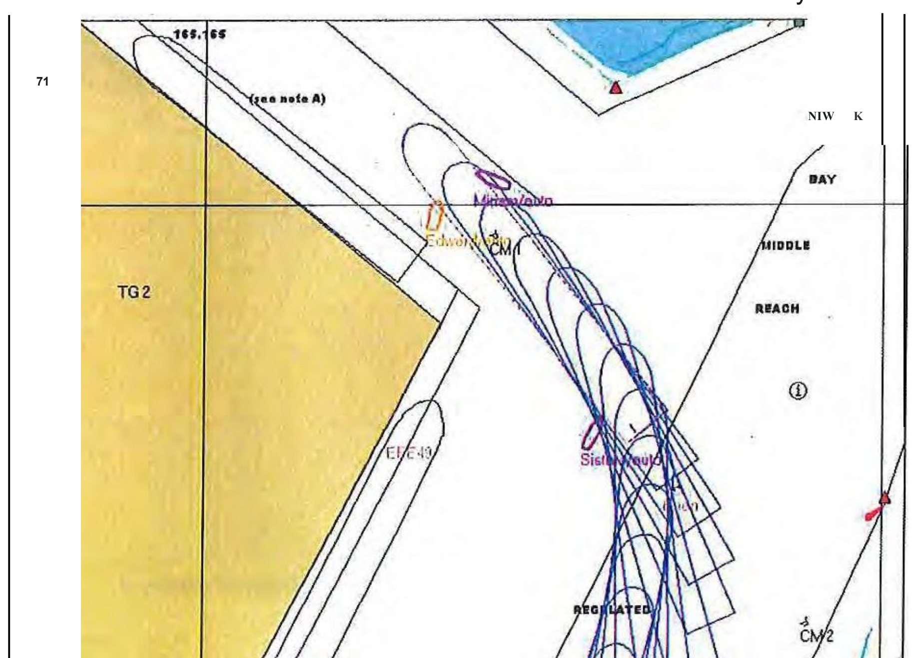


Figure 25: Run 8 -Triple E Turing too early ijt Port Elizabeth

Run 9 Inbound to Port Elizabeth

Pilot: Robert Flannery *Triple E,* Draft 49'

Current/Wind: 1.8 Knots Flood, S - 20 + 3' Tide

Start: NBD Finish: Port Elizabeth

Tugs: CLA *Brian McAllister,* Starboard Bow *Miriam,* CLF *Edward,* Starboard Quarter *Sisters*

Description: .

The ship was making 2.9 knots (SOG) turning into the Port Elizabeth Channel. The DM started his turn into the PE channel a bit too early using the *Edward* (C/L Forward) to initially pull to port at a "45" easy, while he ordered the *Miriam* to push full on the starboard bow. The DM then brought the *Edward* to a 90° angle to port at half power and then up to full. In the meantime, the ship's stern was falling to the north and he had to work the tugs hard to regain control and begin heading into the Port. Eventually the DM regained control, but then came within 45' of the ship on the south side of the channel.

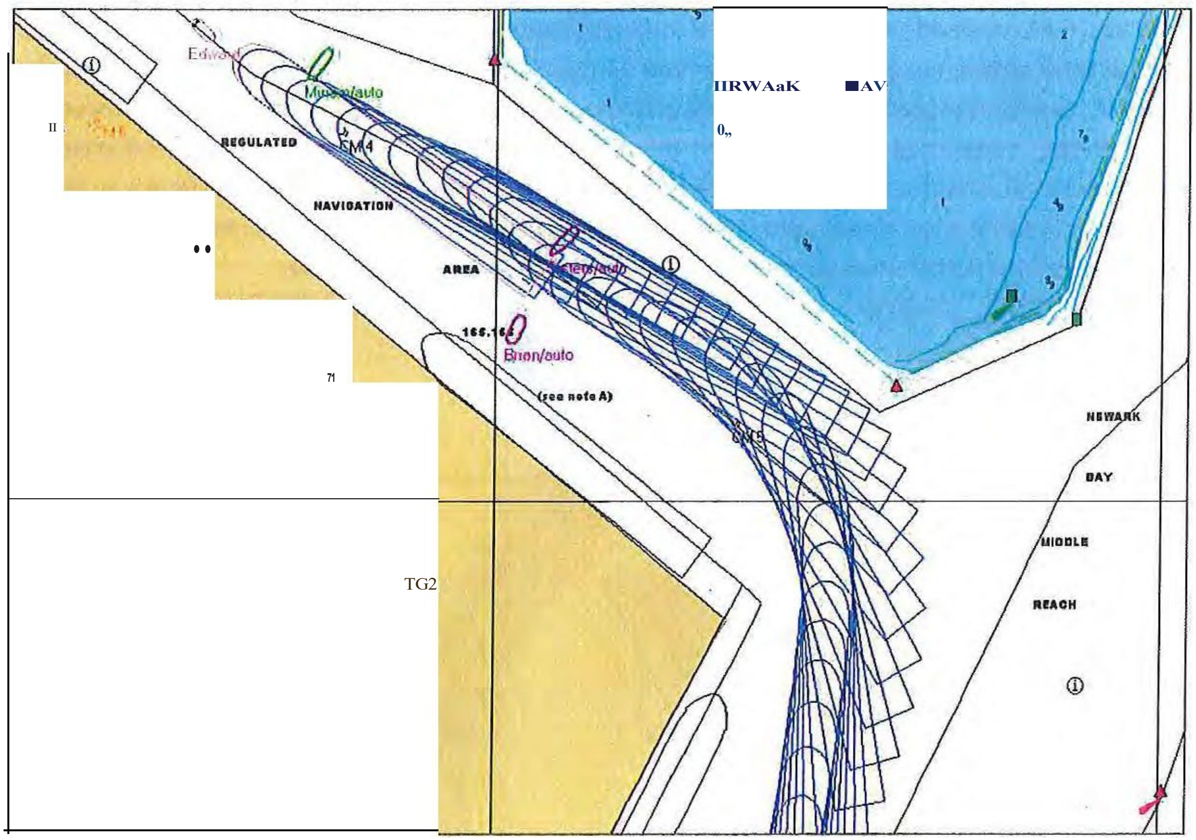


Figure 26: Run 9 - *Triple E* entering Port Elizabeth Chanel

Run 12 Inbound Port Elizabeth

Pilot: Robert Ellis · *Triple E,* Draft 49'

Current/Wind: 1.5 Ebb, NE - 20 +3' tide

Start: Newark Bay Buoy 10 Finish: Port Elizabeth

Tugs: CLA *Brian McAllister,* Starboard Bow *Miriam, Edward Port Bow,* Free *Sisters*

Description:

The model was making 6.1 knots at the start of the exercise. The *Sisters* was ordered to make fast on the port side just aft of the bridge. The *Sisters* dropped back to the quarter and was ordered to push half. The *Brian* performed a powered indirect to starboard at half power. Finally, the *Edward* backed half at a "45" to port. Using the tugs, the DM made a very nice turn into the Port Elizabeth channel and then smoothly moved up to her berth (ships were only moored on the south side of the channel).

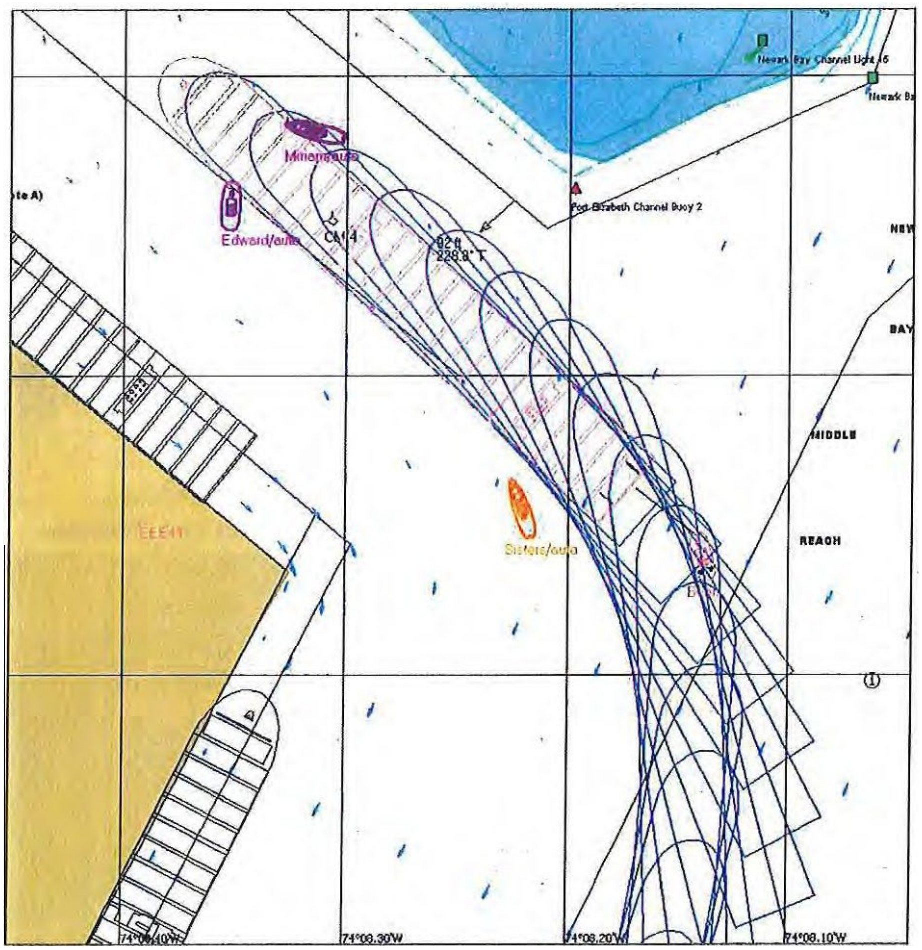


Figure 27: Run 12- *Triple E* turning into Port Elizabeth Channel

Run 13 Inbound Port Elizabeth

Pilot: Robert Flannery. *AMaersk,* Draft 46'

Current/Wind: 1.5 Ebb, NE - 20 +3' Tide

Start: Newark Bay Buoy 10 Finish: Port Elizabeth

Tugs: CLA *Brian McAllister,* Port Bow *Miriam, Edward CLF,* Free - *Sisters*

Description:

This exercise began to explore whether ULCVs could safely transit between two ULCVs at their berths. On this run, the 9,000 TEU *AMaersk* (140'Beam) transited with a *Triple E* Class on either side of the Elisabeth Branch Reach. The DM did a very nice job of turning the *AMaersk* into the Port Elizabeth channel. The *AMaersk* easily passed between the two *Triple E* clearing the Triple E at berth on the north side by 80'.

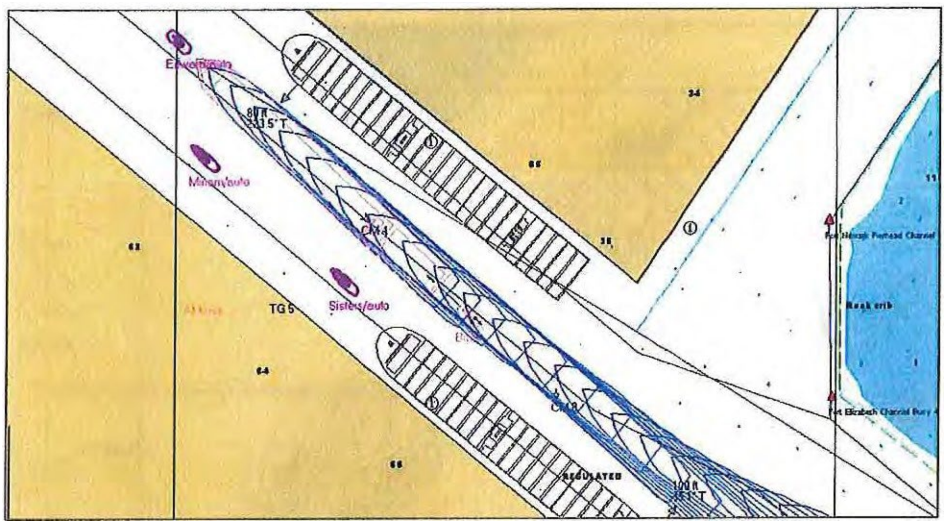


Figure 28: Run 13 *AMaersk* passing between two Triple E's at Port Elizabeth

Figure 29:Run 13 Screen Shot

Run 25 Demonstration Run

Pilot Robert Flannery — *Kalina,* Draft 49'

Current/Wind: 40% Flood, S - 20 — +3' Tide

Start: Newark Bay Buoy 10 — Finish: Port Elizabeth

Tugs: CLA Brian McAllister, Starboard Bow Edward, Starboard Quarter Miriam, Port Bow Sisters

Description:

This was a demonstration run for the NY/NJ Port Authority. With the wind and current pushing the ship to the north, Captain Flannery cut the corner at the southern edge of the Port Elizabeth Channel in order to get the ship lined up on the Port Elizabeth Channel centerline. He finished his turn almost a ship width north of the centerline but well clear of the shoaling to the north. later in the run when the DM attempted to take the ship between two *Kalina* class ships, berthed on either side of the channel, he came within 40' of the moored model on the south side.

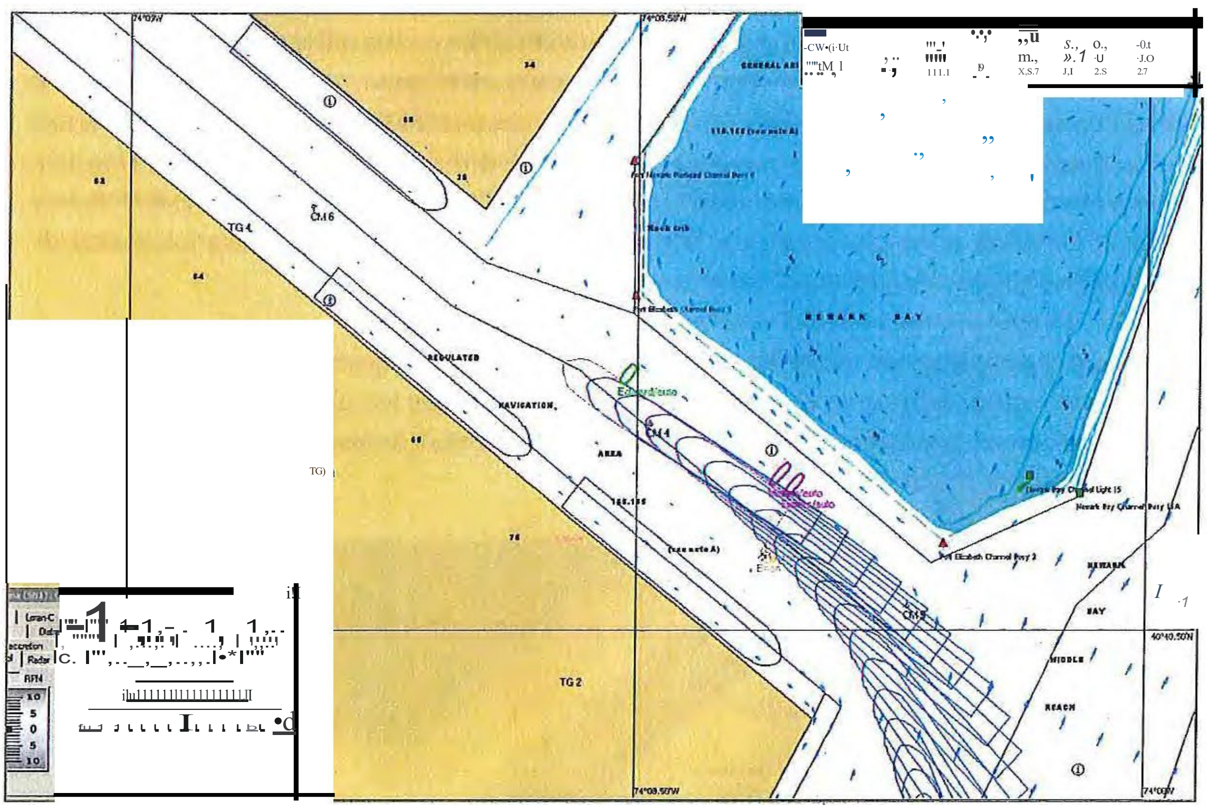


Figure 30: Run 25 Inbound between berthed Kalina Classes.

6.5 OUTBOUND FROM PORT ELIZABETH TO BUOY 10 NEWARK BAY

The following runs focused on outbound from the Port Elizabeth Branch Reach.

Run 10 Outbound from Port Elizabeth to Newark Bay

Pilot: Robert Ellis *Triple E,* Draft - 49'

Current/Wind: 1.5 Knots Flood, S - 20 +3' Tide

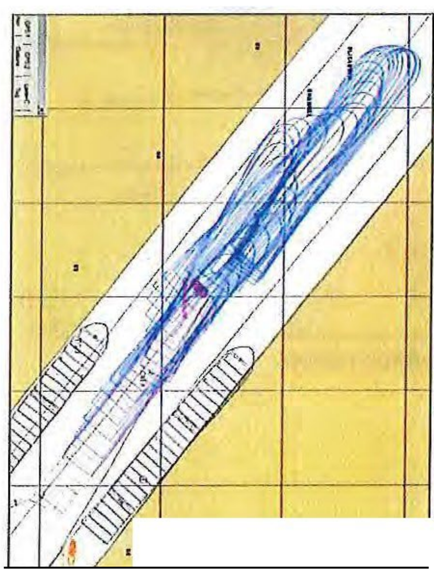
Start: Port Elizabeth Finish: Newark Bay buoy 10

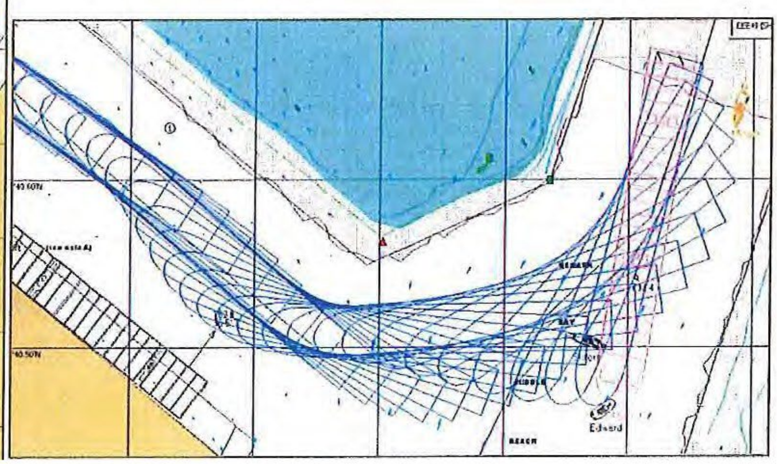
Tugs: CLA *Brian McAllister,* Port Quarter *Miriam,* CLF *Edward,* Starboard Quarter *Sisters* (no line)

Description:

The pilot used the three tugs placed near the ship's wheelhouse aft to control the model. Initially, this did not work *very* well as the OM was overpowering the ship by using too much tug power from too many tugs to control the ship (1st plot below). Once the OM got the ship settled down he made a controlled exit backing smoothly between two other Triple E's. The OM maintained great control over the ship all the way out of the Port Elizabeth channel. Approaching the Newark Bay main channel the OM had the *Sisters* pushing full at the starboard bow and the *Brian* pulling full t.o port at a 45° angle to port as the OM swung the ship's stern into the Newark Bay main channel. The ship's bow cleared the other ship moored at the corner by 160'. When the ship's bow cleared the other ship, the D.M ordered the ship slow ahead and worked his way up to full ahead, but the ship did not realistically slow her sternway and the ship's stern went aground at the edge of the SO' dredging line in the channel. This *was* a run that identified many new issues that the DMs are going to have to get their arms around to successfully handle these large ships. They are as follows:

1. Do not over control the ship when leaving or coming on to a berth,
2. Keep the transit speed within the DM's ability to control the ship based on the assigned tugs,
3. When backing the ship down a waterway use the C/L aft tug in line only, to provide the desired transit speed, and control the heading of the ship using the C/L forward tug.





10B Momentumontrol

IOA Initial Over Control

Figure 31: Run 10Triple E- Control Issues

Run 14 Outbound from Port Elizabeth to Newark Bay

Pilot: Robert Ellis *AMaersk,* Draft 46'

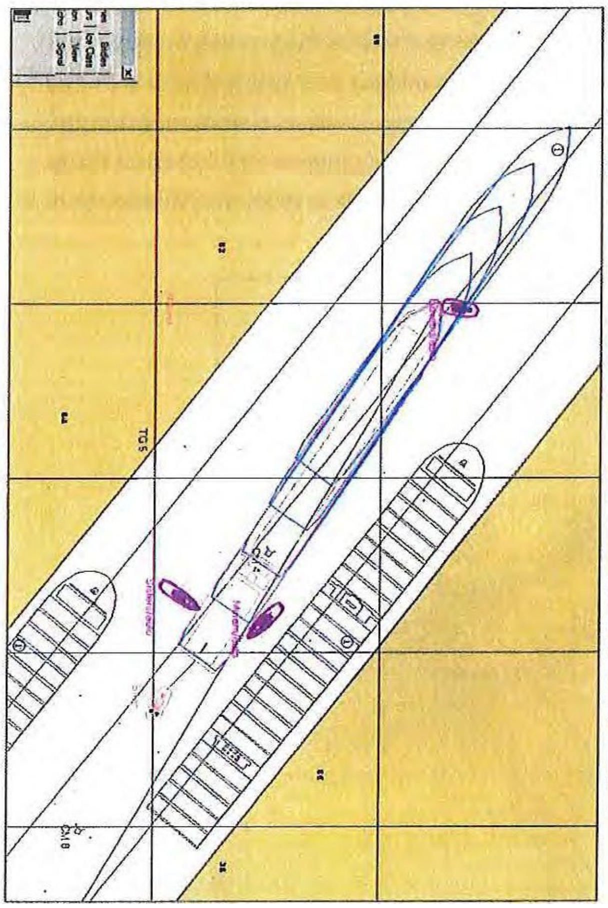
Current/Wind: 1.5 Ebb, NE - 20 +3' Tide

Start: Port Elizabeth Finish: Newark Bay Buoy 10

Tugs: CLA *Brian McAllister,* Free *Miriam,* CLF *Edward,* Free *Sisters*

Description:

Similar to Run 13, the DM was determining the feasibility of a smaller container ship transiting between two, 18,000 TEU containerships berthed in Port Elizabeth Branch Reach. In this exercise Captain EUis set up the two conventional tugs at the quarters *(Sisters* - port, *Miriam* - starboard) and used them to initially steer the ship. Having conventional tugs working on both sides of the ship greatly reduces the room in which the tugs have to work. (The *Sisters* came within 25' of the ship.) This run came close to the *Triple E* berthed on the north side, but was safe.



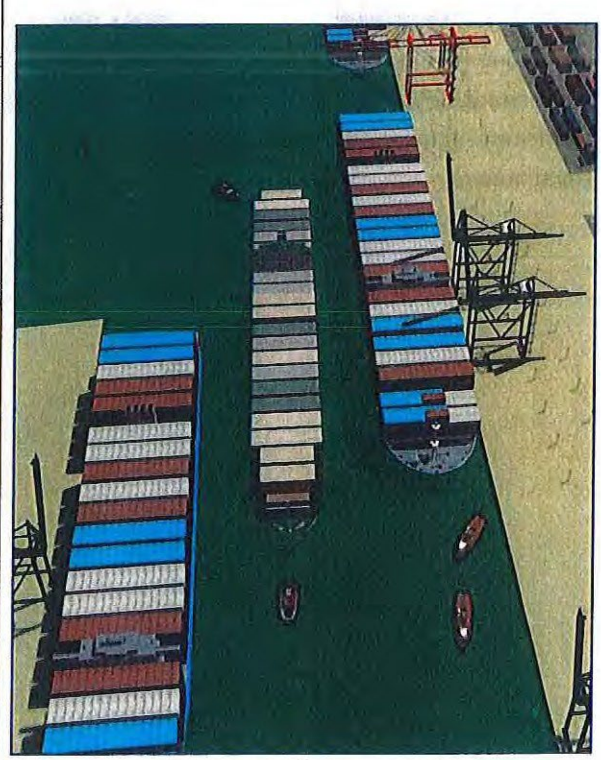


Figure 32: Run 14 Screen Shot

Figure 33: Run 14- AMaersk slipping between two,Triple E models

Run 11

Pilot: Robert Flannery *Triple E* Draft 49'

Current/Wind: 1.5 Knots Ebb, N - 20

Start: Port Elizabeth Finish: Newark Bay buoy 10

Tugs: CLA *Brian McAllister,* Port Quarter *Miriam, Edward* at bow (no line), Port Quarter *Sisters*

Description:

To save time, this exercise started with the ship in t e middle of the channel. The DM backed the model out to Middle Reach. To accelerate the model speed, the *Brian* was used in line at half power. The DM then started to steer the ship using the *Brian* and the two conventional boats at the port quarter. This may not be the most optimum configuration since the ship's pivot point will move towards the stern making it more difficult for the stern and quarter boats to move the ship's stern laterally. A better approach would be to use the *Brian* simply to tow the ship by pulling in line and letting the *Edward* provide the steering control. As the ship squeezed between the two Triple E ships moored on the north and south bank of the channel, the two conventional tugs cleared the ship on thesouth bank by 30'. The DM is still steering the ship with the stern tug. With the ship making 3 knots, the ship was neatly controlled by the DM, but he used a lot of tug orders to get the job done. With the stern entering the main channel, the ship was proceeding at 1.32 knots. Stopping the ship's engine the OM used the tugs to turn the ship fair with the channel, and then the ship's engine was engaged to move the ship south in the waterway.

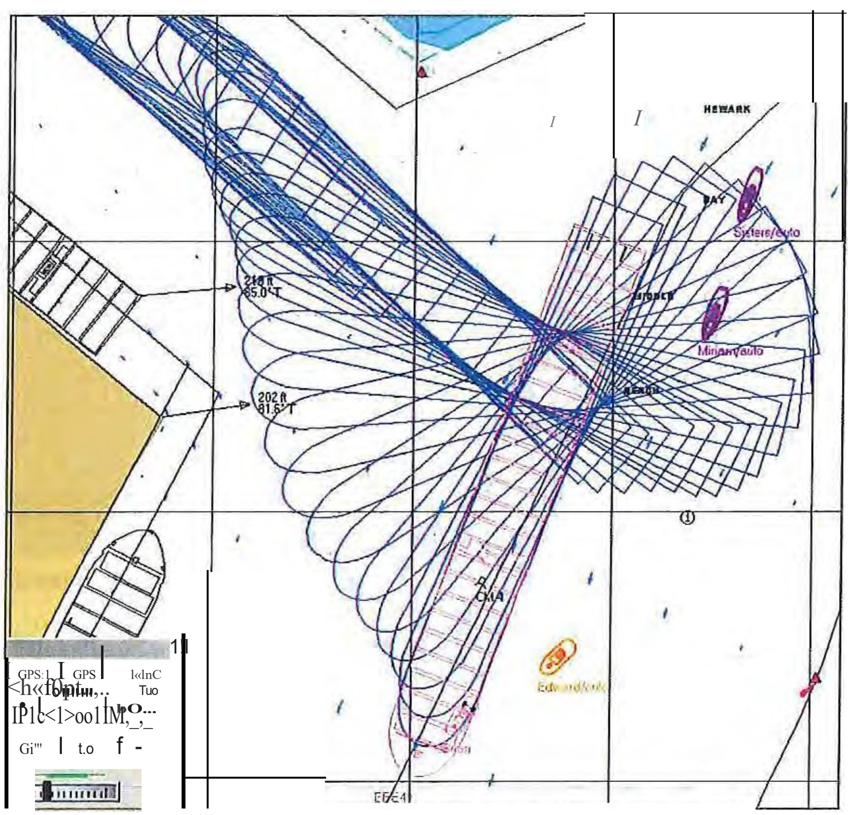


Figure 34: Run 11- Triple E backing out of Port Elizabeth

Run 26 Demonstration Run

Pilot: Robert Ellis — *Triple E,* Draft 49'

Current/Wind: 40% Flood, N - 20 — +3' Tide

Start: Newark Bay Buoy 10 — Finish: Port Elizabeth

Tugs: CLA *Brian McAllister,* Bow (no line) *Edward,* Starboard Quarter *Miriam,* Port Quarter *Sisters*

Description:

This run was a demonstration for the NY/NJ Port Authority. The run was conducted at modest speeds and modest use of the assisting tugs. When the ship's stern was being turned into the main Newark Bay channel the ship's bow came within 85' of the berthed ship moored on the outer southern berth of Port Elizabeth Cannel, but there was no danger of collision as the ship was under very good control.

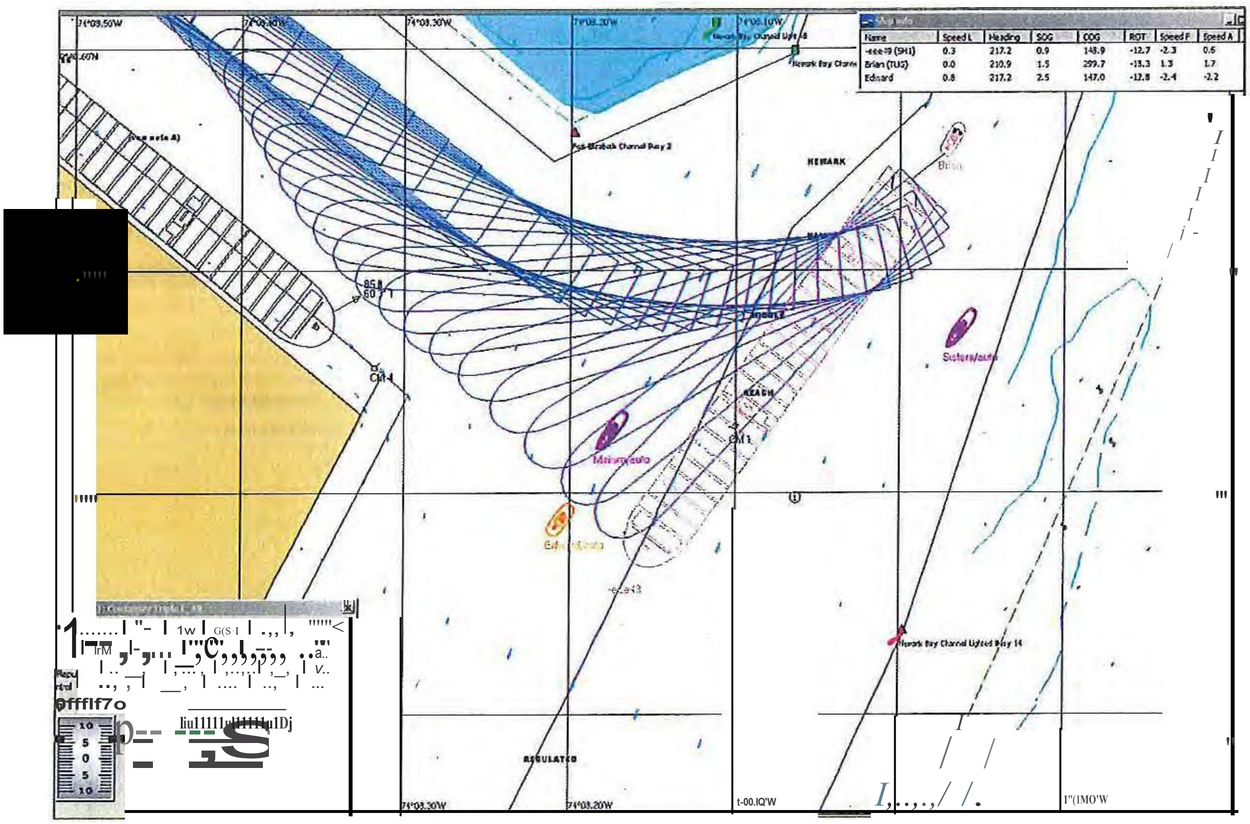


Figure 35: Run 26 -Triple E Backing out of Port Elizabeth Branch Reach

6.6 INBOUND FROM UPPER BAY BUOY 30 TO GLOBAL TERMINAL

These exercises focused on the Global Marine Terminal

Run 19

Pilot: Robert Flannery	*Triple E,* Draft 49'
Current/Wind: Slack, S 20	+3' Tide.
Start: Robbins Reef	Finish: Global Term.

Tugs: CLA *Brian,* Starboard bow *Edward,* Port Bow *Miriam,* Free *Sisters*

Description:

The ship started out at six knots. The *Edward* was initially backed at half power alongside the ship to bleed off some speed. Approaching the entrance channel, the *Brian* was ordered into the powered indirect mode to starboard at half power and then quickly increased to full. Simultaneously, the *Edward* was ordered to push full. Later in the turn the *Brian* was reduced to half. The *Edward* was now pushing half ahead at a "90" when the ship's bow was just passing the entrance buoy to Port Jersey. The OM continued to use various tugs as he lined up the ship for the Port Jersey channel. At the opening of the Port Jersey channel, the ship was making 3.9 knots. When passing the *Quantum of the Seas* the Triple E was making 3.8 knots (STW). Th pilot had been attempting to slow the ship after he made his turn into the Port Jersey Channel, so as to pass the passenger ship at a more modest speed, but could not successfully slow the ship.

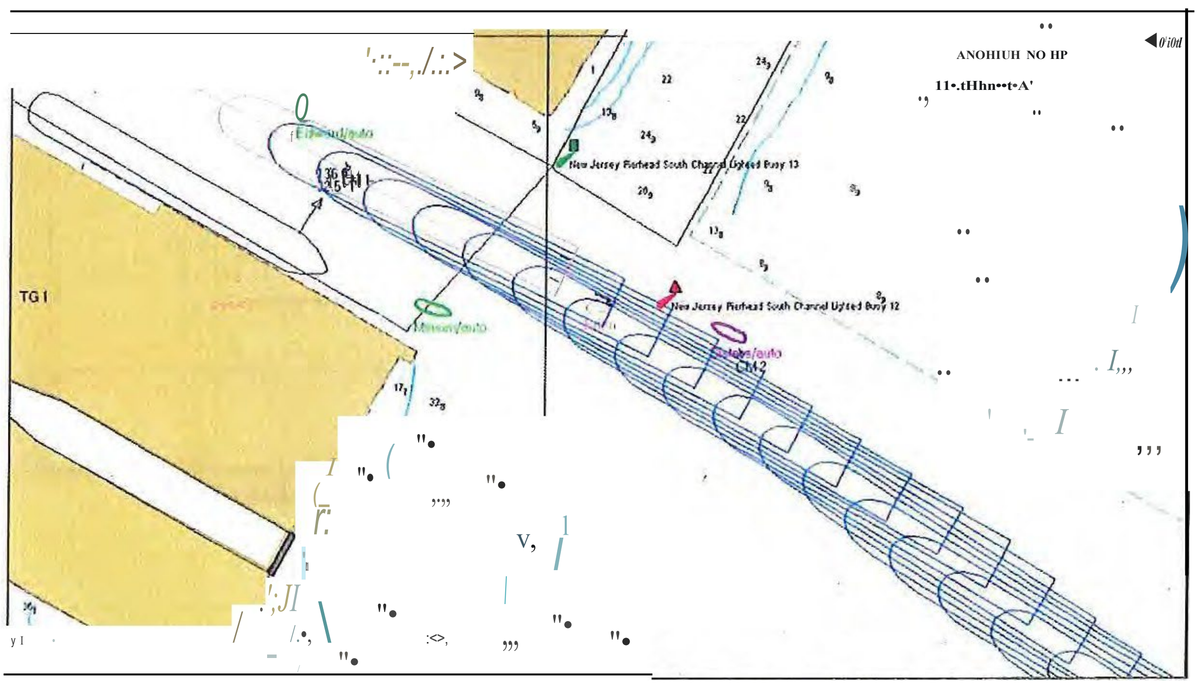


Figure 36: Run 19 - Triple E Entering Port Jersey Channel

Run 20 Inbound Global Marine Terminal

Pilot: Robert Ellis — *Triple E,* Draft 49'

Start: Robbins Reef — Finish: Global Terminal

Current/Wind: Slack, N 20 — +3' Tide

Tugs: CLA *Brian,* Starboard bow *Edward,* Port Bow *Miriam,* Free *Sisters*

Description:

The OM turned into the Port Jersey Channel early to allow room for the wind to set the ship to the north as he completed his turn. During this turn the DM used the *Brian* with the powered indirect maneuver to assist the ship's rudder and to slow the ship. He also used the *Edward* and the *Miriam* to assist slowing the ship down as he approached the passenger ship. In making his approach to the Port Jersey Channel, the DM kept the ship to the north of the channel's centerline to allow more clearance with the Passenger ship.

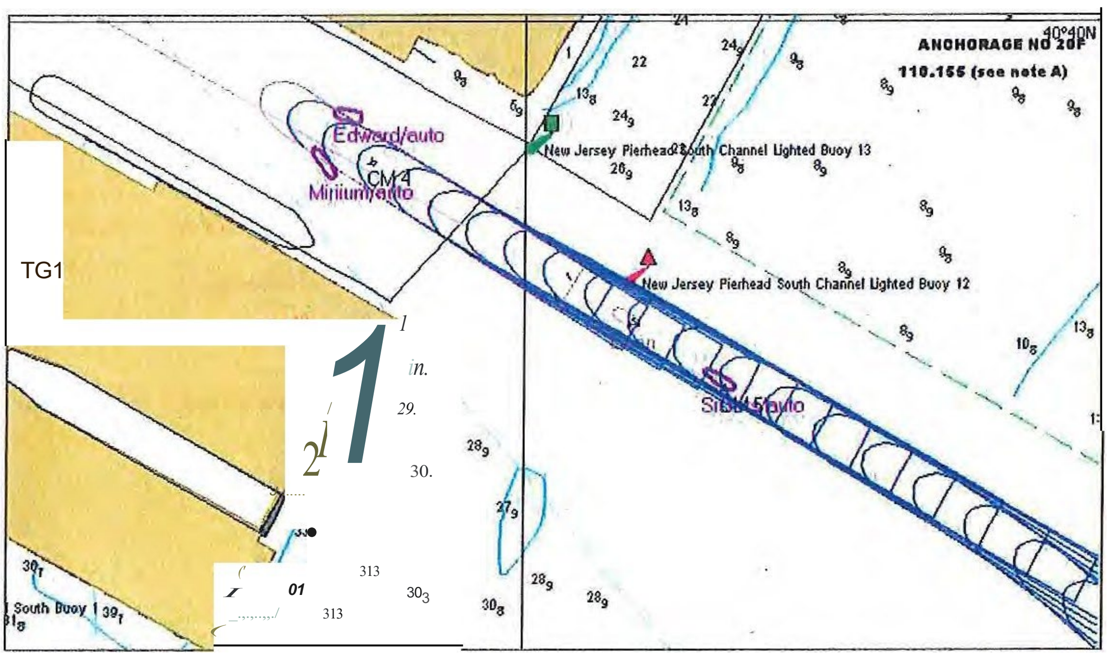


Figure 37: Run 20 - Triple E Entering Port Jersey Channel

Run 27 Demonstration Run

Pilot: Robert Flannery — *Triple E* Draft 49'

Current/Wind: Slack, **N** - 20 — +3' Tide

Start: Robbins Reef — Finish: Global Terminal

Tugs: CLA *Brian McAllister,* Port Bow *Edward,* Port Quarter *Miriam,* Free *Sisters*

Description:

This was another demonstration run for the NY/NJ Port Authority. The DM started his turn before reaching the Port Jersey Channel buoy #1 and then eased the ship around using the tugs. He entered the enclosed channel where the passenger ship was berthed slightly to the north of the channel's centerline.

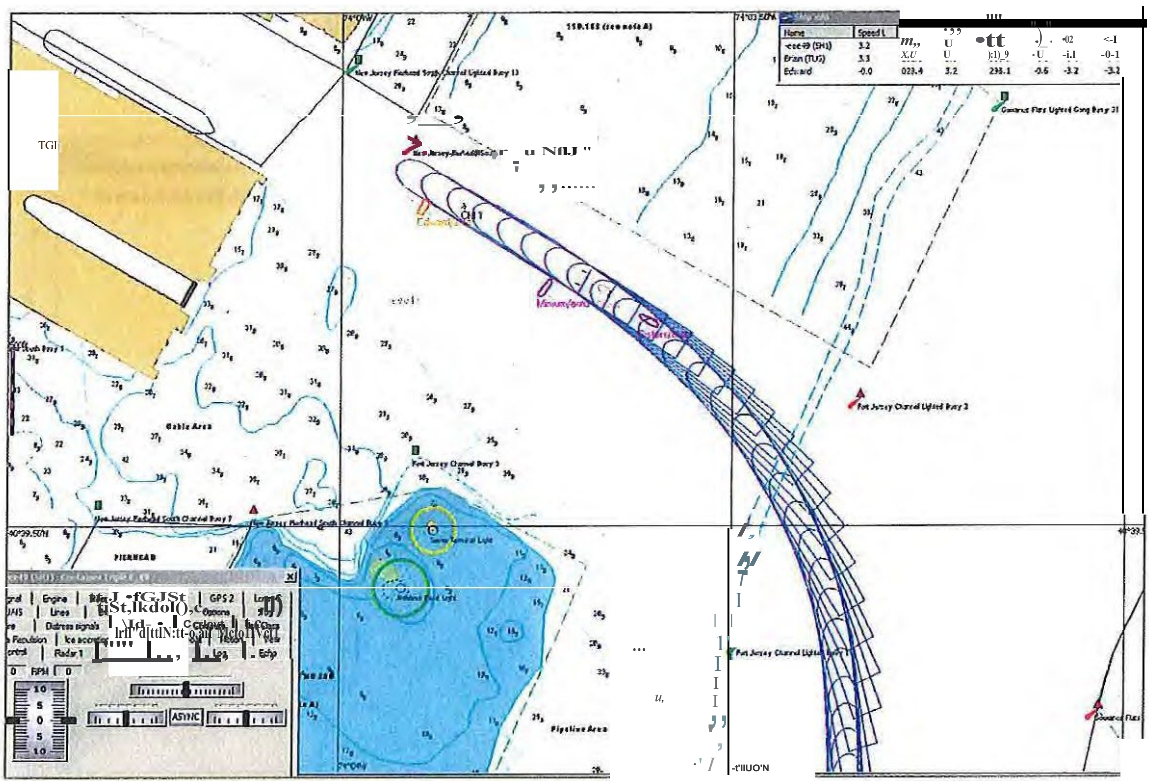


Figure 38: Triple E entering Global Marine Terminal

6.7 OUTBOUND FROM GLOBAL TERMINAL TO UPPER BAY BUOY 30

Run 21

Pilot: Robert Flannery — *Triple E* Draft 49'

Start: Global Term. — Finish: Robbins Reef

Current/ Wind: N 20, Slack — +3' Tide

Tugs: CLA *Brian,* CLF *Edward,* Port Bow *Miriam,* Port Quarter *Sisters*

Description:

To save time, the model was started off of her berth and in mid-channel. Initially the *Brian* was ordered to pull in-line at half power to accelerate the ship. During the transit out of the Port Jersey Channel, the *Miriam* and *Sisters* were used to keep the ship headed down the channel on the desired course of the DM. At times, the *Brian* was also used pulling at a 45° angle to port and to starboard to keep the ship lined up and the DM used the *Edward* to push at the port bow to assist in holding the ship up against the wirid. The ship was making 2.4 knots when the ship passed the passenger ship and she was north of the channel centerline for maximum clearance (181'). The DM continued to back the ship until it entered New York Upper Bat proper at Buoy 2 where Captain Flannery began his turn with the ship to head south in the Upper Bay.

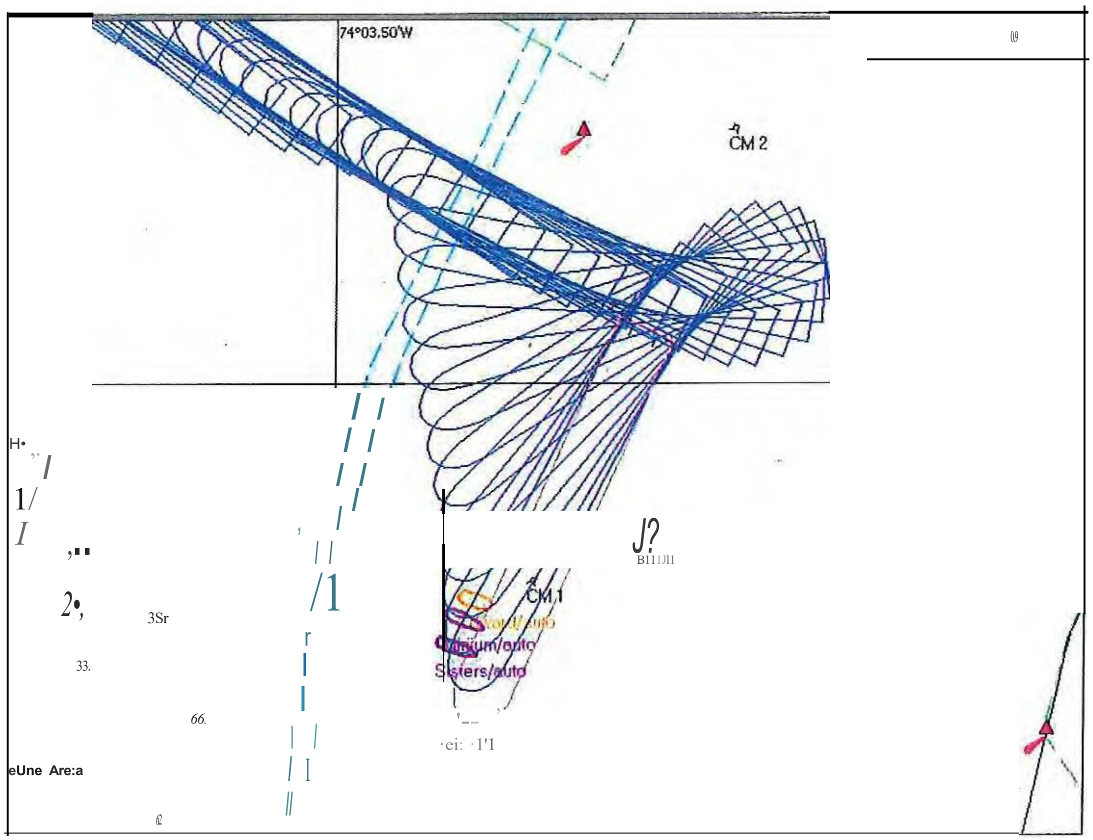


Figure 39: Run 21- *Triple E* backing out of Port Jersey Channel

Run 22

Pilot: Robert Ellis | *Triple E,* Draft 49'

Start: Global Terminal | Finish: Robbins Reef

Current /Wind: S 20, Slack | +3' Tide

Tugs: CLA *Brian,* Starboard Quarter *Miriam,* CLF *Edward,* Port Quarter *Sisters*

Description:

The DM did a very nice job backing the ship out of the Port Jersey Channel using the *Brian* to accelerate the ship and then maintain the ship in the center of the channel. The other two boats aft were used to hold the ship up against the wind. The *Edward* was used as necessary at the ship's bow to keep the ship tracking properly down the channel. When passing the passenger ship, the Triple E was on the channel centerline and cleared the ship by 111'. After clearing the ship, the OM took the ship further to the south to give the ship more room to turn which worked very well.

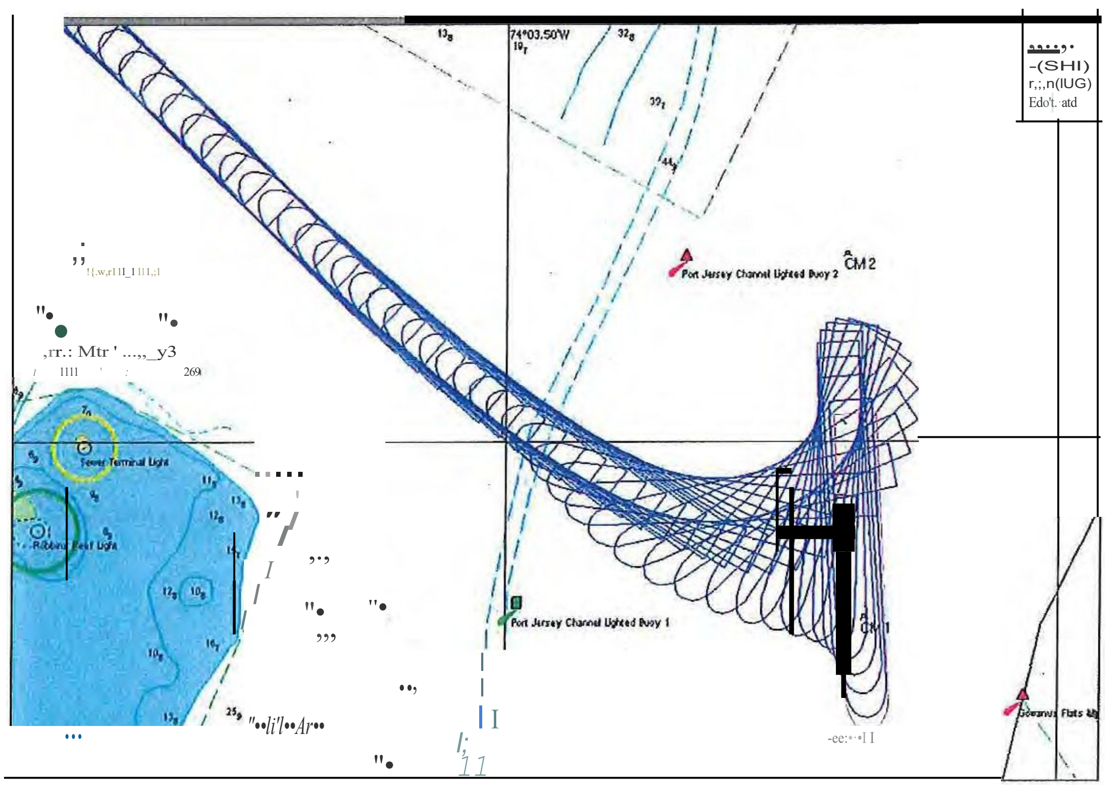


Figure 40: Run 22 - Triple E backing out of Port Jersey Channel

6.8 EMERGENCY TURNS ABOVE AND BELOW THE VERRAZANO NARROWS BRIDGE

Theses runs focused on the ability of the pilot to abort the transit, and turn the ship around above and below the Verrazano Bridge.

Run 23 Emergency Turn South of Verrazano Bridge

Pilot: Richard Schoenlank   *Triple E,* Draft 49'

Start: Norton Point   Finish: Below VN Bridge

Current/Wind: S 20, 2, kn. Flood   +3' Tide

Tugs: CLA *Brian,* Port Bow *Sisters*

Description:

Once the tugs joined the ship, the pilot ordered the *Brian* (positioned center lead aft) into the transverse arrest mode, and then direct pull inline to reduce the speed of the ship. Once the speed had been reduced, the *Brian* pulled at a port "90" full and the *Sisters* pushed at the bow until the ship was turned 180°.

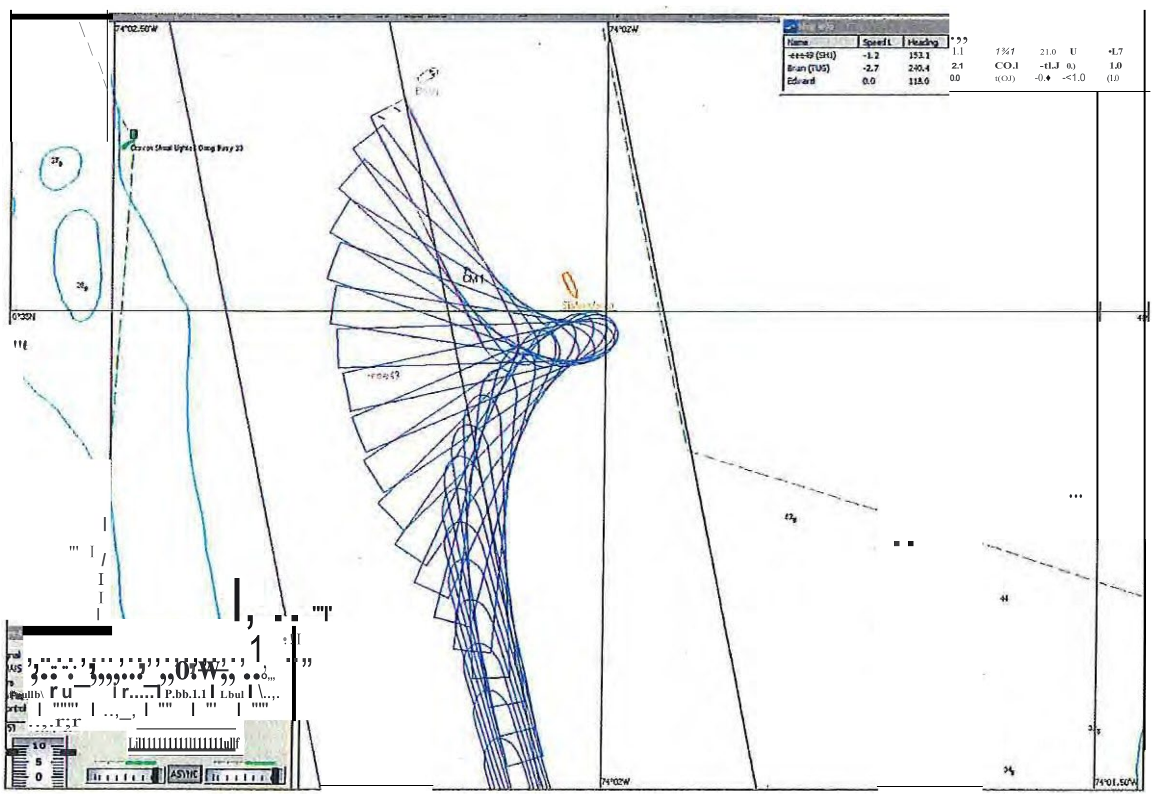


Figure 41: Emergency Turn in the Narrows

Run 24 Emergency Turn South of Verrazano Bridge

Pilot: John Oldmixon *Triple£,* Draft 49'

Start: Off Caven Shoals

Current/Wind: S 20, 2 knots Flood +3' Tide

Tugs: CLA *Brian,* Port Bow *Sisters*

Description:

In this run, the ship was almost stopped when the tugs joined and the pilot immediately ordered the *Sisters* to push at the port bow full and the *Brian* to pull full at the transom, Port "90" full. The round turn was quickly performed.

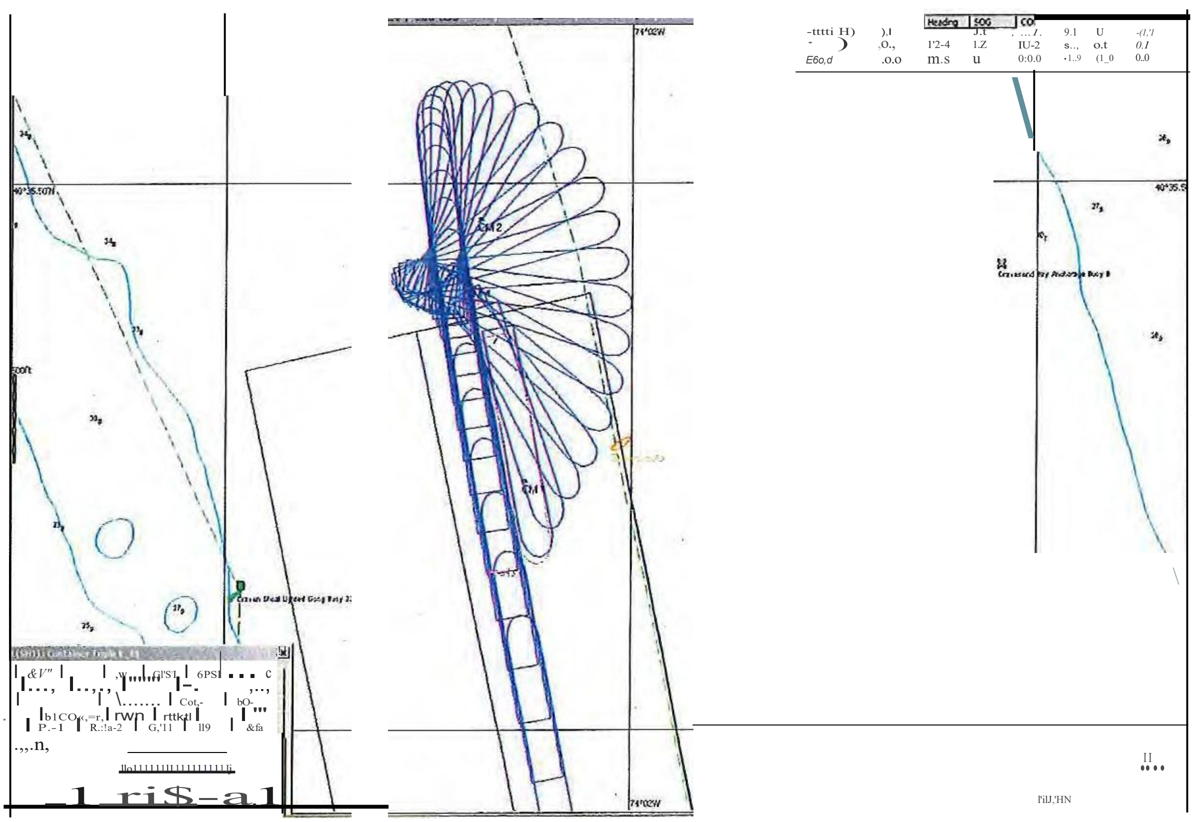
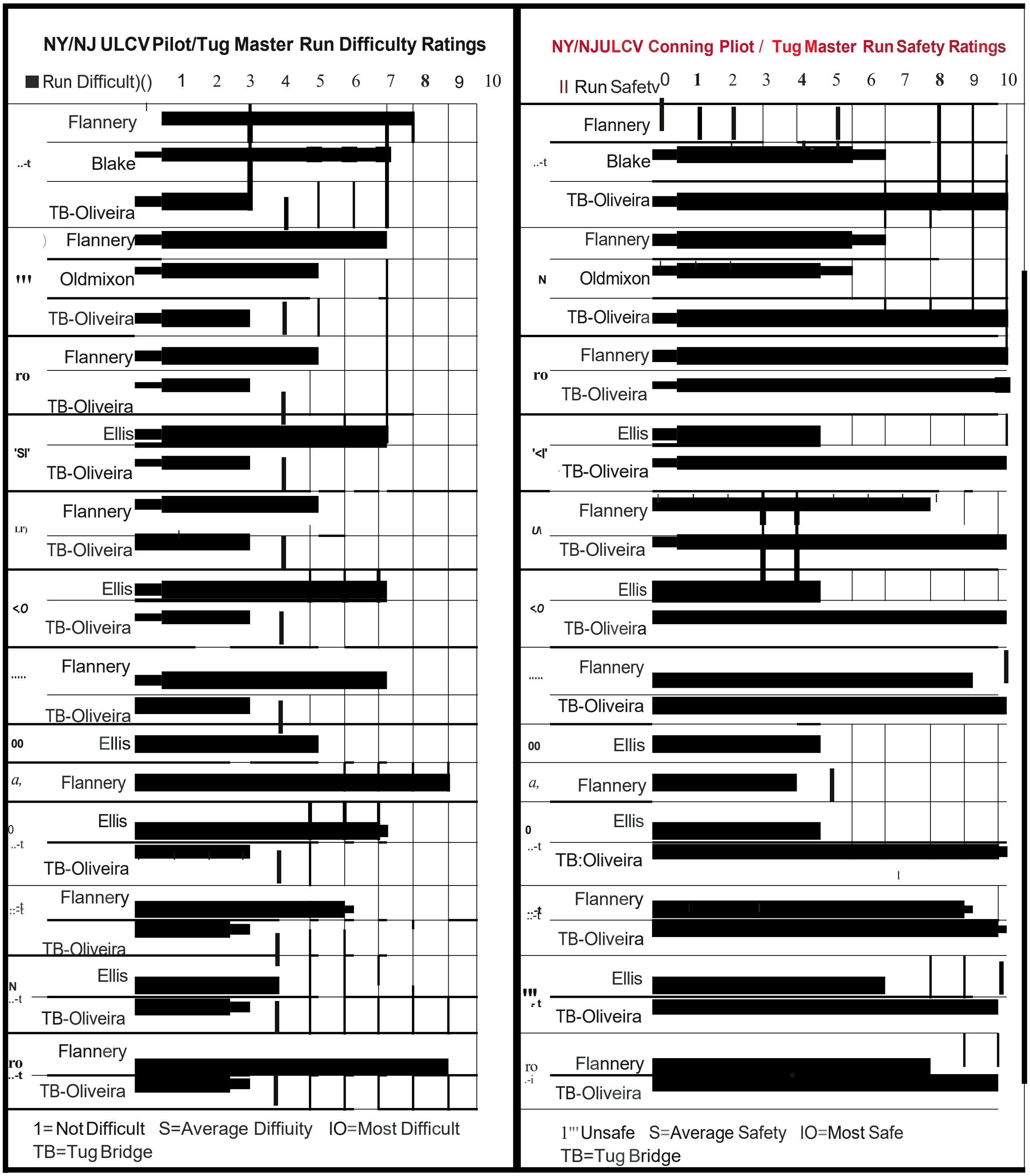
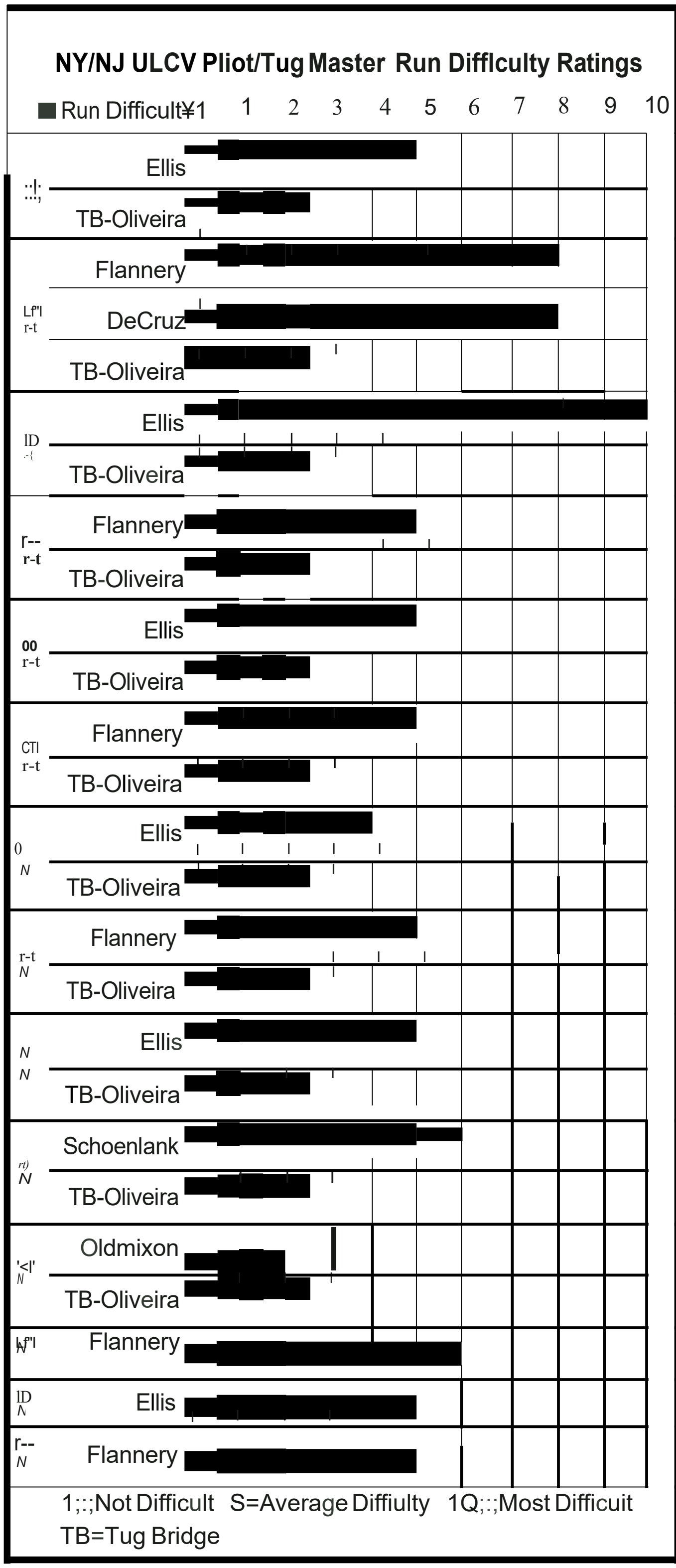


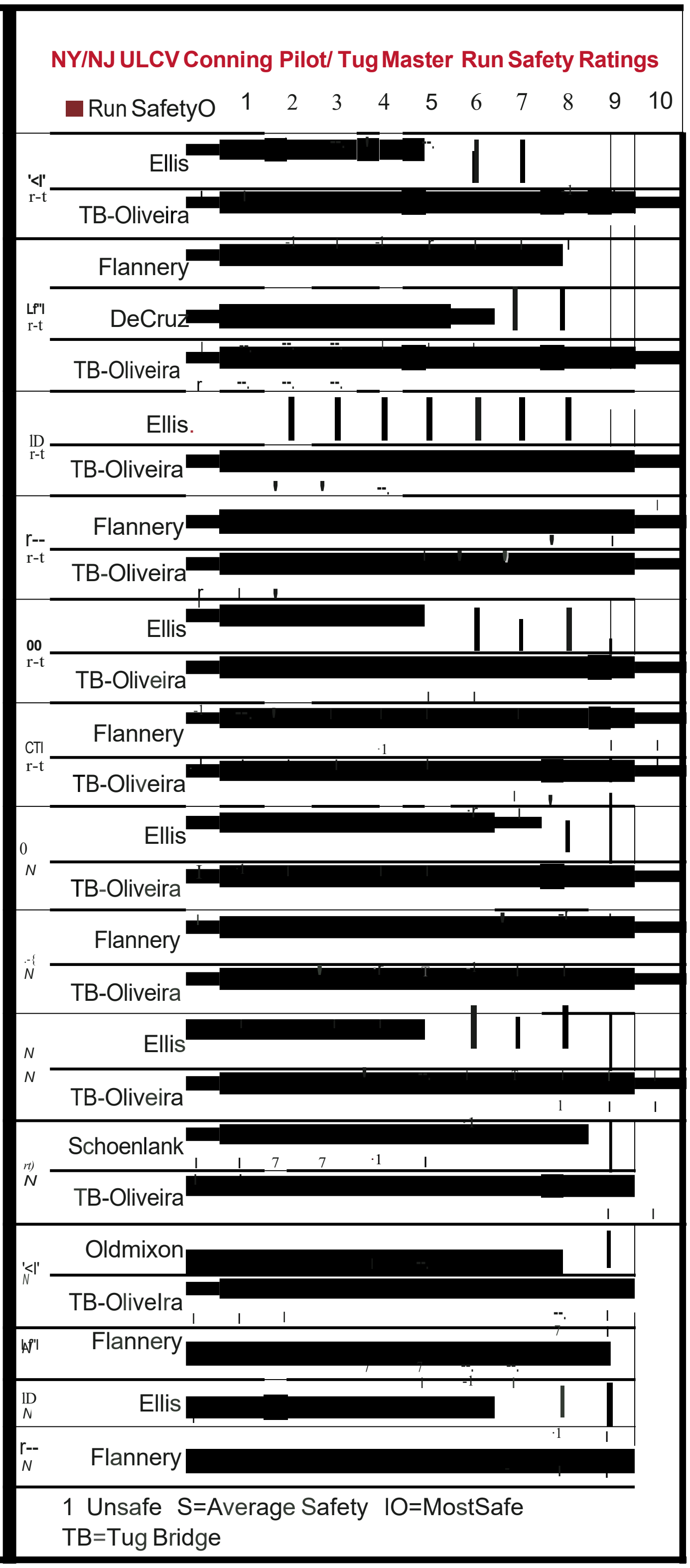
Figure 42: Emergency Turn

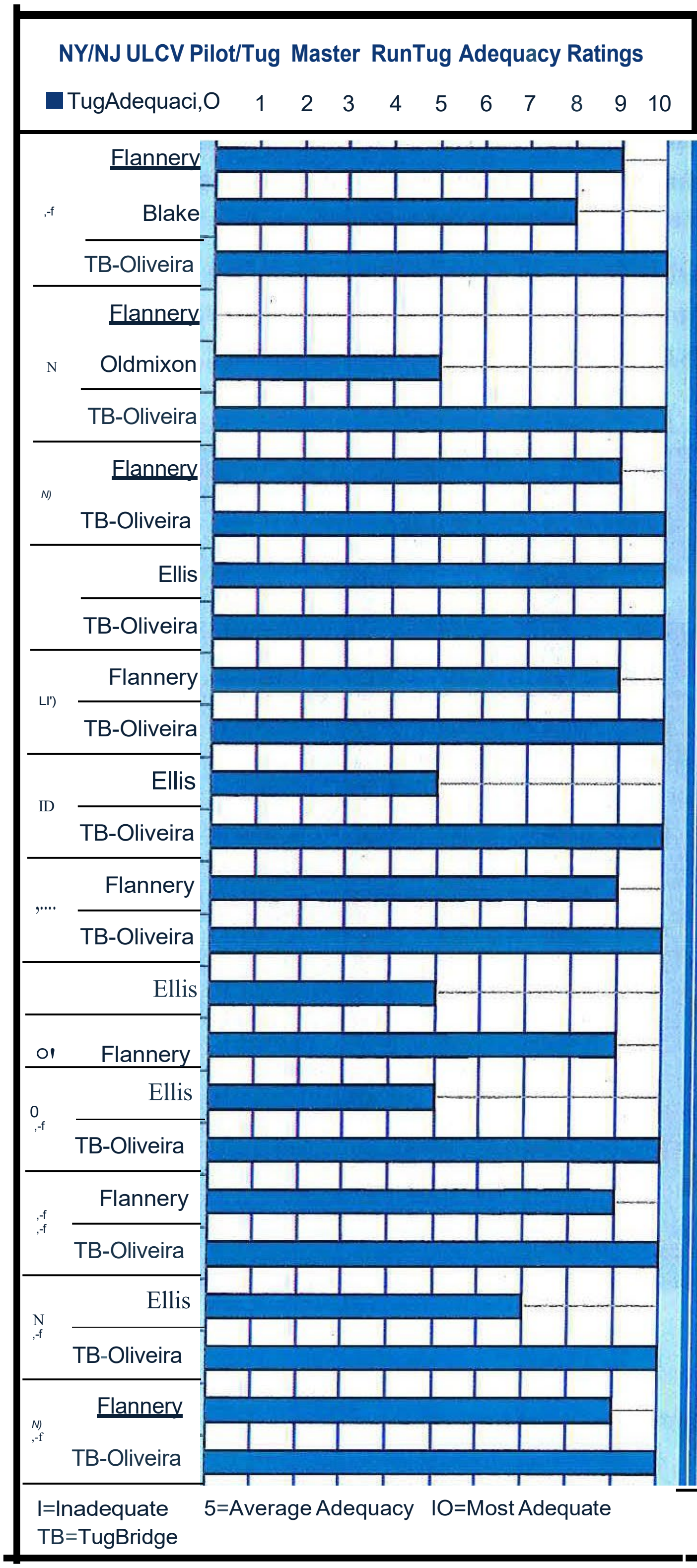
7. PILOT FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

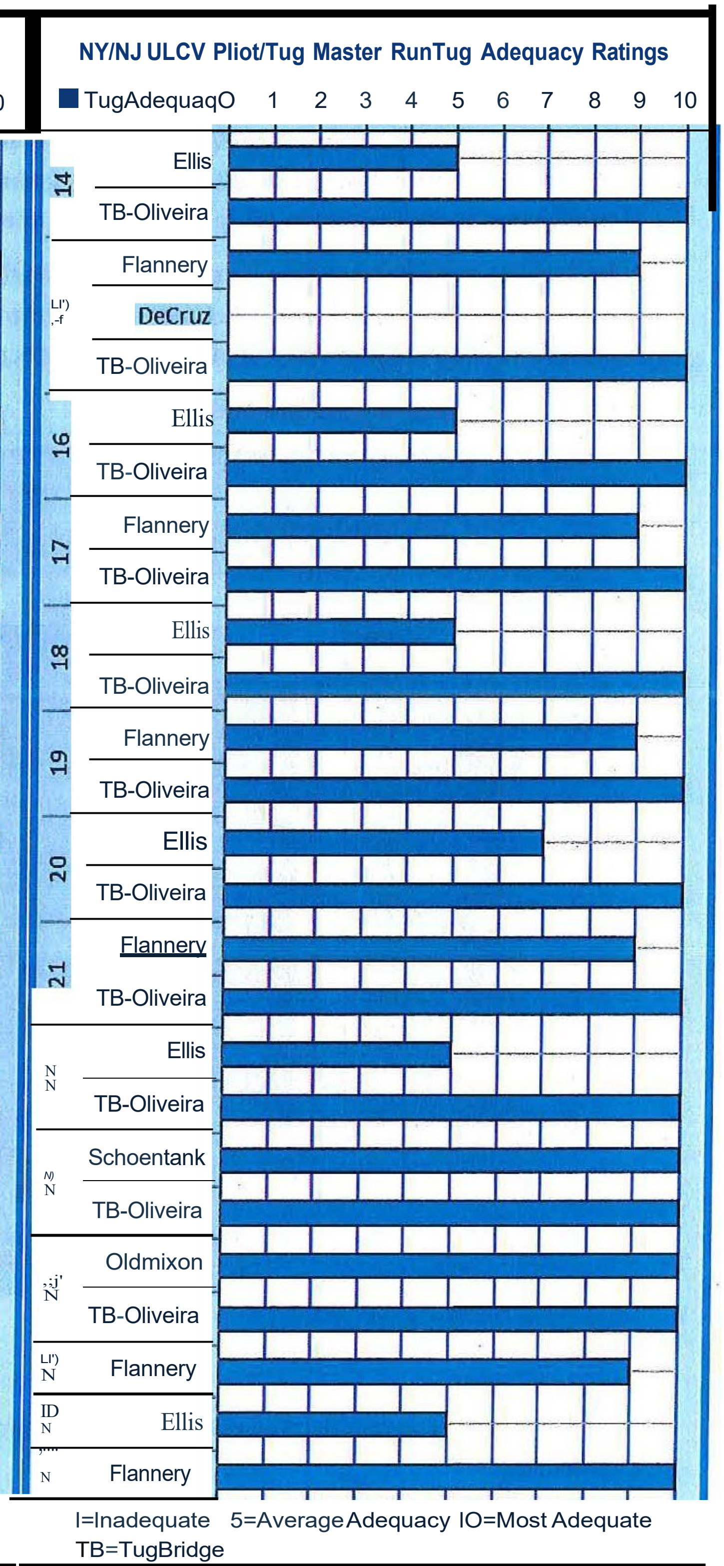
After each run, the conning pilot and tug operator filled out questionnaires that rated the safety and difficulty of the run. The scales used were from 1 to 10 with one being unsafe or not difficult, and 10 being very safe or very difficult. Note that a run can be difficult, but safe. Twenty-seven runs were completed in the August 2016 tests. The following graphs display side by side comparisons of the difficulty and safety ratings of the runs. "Tug Adequacy" graphs follow the difficulty and safety ratings.




NY/NJ ULCV Pliot/Tug Master Run Difficulty Ratings
Run Difficult¥1
1 2 3 4 5 6 7 8 9 10
Ellis
TB-Oliveira
Flannery
DeCruz
TB-Oliveira
Ellis
TB-Oliveira
Flannery
TB-Oliveira
Ellis
TB-Oliveira
Flannery
TB-Oliveira
Ellis
TB-Oliveira
Flannery
TB-Oliveira
Ellis
TB-Oliveira
Schoenlank
TB-Oliveira
Oldmixon
TB-Oliveira
Flannery
Ellis
Flannery
1;:;Not Difficult S=Average Diffiulty 1Q;:;Most Difficuit
TB=Tug Bridge


NY/NJ ULCV Conning Pilot/ Tug Master Run Safety Ratings
Run SafetyO
1 2 3 4 5 6 7 8 9 10
Ellis
TB-Oliveira
Flannery
DeCruz
TB-Oliveira
Ellis.
TB-Oliveira
Flannery
TB-Oliveira
Ellis
TB-Oliveira
Flannery
TB-Oliveira
Ellis
TB-Oliveira
Flannery
TB-Oliveira
Ellis
TB-Oliveira
Schoenlank
TB-Oliveira
Oldmixon
TB-Olivelra
Flannery
Ellis
Flannery
1 Unsafe S=Average Safety IO=MostSafe
TB=Tug Bridge


NY/NJ ULCV Pilot/Tug Master RunTug Adequacy Ratings
TugAdequaci,O 1 2 3 4 5 6 7 8 9 10
Flannery
Blake
TB-Oliveira
Flannery
Oldmixon
TB-Oliveira
Flannery
TB-Oliveira
Ellis
TB-Oliveira
Flannery
TB-Oliveira
Ellis
TB-Oliveira
Flannery
TB-Oliveira
Ellis
Flannery
Ellis
TB-Oliveira
Flannery
TB-Oliveira
Ellis
TB-Oliveira
Flannery
TB-Oliveira
I=Inadequate 5=Average Adequacy IO=Most Adequate
TB=TugBridge

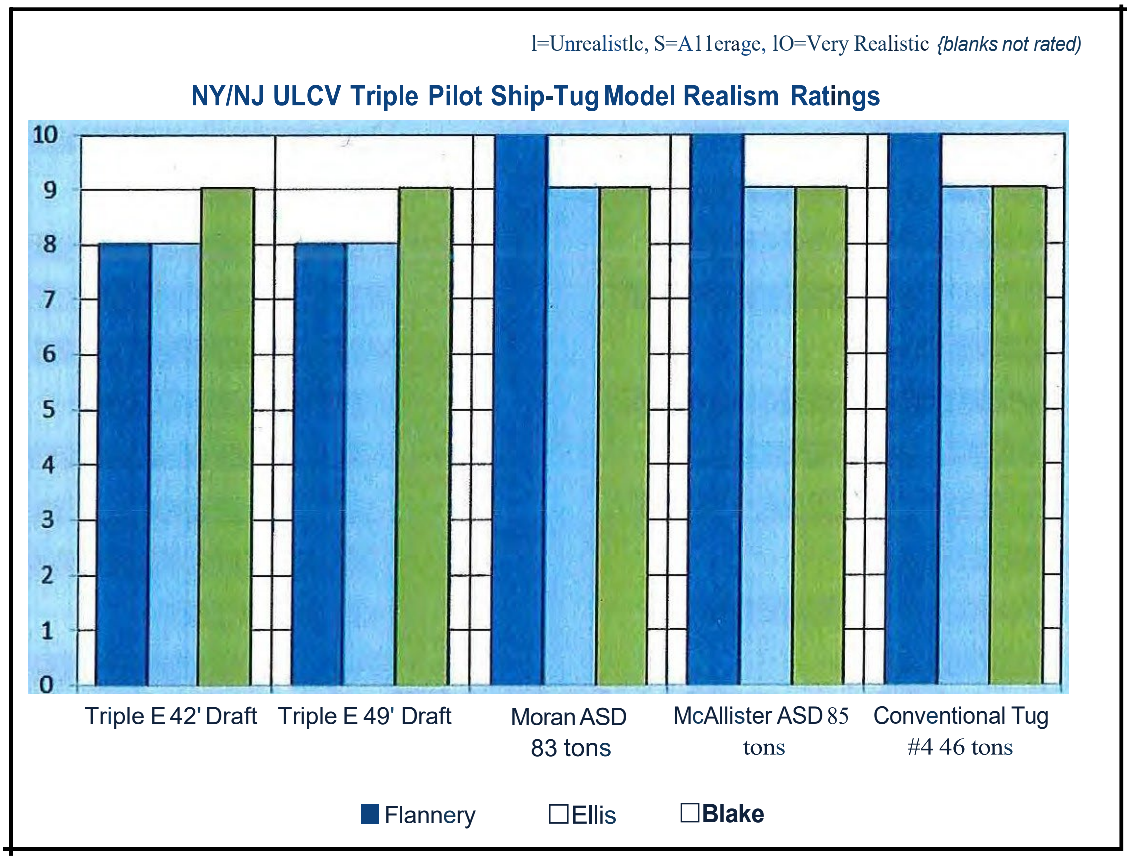

NY/NJ ULCV Pliot/Tug Master RunTug Adequacy Ratings
TugAdequaqO 1 2 3 4 5 6 7 8 9 10
14
Ellis
TB-Oliveira
Flannery
DeCruz
TB-Oliveira
16
Ellis
TB-Oliveira
17
Flannery
TB-Oliveira
18
Ellis
TB-Oliveira
19
Flannery
TB-Oliveira
20
Ellis
TB-Oliveira
21
Flannery
TB-Oliveira
Ellis
TB-Oliveira
Schoentank
TB-Oliveira
Oldmixon
TB-Oliveira
Flannery
Ellis
Flannery
I=Inadequate 5=Average Adequacy IO=Most Adequate
TB=TugBridge

7.1 FINAL QUESTIONNAIRE GRAPHS AND COMMENTS

At the end of the session, all participants were asked to fill out a final questionnaire that included questions about the overall realism of the simulation. The following tables summarize the results followed by the written comments. We can infer that the higher "realism" ratings are good indications of higher confidence levels in the accuracy of the results. The below ratings indicate that the hydrodynamic models were a good approximation of the handling characteristics of these vessels.

Note that sea trial information on the "Brian McAllister" tug model was unavailable since the tug is still under construction. However, the tug model performed as expected for a tug of that class. The other models have been routinely used on numerous projects and found to be performed as expected.

Realism of Ship and Tug Models Ratings Graph



Comments regarding model realism:

Captain Flannery

) I think it is correct that the ship (EEE) doesn't back.

Captain Ellis

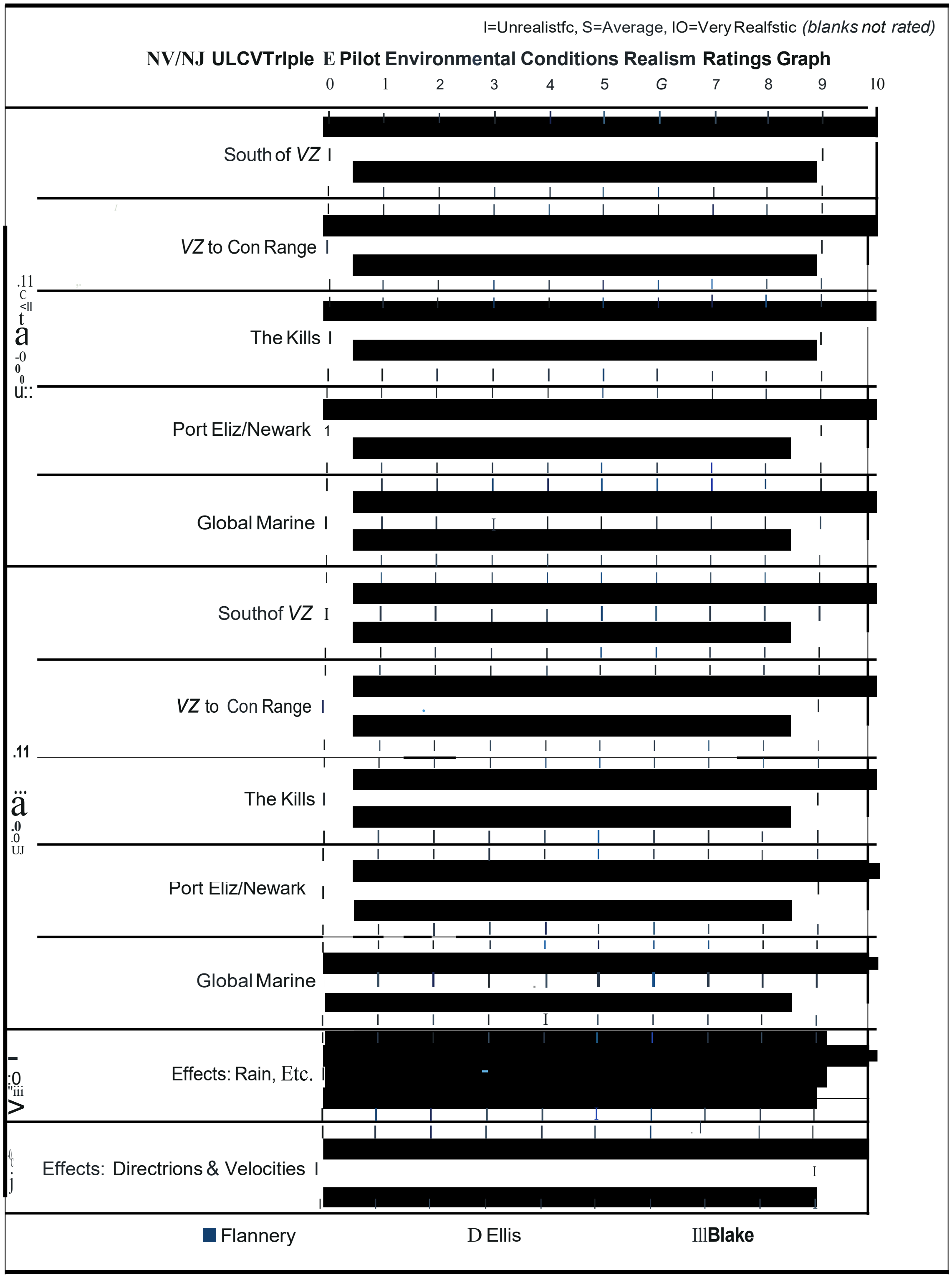
) It may be debatable as to how slow the ship stops. Also, how long it takes to build up sternway when backing out.

Captain Schoenlank

) The models were excellent - concern about lack of astern power, but perhaps that is accuratel

) It was great having a live tug operator- believe it to be valuable for all involved.

Realism of Environmental Conditions Ratings Graph



Comments regarding Environmental Forces Realism

Captain Ellis

) A 3.5 flood current at the approach to KV buoy was not realistic. It was modified later.

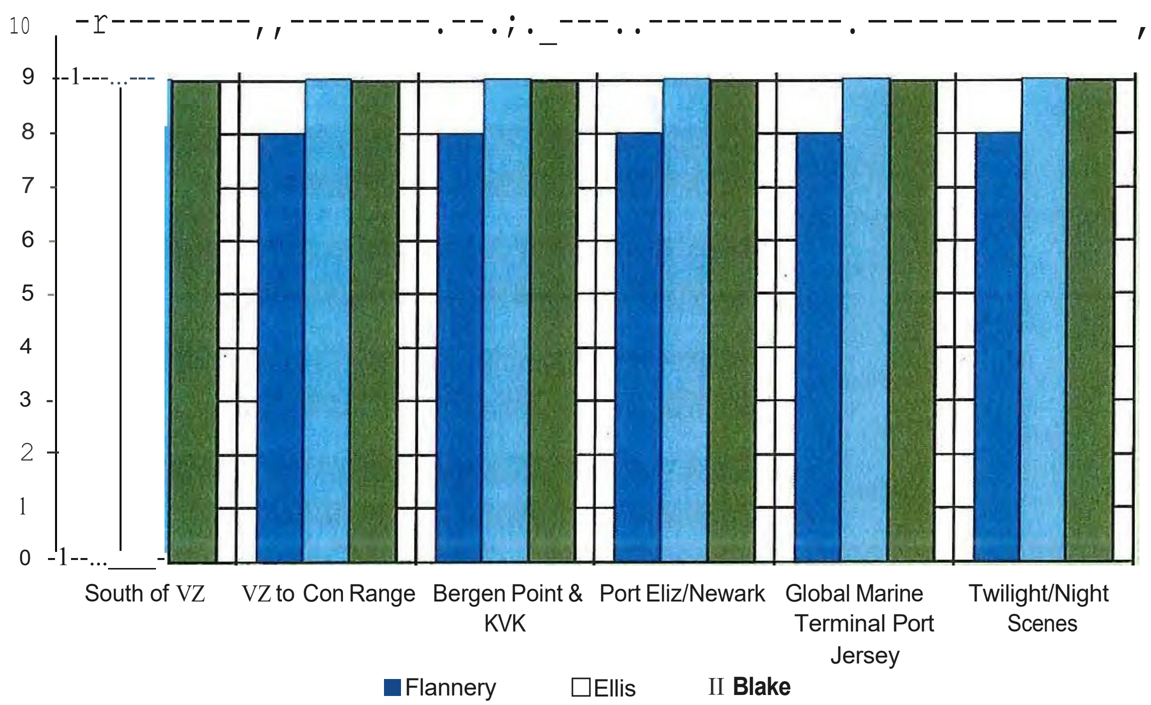
Captain Schoenlank

) Believe the forces were good - would still like a visual of wind on water effect if possible.

Realism of Visual Database Ratings Graph

!=Unrealistic,S=Average, IO=VeryRealistic *(bfanksnotrated)*

NV/NJ ULCVTriple E Pilot Visual Database Realism Ratings Graph



Comments regarding Visual Database Realism

Captain Schoenlank

) The database served the purpose - no problems.

Overall Final Evaluation Comments

1. Based on the simulation exercises, were you able to make the turn at Con Hook Range, transit the KVK, and make the turn at Bergen Point? Additionally, what are the environmental limits, and issues that should be resolved prior to making the final determination on whether this class of ULCV should be allowed to call NY/NJ?

Captain Flannery

) Visibility, 40% Current.

) No more than 20 (knots) wind.

Captain Ellis

) One hour either sid_e of SW at Bergen Point.

) 20 knot wind limit.

) Meeting other commercial vessels not recommended.

Captain Schoenlank

) As experienced and discussed, once the familiarization of the models took place and experienced gained, the transits met with success at the higher level. Believe the parameters on tide and wind are valid at this point. 18K TEU ships are one-way traffic situations.

Captain Blake

) Yes. One hour either side of slack water at Bergen Point.

) 20 knot wind limit.

) No meeting/ no overtaking except light boats.

2. Based on the simulation exercises, were you able to safely make the turn into Port Elizabeth Reach? Additionally, what are the environmental limits, and issues that should be resolved prior to making the final determination on whether this class of ULCV should be allowed to call on these terminals?

Captain Flannery

) Can't go between 2 side by side EEE class.

Captain Ellis

) One hour either side of SW at Bergen Point.

) 20 knot wind limit.

) Meeting other commercial vessels not recommended.

Captain Schoenlank

) Yes, but thought as to other ships berthed needs to be considered - unrealistic to think an 18k TEU should go deep into Port Liz Channel past other vessels.

Captain Blake

) Yes, 20 knot wind limit.

) Cranes up.

) Ships in berth with lines out.

) No backing out between two Triple·Eclass ships.

3. Based on the simulation exercises, were you able to transit in / out of Global Marine Terminal? Additionally, what are the environmental limits, and issues that should be resolved prior to making the final determination on whether this class of ULCV should be allowed to call on this terminal?

Captain Flannery

) Visibility.

) Slack Current.

) No more than 20 (knots) wind.

) One ship at NEAT or Cruise Terminal.

) No two ships same time.

Captain Ellis

) SW and 20 knots max wind.

). Only one moored vessel slowed at the entrance.

Captain Schoenlank

) Yes-again, only one ship should be berthed at either NEAT or Cape Liberty- not bothl

Captain Blake

) 20 knot wind limit.

) Only one ship alongside at either Cape Liberty or NEAT.

) Passengers off the gangways while ship is passing because of interaction.

4. Please list any other issue/ challenges that should be resolved prior to allowing this class of vessel to call on NY/NJ?

Captain Flannery

- Lot of communication.
- Ships must *leave* on time.
- Closing of KVK.
- There's a lot of work to be done.
- My thanks to the MITAGSgroup - par excellent. Professional and fun to wor.k with.

Captain Blake

- There should be a four tug, two tractor, two conventional limit minimum.

Captain Schoenlank

- Strongly believe experience shall be gained first on smaller vessels (14k TEU's).
- Surge issues, traffic arrangements, logistics of tidal parameters, and interaction with other ship transits that need to take place, must be allowed to get worked through. Believe 18k TEU's will further exacerbate this, need gradual experience - not sudden and dramatic.

7.2 MITAGS OBSERVATIONS AND COMMENTS

Overall, the docking masters, the pilots, and tug operators provided a consistent assessment of the difficulty and safety of each run.

ULCV Meeting Situations in the KVK

In addition to the June tests, the pilot ran three more meeting situations in the KVK. For Runs 1, 2, and 15, the exercises used the *Kalina* meeting a smaller tanker. Although successful, the stern of the Kalina swept uncomfortably closed to the moored tanker models on the North side of the KVK. Discussions indicated that a "starboard to starbo,ird" meeting may generate more favorable outcome, but due to time constraints they were not tested. Until further tests can be completed, 14,000 TEU and larger classes should avoid meeting traffic in the KVK.

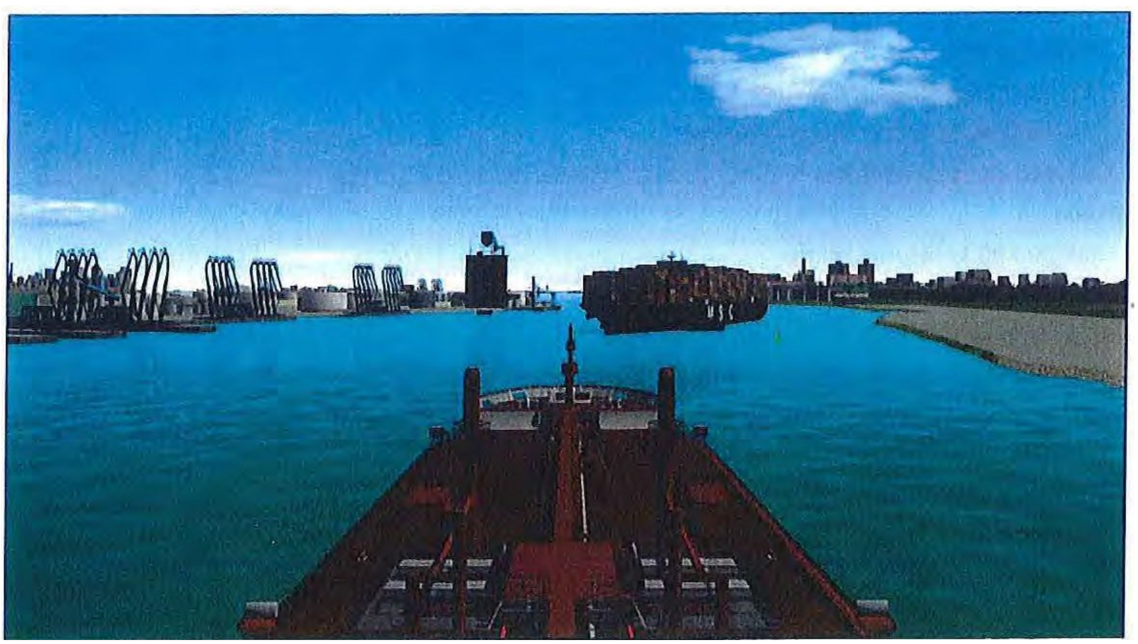


Figure 43: View from the Tanker Meeting theKalina inthe KVK

18,000 TEU Turn into Con Hook Range (Runs 3, 16 -18)

After the grounding on the run into Con Hook Range, the pilots adjusted their techniques and did remarkably well in controlling the turn, and getting the speed down below 5 knots by the time they turned into Constable Hook Reach. Additionally; the "difficulty" rating dropped to a "5" by Run 18.

In some respects, the Triple E model handling characteristics were superior to the *Kalina* model. This is something that will need to be validated over time.

Figure 44: Triple EInbound Constable Hook Reach

18,000 TEU Turn at Bergen Point (Runs 3, 4-7)

The OM executed nearly textbook turning maneuvers at Bergen Point inbound and outbound directions. The DM rated the runs as having high difficulty levels, but with above average safety levels. The DM and the tug master provided above average adequacy ratings for the tugs. They appear to have adapted and applied the "lessons learned" from the *Kalina* tests to the larger 18,000 TEU model.

Port Elizabeth Branch Reach (8 -14)

A good portion of the runs focused on inbound and outbound maneuvers. The exercises had high difficulty ratings and above average safety ratings. The critical challenges include the very limited space for the assist tugs to maneuver when the container berths are filled with other ULCVs. The general consensus, at this time, is the Port should avoid putting two Triple E classvessel across from each other.

Global Marine Terminal (Runs 19 - 22, 27)

The DM generally gave above average difficulty and safety ratings for these maneuvers. The most critical challenge appeared to be the ability to get the way off the model in a timely manner. This may or may not be a function of the model.

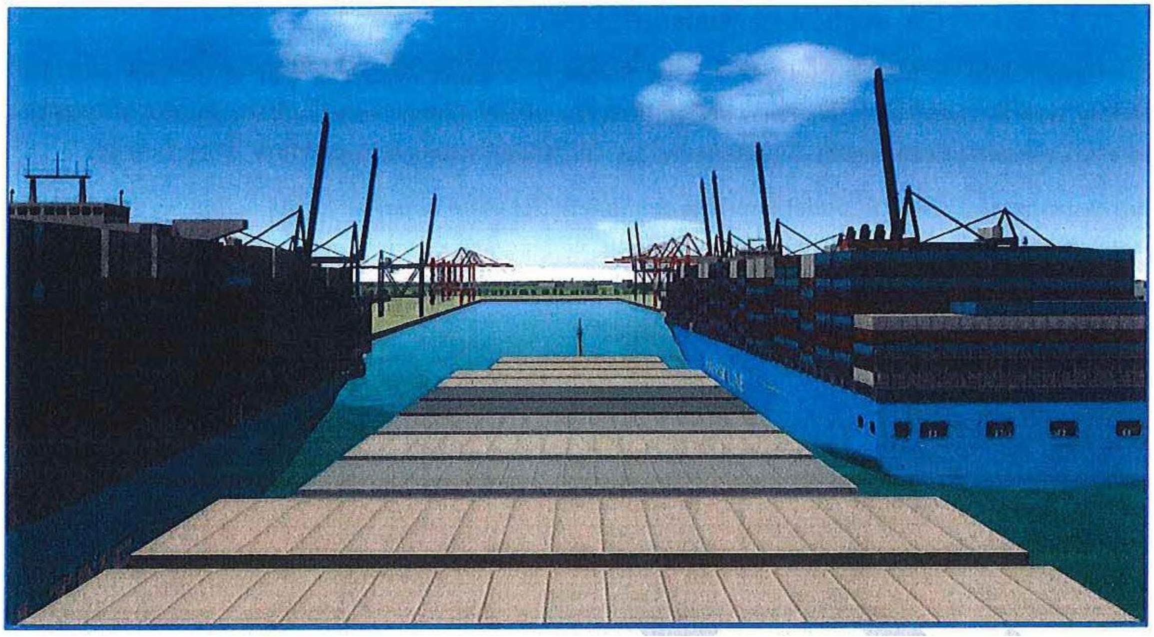


Figure 45: Triple E Inbound into PortElizabeth Branch Reach

Figure 46: Triple E Inbound at Bergen Point

Figure 47: Triple E Inbound to Global Marine Terminal Past Cruise Ship Terminal

The follow.tables provide an estimate on the amount of tug forces needed to offset beam wind and currents.

	load Condition	Wind Velocity (knots)	Wind Force (N)	Wind Force (t)	'current Velocity {knots)	Current Force (NJ	Current Force {t)	Required Effective Bollard Pull (t)
Container Maersk Triple E	loaded (12.8m)	15	395710.3	44.48	0	0.00	0.00	69.4
Displacement {t	206397				1	462805,52	52.02	137.0
Length Over All (m	399				2	1851222.07	208.10	339.9
Length Between Perps {m	376.21				3	4165249.65	468.22	678.1
beam{m	59	20	703485.0	79.08	0	0.00	0.00	123.4
draft{m	12.8				1	462805.52	52.02	191.0
Lateral WindCoefficient	0.75				2	1851222.07	208.10	393.9
Ulteral Sway Coefficient	1				3	4165249.65	468.22	732.0
WindageArea{m²	15633	25	1099195.3	123.56	0	0.00	0.00	192.8
Underwater Profile Area {m²	3412.7				1	462805.52	52.02	260.4
Block Coefficient	0.7087				2	1851222.07	208.10	463.3
Dlsp/Power {LT/hp}	3.48				3	4165249.65	468.22	801.4
(399x 59meters)		30	1582841.3	177.93	0	0.00	0.00	277.6
					1	462805.52	52.02	345.2
					2	1851222.07	208.10	548.1
					3	4165249.65	468.22	886.2

**Formulas Used

Thoresen, C. (2003). Tugboat Assistance. In *Port designer's handbook recommendations and guide/Ines.* London: Thomas Telford.

Zubaly, R. (1996). Applied Naval Architecture.

WindForce= 0.5 x CYwInd x 1.2 (air density) x Wind Velocityh2 x Wfndage Area

CYwlnd range from 0.60to 0.75 *for* contafnershlps. 0.75 used for safety factor.

Current force= 0.5x CYcurient x 1,025 (seawater density) x Current Vefocityh2 x Underwater Profile Area

Required Effective Bollard Pull= Sfx [(Wind Force x Fg) + Current Force], where Sf= Tugboat bollard pull factor= 1.3, Fg= gust factor= 1.2

Newton-to-Ton Conversion Factor= 1 ton/8896 Newton

	Load Condition	Wind velocity (knots)	Wind Force (NJ	Wind Force (t)	Current Velocity (knots)	current Force (N)	(urrent Force(t)	Required Effective Bollard Pull (t)
Container Maersk Triple E	Loaded (i4.94m)	15	419048.4	47.1	0	0.00	0.00	73.5
Displacement (	240904.9				1	540180.81	60.72	152.4
LengthOver All(m	399				2	2160723.26	242.89	389.2
Length Between Perps (m	376.21				3	4861627.33	546.50	783.9
beam(m	59	20	744975.0	83.74	0	0.00	0.00	130.6
draft(m	14.94				1	540180.81	60.72	209.6
Lateral Wind Coefficien	0.75				2	2160723.26	242.89	446.4
Lateral Sway Coefficien	1				3	4861627.33	546.50	841.1
WIndage Area(m²	16555	25	1164023.4	130.85	0	0.00	0.00	204.1
Underwater Profile Area (,m²	3983.3				1	540180,81	60.72	283.
Block Coefficien	0.7087				2	2160723.26	242.89	519.9
Dlsp/Power(LT/hp	4.06				3	4861627.33	546.50	914.6
{399x 59meters		30	1676193.8	188.42	0	0.00	0.00	293.9
					1	540180.81	60.72	372.9
	------'-				2	2160723.26	242.89	609.7
					3	4861627.33	546.50	1004.4

Formulas U ed

Thoresen, c. (2003). Tugboat Assistance. In *Portdesigner's handbook recommendationsand guidelines.* London: Thomas Telford.
IZubaly, R. (1996). Applied Naval Architecture.

Wind Force= 0.5 x CVwind x 1.2 (air density) x Wind VelocityAz x Windage Area
CYwind range from0.60 to 0.75 for containerships. 0.75 used for safety factor.
Current Force= 0.5 x CY,urrent x 1,025 (seawater density) x Current VelocityA2 x Underwater Profile Area
Required Effective Bollard Pull=Sfx [(Wind Force x Fg) +Current Force], where Sf= Tugboat bollardpull factor= 1.3, Fg= gust factor=1.2
Newton-to-Ton Conversion Factor= 1 ton/8896 Newton

For safety purposes, the hydrodynamic model used a full deck load profile for wind area calculations. When the actual pro-forma load profiles are established, there may be value in updating the models to more accurately simulate the wind effects. For example, of the forces created by wind and currents, please review the table below. The figure in the last column is the wind and current forces total plus a 20% safety factor for wind gusts and 30% factor for variabilities of the tugs[3].

Note there are exponential increases in the forces exerted on the vessel as wind and current increase. A doubling of the wind speed (15 to 30 knots) increases the forces by more than three times. Also note the large forces generated by beam water currents. Maneuver outside of near slack water conditions will be a challenge. Accurate real-time wind and current information will be very important components of the pilot's assessment of the situation. Additional assist power may be needed to counteract unexpected conditions.

The tug design and placement are also important factors. The ASD propulsion systems allow the tug to provide more power when alongside. This could be significant when transiting between ULCVs berthed on either side of the channel, and there is not enough room to go out perpendicular to the ship's hull. Making fast on the ships' center leads forward and aft ensures the maximum safe working loads, and

[3] Thoresen, C. (2003). Tugboat Assistance. In Port designer's handbook recommendations and guidelines. London: Thomas Telford, and Zubaly, R. (1996). Applied Naval Architecture.

provides additiqnal leverage. Tugs capable of safely performing "power indirect" commands with short leads add an additional layer of safety.

General Information on the Maneuverability of the Triple E Class ULCV

From simulation studies and observations from conning pilots, we can make some general comments about the expected maneuvering characteristics of the *18,000 TEU Triple E Class* in the real-world.

In general, the design characteristics and anecdotal evidence indicates the Triple E Class handles well for a ship of its size, but does have difficulty in taking way off quickly. The large deck load obstructs the pilot's view, and makes the use of electronic navigation systems critically important. The model and field evidence[4] indicates the vessel takes longer than expected to slow down in confined waters. This condition maybe exacerbated for the under keel clearances of less than 10% of draft.

Future Considerations

The study used water current models originally developed by the Army Corps of Engineers and modified by the Waterway Simulation Technology (WST) Study for loading into the Transas ship simulator. At the time of the St'udy, there were no current meters at Bergen Point (the most critical area) to validate the velocities. In order to achieve the proper ship model behavior at Bergen Point the current velocities were increased over the original algorithms. Once the water current meters have been installed at Bergen Point, the data should be compared against current models used in this study, and select exercises should be re-run to validate the accuracy of the current velocities used in the study.

The large underwater volume of the ULCVs relative to the channel volume could create significant surge forces on moored vessels in confined waters. Keeping the speed off these vessels will be critical to managing the surge forces[5]. However, even at very slow speeds, surge may still be a significant factor in areas such as Global Marine Terminal, and / or Port Elizabeth Channel Reach where the water flow is restricted by the berths and other vessels. Suggest further study of the water flows created by a ULCV entering and departing these areas, to determine maximum safe speed of approach. These studies may indicate a need for changes in the mooring line configurations and stronger bollard and tendering arrangements.

The numbers, locations and sizes of the vessels at the berths in the Port Elizabeth / Global Marine Terminals will be significant factors in determining whether it is safe to transit. Various combinations of berth ships were evaluated and some had assist tug clearances of less than twenty feet. Suggest further study to develop guidelines for maximum beam combinations. Other suggestions include requiring the container crane booms in the up position, and berth vessels fully secured until the ULCV docking / undocking evolutions have been completed.

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[4] From Capt. Ian Love, Pilot, Flexistowe, UK; and SHS Consultant. Capt. Love was brought over from the UK to assist in the pre-validation of the Kalina and Triple models.

[5] Please refer to the separate Waterway Simulation Technology Study mentioned in Section 4 of this report.

Even within the same ULCV Class, vessel maneuvering behavior can be different. Suggest the pilots consider simulating other classes of ULCV that are expected to call on NY/NJ.

ULCV transit restrictions will be a significant factor in managing the vessel traffic through the Kill Van Kull. Suggest the Port consider mechanisms for coordinating the activities of the various stake holders that use this waterway.

Due to time constraints, only a limited number of "emergency exercises" were run in the vicinity of the Verrazano Bridge. Suggest further simulation to develop "best practices" for handling emergencies (propulsion/ tug failures, etc.) at other points along the transit.

On behalf of the MITAGS-PMI team, we thank the participants and Port Authority, and the NY/NJ Shipping Association for their confidence in our simulation capabilities. We hope the lessons learned will contribute, in a small way, to the safe and efficient handling of the next generation of containerships. We wish the pilots and the Port every success in this new endeavor. Additionally, we look forward to the pilots' feedback on the simulation after they have handled the ULC\t'.s under real-world conditions.

8. FINAL TEST MARIX

RunNo. & Direction	1 Inbound Meeting			1 Outbound Meeting	2 Inbound Meeting			2 Outbound Meeting
Pilot Name(s)	Flannery (Docking)			Blake	Flannery (Docking)			Oldmixon
Starting Location	Con Hook Range			Shooters Island	Con Hook Range			Bergen Point
Initial Heading & Speed	345 ° @ 8 Knots			112° @ 6.3 knots	291°@ 6.7 knots			111°@ 7.1 knots
Database Used	NewYork_F				NewYork_F			
Ship Model & Condition	49' Kalina Loaded			Tanker OH CPP R	49' Kalina			Tanker_OH_Memphis
Current File Name, Tide	2353 (1.5) Flood 1.8 knots@ Bergen				2353 (1.5) Fl.ood 1.8 knots @ Bergen, Tide+ 3'			
Wind Dir. "From" Speed	S@ 20 knots				S@ 20 Knots			
Visibility	Clear-Day				Clear-Day			
Tugs McAllister! Moran	Edward	Brian	Conv.	Conv.	Conv.	Brian	Edward	Conv.
Bollard Pull	80	85	46	46	46	85	80	46
Live or Auto	Live	Auto	Auto	Auto	Auto	Auto	Live	Auto
Tug Initial Position	CLA	SB.	PB	PB	PB	SB	CLA	Escort Aft
All Fast Order								
CPA to Meeting Ship	354'				204'			
Ending Location	Buoy9			IMITDock	Con Hook @ Bergen Point E			Con Hook Range
Simulation Time	30.5 Minutes				34 minutes			

Run No. & Direction	31nbound				41nbound				5 Outbound			
Pilot **Name(s)**	Flannery (Docking)				Ellis (Docking)				Flannery (Docking)			
Starting Location	Stapleton Anchorage				Pier A Bayonne City Dock				Bayonne City D ck			
Initial Heading & Speed	351° @ 6.6 knots				246° @ 6.5 knots				246° @ 6.5 knots			
Database Used	NewYork F				NewYork F				New York F			
Ship Model & Condition	42' Triple **E**				49'Triple E				49'Triple E			
Current File Name, Tide	None				3126 (1.25) Ebb: 0.8 knots@ Bergen, Tide+ 3'				2353(1.5} Flood: 1.8 knots @ Bergen, Tide + 3'			
Wind Dir. "From" Speed	N @5 Knots				NE@ 20 Knots				NE@ 20 Knots			
Wave/Swell Dir. "From" Height (meters); Model					Height: 1.3' NE . Pierson-Moskowitz				Height: 1.3' NE Pierson-Moskowitz			
Visibility	Clear-Day				Clear-Day				Clear- Day			
Tugs McAllister Moran	Edward	Brian	Miriam	Sisters	Edward	Brian	Miriam	Sisters	Edward	Brian	Miriam	Sisters
Bollard Pull	80	85	46	46	80	BS	46	46	80	85	46	46
Live or Auto	Live	Auto	Auto	Auto	Live	Auto	Auto	Auto	Live	Auto	Auto	Auto
Tug Initial Position	CLA	SSB	PB	STBY	CLA	SB	PB	Escort Aft	CLA	SB	PB	Escort
All Fast Order	1	3	2		2	1	3					
Ending Location	Newark Buoy 5				Port Eliz/ Newark Buoy 5				Old Bay Draw Newark Buoy 5			
Simulation Time	1 hour 12 minutes				30:5 minutes				28 Minutes			

Run No. & Direction	6 Outbound				7 Outbound				8 Inbound			
Pilot Name(s)	Ellis (Docking)				Flannery (Docking)				Ellis (Docking)			
Starting Location	Old Bay Draw Port Eliz/ Newark				Port Eliz/ Newark				Bayonne City Dock			
Initial Heading & Speed	205° @ 6.5 knots				205° @ 6.5 knots				216° @ 6.5 knots			
Database Used	NewYork F				New York F				New York F			
Ship Model & Condition	49' Triple E				49' Triple E				49' Triple E			
Current File Name, Tide	2353 Flood: 1.2 knots@ Bergen, Tide+ 3'				3126 (1.25) Ebb: 1.3 knots@ Bergen, Tide + 3'				2359 {1.5) Ebb, Tide +3'			
Wind Dir. "From" Speed	NW@ 20 Knots				NW@20Knots				N@ 20 Knots			
Wave/Swell Dir. "From" Height (meters); Model	Height: 1.3' NE Pierson-Moskowitz				Height: 1.3' NE Pierson-Moskowitz				Height: 1.3' N Pierson-Moskowitz			
Visibility	Clear- Day				Clear- Day				Clear- Day			
Tugs McAllister Moran	Edward	Brian	Miriam	Sisters	Edward	Brian	Miriam	Sisters	Brian	Edward	Miriam	Sisters
Bollard Pull	80	85	46	46	80	85	46	46	85	80	46	46
Live or Auto	Live	Auto	Autb	Auto	Live	Auto	Auto	Auto	Live	Auto	Auto	Auto
TugInitial Position	CLA	PB	SB	Escort	CLA	PB	SB	Escort	CLA	PB	SB	Escort
All Fast Order	3	1	2		3	2	1		1	2	3	
GPA in Kills					43' South Side Channel @ Bridge							
Ending Location	KVK Buoy 13				KVK Buoy 22				Port Elizabeth			
Simulation Time	27 minutes				29 minutes				60 Minutes			

Run No. & Direction	Run 9 Inbound				Run 10 Outbound				11 Outbound			
Pilot Name(s),	Flannery (Docking)				Ellis (Docking)				Flannery (Docking)			
Starting Location	Newark Bay				Berth 59 Port Newark				Berth 59			
Initial Heading & Speed	025° @ 6.5 knots				309° @ 0 knots				309°@ 0 knots			
Database Used	NewYork F				New York F				NewYork F			
Ship Model & Condition	49' Triple E				49' Triple E				49' Triple E			
Current File Name, Tide	2353 (1.5) Flood: 1..8 @ Bergen, Tide +3'				2353 (1.5) Flood: 1..8 @ Bergen, Tide +3'				2359 {1.5), Tide +3'			
Wind Dir. "From" Speed	5@20 Knots				S@ 20 Knots				N@ 20 Knots			
Wave/Swell Dir. "From" Height (meters); Model	Height: 1.3' S Pierson-Moskowitz				Height: 1.3' S Pierson-Moskowitz				Height: 1.3' N Pierson-Moskowitz			
Visibility	Clear-Day				Clear- Day				Clear- Day			
Tugs McAllister Moran	Edward	Brian	Miriam	Sisters	Brian	Edward	Miriam	Sisters	Brian	Edward	Miriam	Sisters
Bollard Pull	80	85	46	46	85	80	46	46	85	80	46	46
Live or Auto	Live	Auto	Auto	Auto	Live	Auto	Auto	Auto	Live	Auto	Auto	Auto
Tug Initial Position	CLF	CLA	SB	SQ	CLA	CLF	PQ	SQ	CLA	Bow	PQ	PQ
All Fast Order	4	1	2	3	3	1	2	4				
CPA Other									66' to ship on starboard			
Ending Location	Berth 59 Port Newark				Newark Bay				Newark Bay			
Simulation Time	45 minutes				42 minutes				40 Minutes			

Run No. & Direction	121nbound				13Inbound				140utbound			
Pilot Name(s)	Ellis (Docking)				Flannery (Docking)				Ellis (Docking)			
Starting Location	Newark Bay Buoy 10				Newark Bay Buoy 10				Berth 59 Port Newark			
Initial Heading & Speed	027°@ 6.5knots				027° @ 6.2 knots				310° @ 0 knots			
Database Used	NewYork F				New York F				NewYork F			
Ship Model & Condition	**49' Triple** E				**45.9' AMaersk**				**45.9' AMaersk**			
Current File **Name**, Tide	2359 (1.5) Ebb, Tide +3' .				2359 (1.5) Ebb, Tide +3'				2359 (1.5) Ebb, Tide +3'			
Wind Dir. "From" Speed	**NE@20 Knots**				**NE@20 Knots**				**NE@ 20 Knots**			
Wave/Swell Dir. "From" **Height (meters); Model**	Height: 1.3' **NE** Pierson-Moskowitz				Height: **1.3' NE** Pierson-Moskowitz				Height: 1.3' NE Pierson-Moskowitz			
Visblllty	**Clear-Day**				**Clear- Day**				**Clear-Day**			
Tugs | McAllister | Moran	Brian	Edward	Miriam	Sisters	Brian	Edward	**Miriam**	Sisters	Brian	Edward	Miriam	Sisters
Bollard Pull	**85**	**80**	46	46	**85**	**80**	**46**	46	**85**	**80**	46	46
Live or Auto	Live	Auto	Auto	Auto	Live	Auto	Auto	Auto	Live	Auto	Auto	Auto
Tug Initial Position	CLA	PB	SB	Escort	CLA	CLF	PB	Escort	CLA	CLF	Escort	Escort
All Fast Order	3	1	2						3	4	1	2
CPA Other									Sterns of 46t tugs 25' to ships both sides			
Ending Location	Berth 61 Port Newark				Berth 59 Port Newark				Newark Bay Buoy 10			
Simulation Time	28 minutes				33 minutes				25 Minutes			

Run No. & Direction	**15 Inbound Meeting**				**15 Outbound Meeting**	**16Inbound**			
Pilot Name(s)	Flannery (Docking)				DeCruz	Ellis (Docking)			
Starting Location	Con Hook Range				Shooters Island Reach	Buoy 2 Bay Ridge			
Initial Heading & **Speed**	000° @ 6.7 knots				103° @ 6.9 knots	346° @ 6.5 knots			
Database Used	New York F					NewYork F			
Ship Model & Condition	49' Kalina				Tanker Memphis	49' Triple E			
Current File Name, Tide	Flood 2353(1.5) Flood: 1.8 @ Bergen, Tide+ 3'					2353 (1.5) Flood: 1.8@ Bergen, Tide+ 3'			
Wind Dir. "From" Speed	S@ 20 Knots					5@20 Knots			
Wave/Swell Dir. "From" Height (meters); Model	Height: Pierson-Moskowitz					Height: 1.3' S Pierson-Moskowitz			
Visibility	Clear-Day					Clear- Day			
Tugs | McAllister | Moran	Brian	Edward	Miriam	Sisters	None	Brian	Edward	Miriam	Sisters
Bollard Pull	85	80	46	46		**85**	80	46	46
Live o·r Auto	Live	Auto	Auto	Auto		Live	Auto	Auto	Auto
TugInitial Position	CLA	**PB**	SB	Escort		CLA	PB	Escort	**SB**
All Fast Order	3	1	2			1	2	3	3
CPA in Kills	270' to ship at berth to starboard								
CPA to meeting ship	152'					O' @ buoy 2 Port Elizabeth			
Ending Location	KVKBuoy 10					Con Range			
Simulation Time	33 minutes					12.5 Minutes			

Run No. & Direction	17inbound				181nbound				191nbound			
Pilot Name(s)	Flannery (Docking)				Ellis (Docking)				Flannery (Docking)			
Starting Location	Buoy2				Bay Ridge Buoy 2				Upper Bay Buoy 28			
Initial Heading & Speed	346° @ 6.5 knots				346° @ 6.5 knots				000° @ 6.5 knots			
Database Used	NewYork F				NewYork F				NewYork_F			
Ship Model & Condition	49' Triple E				49' Triple.E				49' Triple E			
Current File Name, Tide	3135 (1.25) Flood, Tide +3'				Ebb 2357 (1.25)				Slack, Tide +3'			
Wind Dir. "From" Speed	S@ 20 Knots				N @20 Knots				NW@20 Knots			
Wave/Swell Dir. "From" Height (meters); Model	Height: 1.3' S Pierson-Moskowitz				Height: 1.3' N Pierson-Moskowitz				Height: 1.3' S Pierson-Moskowitz			
Visibility	Clear-Day				Clear- Day				Clear- Day			
Tugs McAllister Moran	Brian	Edward	Miriam	Sisters	Brian	Edward	Miriam	Sisters	Brian	Edward	Miriam	Sisters
Bollard Pull	**85**	**80**	46	46	**85**	**80**	46	46	85	**80**	46	46
Live or Auto	Live	Auto	Auto	Auto	Live	Auto	Auto	Auto	Live	Auto	Auto	Auto
TugInitial Position	CLA	PB	SB	Escort	CLA	**PB**	**SB**	Escort	CLA	SB	**PB**	Escort
All Fast Order	1	2	3		3	2	1		3	1	2	
CPA to Chan. toe line **during transit**	· 56' at KVK 7											
CPA Other	276' to ship at berth on starboard											
Ending Location	KVK Buoy 8				**KVK8**				Port Jersey Buoy 2			
Simulation Time	37 minutes				40 minutes				29 Minutes			

Run No. & Direction	20 Inbound				21 Outbound				22 Outbound			
Pilot Name(s)	Ellis(Docking)				Flannery (Docking)				Ellis (Docking)			
Starting Location	Buoy28				Port Jersey				Port Jersey			
Initial Heading & Speed	000° @ 6.5 knots				299° @ 0 knots				299°@ 0 knots			
Database Used	NewYork_F				NewYork F				New York F			
Ship Model & Condition	49'Tripie E				49' Triple E				49' Triple E			
Current File Name, Tide	Slack, Tide + 3'				Slack, Tide +3'				Slack, Tide + 3'			
Wind Dir. "From" Speed	N @20 Knots				N@ 20 Knots				S@ 20 Knots			
Wave/Swell Dir. "From" Height (meters); Model	Height: 1.3' N Pierson-Moskowitz				Height: 1.3' **N** Pierson-Moskowitz				Height: 1.3' S Pierson-Moskowitz			
Visibility	Clear-Day				Clear- Day				Clear- Day			
Tugs McAllister Moran	Brian	Edward	Miriam	Sisters	Brian	Edward	Miriam	Sisters	Brian	Edward	Miriam	Sisters
Bollard Pull	85	80	46	46	85	80	46	46	85	**80**	46	46
Live or Auto	Live	Auto	Auto	Auto	Live	Auto	Auto	Auto	Live	Auto	Auto	Auto
TugInitial Position	CLA	SB	PB	Escort	CLA	CLF	PB	PQ	CLA	CLF	SQ	PQ
All Fast Order .	2	1	2		2	1	3	4	3	1	2	4
CPA Other					191 to ship on port at dock				111' to Cruise Ship			
Ending Location	Port Jersey				KVK Buoy				Port Jersey Buoy 1			
Simulation lime	29.5 minutes				SOMinutes				50 minutes			

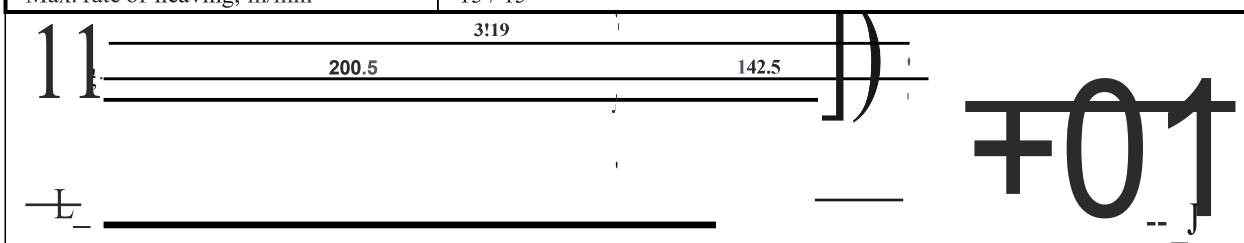
Run No. & Direction	231nbound		241nbound		251nbound			
Pilot Name(s)	Schoenlank		Oldmixon		Flannery (Docking)			
Starting Location	VZ Bridge Buoy 20		VZ Bridge Buoy 20		Newark Bay Buoy 10			
Initial Heading & Speed	349° @ 6.4 knots		349° @ 6.5 knots		027°@ 6.7 knots			
Database Used	NewYork_J		NewYork F		NewYork F			
Ship Model & Condltion	49' Triple E		49' Triple E		49'Triple E			
Current File Name, Tide	3135 (1.5) Flood: 3.8 knots at Bergen, Tide +3'		2359 (1.5) Ebb, Tide +3'		2352 (1.5) Flood: 1.8 @ Bergen, Tide +3'			
Wind Dir."From" Speed	5@20 Knots		N @20 Knots		5@20 Knots			
Wave/Swell Dir. "From" Height (meters); Model	Height: 1.3' S Pierson-Moskowitz		Height: 1.3' @ 000° Pierson-Moskowitz		Height: 1.3; S Pierson-Moskowitz			
Visibility	Clear-Day		Clear- Day		Clear- Day			
Tugs McAllister !Moran	Brian	Sisters	Brian	Sisters	Brian	Edward	Miriam	Sisters
Bollard Pull	85	46	85	46	85	80	46	46
Live or Auto	Live	Auto	Live	Auto	Live	Auto	Auto	Auto
Tug Initial Position	CLA	PB	CLA	PB	CLA	SB	Escort	PB
All Fast Order	2	1	1	2	3	2		3
CPA Other					46' to Ship on port side			
Ending Location	Craven Shoal Buoy 23		Craven Shoal Buoy 23		Port Elizabeth Berth 59			
Simulation Time	28 minutes		18 minutes		25 Minutes			

Run No. & Direction	26 Outbound				271nbound			
Pilot Name(s)	Ellis				Flannery			
Starting Location	Port Elizabeth Berth 61				Gowanus Buoy 28			
Initial Heading & Speed	306° @ 10 knots				000° @ 6.5 knots			
Database Used	NewYork F				New York F			
Ship Model & Condition	49' Triple E				49' Triple E			
Current File Name, Tide	2359 (1.5) Tide +3'				Slack, Tide + 3'			
Wind Dir. "From" Speed	N @20 Knots				N@ 20 Knots			
Wave/Swell Dir. "From" Height (meters); Model	Height: i.3 N Pierson-Moskowitz				Height: 1.3 @ 000° Pierson-Moskowitz			
Visibility	Clear-Day				Clear-Day			
Tugs !McAllister !Moran	Brian	Edward	Sisters	Miriam	Brian	Edward	Miriam	Sisters
Bollard Pull	85	80	46	46	85	80	46	46
Live or Auto	Live	Auto	Auto	Auto	Live	Auto	Auto	Auto
TugInitial Position	CLA	CLF	PQ	Escort SQ	CL.A	PB	PQ	SB
All Fast Order	2	1	3	4	4	1	3	2
CPA0ther	85' to ship at port during swing							
Ending Location	Port Newark				Port Jersey Global			
Simulation Time	27 minutes				25 minutes			

Container Triple E_3.0.55.2 * 42' draft

PILOT CARD			
Ship name	Container Triole E 42 3.0.55.2 *	Date	119.04.2016
IMO Number	NIA lean Sign	NIA	Year built IN/A
Load Condition	Loaded		
Displacement	206397 tons	Draft forward	12.8 m / 42 ft 1 in
Deadweight	171310 tons	Draft forward extreme	12.8 m / 42 ft 1 in
Capacity		Draft after	12.8 m / 42 ft 1 in
Air draft	62.54 m / 205 ft 8 in	aft after extreme	12.8 m / 42 ft 1 in

Ship's Particulars			
Length overall	399 m	!Typeofbow	IBulbous
Breadth	59 m	I Type c.if stern	ITransom
Anchor(s) (No./types)	2 (PortBow / StbdBow)		
No. of shackles	14 / 14		I(1 shackle =27.5 m / 15 fathoms)
Max. rate of heaving, m/min	15 / 15		



Steering characteristics			
Steering device(s) (tvoe/No.)	Semisusoended / 2	Number of bow thrusters	2
Maximum angle	35	Power	2500 kW/ 2500 kW
Rudder angle for neutral effect	0 degrees	Number of stern thrusters	NIA
Hard over to over(2 pumps)	12 seconds	Power	NIA
Flanking Rudder(s)	0	Auxiliary Steering Device(s)	NIA

Stopping			, Turning circle	
Description	Full Time	Head reach	Ordered Engine: 100% Ordered rudder: 35 degrees	
FAHtoFAS	1039 s	18.02 chis	Advance	5.63 cbls
HAHtoHAS	1322.8 s	17.9 chis	Transfer	2.06 chis
SAHto SAS	1761.7 s	17.83 cbls	Tactical diameter	5.34 chis

Main Engine(s)			
Tyoe of Main Engine	Low speed diesel	Number of propellers	2
Number of Main Engine(s	2	Propeller rotation	Right/Left
Maximum power per shaft	2x29680 kW	Prooeller type	FPP
Astern oower	85 %ahead	**Min.RPM**	9.99
Time limit astern	NIA	Emergencv FAH to FAS	37.2 seconds

Eu{ine Telegranh Table

Engine Order	Soeed, knots	Engine power kW	RPM	Pitch ratio
"FSAH"	23.4	56392	70.6	1.04
"FAH"	**16.9**	21258	**51**	1.04
III-IA.I-111	13.3	10256	40	1.04
"SAR"	10	4327	30	1.04
"DSAH"	6.7	1282	20	1.04
"DSAS"	-3.4	3043	-20	1.04
"SAS"	-5.1	10270	-30	1.04
"HAS"	-6.8	24343	-40	1.04
."FAS"	-8.6	50456	-51	1.04
"FSAS"	-8,6	50456	-51	1.04

MITB-PMI

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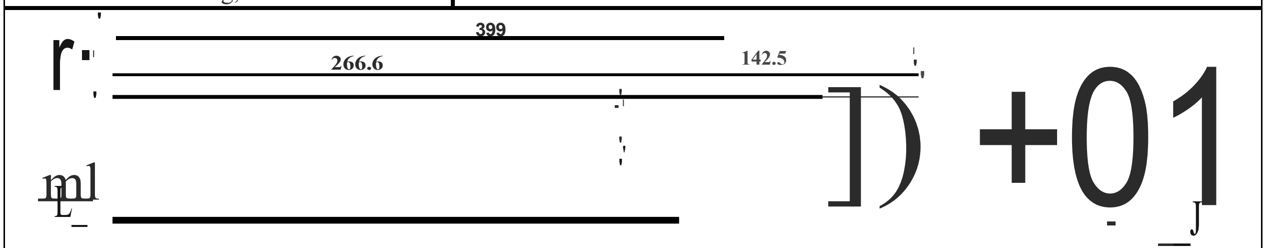
Container Triple E_ 3.0.52.1 * 49' Draft

PILOTCARD			
Ship name	Container Triple E 49 3.0.52.1 *	Date	I19.04.2016
IMO Number	NIA ICall Sign NIA	Year built	IN/A
Load Condition	Loaded		
Displacement	240904.9 tons	Draft forward	14.94m 149ft lin
Deadweight	194153.4 tons	Draft forward extreme	14.94III / 49 ft 1 in
Capacity		Draft after	14.94m / 49ft 1 in
Airdraft	60.4m / 198 ft 8 in	Draft after extreme	14.94m / 49ft 1 in

Ship's Particulars			
Length overall	399 III	I Type of bow	IBulbous
Breadth	59 III	Type of stern	I Transom
Anchor(s) (No./types)	2 (PortBow / StbdBow)		
No. of shackles	14 / 14	I (1 shackle =27.5 m / 15 fathoms)	
Max. rate of heaving, m/min	15 / 15		



Steering characteristics			
SteerinJ!: device(s) (type/No.)	Semisuspended / 2	Number of bow thrusters	2
Maximum anJ?:le	35	Power	2500 kW/ 2500 kW
Rudder anJ?:le for neutral effect	0 deJ?:rees	Number of stern thrusters	NIA
Hard over to over 2 pumps)	12 seconds	Power	NIA
Flanking Rudder(s)	0	Auxiliary Steering Device(s	NIA

StonninJ?:			Turning circle	
Description	Full Time	Head reach	Ordered Engine: 100%, Ordered rudder: 35 degrees	
FAR to FAS	1422.9 s	22.04 cbls	Advance	5.23 cbls
HAHtoHAS	1811.2 s	21.94 chis	Transfer	1.75 cbls
SAHto SAS	2414 s	21.87 chis	Tactical diameter	4.35 chis

Main Engine(s)			
Type of Main Engine	Low soeed diesel	Number of orooellers	2
Number of Main Engine(s)	2	Prooeller rotation	Ril!ht/Left
Maximum power per shaft	2x29680 kW	Prooeller tvne	FPP
Astern power	85 % ahead	Min. RPM	9.99
Time limit astern	NIA	Emere.encv FAH to FAS·	37.2 seconds

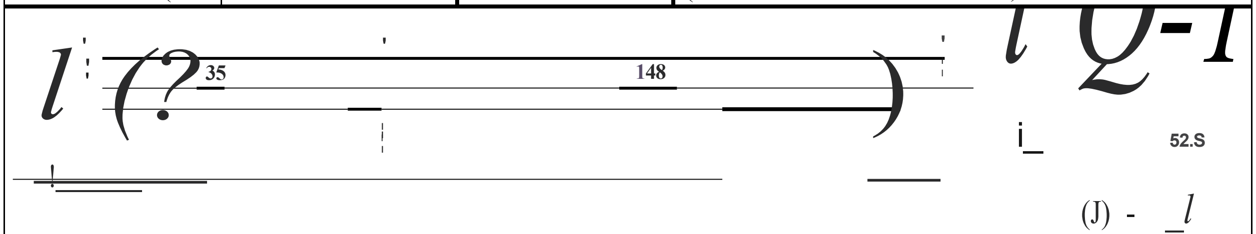
Enl!ine Tele11ranh Table

Engine Order	Sneed, knots	Engine oower, kW	RPM	Pitch ratio
"FSAH"	23	56392	70.6	1.04
"FAH"	16.6	21258	51	1.04
"HAH"	13	10256	40	1.04
"SAH"	9.8	4327	30	1.04
"DSAH"	6.5	1282	20	1.04
"DSAS"	-2.6	3043	-20	1.04
"SAS"	-3.8	10270	-30	1.04
"HAS"	-5.1	24343	-40	1.04
"FAS"	-6.5	50456	-51	1.04
"FSAS"	-6.5	50456	-51	1.04

Tanker OH (Disp 57575t)_CPP_FL_8 v03.17.VSY

PILOT CARD			
Ship name	Tanker OH Disp 57575t) CPP FL 8 v03.17.VSY		Date I01.09.16
IMONwnber	NIA ICall Sign	NIA	Year built IN/A
Load Condition	Full load		
Displacement	57575 tons	Draft forward	12.5 m / 41 ft 1 in
Deadweight	49500 tons	Draft forw11rd extreme	12.5 m / 41 ft 1 in
Capacity		Draft after	12.5 m / 41 ft 1 in
Air draft	40.34 m / 132 ft 8 in	Draft after extreme	12.5 m / 41 ft 1 in

Ship's Particulars			
Length overall	**183** m	T)'Pe of bow	lBulbous
Breadth	32.2 m	Type of stern	IV-shaped
Anchor Chain{Port)	14 shackles		
Anchor Chain(Starboard)	9 shackles		
Anchor Chain(Stern	4 shackles	(1 shackle =27.5 m / 15 fathoms)	



Steering characteristics			
Rudder(s) (type/No.)	Schilling rudder / 1	Number of bow thrusters	1
Maximum angle	35	Power	1550kW
Rudder angle for neutral effect	1 degrees	Number of stern thrusters	NIA
Hard over to over 2 pumps)	26 seconds	Power	NIA
Flanking Rudder(s)		Auxiliary Steering Device(s)	

Stoooing			Turning circle	
Description	Full Time	Head reach	Ordered Engine: 100%, Ordered rudder: 35 degrees	
FAHtoFAS	390.5 s	7.89 chis	Advance	25 chis
HAHtoHAS	305 s	3.66 chis	Transfer	35 chis
SAHto SAS	358.5 s	2.9 chis	Tactical diameter	81 chis

Main Engine(s)			
ttvpe of Main Engine	!Medium speed diesel	Number ofprooellers	1
umber of Main Engine(s)	1	lProoeller rotation	IRiuht
Maximum power per shaft	1 x 8647 kW	IProoeller tvoe	CPP
!Astern power	50 % ahead	!Min.RPM	87.2
tnme limit astern	IN/A	!Emergency F AH to FAS	135 seconds

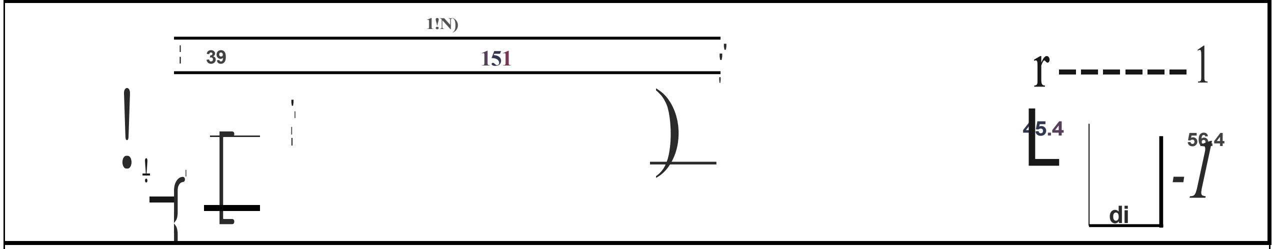
En1!ine Telei>ranh Table

Engine order	Speed, knots	Ene:ine oower, kW	RPM	Pitch ratio
100 %	12	6200.3	120.01	1.15
80 %	12	6200.3	120.01	1.15
60 %	8.9	3200.1	120.01	0.81
40 %	6.3	1469.9	120	0.54
20 %	3.7	1199.9	120	0.34
-20 %	-2.3	1180	120.01	**-0.18**
-40 %	-3	1330	120.01	-0.28
-60 %	-4.1	2400.1	120.02	-0.42
-80 %	-4.7	4496.2	120.01	-0.56

Tanker Memphis 3.0.26.0 *

PILOT CARD			
Ship name	Tanker Memphis 3.0.26.0 *	Date	I01.09.2016
IMO Number	NIA I Call Si!!:n	NIA	Year built 12007
Load Condition	Pmtial Loaded 2		
Displacement	42000 tons	Draft forward	10 m / 32 ft 10 in
Deadweight	32300 tons	Draft forward extreme	10 m / 32 ft 10 in
Capacity		Draft after	10 m / 32 ft 10 in
Air draft	45.4 m / 149 ft 4 in	Draft after extreme	10 m / 32 ft 10 in

Ship's Particulars		
Length overall	190 m I Type of bow	!Bulbous
Breadth	32.3 m I Type of stern	IV-shaped
Anchor(s) (No./types)	2 PortBow / StbdBow)	
No. of shackles	14 / 14	I(1 shackle =25 m / 13.7 fathoms)
Max. rate of heaving, m/min	18 /18	



Steering characteristics			
Steerinl!: device(s) type/No.)	SernisusJJended / 1	Number of bow thrusters	NIA
Maximum angle	35	Power	NIA
Rudder angle for neutral effect	0.22 degrees	Number of stern thrusters	NIA
Hard over to over 2 pumps)	20 seconds	Power	NIA
Flanking Rudder(s)	0	Auxiliary Steerin!!: Device(s)	NIA

Stooning			Turning circle	
Description	Full Time	Head reach	Ordered Engine: 100%, Ordered rudder: 35 de!!:rees	
FAHtoFAS	577.6 s	7.67 chis	Advance	3.54 cbls
HAHtoHAS	733.6 s	7.25 cbls	Transfer	1.67 chis
SAHto SAS	1079.7 s	6.74 cbls	Tactical diameter	33 chis

Main Engine(s)			
Type of Main Engine	Low sneed diesel	Number oforooellers	1
Number ofMain Engine(s	1	Prooeller rotation	Rivht
Maximum power per shaft	1 x9800 kW	Prooeller tvoe	FPP
Astern power	77.6 %ahead	Min.RPM	10
Time limit astern	NIA	Emernencv FAH to FAS	35.2 seconds

· En ine Tele 1·anh Table

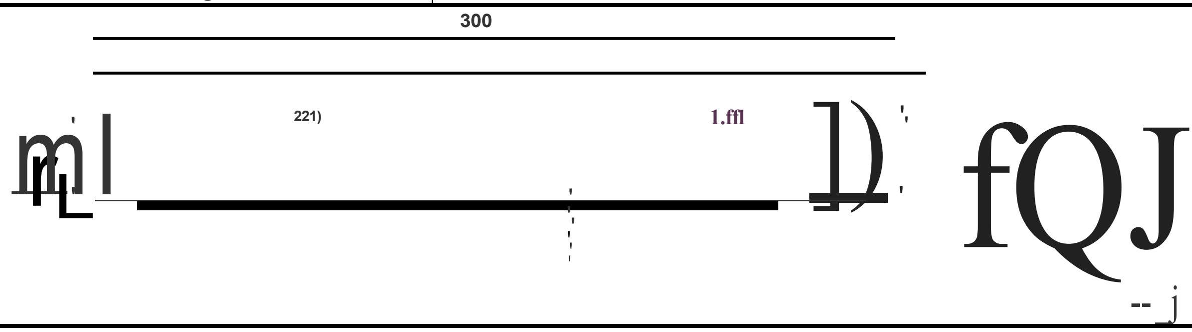
Engine Order	Sneed, knots	Engine nower. kW	RPM	Pitch ratio
"100%"	14.5	8330	90	0.74
"80%"	11.3	3919	70	0.74
"60%"	8.8	1901	55	0.74
"40%"	5.6	490	35	0.74
"20%"	3.2	91	20	0.74
"-20%"	-1.4	102	-19	0.74
"-40%"	-2.5	534	-33	0.74
"-60%"	-3.8	1857	-50	0.74
"-80%"	-4.9	4079	-65	0.74
"-100%"	-6	7605	-80	0.74

MITAGS·PMIC#

Container Kalina_NewYork 3.0.45.1 * 42' **Draft**

PILOT CARD			
Ship name	Container Kalina NewYork 3.0.46.1 *	Date	126.05.2016
IMO Number	NIA · Call Sign · NIA	Year built	11995
Load Condition	Partial Loaded 2		
Displacement	172769.22 tons	Draft forward	12.8 m / 42 ft 1 in
Deadweight	135460 tons	Draft forward extreme	12.8 m / 42 ft 1 in
Capacity		Draft after	12.8 m / 42 ft 1 in
Air draft	52.2 m / 171 ft 8 in	Draft after extreme	12.8 m / 42 ft 1 in

Ship's Particulars			
Length overall	366 m	Type of bow	Bulbous
Breadth	51.2 m	Type of stem	Transom
Anchor(s) (No./types)	2 (P01tBow / StbdBow)		
No. of shackles	14/14	(1 shackle =27.5 m / 15 fathoms)	
Max. rate of heaving, m/min	15 / 15		



Steering characteristics			
Steering device(s) (type/No.)	Semisuspended / 1	Number of bow thrusters	2
Maximum angle	35	Power	1700 kW / 1700 kW
Rudder angle for neutral effect	0.2 degrees	Number of stern thrusters	NIA
Hard over to over(2 pumps		Power	NIA

Flanking Rudder(s)	0	Auxiliary Steering Device(s)	*NIA*

Stopping	Turning circle

HAR to HAS	514.6 s	8.96 cbls	Transfer	2.08 cbls

Main Engine(s)			
Type ofMain Engine	Low speed diesel	Number ofpropellers	1

Number of Main Engine(s		1	Prooeller rotation	Rie:ht

Engine Order	Speed, knots	Ene:ine oower, kW	RPM	Pitch ratio
"FSAH"	25.1-	66723	100.7	1.03
"FAH"	17.6	23280	70.4	1.03

"DSAH"	7.9	1538	28.3	1.03
"DSAS"	-3_.1	1856	-28	1.03
"SAS"	-5	7591	-45.1	1.03
"HAS"	-6.2	13810	-55.1	.1.03
"FAS"	-7.3	22736	-65.1	1.03
"FSAS"	-9.9	60189	-90.2	1.03

Container Kalina_NewYork 3.0.46.1 * 49' Draft

PILOT CARD			
Ship name	Container Kalina NewYork 3.0.46.1 *	Date	26.05.2016
IMO Number	NIA lean Sign NIA	Year built	1995
Load Condition	Loaded		
Displacement	198160 tons	Draft forward	14.9 m / 49 ft O in
Deadweig;ht	135460 tons	Draft forward extreme	14.9m / 49 ft O in
Capacity		Draft after	14.9 m / 49 ft O in
Air draft	50.1 m / 164 ft 9 in	Draft after extreme	14.9 m / 49 ft O in

Ship's Particulars			
Length overall	366 m	Type of bow	Bulbous
Breadth	51.2 m	Type of stern	Transom
Anchor(s) (No./types)	2 (PortBow / StbdBow)		
No. of shackles	14 /14	(1 shackle =27.5 m / 15 fathoms)	
Max. rate of heaving, m/min	15 / 15		

Steering characteristics			
Steering device(s) (type/No.)	Semisuspended / 1	Number of bow thrusters	2
Maximum angle	35	Power	1700 kW / 1700 kW
Rudder angle for neutral effect	0.2 degrees	Number of stern thrusters	NIA
Hard over to over(2 pumps)	21 seconds	Power	NIA
Flanking Rudder(s)	0	Auxiliary Steering Device(s)	NIA

Stopping			Turning circle	
Description	Full Time	Head reach	Ordered Engine: 100%, Ordered rudder: 35 degrees	
FAHtoFAS	475.6 s	9.97 cbls	Advance	5.6 cbls
HAHtoHAS	555.6 s	9.39 cbls	Transfer	2.07 cbls
SAHto SAS	668.6 s	9.44 cbls	Tactical diameter	5.11 cbls

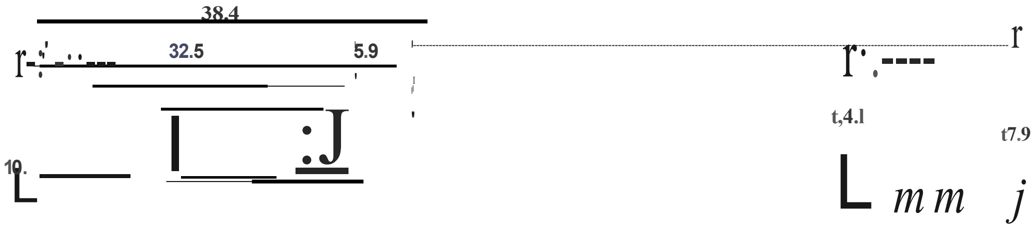
Main Engine(s)			
Type of Main Engine	Low speed diesel	Number of propellers	1
Number of Main Engine(s)	I	Propeller rotation	Rfaht
Maxımum power per shaft	Ix 73340 kW	Proneller tvne	FPP
Astern power	82 %ahead	Min.RPM	21
Time limit astern	NIA	Emergencv FAH to FAS	26.2 seconds

En!!inc Tele!!ranh Table				
Engine Order	Speed, knots	Engine power, kW	RPM	Pitch ratio
"FSAH"	23.7	67444	99.9	1.03
"FAH"	16.8	23214	70	1.03
IIHAHII	13.6	11310	55.1	1.03
"SAR"	11.4	6236	45.2	1.03
"DSAH"	7.6	1536	28.2	1.03
"DSAS"	-3	1855	-28	1.03
"SAS"	-4.8	7585	-45	1.03
"HAS"	-5.8	13797	-55	1.03
"FAS"	-6.9	22712	. -65	1.03
"FSAS"	-9.3	60143	-90	1.03

Conventional Twin Screw Tug 4 (bp 46.3t) TRANSAS 2.31.17.0 *

PILOT CARD			
Ship name	Conventional twin screw tuir 4 bp 46.3t) TRANSAS 2.31.17.0 *	Date	06.06.2013
IMO Number	NIA Call Sfo.n	NIA	Year built NIA
Load Condition	Full load		
Displacement	686 tons	Draft forward	3.8 m / 12 ft 6 in
Deadweight	NIA tons	Draft forward extreme	3.8 m / 12 ft 6 in
Capacity		Draft after	3.8 m / 12 ft 6 in
Air draft	14.11 m / 46 ft 4 in	Draft after extreme	3.8 m / 12 ft 6 in

Ship's Particulars			
Length overall	38.43 m	Type of bow	-
Breadth	10.37 m	Type of stern	Transom
Anchor(s) (No./tyoes)	I (StbdBow)		
No. of shackles	9		(1 shackle =27.4 m / 15 fathoms)
Max. rate of heaving, m/min	30		



Steering characteristics			
Steering device(s) (type/No.)	Suspended / 2	Number-of bow thrusters	NIA
Maximum angle	35	Power	NIA
Rudder angle for neutral effect	0 degrees	Number of stern thrusters	NIA
Hard over to over(2 pumps)	7 seconds	Power	NIA
Flanking Rudder(s	0	Auxiliary Steering Device s)	NIA

Stoooing			Turning circle	
Description	Full Time	Head reach	Ordered Engine: 100%, Ordered rudder: 35 degrees	
FAHtoFAS	28.25 s	0.5_1 chis	Advance	51 cbls
HAHtoHAS	25.25 s	0.39 cbls	Transfer	18 cbls
SAHto SAS	24.25 s	0.27 cbls	Tactical diameter	46 chis

Main Engine(s)			
Type of Main Engine	High speed diesel	Number of propellers	2
Number of Main Engine(s)	2	Propeller rotation	Inward
Maximum power per shaft	2x 1840 kW	Propeller type	FPP
Astern power	80 %ahead	Min.RPM	5.83
Time limit astern	NIA	Emergency F AH to FAS	5.15 seconds

Eneine Telceranh Table

Emdneorder	Sneed, knots	Engine power, kW	RPM	Pitch ratio
"FSAH"	13.2	3652	252	0.64
"FAH"	11.8	2389	219.1	0.64
U_HAHII	10.3	1455	185.9	0.64
"SAH"	8.6	792	151.4	0.64
"DSAH"	6.8	397	119.3	0.64
"DSAS"	-3.6	739	-110.8	0.64
"SAS"	-4.2	1083	-126	0.64
"HAS"	-4.8	1595	-143.9	0.64
"FAS"	-5.4	2207	-160.6	0.64
"FSAS"	-5.9	2920	-176.3	0.64

Tug Brian McAllister (85t bp) 3.0.57.1 *

PILOT CARD			
Ship name	Tug Brian McAllister (85tbp) 3.0.57.1 *	Date	122.06.2016
IMO Number	NIA I Call Sign	NIA	Year built IN/A
Load Condition	Full Load		
Displacement	763 tons	Draft forward	5.6 m / 18 ft 5 in
Deadweight	343.35 tons	Draft forward extreme	5.6 m / 18 ft 5 in
Capacity		Draft after	5.6 m / 18 ft 5 in
Air draft	13.6m / 44 ft 8 in	Draft after extreme	5.6 m / 18 ft 5 in

Ship's Particulars	
Length overall	30.5 m !Type ofbow I-
Breadth	12.2 m I Type of stern ID-shaped
Anchor(s) (No./types)	2 (PortBow / StbdBow)
No. of shackles	11 / 11 I(1 shackle =25 m / 13.7 fathoms)
Max. rate of heaving, m/min	10.2/ 10.2

Steering characteristics			
Steering device(s type/No.)	Z-Drive/2	Number of bow thrusters	NIA
Maximum angle	180	Power	NIA
Rudder angle for neutral effect	0 degrees	Number of stern thrusters	NIA
Hard over to over 2 pumps)	2 seconds	Power	NIA
Flanking Rudder(s	0	Auxiliar:,, Steering Device s)	NIA

Stoooing			Turning circle	
Description	Full Time	Head reach	Ordered Engine: 100%, Ordered rudder: 35 degrees	
FAR to FAS	10.7 s	0.16 cbls	Advance	0.21 chis
HAHtoHAS	11.8 s	0.15 cbls	Transfer	0.06 cbls
SAHto SAS	12.9 s	0.13 cbls	Tactical diameter	0.16 chis

Main Engine(s)			
Type of Main Engine	High speed diesel	Number of propellers	2
Nmnber of Main Engine(s	2	Propeller rotation	Right/Left
Maximum power per shaft	2x2524 kW	Propeller type	AzimuthFPP
Astern power	0 % ahead	Min.RPM	84.86
Time limit astern	NIA	Emergency FAHto FAS	11.9 seconds

Engine Telegraph Table

Engine Order	Speed knots	Engine power, kW	RPM	Pitch ratio
"100%"	11.9	4226	235	1
"90%"	9.8	2446	195.8	1
"80%"	9.1	1988	182.8	1
"70%"	8.4	1592	169.7	1
"60%"	7.8	1252	156.7	1
"50%"	7.2	965	143.6	1
"40%"	6.5	725	130.6	1
"30%"	5.8	528	117.5	1
"20%"	4.6	249	91.4	1
"10%"	4.2	199	84.9	1

Tug Edward Moran 3.0.63.0 *

PILOTCARD			
Ship name	Tug Edward Moran 3.0.63.0 *	Date	I21.06.2016
IMO Number	NIA I Call Sign NIA	Year built	lNIA
Load Condition	Full Load		
Displacement	442.69 tons	Draft forward	4.88m / 16ft 0in
Deadweight	105 tons	Draft forward extreme	4.88 m / 16 ft O in
Capacity		Draft after	4.88 m / 16 ft O in
Air draft	12.52 m / 41 ft 2 in	Draft after extreme	4.88 m / 16 ft O in

Ship's Particulars			
Length overall	30 m	Type of bow	I-
Breadth	11.3 m	I Tyoe of stern	ID-shaped
Anchor(s) (No./types)	2 (PortBow / StbdBow)		
No. of shackles	11/ 11		I(l shackle =25 rn / 13.7 fathoms)
Max. rate of heaving, rn/min	10.2 / 10.2		

Steering characteristics			
Steering device(s) type/No.)	Z-Drive / 2	Number of bow thrusters	NIA
Maximum angle	180	Power	NIA
Rudder angle for neutral effect	-1.67 degrees	Number of stern thrusters	NIA
Hard over to over 2 pumps)	6 seconds	Power	NIA
Flanking Rudder(s	0	Auxiliarv Steering Device(s)	NIA

Stoooing			Turning circle	
Description	Full Time	Head reach	Ordered Engine: 100%, Ordered rudder: 35 degrees	
FAHtoFAS	10.7 s	0.2 chis	Advance	0.22 cbls
HAHtoHAS	10.7 s	0.18 cbls	Transfer	0.11 cbls
SAHto SAS	10.7 s	0.17 cbls	Tactical diameter	0.2·cbls

Main Engine(s)			
Type of Main Engine	High speed-diesel	Number of orooellers	2
Number of Main Engine(s	2	Prooeller rotation	Left/Right
Maximum power oer shaft	2x2424.5 kW	Prooeller tvoe	AzimuthFPP
Astern oower	0 % ahead	Min.RPM	84.86
Time limit astern	NIA	Emergency FAH to FAS	15.6 seconds

Em?ine Tcle2raoh Table

Engine Order	Sneed, knots	Engine cower kW	RPM	Pitch ratio
"100%"	12.5	4607	235	1
"90%"	12.5	3548	215.4	1
"80%"	11.7	2774	198.5	1
"70%"	10.8	2167	182.8	1
"60%"	10.1	1735	169.7	I
"50%"	9.7	1365	156.7	1
"40%"	9.2	1201	150.1	1
"30%"	8.I	790	130.6	I
"20%"	6.7	404	104,5	I
"10%"	5.6	217	84.9	I

Table 5: Swept Path: Kalina (meters)

Bearing	length	Width	Total Swept Width	Percentage of Beam
1	366	51.2	57.58	112.46%
2	366	51.2	63.94	124.89%
3	366	51.2	70.28	137.27%
4	366	51.2	76.61	149.62%
5	366	51.2	82.90	161.92%
6	366	51.2	89.18	174.17%
7	366	51.2	95.42	186.37%
8	366	51.2	101.64	198.51%
9	366	51.2	107.82	210.60%
10	366	51.2	113.98	222.61%
11	366	51.2	120.10	234.56%
12	366	51.2	126.18	246.44%

Table 6: Swept Path: Container Triple E (meters)

Bearing	Length	Width	Total Swept Width	Percentage of Beam
1	399	59	65.95	111.79%
2	399	59	72.89	123.54%
3	399	59	79.80	135.26%
4	399	59	86.69	146.93%
5	399	59	93.55	158.56%
6	399	59	100.38	170.14%
7	399	59	107.19	181.67%
8	399	59	113.96	193.15%
9	399	59	120.69	204.56%
10	399	59	127.39	215.91%
11	399	59	134.05	227.20%
12	399	59	140.67	238.42%

MEMORANDUM FOR: Glen Paine, Maritime Institute of Technology & Graduate Studies

SUBJECT: Navigation Channel Deepening in New York/New Jersey Harbor

The purpose of this memorandum is to provide a smmnary of the development of the numerical model currents developed for use by MITAGS in navigation analysis of various channels in the New York/New Jersey Harbor.

The numerical model used for the development of these currents was the current Adaptive Hydraulics (ADH) model being applied to the ongoing *Shoaling Associated with Navigation Channel Deepening in New York/New Jersey Harbor Study.* The current model for the NY/NJ area was developed by hydraulic engineers at the U.S. Army Engineers Engineering Research and Development Center (ERDC) in Vicksburg, Mississippi.

The model was developed for project deepened conditions with a 50-ft depth for the navigation channels.

The numerical model simulation from which the data were extracted was the depth-averaged version of the study model. Therefore, the reported data are depth-averaged current velocities.

The numerical model resolution with bathymetric contours is show in Figure 1 for the harbor area. Also shown in Figure 1 are the zones within which hydrodynamic data were extracted.

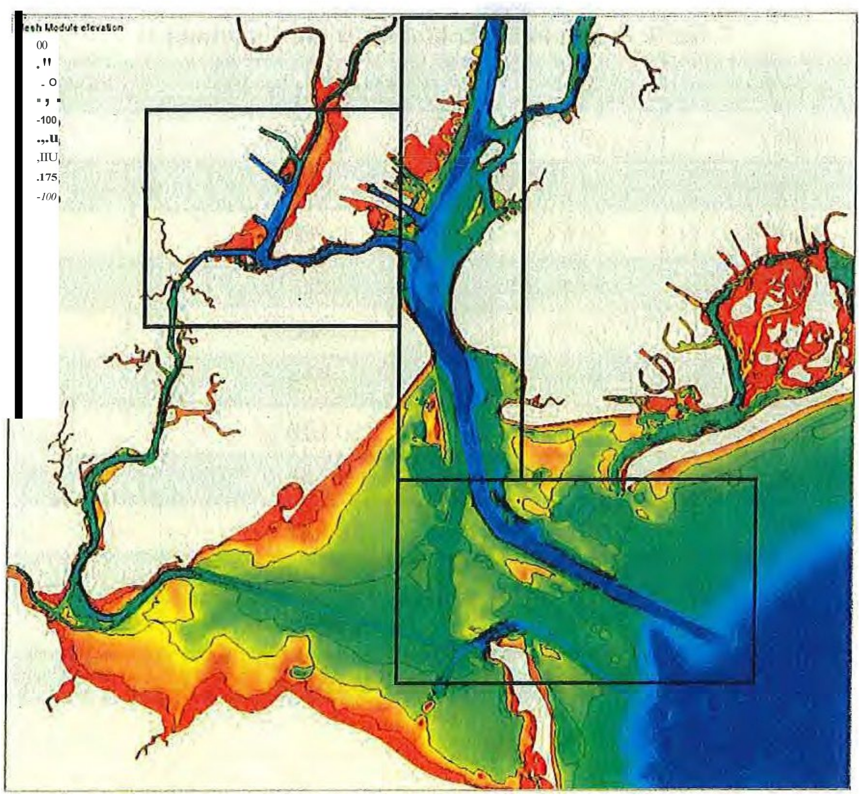


Figure 1. Numerical model bathymetric resolution and the extract windows for hydrodynamic data.

Details of tidal conditions and Hudson River discharge between hours 2000 (8AM 24 March) and 3500 (8PM 25 May) are presented in Figures 2 & 3. Two periods when data were extracte<fare highlighted in the figure. The two periods for extraction were 2352-2376 (8 April) and 3120-3144 (10 May). These two periods were selected because the first had full spring tides with a relatively low flow on the Hudson River of around 200 ems (7000 cfs). The second period was just following a spring tide with higher flows on the Hudson River, having just peaked on the previous day at 1453 ems (51300 cfs).

Current velocity patterns for the two periods are shown in Figures 4 through 9 for areas around the navigation cham1els.

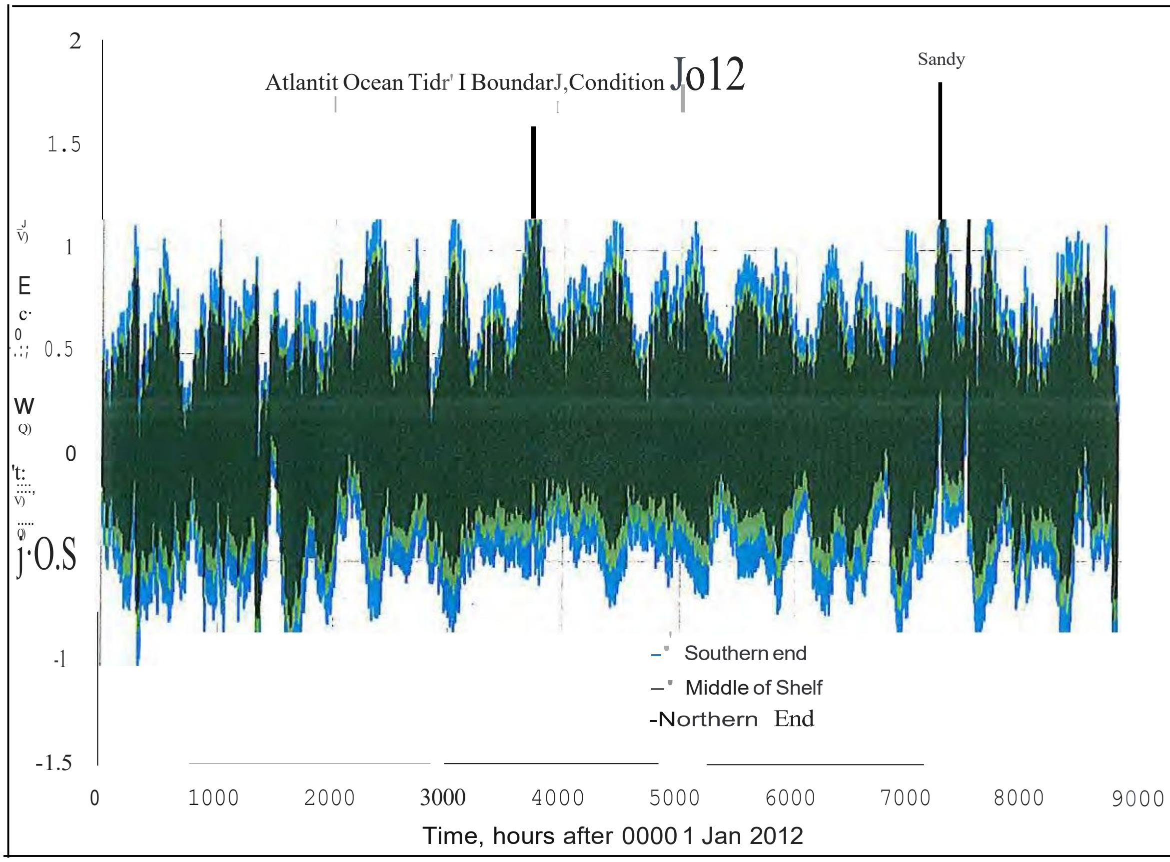


Figure 2. Tidal boundary conditions for the 2012 simulation.

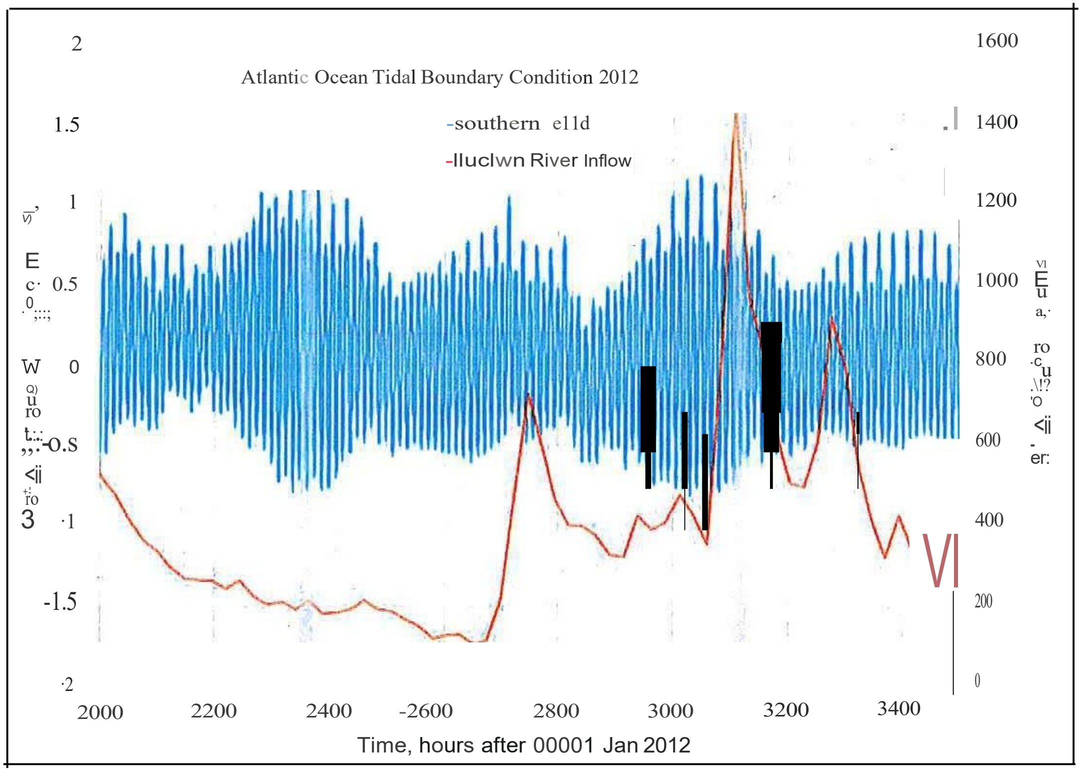


Figure 3. Details of tidal conditions and Hudsori River discharge. The two periods when data were extracted are highlighted in the figure.

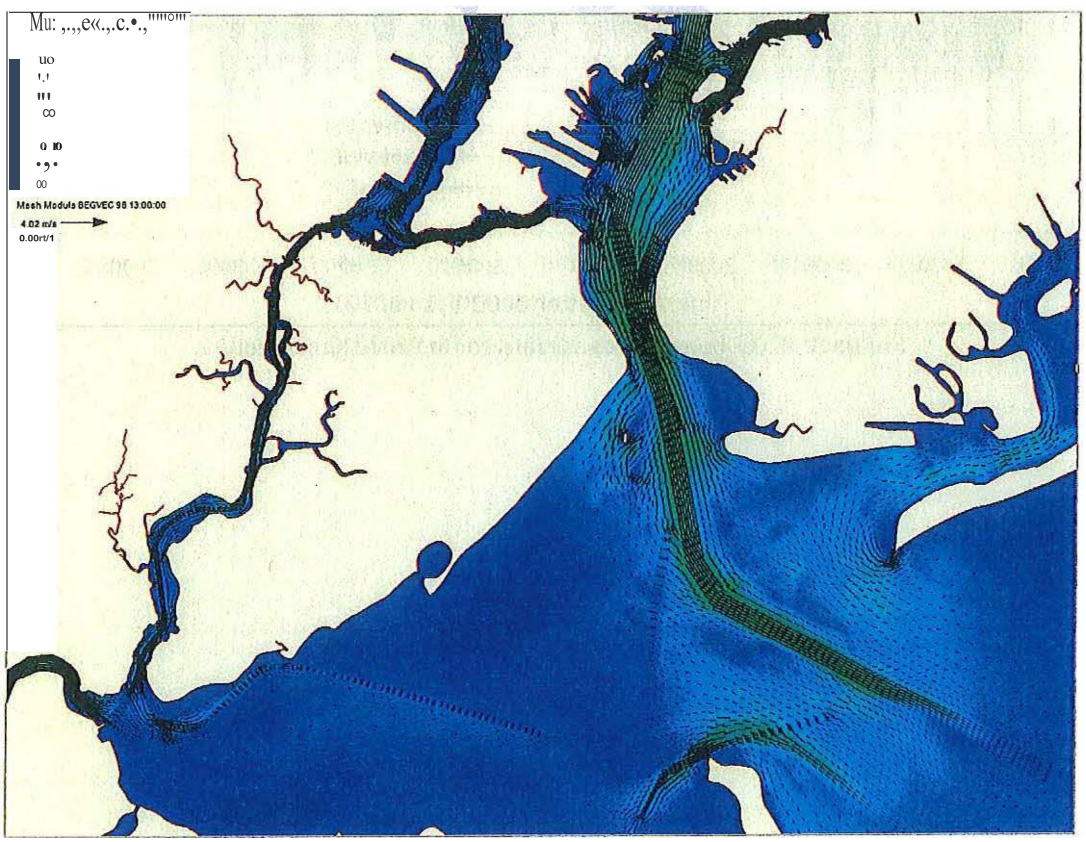


Figure 4. Flood currents over the navigation channel for time period 1, with low river flows

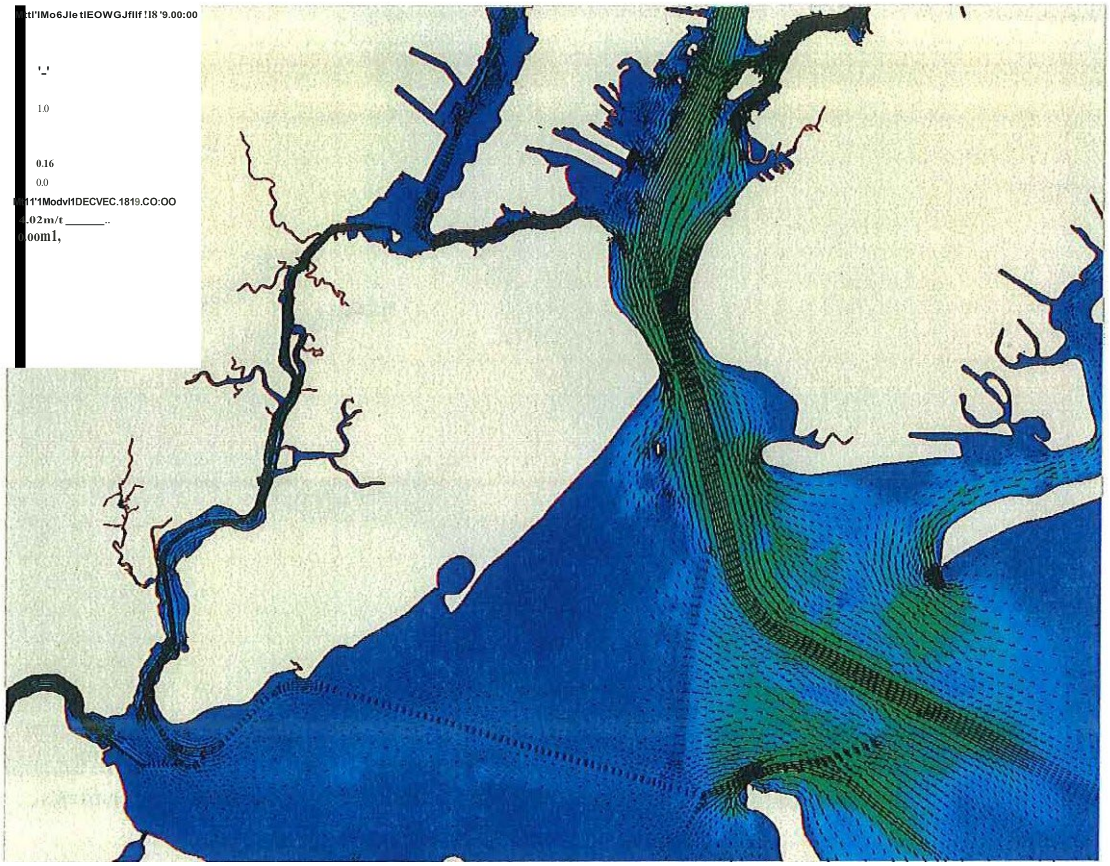


Figure 5. Ebb currents over the navigation channel for time period **1,** with low river flows

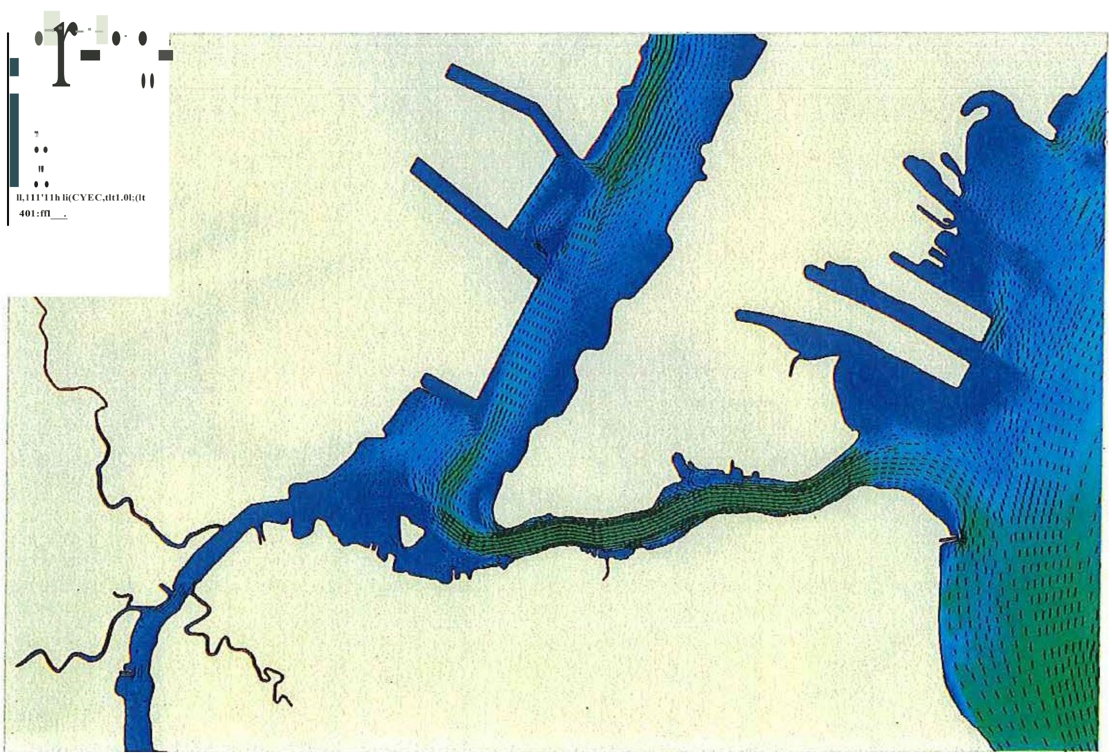


Figure 6. Flood currents in the inner navigation channel for time period **1,** with low river flows

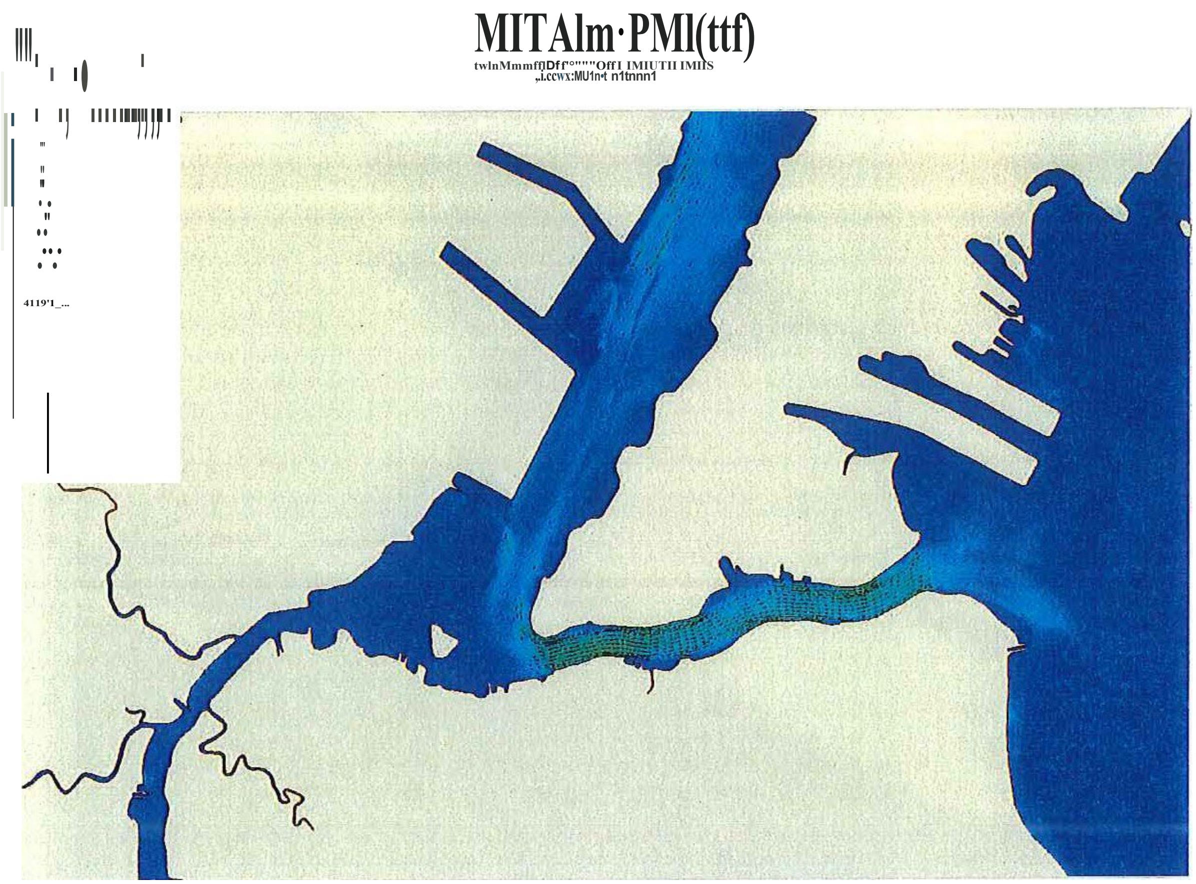


Figure 7. Ebb currents over the inner navigation channels for time period 1, with low river flows

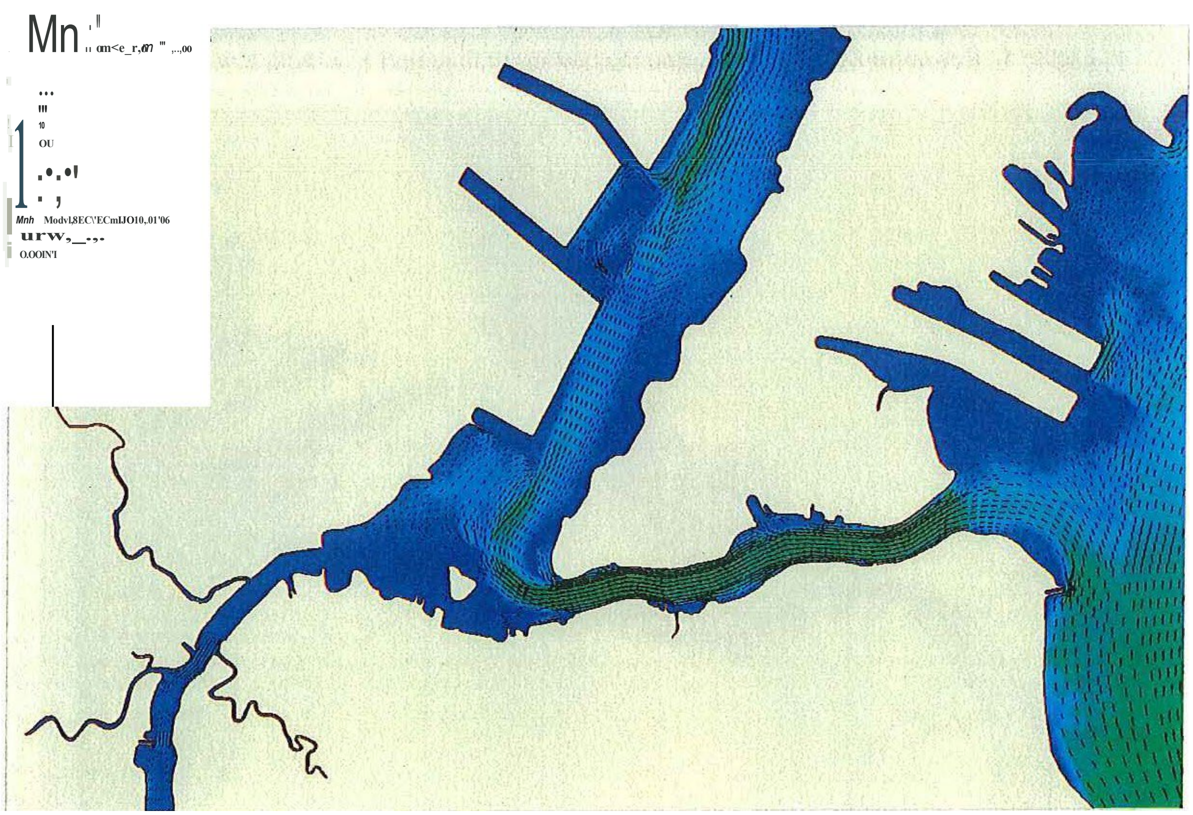


Figure 8. Flood currents over the inner navigation channel for time period 2, with high river flows

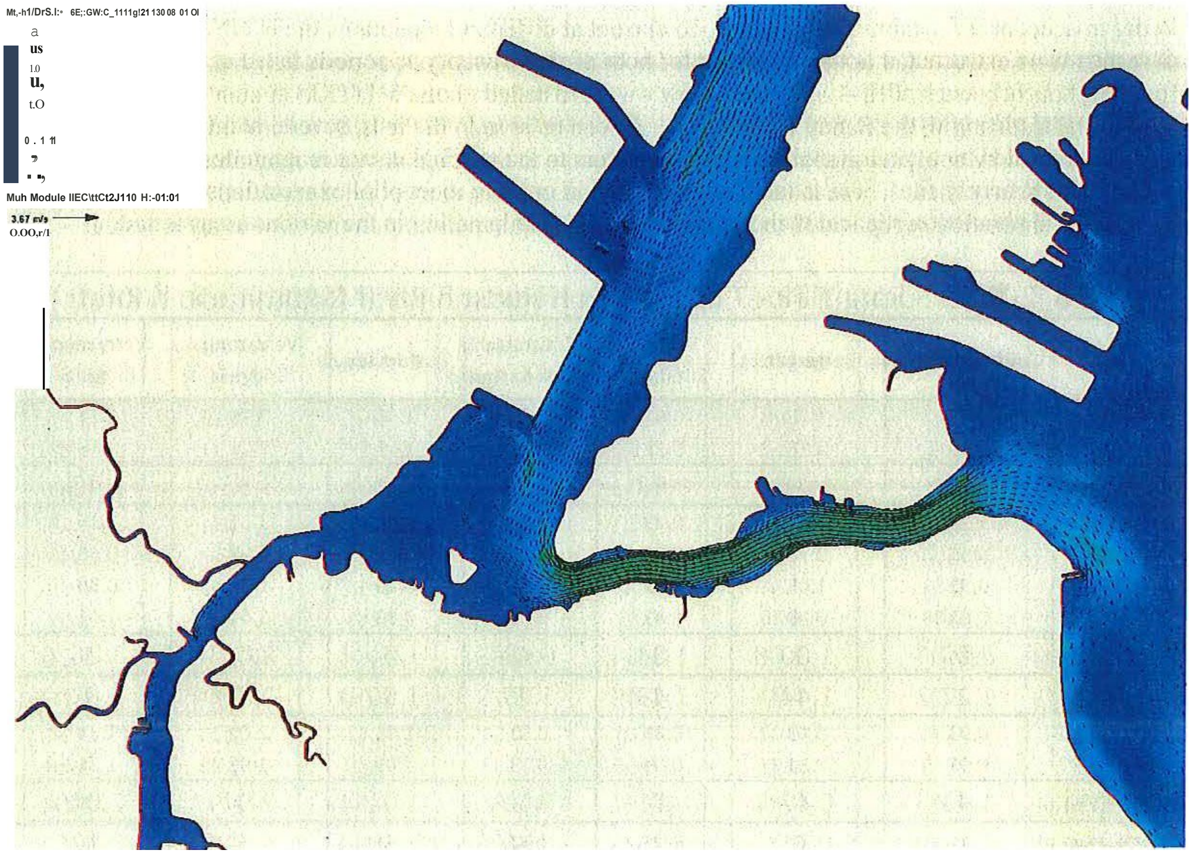


Figure 9. Ebb currents over the inner navigation channel for time period 2, with high river flows

In order to account for maximum ebb and flood current at different location_s in the NY/NJarea, model data results were extracted at hourly intervals f01' both of the twenty-four periods listed earlier. These forty-eight hourly current files - tabulated below - were installed on the MITAGS simulator for use during initial testing wlth the Sandy Hook pilots. As can be seen in the lists, several additional cunent files were created by applying global multiplying factors to the original vector magnitudes contained in the individual hourly files. These latter files were used in order to meet pilot expectations in regard to how well the simulation replicated their experiences with ship handling in the various areas tested.

April 8, 2012 - Spring Tide - 7,062 cfs on Hudson River (Magnitude in Knots)

File	Goethals Bridge	Bergen Pt.	Port Elizabeth	Constable Hook Range	Port Jersey	Verrazano Bridge N	Verrazano Bridge 5
NY-2352	0.97	1.78	0.62	0.95	1.03	2.19	1.77
NY-2353	1.40	1.18	0.52	0.62	1.14	2.21	1.63
NY-2353(1.5)	2.10	1.77	0.83	0.93	1.71	3.32	2.45
NY-2354	1.24	0.31	0.29	0.10	0.95	1.51	1.16
NY-2355	0.58	0.70	0.14	0,62	0.45	0,27	0.45
NY-2356	0.31	1.05	0.72	0.76	0.19	1.01	0.39
NY-2357	0,68	0,80	0,83	0.78	0.83	1,61	1.01
NY-2357(1.25)	0.85	1.00	1.04	0.98	1.04	2.01	1.26
NY-2357(1.8)	1.22	1.44	1.49	1.75	1.50	2.90	1.82
NY-2358	0,93	0.43	0,66	0.52	1.01	2.00	1.34
NY-2359	0.95	0.31	0.54	0.33	1.09	1.98	1.36
NY-2359(1.5)	1.43	0.47	0.81	0.50	1.64	2.97	2.04
NY-2359(2.3)	2.19	0.71	1.25	0.76	2.50	4.55	3.12
NY-2360	0.91	0.23	0,50	0.31	0.97	1.69	1.16
NY-2361	0.87	0.10	0.35	0.12	0.74	1.09	0.78
NY-2362	0.74	0.78	0.04	0.49	0.37	0.12	0.14
NY-2363	0.31	1.86	0.33	0.91	0.23	1.34	0.99
NY-2364	0.35	2.15	0.60	1.05	0,80	1.94	1.55
NY-2365	1.18	1.73	0,60	0.83	1.01	2.08	1,63
NY-2366	1.26	0.43	0.25	0.08	0.91	1.53	1.28
NY-2367	0.52	0.43	0.17	0.49	0.58	0,70	0.70
NY-2368	0.23	0.80	0,52	0.58	0.17	0.19	0.17
NY-2369	0.43	0.50	0,54	0.47	0.43	1.16	0.47
NY-2370	0.72	0.43	0.50	0,54	0.89	1;73	1.18
NY-2371	0.91	0.45	0.56	0.52	1.03	2.02	1.38
NY-2372	0,99	0.41	0.60	0,41	0.99	1.77	1.24
NY-2373	1.01	0.19	0.37	0.10	0.70	0.91	0.64
NY-2374	0,64	1.28	0.12	0.70	0.33	0.19	0.14
NY-2375	0.04	1.63	0.39	0.74	0.16	1.09	0.81

Flood Tide
Ebb Tide

May 10, 2012 - After Spring Tide - 51,300 cfs on Hudson River (Magnitude in Knots)

File	Goethals Bridge	Bergen Pt.	Port Elizabeth	Constable Hook Range	Port Jersey	Verrazano Bridge N	Verrazano Bridge S
NY-3120	0.31	1.28	0.29	0.60	0.08	0.50	0.29
NY-3121	0.16	1.44	0.39	0.70	0.39	1.26	0.91
NY-3122	0.54	1.57	0.50	0.85	0.81	1.73	1.40
NY-3123	1.03	1.36	0.49	0.76	1.01	1.98	1.59
NY-3124	1.18	0.60	0.31	0.23	0.97	1.67	1.26
NY-3125	0.78	0.54	0.04	0.43	0.58	0.62	0.60
NY-3126	0.12	1.03	0.58	0.70	0.00	0.70	0.21
NY-3126(1.25)	0.15	1.29	0.73	0.88	0.00	0.88	0.26
NY-3127	0.60	0.76	0.80	0.70	0.64	1.46	0.85
NY-3128	0.87	0.35	0.62	0.52	0.91	1.77	1.14
NY-3129	0.95	0.10	0.47	0.27	0.99	1.78	1.20
NY-3130	0.89	0.04	0.37	0.19	0.93	1.59	1.09
NY-3131	0.85	0.12	0.25	0.06	0.74	1.16	0.83
NY-3132	0.68	0.37	0.08	0.19	0.50	0.64	0.49
NY-3133	0.47	0.76	0.10	0.45	0.14	0.23	0.16
NY-3134	0.12	1.67	0.37	0.85	0.43	1.46	1.09
NY-3135	0.49	2.04	0.62	1.05	0.89	2.00	1.61
NY-3135(1.25)	0.61	2.55	0.78	1.31	1.11	2.50	2.01
NY-3135(1.5)	0.74	3.80	0.93	1.60	1.34	3.00	2.42
NY-3136	1.38	1.32	0.54	0.66	0.97	1.80	1.47
NY-3137	1.13	0.37	0.04	0.45	0.62	0.70	0.76
NY-3138	0.31	1.09	0.70	0.58	0.12	0.35	0.21
NY-3139	0.74	0.50	0.74	0.41	0.29	0.95	0.14
NY-3140	0.72	0.16	0.37	0.21	0.64	1.09	0.66
NY-3141	0.72	0.06	0.31	0.25	0.87	1.63	1.13
NY-3142	0.91	0.16	0.43	0.37	0.95	1.75	1.16
NY-3143	1.01	0.19	0.49	0.25	0.76	1.28	0.89

	Flood Tide
	Ebb Tide

APPENDIX D: Introduction to MITAGS and PMI

The Maritime Institute of Technology and Graduate Studies (MITAGS) and the Pacific Maritime Institutes (PMI) are non-profit, continuing education centers for professional mariners. The Institutes provide training for both civilian and military mariners at every level of their career.

MITAGS Location and General Facility Description

MITAGS is located less than five (5) miles from the Baltimore-Washington International Thurgood Marshall Airport (BWI). Complimentary shuttle links the campus with the airport, BWI Amtrak Rail, Baltimore Light Rail, and regional bus services. It is also near major tourist destinations; including Baltimore, Annapolis, and Washington, DC.

The MITAGS campus encompasses over forty (40) acres. The 300,000 square-feet facilities include:

- on campus hotel with 232 hotel rocims (3-STAR equivalent). Hotel and conference facilities approved by the International Association of Conference Centers (IACC).
- 500-seat dining facility, 250-seat auditorium, pub, and store.
- Indoor swimming pool, Jogging/ walking trails, Nautilus® Fitness Room.
- Maritime Museum.
- ECDIS, Stability, LNG Cargo and Engine Room Training Software.
- Emergency Medical Lab.
- 16-station networked computer Lab.
- Two, 360° Transas Full-Mission Shiphandling Simulator integrated with a 120° Bridge Tug and a 300° Bridge Tug Simulators.
- 8-Ship Radar, Automatic Radar Plotting Aids (ARPA), and Electronic Chart Display and Information Systems (ECDIS) Simulators.
- Global Maritime Distress and Safety Systems (GMDSS) Communications Lab.
- Vessel Traffic System (VTS) Watchstander Training Lab.

PMI Location and General Facility Description

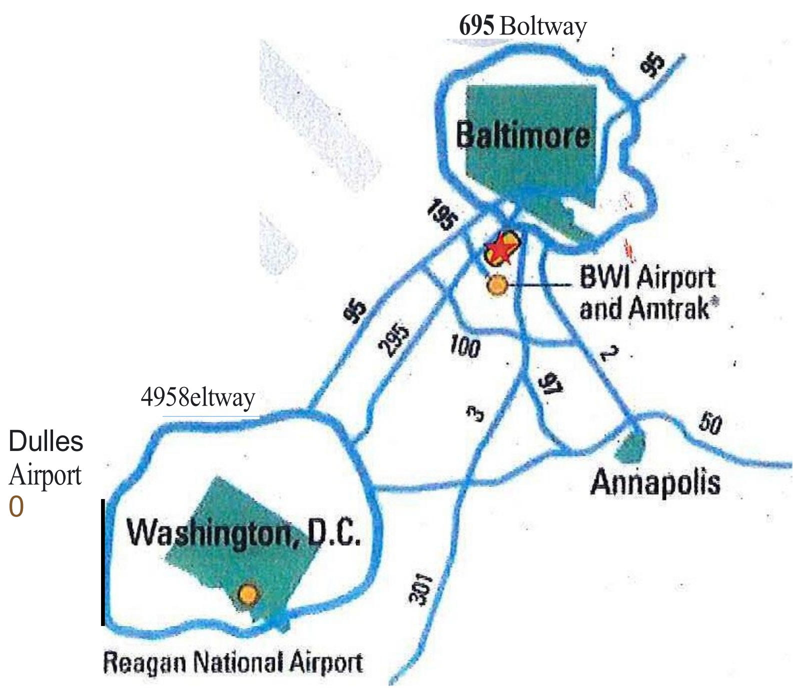
The Pacific Maritime Institute (PMI) is a subsidiary of MITAGS in Seattle, Washington. PMI is located approximately twenty (20) minutes from Seattle Tacoma (SEA-TAC) International Airport. Their waterfront facility is positioned directly within the Maritime Technology and Career Center. PMI offers the following onsite technology and training support facilities:

- 240° DNV Class A Full-Mission Bridge Simulator.
- Two 300° Full-Mission Tugboat Simulator.
- 6-Radar/Automatic Radar Plotting Aids (ARPA) Simulators.
- Two Electronic Chart Display and Information Systems (ECDIS)/Electronic Navigation Labs.
- Global Maritime Distress and Safety Systems (GMDSS) Communications Lab.
- 2-Simulation Debriefing Rooms and 12 conference/ classrooms.
- Complimentary parking.

MITAGS DNV Class A Full-Mission Ship Simulator #1 (Bridge for Phase I and II Tests)

MITAGS Tug Bridge Simulator (Bridge for Phase I and II Tests)

Aerial Photograph of MITAGS Campus and Location Diagram



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ATTACHMENT 6

RELATIVE SEA LEVEL CHANGE TABLES

HDCI

8518750, The Battery, NY

NOAA's 2006 Published Rate: 0.00909 feet/yr

All values are expressed in feet relative to NAVD88

Year	USACE Low	USACE Int	USACE High
1992	-0.21	-0.21	-0.21
1993	-0.2	-0.2	-0.2
1994	-0.19	-0.19	-0.19
1995	-0.18	-0.18	-0.18
1996	-0.17	-0.17	-0.17
1997	-0.17	-0.16	-0.16
1998	-0.16	-0.15	-0.14
1999	-0.15	-0.14	-0.13
2000	-0.14	-0.13	-0.11
2001	-0.13	-0.12	-0.1
2002	-0.12	-0.11	-0.08
2003	-0.11	-0.1	-0.07
2004	-0.1	-0.09	-0.05
2005	-0.09	-0.08	-0.03
2006	-0.08	-0.07	-0.01
2007	-0.07	-0.05	0.01
2008	-0.07	-0.04	0.03
2009	-0.06	-0.03	0.05
2010	-0.05	-0.02	0.07
2011	-0.04	-0.01	0.1
2012	-0.03	0.01	0.12
2013	-0.02	0.02	0.14
2014	-0.01	0.03	0.17
2015	0	0.05	0.2
2016	0.01	0.06	0.22
2017	0.02	0.07	0.25
2018	0.03	0.09	0.28
2019	0.04	0.1	0.31
2020	0.04	0.11	0.34
2021	0.05	0.13	0.37
2022	0.06	0.14	0.4
2023	0.07	0.16	0.43
2024	0.08	0.17	0.46
2025	0.09	0.19	0.49
2026	0.1	0.2	0.53
2027	0.11	0.22	0.56
2028	0.12	0.23	0.6
2029	0.13	0.25	0.63
2030	0.14	0.26	0.67
2031	0.14	0.28	0.71
2032	0.15	0.3	0.75
2033	0.16	0.31	0.79
2034	0.17	0.33	0.83
2035	0.18	0.35	0.87
2036	0.19	0.36	0.91
2037	0.2	0.38	0.95
2038	0.21	0.4	0.99
2039	0.22	0.41	1.04
2040	0.23	0.43	1.08
2041	0.24	0.45	1.13
2042	0.24	0.47	1.17
2043	0.25	0.49	1.22
2044	0.26	0.5	1.26
2045	0.27	0.52	1.31
2046	0.28	0.54	1.36
2047	0.29	0.56	1.41
2048	0.3	0.58	1.46
2049	0.31	0.6	1.51
2050	0.32	0.62	1.56
2051	0.33	0.64	1.62
2052	0.34	0.66	1.67
2053	0.34	0.68	1.72
2054	0.35	0.7	1.78
2055	0.36	0.72	1.83
2056	0.37	0.74	1.89
2057	0.38	0.76	1.95
2058	0.39	0.78	2.01
2059	0.4	0.8	2.06
2060	0.41	0.82	2.12
2061	0.42	0.84	2.18
2062	0.43	0.86	2.24
2063	0.44	0.88	2.3
2064	0.44	0.91	2.37

Year	USACE Low	USACE Int	USACE High
2065	0.45	0.93	2.43
2066	0.46	0.95	2.49
2067	0.47	0.97	2.56
2068	0.48	0.99	2.62
2069	0.49	1.02	2.69
2070	0.5	1.04	2.75
2071	0.51	1.06	2.82
2072	0.52	1.09	2.89
2073	0.53	1.11	2.96
2074	0.54	1.13	3.03
2075	0.54	1.16	3.1
2076	0.55	1.18	3.17
2077	0.56	1.21	3.24
2078	0.57	1.23	3.31
2079	0.58	1.25	3.39
2080	0.59	1.28	3.46
2081	0.6	1.3	3.54
2082	0.61	1.33	3.61
2083	0.62	1.35	3.69
2084	0.63	1.38	3.76
2085	0.64	1.4	3.84
2086	0.64	1.43	3.92
2087	0.65	1.46	4
2088	0.66	1.48	4.08
2089	0.67	1.51	4.16
2090	0.68	1.54	4.24
2091	0.69	1.56	4.32
2092	0.7	1.59	4.41
2093	0.71	1.62	4.49
2094	0.72	1.64	4.57
2095	0.73	1.67	4.66
2096	0.74	1.7	4.75
2097	0.74	1.72	4.83
2098	0.75	1.75	4.92
2099	0.76	1.78	5.01
2100	0.77	1.81	5.1
2101	0.78	1.84	5.19
2102	0.79	1.87	5.28
2103	0.8	1.89	5.37
2104	0.81	1.92	5.46
2105	0.82	1.95	5.55
2106	0.83	1.98	5.64
2107	0.84	2.01	5.74
2108	0.84	2.04	5.83
2109	0.85	2.07	5.93
2110	0.86	2.1	6.02
2111	0.87	2.13	6.12
2112	0.88	2.16	6.22
2113	0.89	2.19	6.32
2114	0.9	2.22	6.42
2115	0.91	2.25	6.52
2116	0.92	2.28	6.62
2117	0.93	2.32	6.72
2118	0.94	2.35	6.82
2119	0.94	2.38	6.92
2120	0.95	2.41	7.03
2121	0.96	2.44	7.13
2122	0.97	2.47	7.24
2123	0.98	2.51	7.34
2124	0.99	2.54	7.45
2125	1	2.57	7.56
2126	1.01	2.6	7.67
2127	1.02	2.64	7.77
2128	1.03	2.67	7.88
2129	1.03	2.7	7.99
2130	1.04	2.74	8.1
2131	1.05	2.77	8.22
2132	1.06	2.81	8.33
2133	1.07	2.84	8.44
2134	1.08	2.87	8.56
2135	1.09	2.91	8.67
2136	1.1	2.94	8.79
2137	1.11	2.98	8.9
2138	1.12	3.01	9.02

HDCI

8531680 Sandy Hook, NJ

NOAA's 2006 Published Rate: 0.01280 feet/yr

All values are expressed in feet relative to NAVD88

Year	USACE Low	USACE Int	USACE High
1992	-0.24	-0.24	-0.24
1993	-0.23	-0.23	-0.23
1994	-0.21	-0.21	-0.21
1995	-0.2	-0.2	-0.2
1996	-0.19	-0.19	-0.18
1997	-0.18	-0.17	-0.17
1998	-0.16	-0.16	-0.15
1999	-0.15	-0.15	-0.13
2000	-0.14	-0.13	-0.11
2001	-0.13	-0.12	-0.1
2002	-0.11	-0.1	-0.08
2003	-0.1	-0.09	-0.05
2004	-0.09	-0.07	-0.03
2005	-0.07	-0.06	-0.01
2006	-0.06	-0.04	0.01
2007	-0.05	-0.03	0.04
2008	-0.04	-0.01	0.06
2009	-0.02	0	0.09
2010	-0.01	0.02	0.11
2011	0	0.04	0.14
2012	0.02	0.05	0.16
2013	0.03	0.07	0.19
2014	0.04	0.09	0.22
2015	0.05	0.1	0.25
2016	0.07	0.12	0.28
2017	0.08	0.14	0.31
2018	0.09	0.15	0.34
2019	0.11	0.17	0.38
2020	0.12	0.19	0.41
2021	0.13	0.21	0.44
2022	0.14	0.22	0.48
2023	0.16	0.24	0.51
2024	0.17	0.26	0.55
2025	0.18	0.28	0.59
2026	0.2	0.3	0.62
2027	0.21	0.32	0.66
2028	0.22	0.34	0.7
2029	0.23	0.36	0.74
2030	0.25	0.38	0.78
2031	0.26	0.39	0.82
2032	0.27	0.41	0.87
2033	0.28	0.43	0.91
2034	0.3	0.45	0.95
2035	0.31	0.48	1
2036	0.32	0.5	1.04
2037	0.34	0.52	1.09
2038	0.35	0.54	1.13
2039	0.36	0.56	1.18
2040	0.37	0.58	1.23
2041	0.39	0.6	1.28
2042	0.4	0.62	1.33
2043	0.41	0.64	1.38
2044	0.43	0.67	1.43
2045	0.44	0.69	1.48
2046	0.45	0.71	1.53
2047	0.46	0.73	1.59
2048	0.48	0.76	1.64
2049	0.49	0.78	1.69
2050	0.5	0.8	1.75
2051	0.52	0.82	1.81
2052	0.53	0.85	1.86
2053	0.54	0.87	1.92
2054	0.55	0.9	1.98
2055	0.57	0.92	2.04
2056	0.58	0.94	2.1
2057	0.59	0.97	2.16
2058	0.6	0.99	2.22
2059	0.62	1.02	2.28
2060	0.63	1.04	2.34
2061	0.64	1.07	2.41
2062	0.66	1.09	2.47
2063	0.67	1.12	2.54
2064	0.68	1.14	2.6
2065	0.69	1.17	2.67
2066	0.71	1.19	2.74
2067	0.72	1.22	2.81
2068	0.73	1.25	2.87
2069	0.75	1.27	2.94
2070	0.76	1.3	3.01
2071	0.77	1.33	3.09
2072	0.78	1.35	3.16
2073	0.8	1.38	3.23
2074	0.81	1.41	3.3
2075	0.82	1.44	3.38
2076	0.84	1.46	3.45
2077	0.85	1.49	3.53
2078	0.86	1.52	3.6
2079	0.87	1.55	3.68
2080	0.89	1.58	3.76
2081	0.9	1.6	3.84
2082	0.91	1.63	3.92
2083	0.92	1.66	3.99
2084	0.94	1.69	4.08
2085	0.95	1.72	4.16
2086	0.96	1.75	4.24
2087	0.98	1.78	4.32
2088	0.99	1.81	4.41
2089	1	1.84	4.49
2090	1.01	1.87	4.57
2091	1.03	1.9	4.66
2092	1.04	1.93	4.75
2093	1.05	1.96	4.83
2094	1.07	1.99	4.92
2095	1.08	2.02	5.01
2096	1.09	2.05	5.1
2097	1.1	2.08	5.19
2098	1.12	2.12	5.28
2099	1.13	2.15	5.37
2100	1.14	2.18	5.47
2101	1.16	2.21	5.56
2102	1.17	2.24	5.65
2103	1.18	2.28	5.75
2104	1.19	2.31	5.84
2105	1.21	2.34	5.94
2106	1.22	2.37	6.04
2107	1.23	2.41	6.13
2108	1.24	2.44	6.23
2109	1.26	2.47	6.33
2110	1.27	2.51	6.43
2111	1.28	2.54	6.53
2112	1.3	2.58	6.63
2113	1.31	2.61	6.74
2114	1.32	2.64	6.84
2115	1.33	2.68	6.94
2116	1.35	2.71	7.05
2117	1.36	2.75	7.15
2118	1.37	2.78	7.26
2119	1.39	2.82	7.37
2120	1.4	2.86	7.47
2121	1.41	2.89	7.58
2122	1.42	2.93	7.69
2123	1.44	2.96	7.8
2124	1.45	3	7.91
2125	1.46	3.04	8.02
2126	1.48	3.07	8.13
2127	1.49	3.11	8.24
2128	1.5	3.15	8.36
2129	1.51	3.18	8.47
2130	1.53	3.22	8.59
2131	1.54	3.26	8.7
2132	1.55	3.29	8.82
2133	1.56	3.33	8.94
2134	1.58	3.37	9.05
2135	1.59	3.41	9.17
2136	1.6	3.45	9.29
2137	1.62	3.49	9.41
2138	1.63	3.52	9.53