US Army Corps
of Engineers®
New York District

NEW YORK AND NEW JERSEY HARBOR DEEPENING CHANNEL IMPROVEMENTS

NAVIGATION STUDY

DRAFT 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.

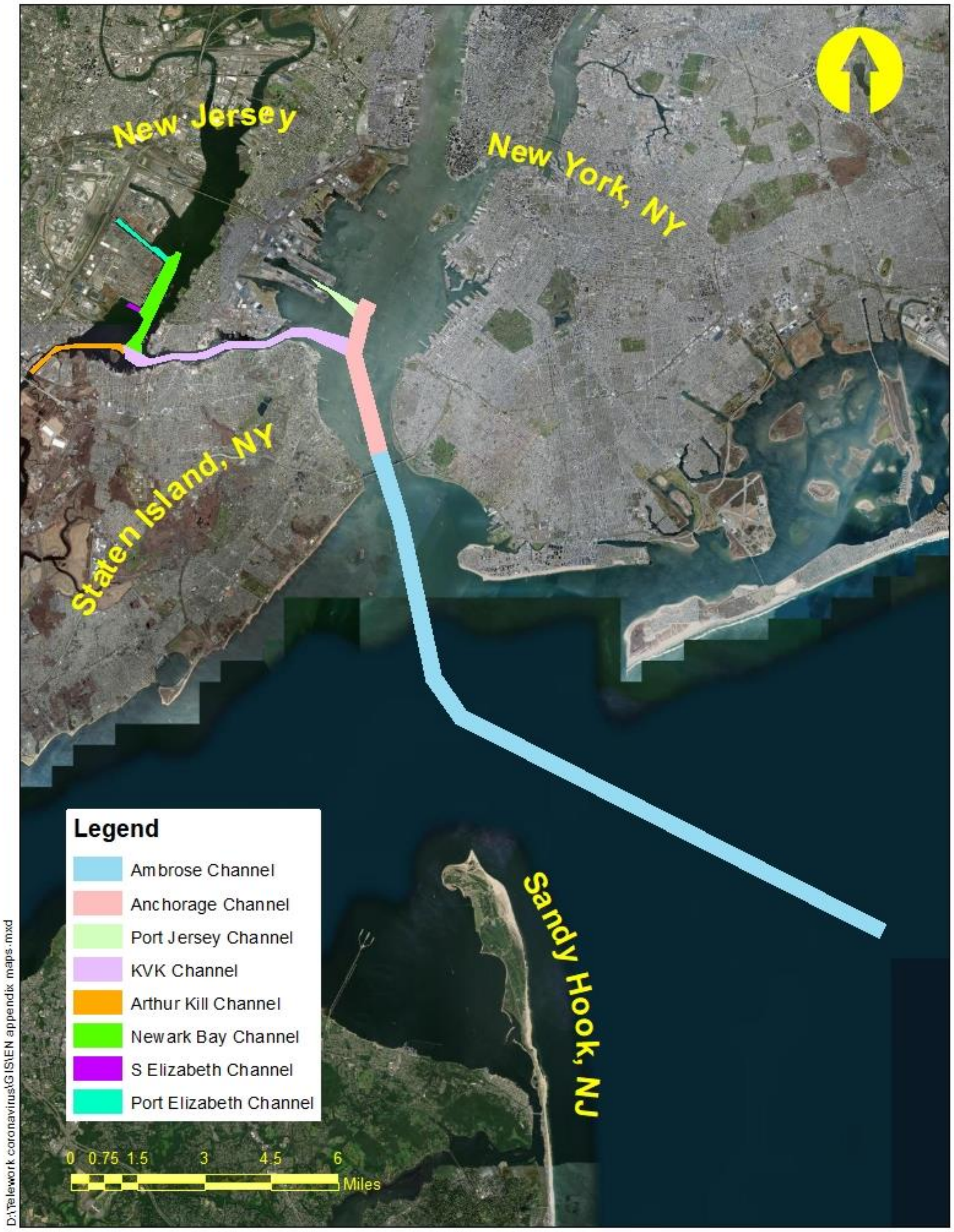

Figure 1. Location Map of NY & NJ Harbor

2.1.1. Ambrose Channel

Ambrose Channel is the entrance channel into NY & NJ Harbor. The channel extends for a distance of 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 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 (Station ID 851870)	Sandy Hook, NJ (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. Publically 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.

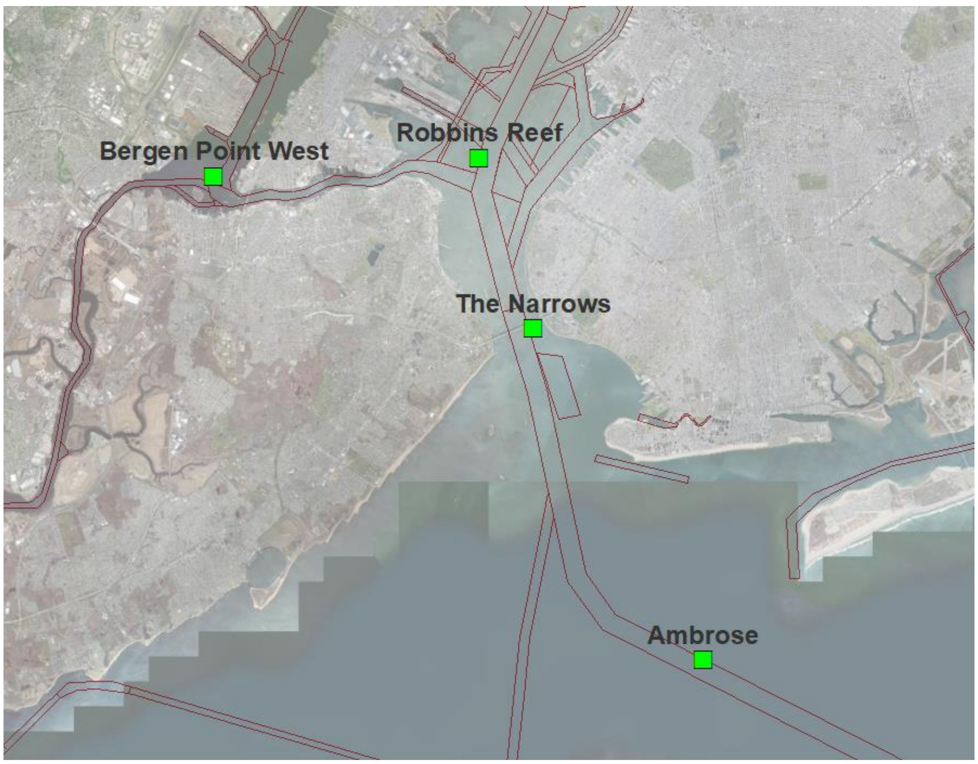

Figure 2. NOAA Current Data Locations

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.

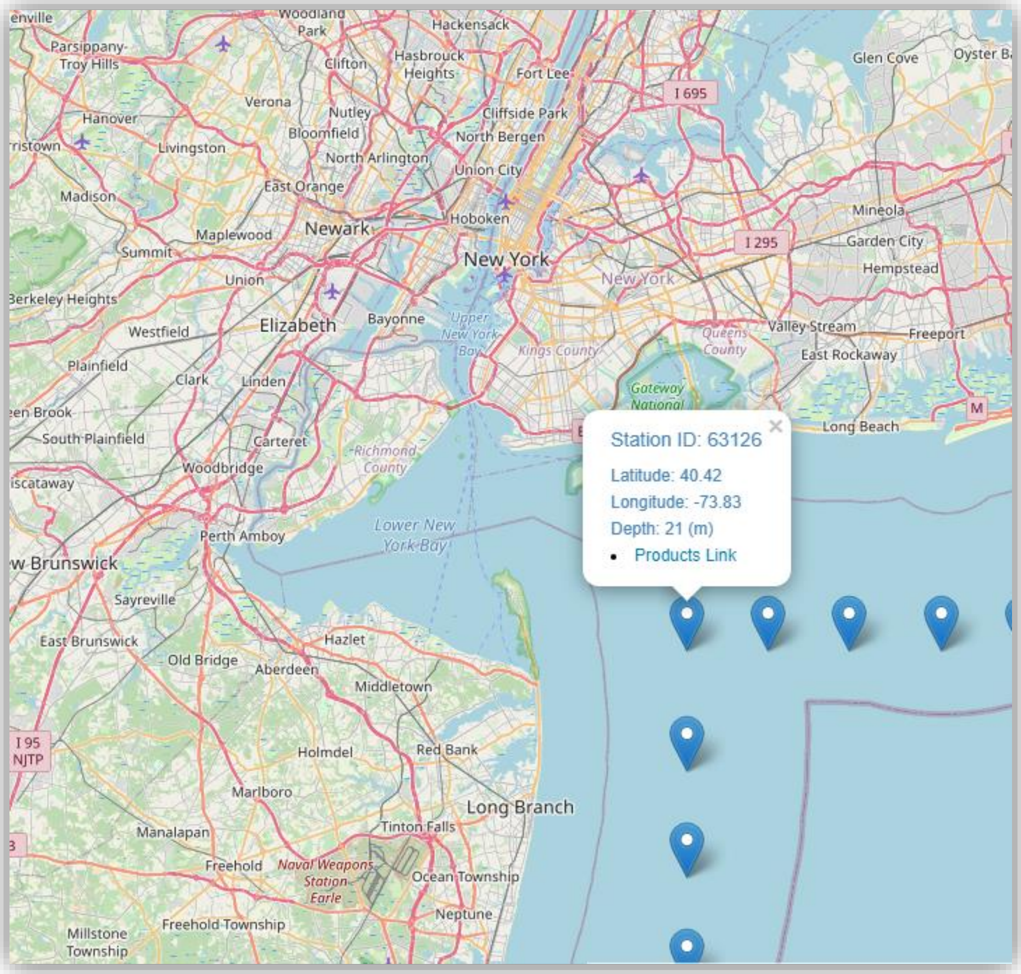

Figure 3. Location of WIS Station ID 63126

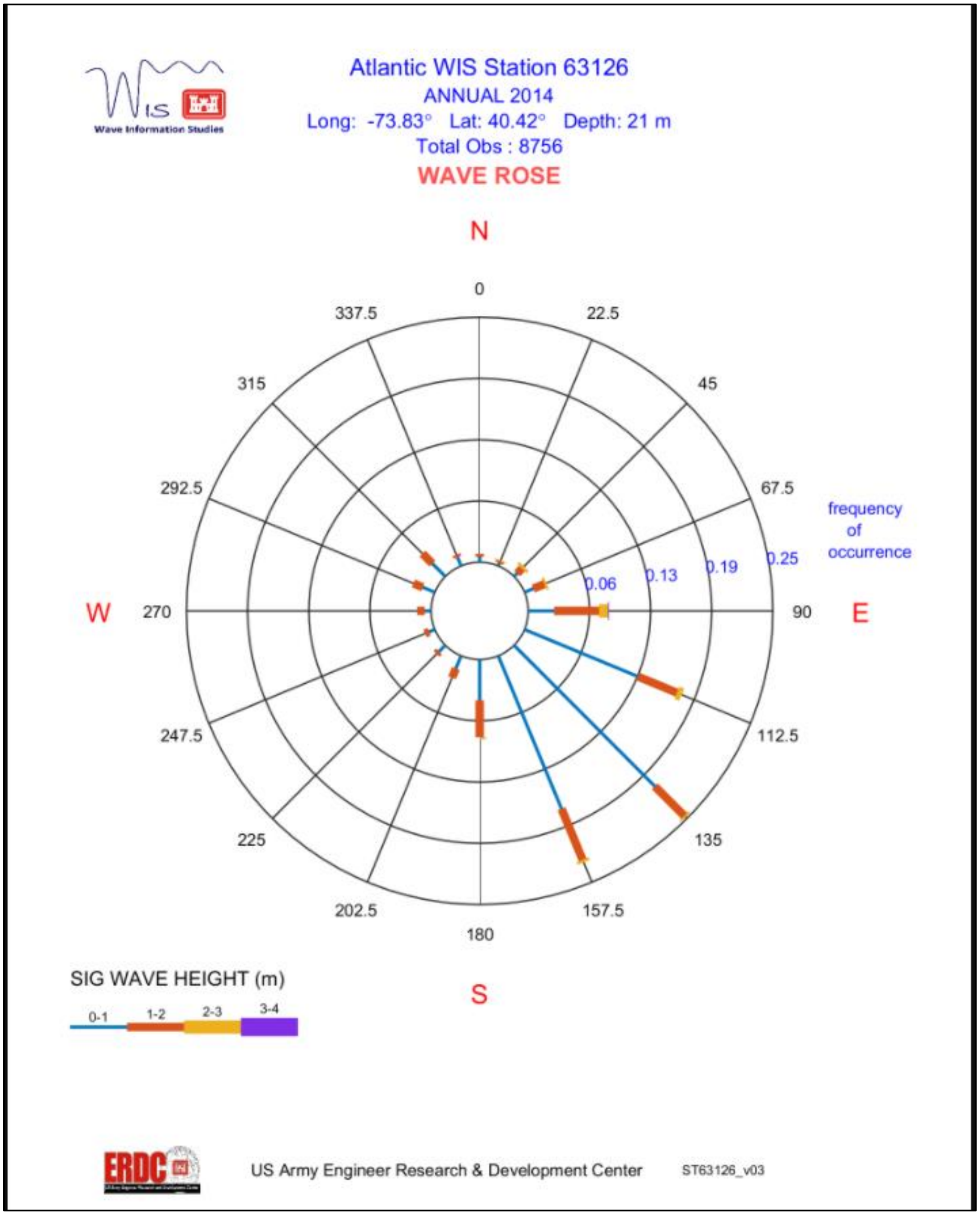

Figure 4. Wave Rose Created by the USACE Wave Information Studies (WIS), Station ID 63126

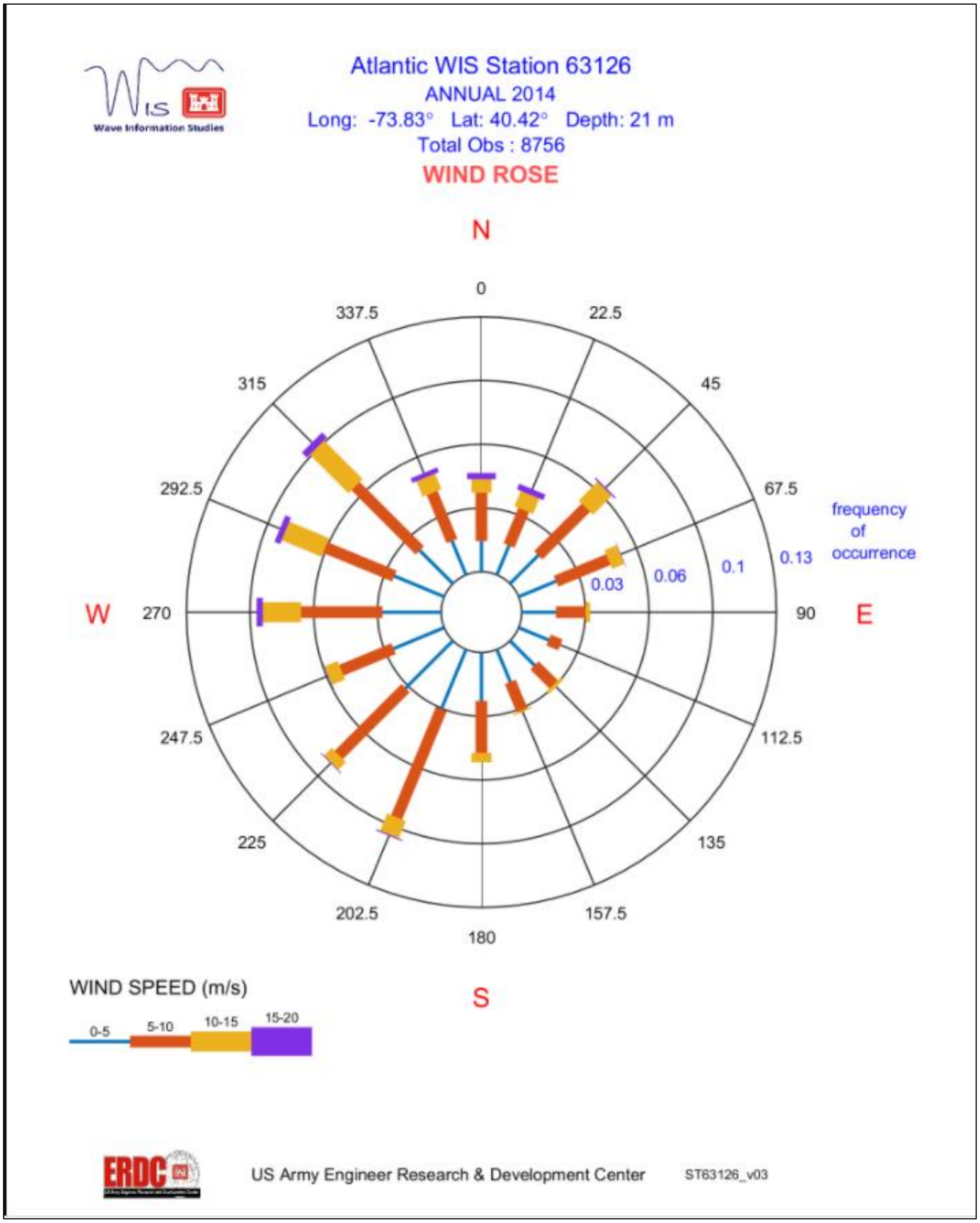

Figure 5. Wind rose Created by the USACE Wave Information Studies (WIS), Station ID 63126

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

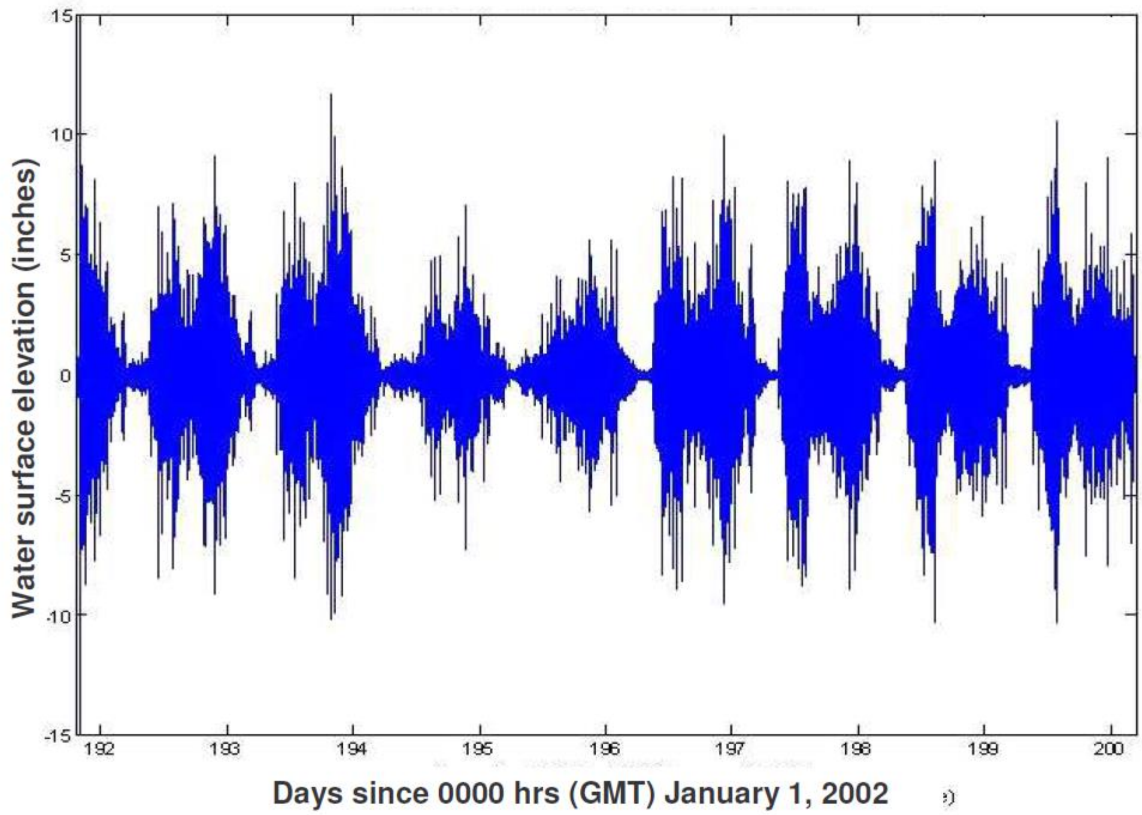

Figure 7. Time History of Water Surface Elevation 8-Day Time Span.

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

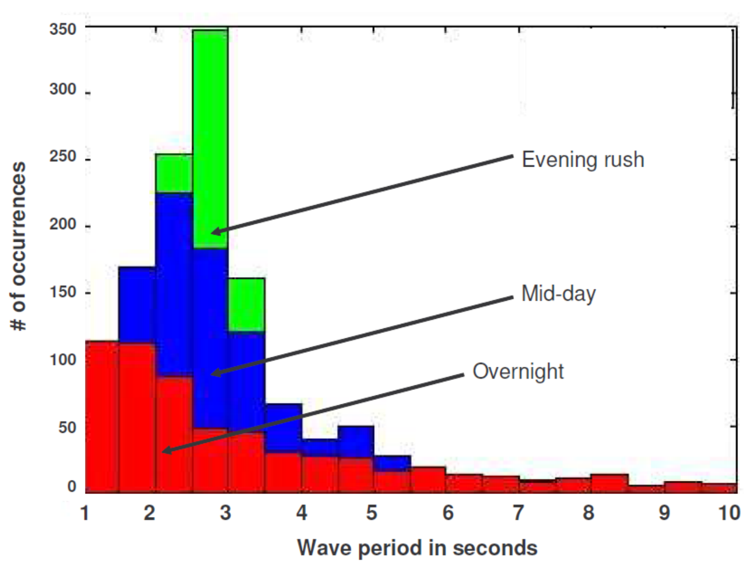

Figure 8. Histogram of Wave Period Occurrences for 8-Day Time Span

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.

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 2017, 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, <u>New York/New Jersey Harbor Sedimentation Study Numerical Modeling of Hydrodynamics and Sediment Transport</u> (McAlpin, et al. 2017) (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 south west 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 under consideration (Figure 9).

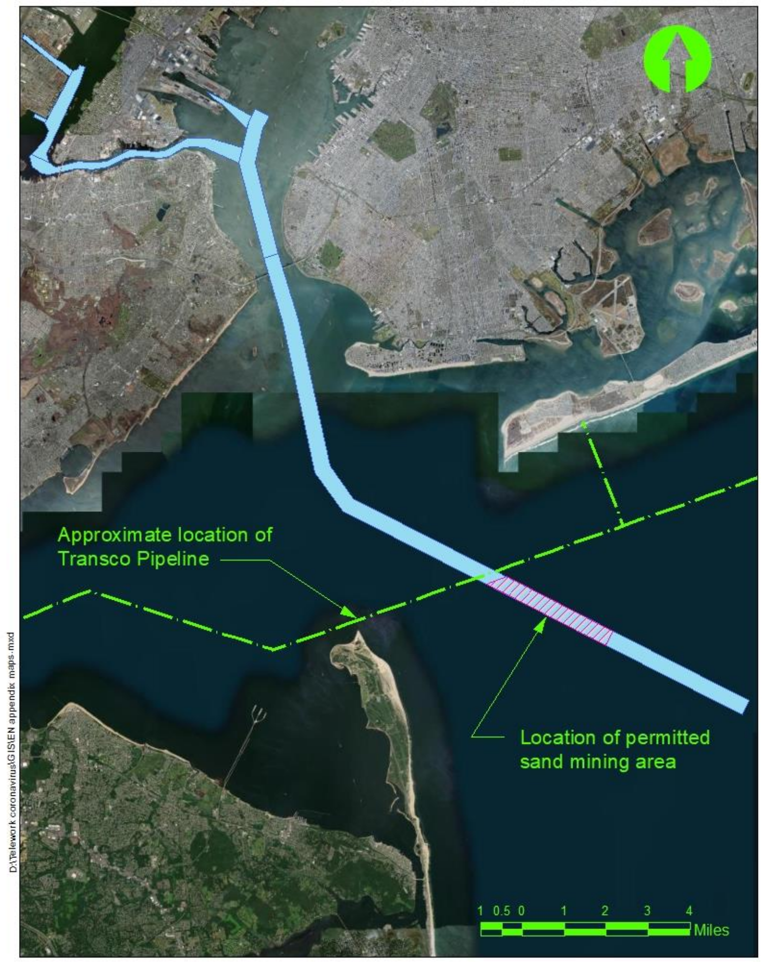

Figure 9. Transco Pipeline and Sand Mining Permit Location.

Average annual dredging volumes for the New York and New Jersey Harbor channels are summarized 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 post-2007 volumes is not known and is assumed to be 2015. The post-2007 dredging volumes are shown as those volumes that were reported purely as maintenance dredging in the fourth and fifth columns of Table 4. However, a portion of the dredging reported as "new-work" included material that required special upland disposal as it was unacceptable for open water disposal at the Historic Area Remediation site (HARS) placement site. 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). 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 provided in the two final columns of Table 4.

The impacts on maintenance dredging for the prior deepening project are discussed in detail in McAlpin, et al, 2017 (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 (2017).

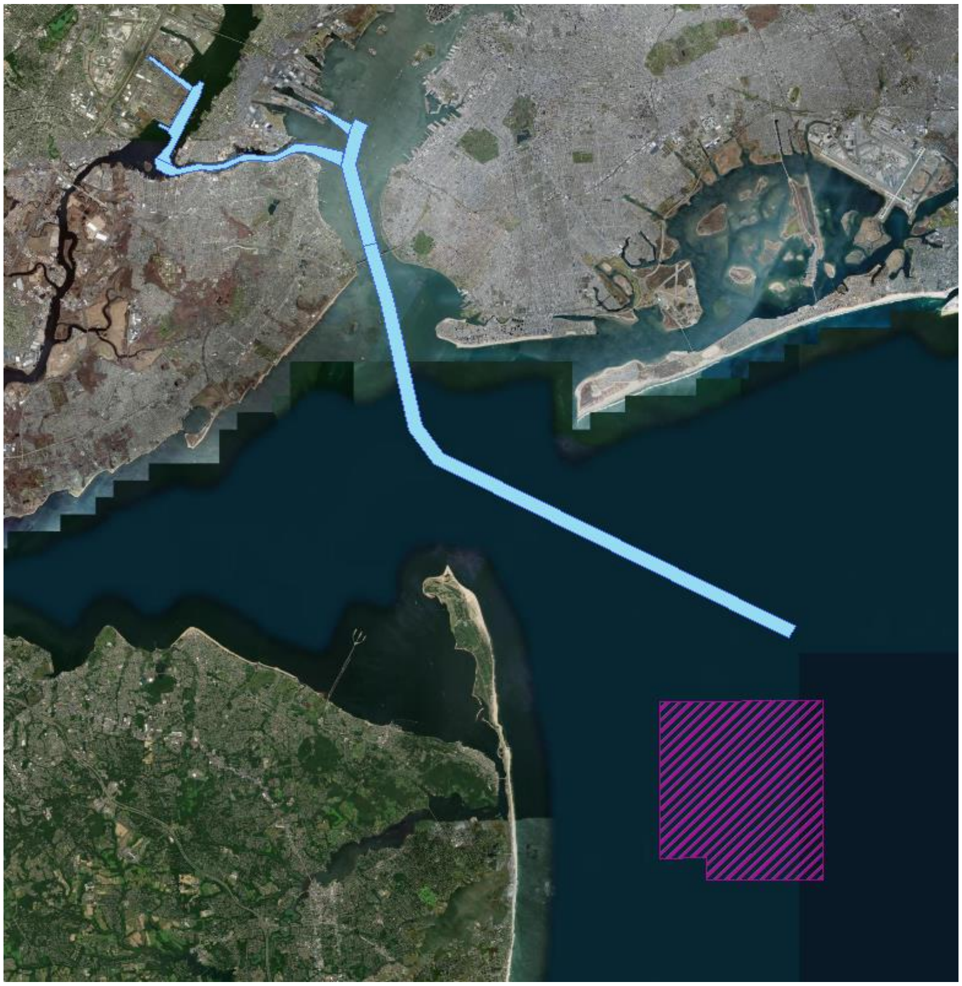

Figure 10. HARS Placement Site

Table 4. Annual Dredging Volumes (cy)

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	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.

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.

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 such factors such as ship speed, prevailing cross winds, both cross currents 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 such factors 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 salt water 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 under keel 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).

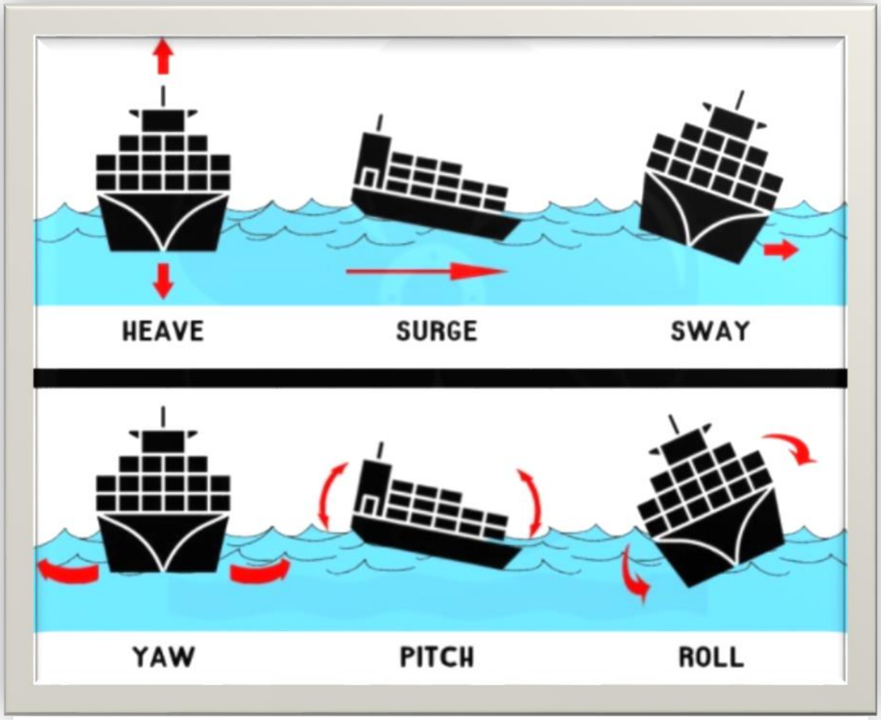

Figure 11. Types of Vertical and Horizontal Ship Motion (Credit: Thomas Smith Shipping)

4.2.2.1. Ship Motion Study

A vertical ship motion study 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 both design vessels (tanker and container ship) for both inbound and outbound transits, and normal as well as design (1 year) wave conditions.

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, 2017) (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 fresh water 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

The depths proposed for the NY & NJ Harbor channels are + 4 feet and + 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 using in this study is presented below in Table 7.

Table 7. Total Underkeel Clearance for both an Additional 4 feet and 5 Feet from Current Design Depth of 50 feet.

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

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 8).

Table 8. 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 9 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 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.

Figure 12. HDCI Reaches that are combined into Pathways

Table 9. 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 10H: 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.

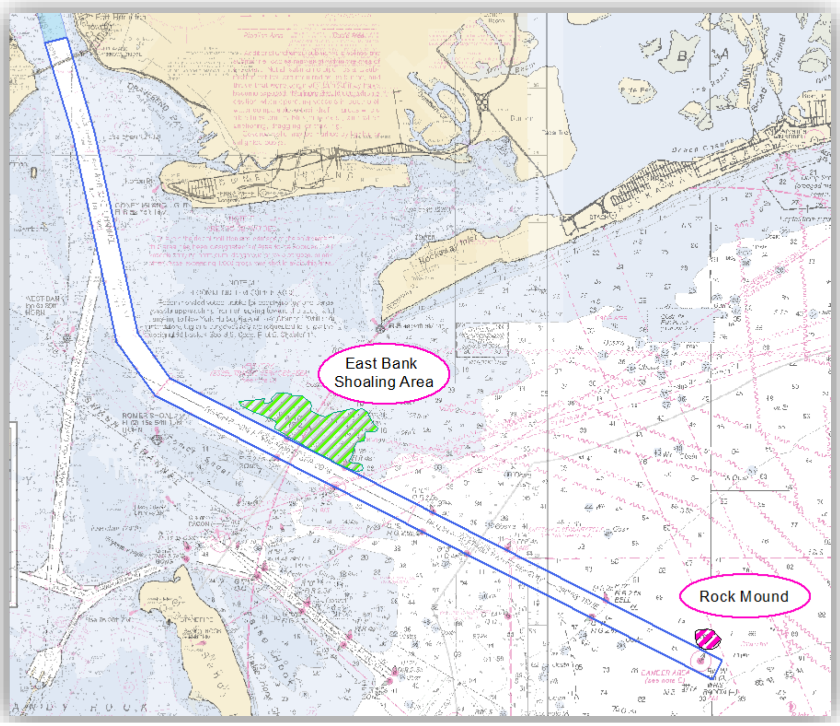

Figure 13. East Bank Shoaling Area and Rock Mound adjacent to Ambrose Channel.

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 4,500 feet beyond the centerline of the 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. 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.

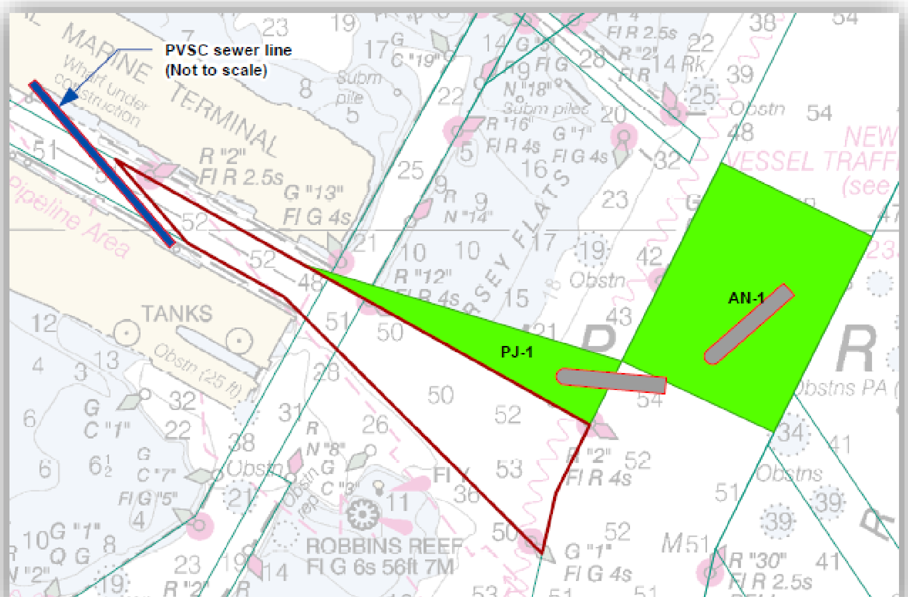

Figure 14. Port Jersey Channel, Showing Location of PVSC Trunk Line as it Crosses the Channel, Area PJ-1 and Area AN-1. (Design Ships are Shown to-Scale.)

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 do not 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.

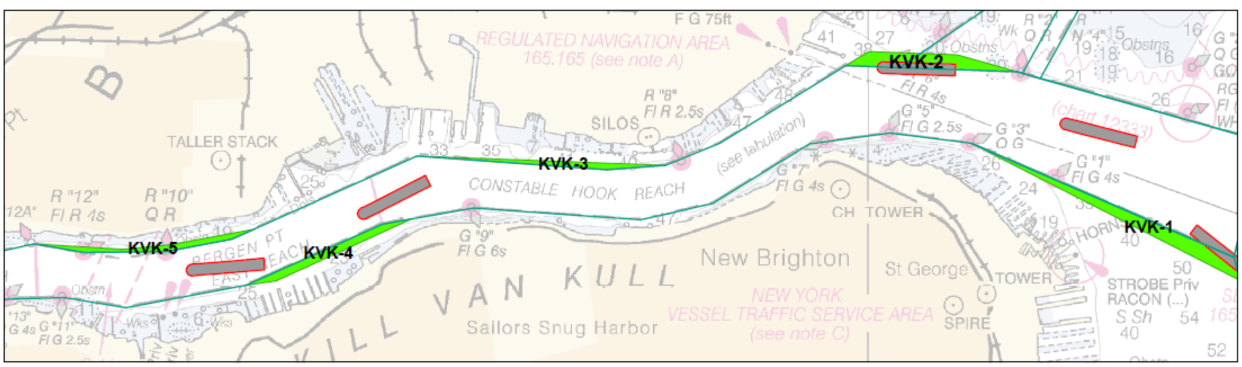

Figure 15. Areas of Widening and Efficiency (KVK-2) within the Kill Van Kull Channel (Design Ships Shown to Scale.

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).

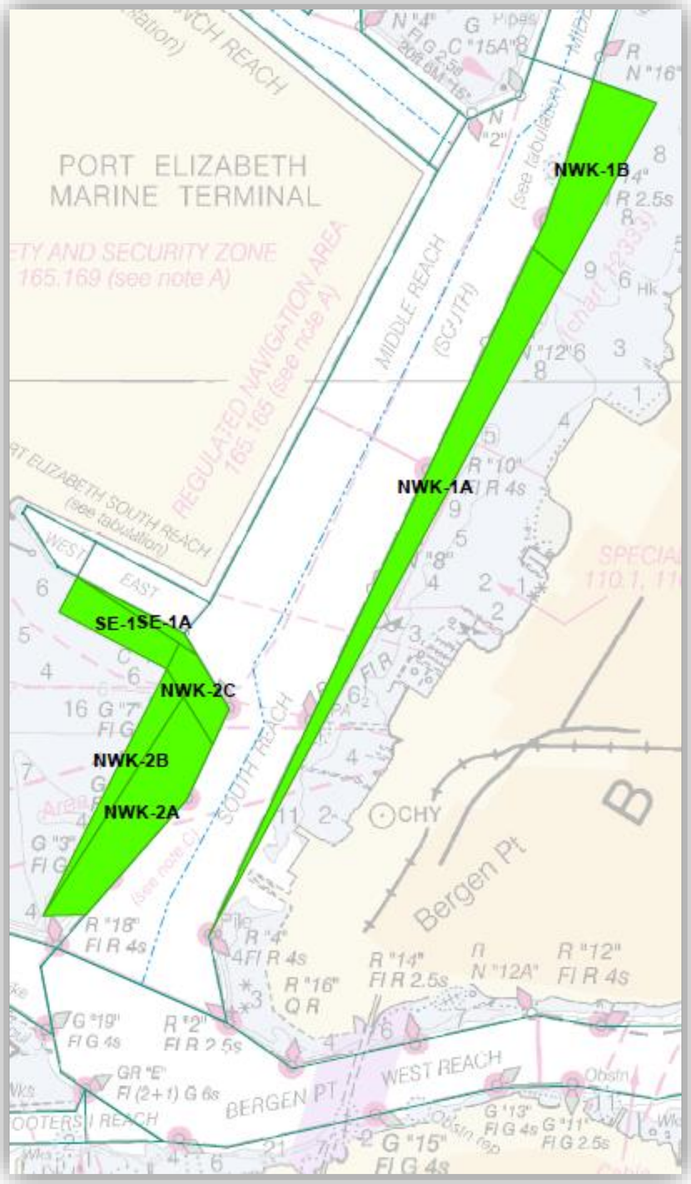

Figure 16. Newark Bay Channel with Preliminary Areas of Widening.

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.

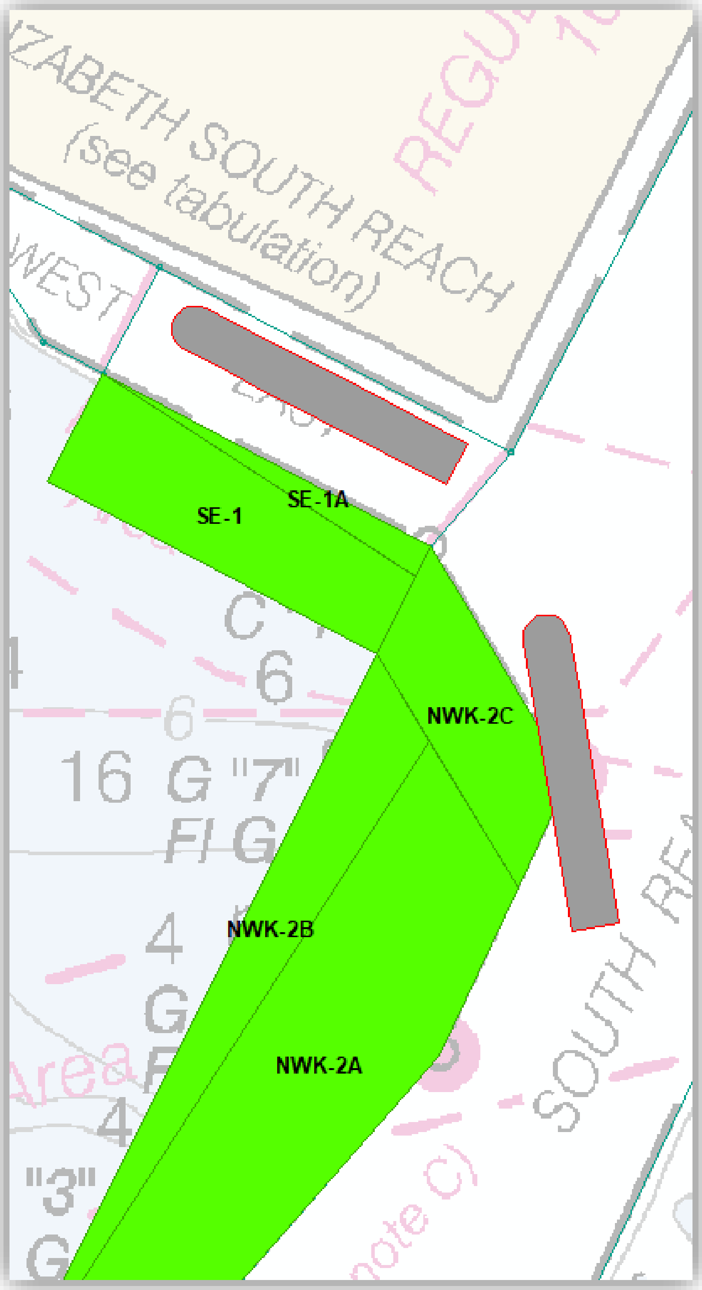

Figure 17. South Elizabeth Channel and Newark Bay South, Preliminary Widenings

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 where 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.

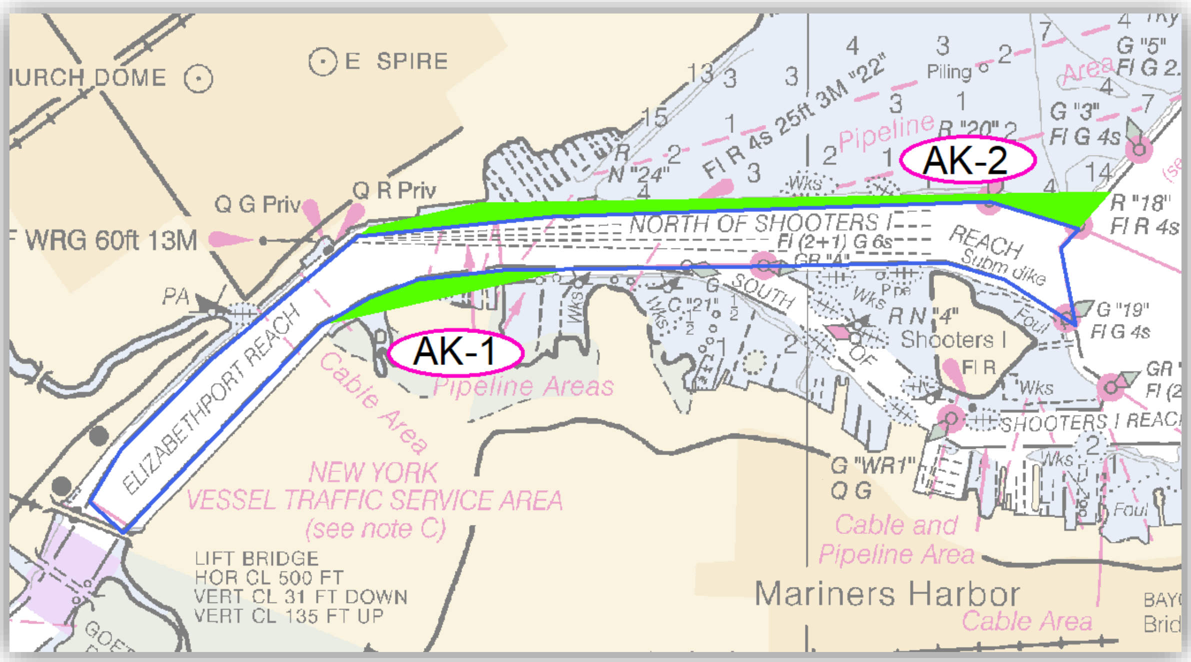

Figure 18. Arthur Kill Widenings AK-1 and AK-2

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 10 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 10. 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 1/9th arc-second cell size and were retrieved from the Hurricane Sandy Digital Elevation Model (HSDEM), Mid-Atlantic Region, collected in 2012. The 1/9th 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, 2017 (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 11. 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 11. 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 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 set at 1H: 1V (Figure 19). 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 10H: 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 12.

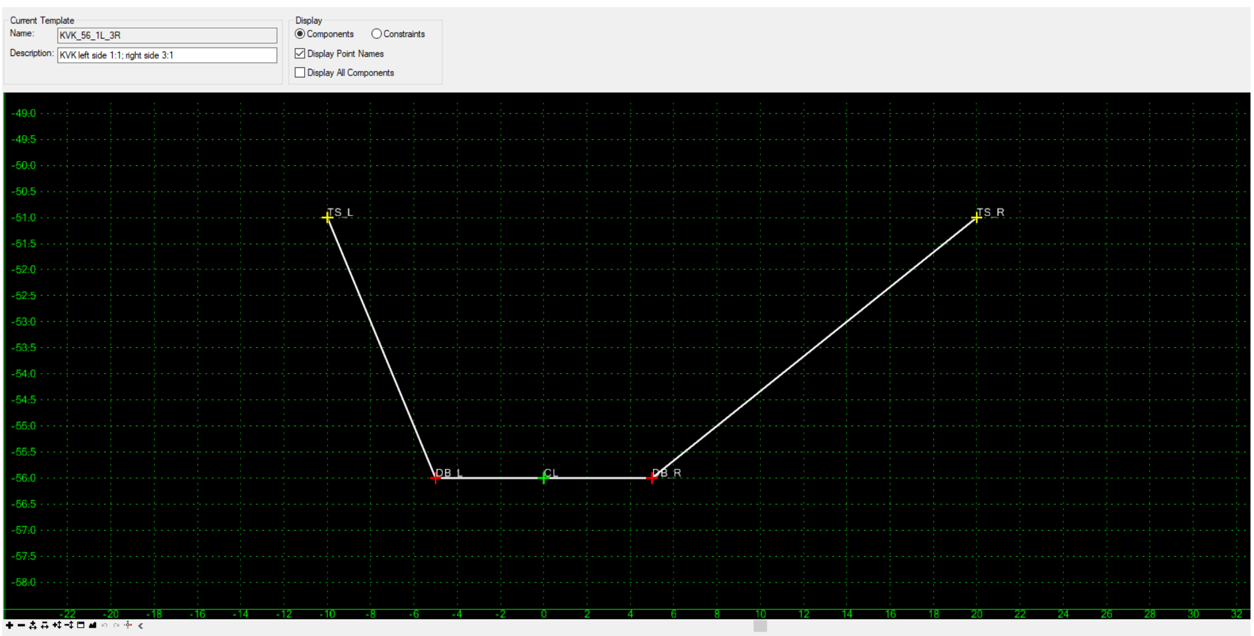

Figure 19. Sample Proposed Channel Template showing 1H: 1V Side Slope on the left; 3H: 1V Side Slope on the right

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 12. Proposed Channel Side Slopes through each type of Material

Material	Slope
Soft material (Sand and sediment)	3H: 1V
Rock	1H: 1V
East Bank Shoal – Ambrose Channel	10 H: 1V

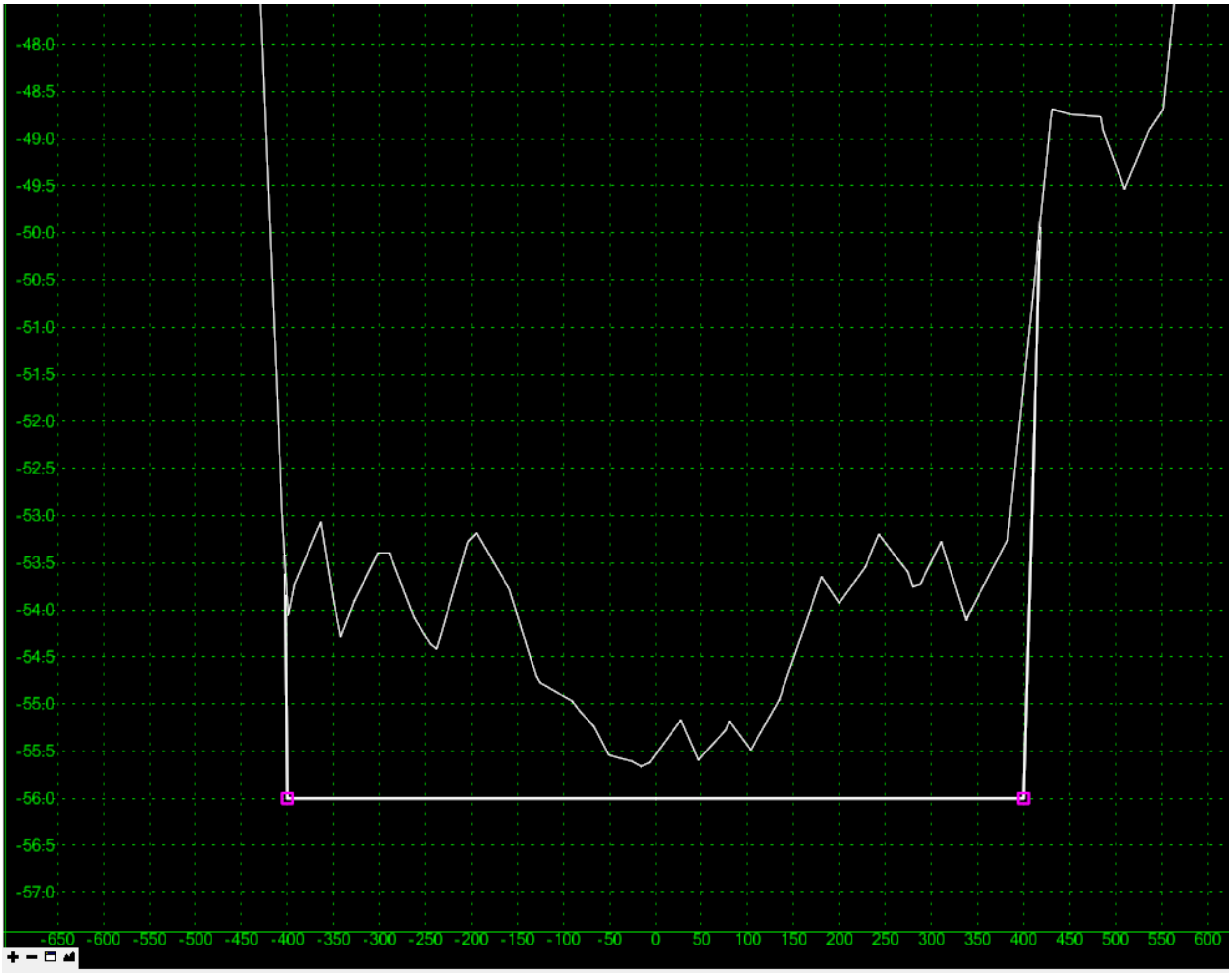

Figure 20. Proposed Channel Template being "pushed" through Existing Conditions Surface

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.

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 21. 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.

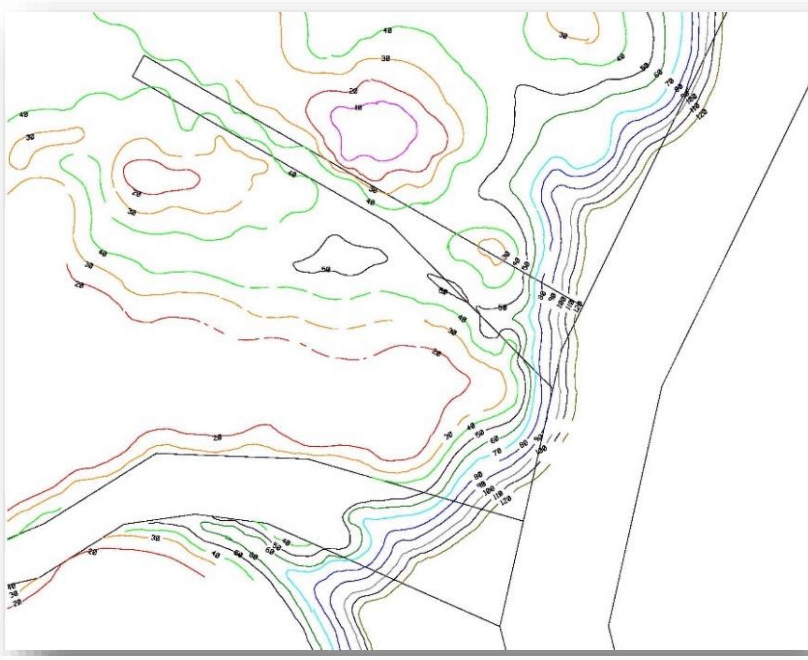

Figure 21. Pleistocene Layer near Port Jersey Channel and the Eastern End of the Kill Van Kull Channel.

6.3.3. Rock Quantities

Rock quantities were estimated from existing data from the previous deepening study. Figure 22 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.

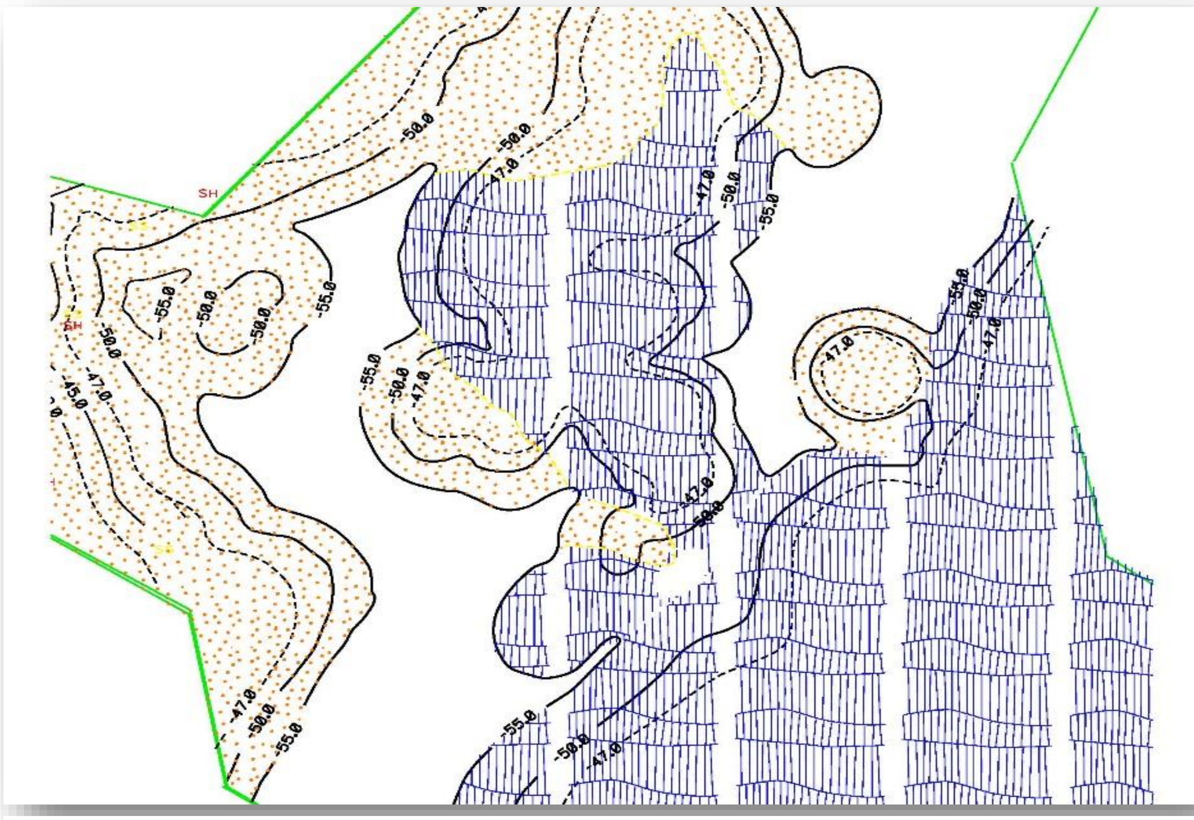

Figure 22. Sample File Showing Rock Types in the Vicinity of Bergen Point.

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 23). 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)).

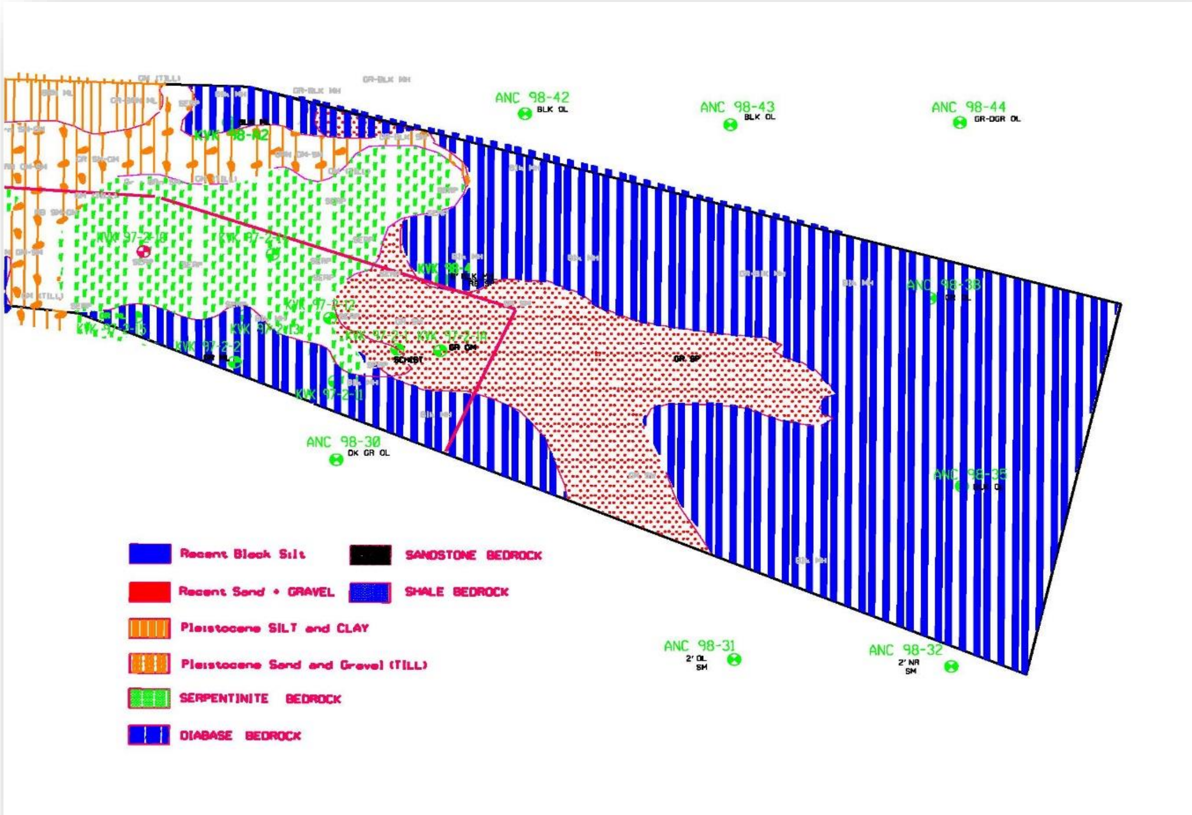

Figure 23. Sample File Showing Material Types in the vicinity of the Eastern Kill Van Kull Channel

6.4. Excavated Depth Summary

Figure 24 provides an illustration of the different dredge zones referenced in developing quantities. These horizons are defined below.

6.4.1. Existing Condition

Based on the most recent eHydro data at the start of the study. (For this study, existing conditions elevations 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.

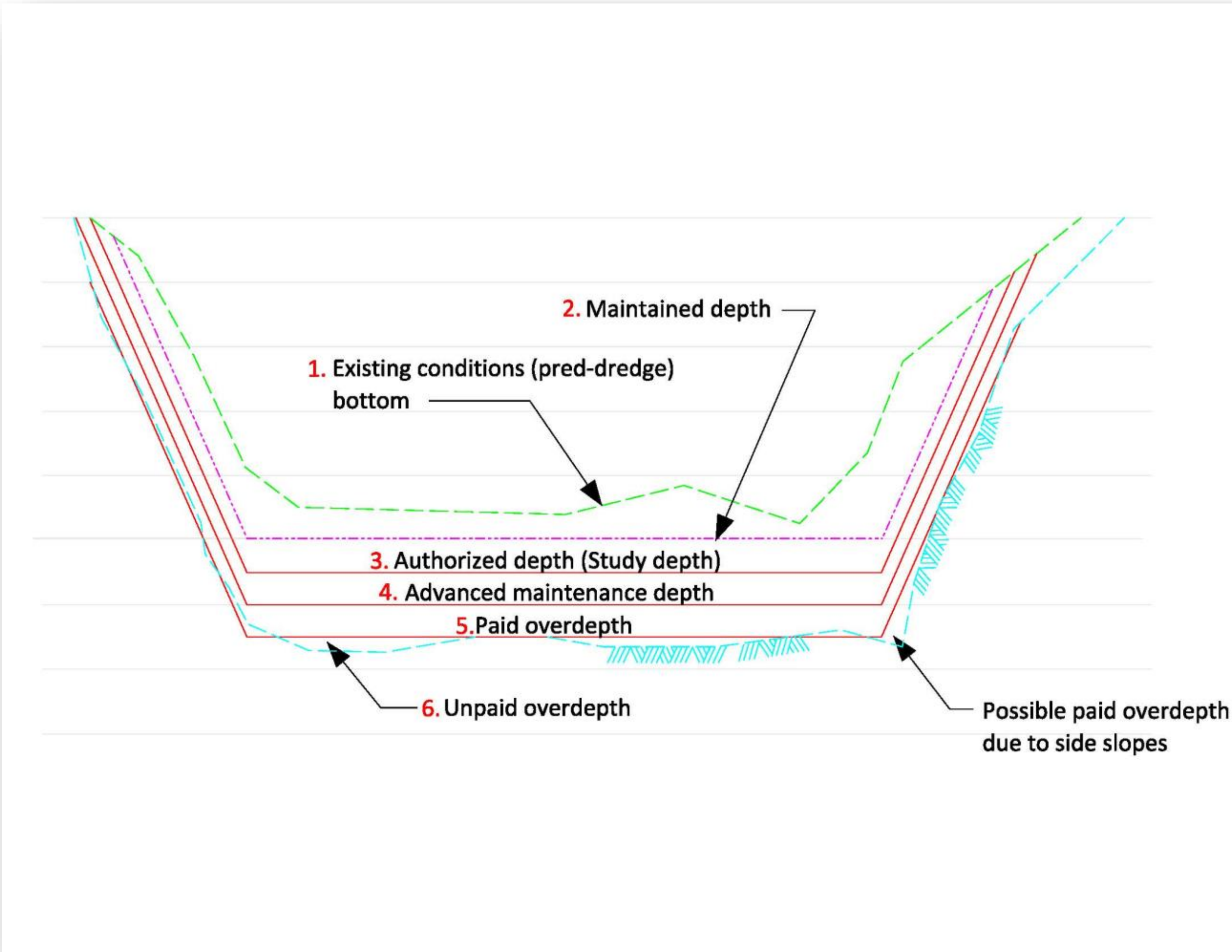

Figure 24. Typical Dredge Zones

6.4.5. 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.

6.4.6. Unpaid Overdepths

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. Finally. 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.

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 up to 5 feet, from its authorized depth of -53 feet, MLLW 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 to in the vicinity of the East Bank Shoal to reduce sloughing of sand into the channel will be reduced. This reduction is preliminarily set to approximately 10H: 1V but will refined during the detailed design phase of this study.

7.1.2. Anchorage Channel

Anchorage Channel will be deepened by up to 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 up to 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 25)

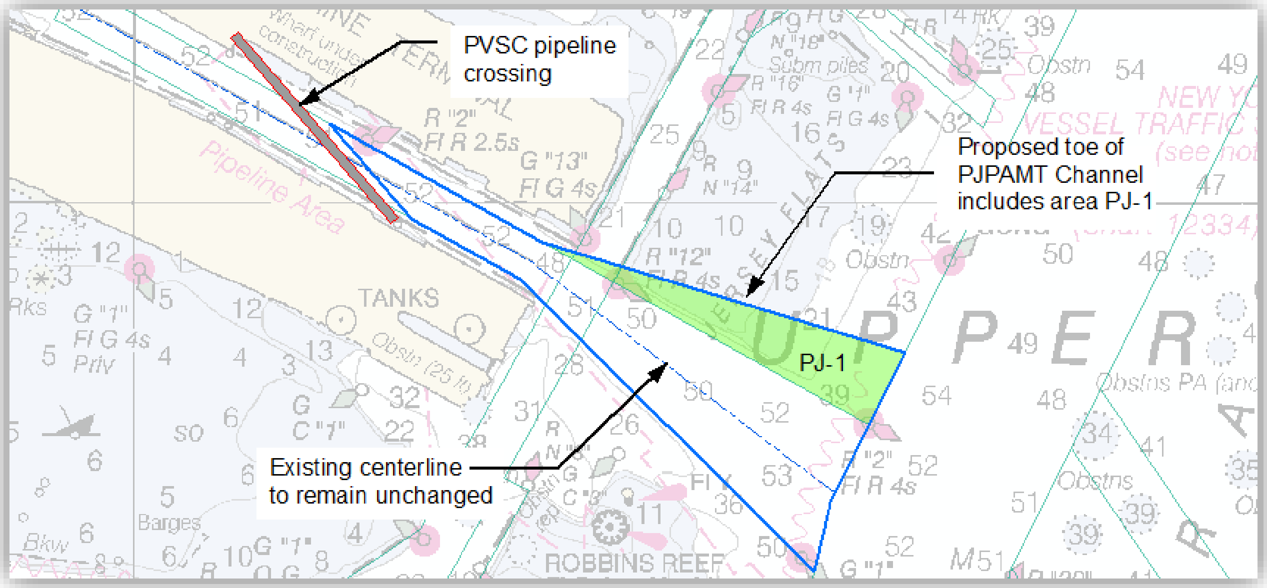

Figure 25. The Port Jersey Channel Footprint is Changed by the Addition of Area PJ-1; the Channel Centerline Remains Unchanged.

7.1.4. Kill Van Kull Channel

Kill Van Kull Channel will be deepened by up to 5 feet from its authorized depth of -50 feet, MLLW. The footprint of the Kill Van Kull Channel will be changed to include the areas of widening: KVK-1, KVK-3, KVK-4, and KVK-5. 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 26).

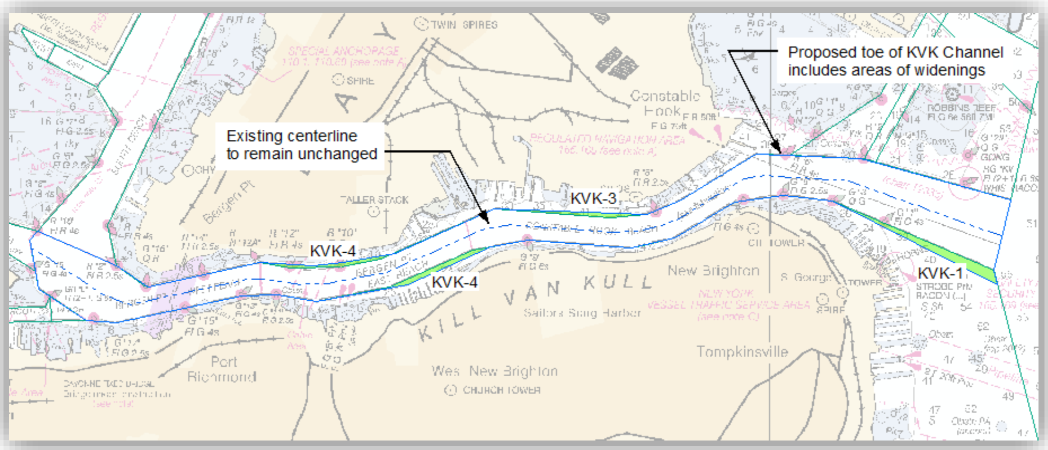

Figure 26. The KVK Channel Footprint is Changed by the Addition of Areas KVK-1, KVK-3, KVK-4, KVK-5; the Channel Centerline Remains Unchanged.

7.1.5. Newark Bay Channel

Newark Bay Channel will be deepened by up to 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 27, but this relocation is subject to change and must be confirmed and agreed to by the NY District Operations Division.

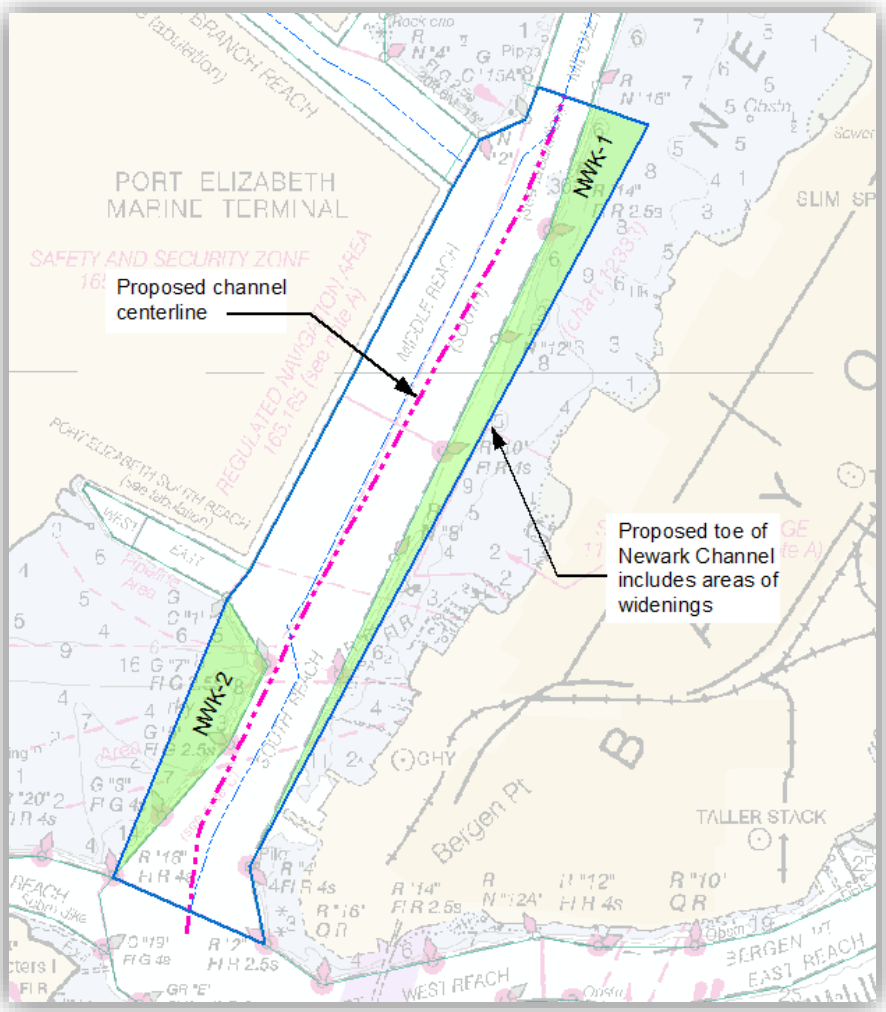

Figure 27. The Newark Bay Channel Footprint is changed by the Addition of Areas NWK-1 and NWK-2. The Proposed Channel Line is shown.

7.1.6. South Elizabeth Channel

South Elizabeth Channel will be deepened by up to 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 28).

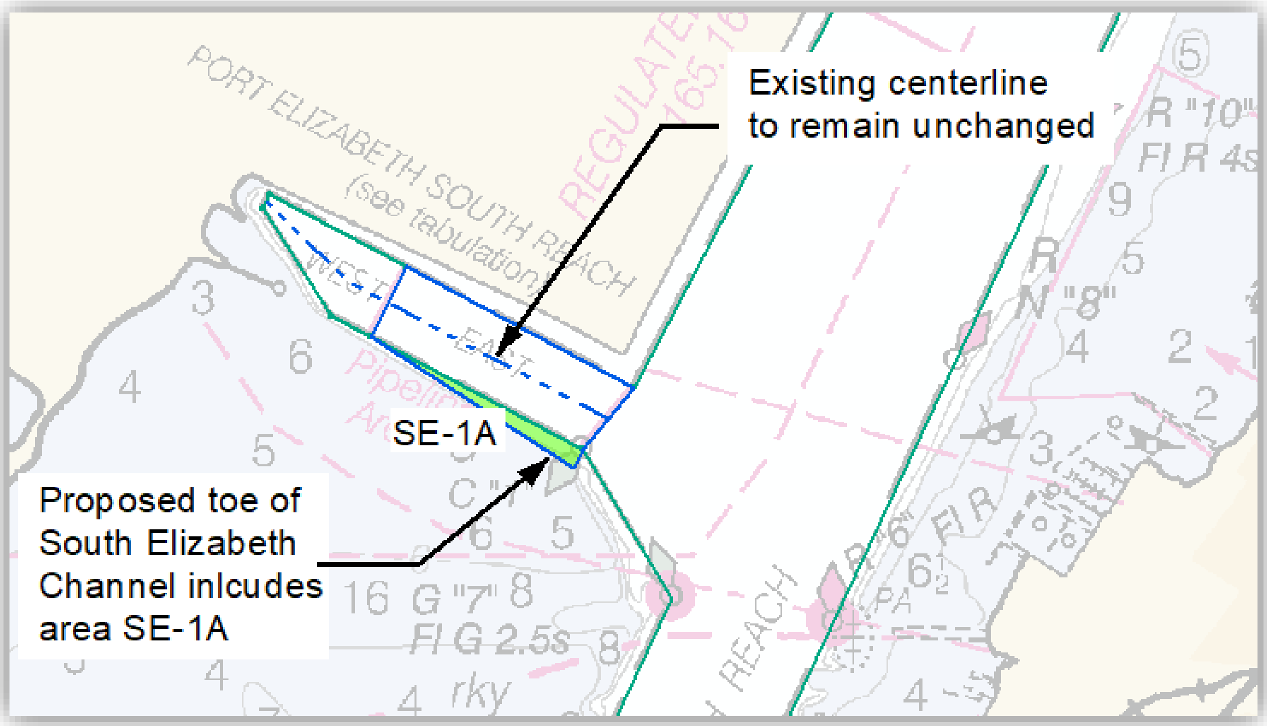

Figure 28. The Footprint of South Elizabeth Channel is Changed by the Addition of Area SE-1A; the Channel Centerline Remains Unchanged.

7.1.7. Port Elizabeth Channel

Port Elizabeth will be deepened by up to 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 that 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 13. Detailed volumes can be found in Attachments 3A and 3B of this appendix.

Table 13. Tentatively Selected Plan, Nominal Volumes

Channel	4 foot Deepening (CY)	5 foot Deepening (CY)
Ambrose Channel	4,137458	6,389,068
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	4,451,286
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 14. These estimates were calculated by simply multiplying the area of each proposed widening by the derived annual elevation change presented in Table 11, Deposition Volumes and Elevation Change. Increases in O&M dredging requirements resulting from the channel deepenings proposed here 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 14, 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 14. 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, 2017**				

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. USACE engineering documents require that planning studies and engineering designs evaluate the entire range of possible future rates of sea-level change, represented by three scenarios of "low", "intermediate", and "high" sea-level change (USACE 2013; USACE 2014).

The use of sea level change scenarios as opposed to individual scenario probabilities underscores the uncertainty in how local relative sea levels will actually play out into 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.

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), provide guidance on how to incorporate sea level change for civil works projects. 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.

SLC has been a persistent trend for decades in the United States and elsewhere in the world. 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).

8.2. Sea Level Change Analysis

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 29 and 30. Each figure notes the projected construction start dates for each site and the combined period of analysis for each possible deepening (2037 –2086 and 2039-2088 for deepening by 4 or 5 feet, respectively). There were no relevant SLC thresholds identified for the HDCI project.

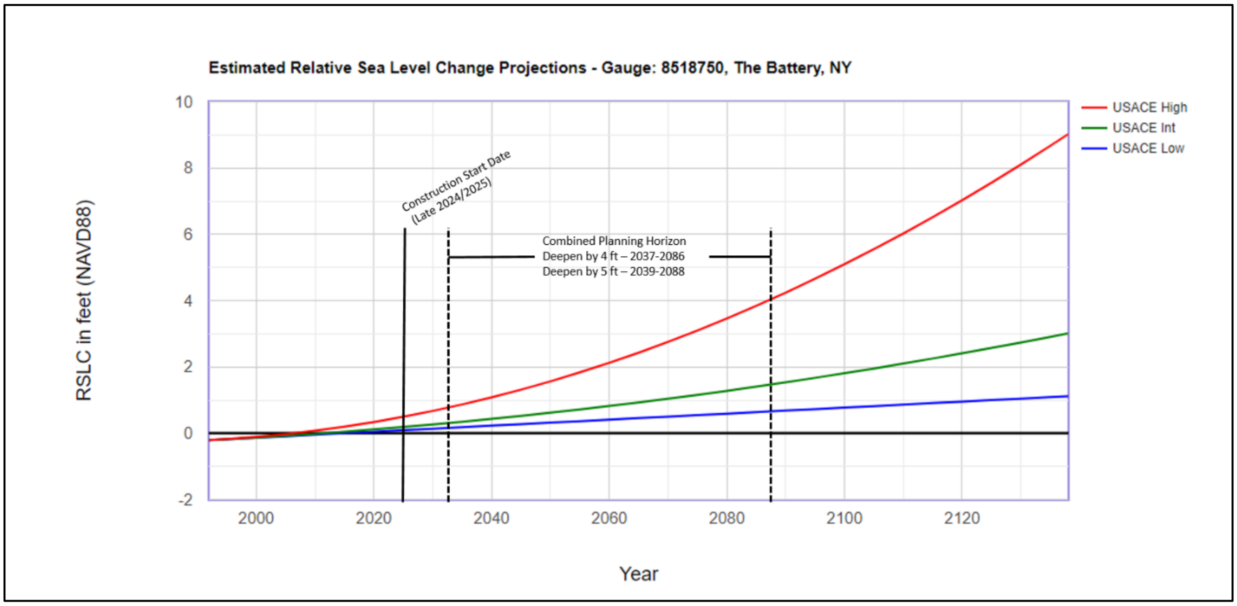

Figure 29. NOAA Gauge: The Battery, NY (#8518750) Relative Sea Level Change Projections, 1992-2138, with HDCI Construction Start Date and Planning Horizon.

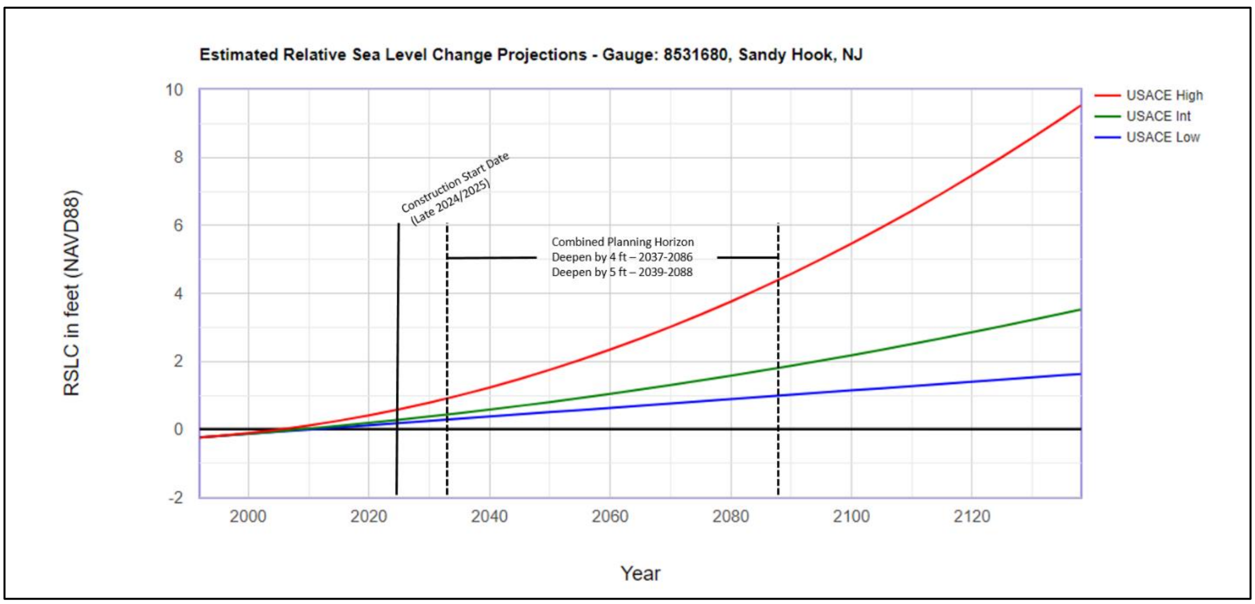

Figure 30. NOAA Gauge: Sandy Hook, NJ (#8518750) Relative Sea Level Change Projections, 1992-2138, with HDCI Construction Start Date and Planning Horizon.

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.

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. Current USACE guidance

(ER 1100-2-8162 and ETL 1100-2-1) requires planning studies to consider SLC in the development and assessment of planning alternatives. ETL 1100-2-1 recommends that analyses assess the effects of SLC on the project at three 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.

8.2.1. Tidal Datum Change Projections

Table 15 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 16 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), 2038, which represents the averaged year one for both possible deepenings and the years 2057, 2087, 2117 and 2137, which represent years 20, 50, 80 and 100 respectively.

Table 15. 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)			2038 (ft, NAVD88)			2057 (ft, NAVD88)		
		LOW	INT	HIGH	LOW	INT	HIGH	LOW	INT	HIGH
MHHW	2.28	2.58	2.68	2.98	2.70	2.89	3.48	2.87	3.25	4.44
MHW	1.96	2.26	2.36	2.66	2.38	2.57	3.16	2.55	2.93	4.12
MTL	-0.30	0.00	0.10	0.4	0.12	0.31	0.9	0.29	0.67	1.86
MLW	-2.57	-2.27	-2.17	-1.87	-2.15	-1.96	1.37	-1.98	-1.60	-0.41
MLLW	-2.77	-2.47	-2.37	-2.07	-2.35	-2.16	-1.57	-2.18	-1.80	-0,61
Datum	**1992**	**2087 (ft, NAVD88)**			**2117 (ft, NAVD88)**			**2137 (ft, NAVD88)**		
		LOW	INT	HIGH	LOW	INT	HIGH	LOW	INT	HIGH
MHHW	2.28	3.14	3.95	6.49	3.42	4.81	9.21	3.6	5.47	11.39
MHW	1.96	2.82	3.63	6.17	3.10	4.49	8.89	3.28	5.15	11.07
MTL	-0.30	0.56	1.37	3.91	0.84	2.23	6.63	1.02	2.89	8.81
MLW	-2.57	-1.71	-0.90	1.64	-1.43	-0.04	4.36	-1.25	0.62	6.54
MLLW	-2.77	-1.91	-1.50	-1.10	1.44	-0.24	4.16	-1.45	0.42	6.34

Table 16. 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)			2038 (ft, NAVD88)			2057 (ft, NAVD88)		
		LOW	INT	HIGH	LOW	INT	HIGH	LOW	INT	HIGH
MHHW	2.41	2.71	2.81	3.11	2.83	3.02	3.61	3.00	3.38	4.57
MHW	2.08	2.38	2.48	2.78	2.50	2.69	3.28	2.67	3.05	4.24
MTL	-0.27	0.03	0.13	0.43	0.15	0.34	0.93	0.32	0.70	1.89
MLW	-2.62	-2.32	-2.22	-1.92	-2.20	-2.01	-1.42	-2.03	-1.65	-0.46
MLLW	-2.82	-2.52	-2.42	-2.12	-2.40	-2.21	-1.62	-2.23	-1.85	-0.66

Datum	1992	2087 (ft, NAVD88)			2117 (ft, NAVD88)			2137 (ft, NAVD88)		
		LOW	INT	HIGH	LOW	INT	HIGH	LOW	INT	HIGH
MHHW	2.28	3.27	4.08	6.62	3.55	4.94	9.34	3.73	5.6	11.52
MHW	1.96	2.94	3.75	6.29	3.22	4.61	9.01	3.40	5.27	11.19
MTL	-0.30	0.59	1.40	3.94	0.87	2.26	6.66	1.05	2.92	8.84
MLW	-2.57	-1.76	-0.95	1.59	-1.48	-0.09	4.31	-1.30	0.57	6.49
MLLW	-2.77	-1.96	-1.15	1.39	-1.68	-0.29	4.11	-1.50	0.37	6.29

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. Suggested 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 provide high accuracy data that fully covers the entire area within the channels. Equally high resolution data for the channel walls and the flats and 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 publically 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 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 is also especially needed for the lower limits of proposed excavation and in certain areas of channel walls. Blasting from the previous deepening has left some material in place such that it can be easily broken and scraped with a back hoe rather than necessitate its being blasted again. Additional borings can identify these locations of looser material, potentially saving cost and environmental consequences. Additional geotechnical analysis is also needed. These considerations are more fully discussed in the Geotechnical Appendix (Appendix B2). These geotechnical considerations are a source of significant uncertainty and represent a significant cost risk to the present conclusions of this study.

9.3. 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. 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, 2017) 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. 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.

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. 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.

9.6. 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. 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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