BLUE HILL HARBOR
MAINE
NAVIGATION IMPROVEMENT PROJECT

APPENDIX C
ENGINEERING DESIGN

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Table of Contents

List of Tables and Figures

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1.0 Existing Conditions

The Town of Blue Hill, Maine is located on the western shore of Blue Hill Bay in Hancock County, Maine. The harbor is located about 30 miles south-southeast of Bangor and 13 miles southwest of Ellsworth. Blue Hill Harbor is located off the northwest end of Blue Hill bay just west-northeast of Long Island and due west of Union River Bay. The harbor is divided into three parts known locally as the outer, middle, and inner harbors. The outer harbor, situated southeast of Parker and Sculpin Points, has depths ranging from 24 to 48 feet and is exposed to easterly and southerly winds. The middle harbor has depths ranging from 6 to 30 feet and is well protected. The outer and middle harbors are connected by a deep natural channel between Parker and Sculpin Points. This channel has a width of about 150 feet and a controlling depth of 20 feet. The middle harbor connects to the inner harbor through a natural channel passing between Parker and Peters Points. This channel has a minimum width of 150 feet and controlling depth of 19 feet. The western half of the inner harbor shallow depths prevail, ranging from 6 feet to +3.5 feet at the Town Wharf. The mean range of the tide is 10.59 feet. At low tide the Town Wharf and docks are dry.

Blue Hill Harbor is home to a sizeable lobster fleet as well as numerous recreational craft and charter fishing boats, and other inshore and offshore commercial fishing craft. All of Blue Hill is served by two public landings, a fish pier, a marina, a boat club, and rental boat facilities. Much of the commercial fleet works year-round and shifts operations with the seasons due to available mooring space, active offloading and servicing facilities, and icing of portions of the harbor. In 2012, the Town of Blue Hill rehabilitated the central harbor wharf, which included a new crane as well as water and electricity service. The wharf improvements provide the facility with year-round support to the town's commercial fishing industry.

2.0 Field Explorations

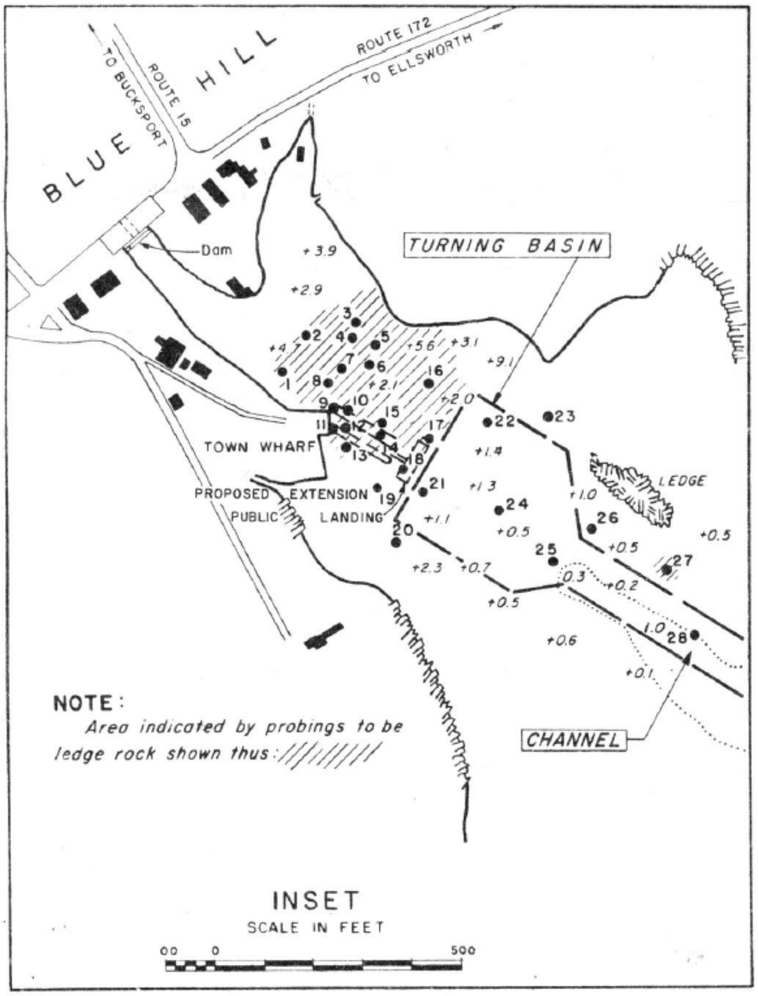
Field explorations included hydrographic surveys of the proposed dredge areas, subsurface explorations to delineate the area of ledge in the harbor and define the nature of the substrate at depth, and sediment sampling to determine the nature of the dredge material to evaluate potential disposal options. The information obtained from these field investigations was used to develop and evaluate alternative plans of improvement.

Hydrographic Surveys

A hydrographic survey of the project area conducted in 1951 was supplemented by a May 1970 hydrographic and topographic survey to lay-out and evaluate the proposed project and alternatives included in the 1972 detailed project report. A bathymetric survey of the proposed improvement area was conducted in 2012 and used to re-evaluate the project for this study. The results of the 2012 survey are shown on Attachment A.

Subsurface Explorations

In 1948 the U.S. Army Corps of Engineers conducted a hydrograph and topography survey of Central Blue Hill Harbor. Figure C-1 lists the probings with their results and locations. The probings were conducted with a 1-inch diameter pipe drive and an 8-pound hammer. The probings indicate that the inner harbor material was made up mostly of sand, gravel, looser rock and rock. The outer harbor material was made up of mostly sand and mud.



← TO SOUTH BLUE HILL

LIST OF PROBINGS

NUMBER *	ELEVATIONS GROUND	ELEVATIONS LIMIT OF PROBING	MATERIAL
1	+ 2.6	+ 1.9	Sand, Gravel, Loose Rocks, Rock
2	+ 2.7	- 0.4	" " " " "
3	+ 2.6	+ 0.3	" " " " "
4	+ 2.5	+ 0.3	" " " " "
5	+ 2.9	+ 1.4	" " " " "
6	+ 2.0	- 2.5	" " " " "
7	+ 2.3	- 0.7	" " " " "
8	+ 2.4	- 0.1	" " " " "
9	+ 2.3	+ 0.7	" " " " "
10	+ 2.1	+ 0.6	" " " " "
11	+ 2.9	- 5.6	" " " " "
12	+ 2.2	- 0.3	" " " " "
13	+ 1.8	- 4.8	" " " " "
14	+ 1.6	- 4.3	" " " " "
15	+ 1.6	- 4.1	" " " " "
16	+ 3.0	- 3.1	Gravel, Stones, Rock
17	+ 1.2	- 0.9	" " "
18	+ 1.5	- 6.1	Sand, Gravel, Stones
19	+ 0.6	- 6.8	Gravel, Stones, Rock
20	+ 1.5	- 7.8	Medium Packed Sand, Clay, Gravel
21	+ 1.4	- 5.4	" " " " "
22	+ 1.2	- 8.1	Hard " " " "
23	+ 1.8	- 7.8	Hard Packed Sand And Clay
24	+ 1.4	- 8.0	Medium Packed Sandy Clay
25	+ 0.7	- 8.3	Sand, Clay, Mud
26	+ 0.8	- 8.1	Sand, Clay, Light Gravel, Hard Packed
27	+ 0.4	- 4.1	Sand, Clay, Gravel, Rock
28	- 0.0	- 8.0	Sand, Clay, Mud
29	- 0.2	- 8.5	" " "
30	- 0.1	- 8.1	" " "
31	- 0.0	- 9.8	Mud
32	- 0.2	- 9.5	"
33	- 0.2	- 9.2	"
34	- 0.6	- 9.4	"
35	- 0.6	- 9.2	"
36	- 1.0	- 9.3	"
37	- 0.5	- 9.2	"
38	- 0.4	- 8.6	"
39	- 1.4	- 8.7	"
40	- 0.3	- 8.5	"
41	+ 0.1	8.6	"
42	- 2.0	- 8.2	"
43	- 2.6	- 8.5	"
44	- 5.4	- 8.5	"
45	- 1.9	- 8.6	"

** Probings are as shown on Map File No 1045 D-6-2, but are given new key numbers. Map not published.*

Figure C-1 - 1948 Probes

The U.S. Army Corps of Engineers (USACE) went out October 23, 2015 to collect sediment vibracores from seven locations throughout the proposed dredging area identified as Stations A through G on Figure C-2.

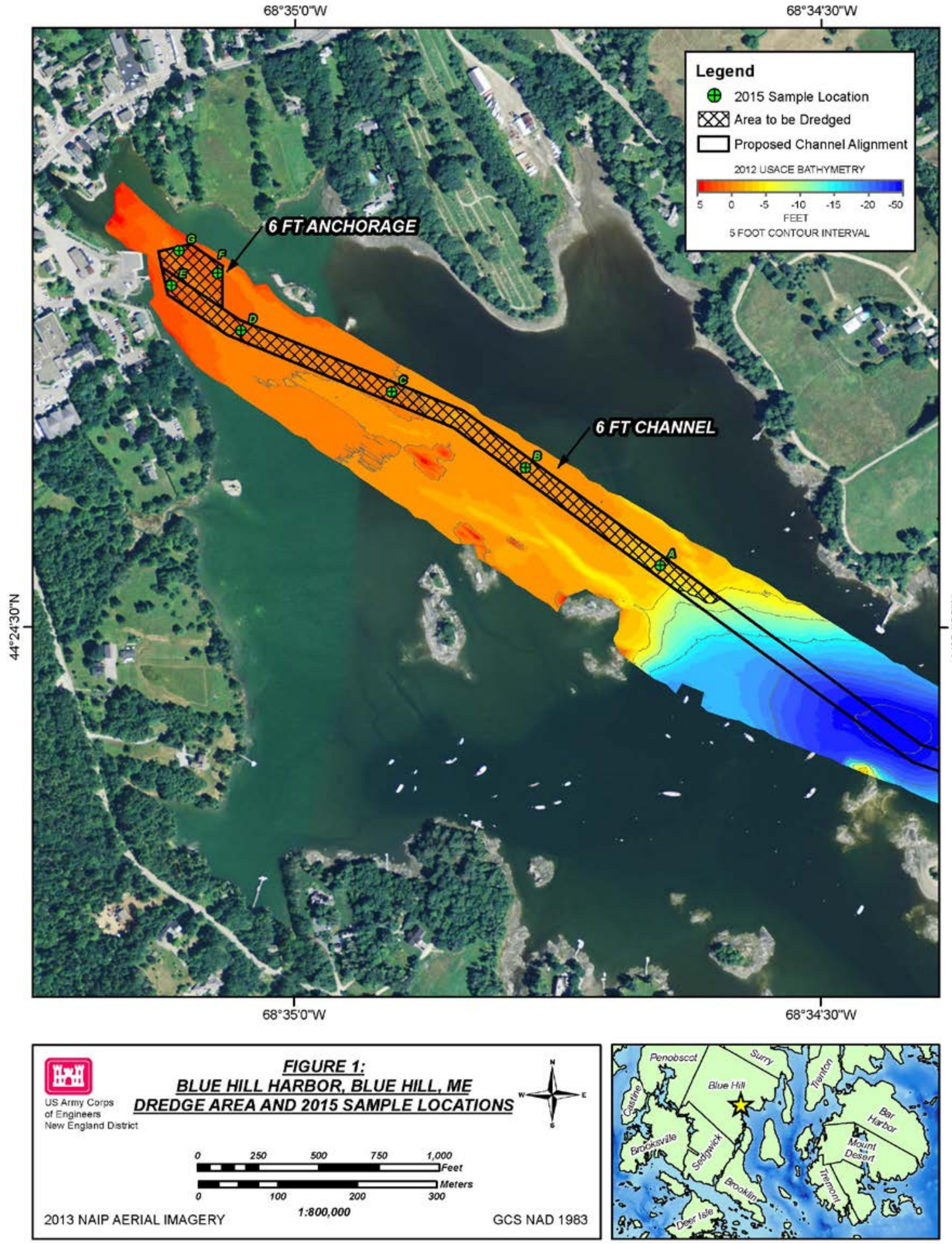


Figure C-2 - 2015 Sampling Locations

Core penetration at the inner harbor stations (D, E, F, and G) was limited due to gravel and sand deposits near the sediment surface and was 2.0 feet or less at Stations D, F, and G. Due to the inability to penetrate inner harbor sediments to the design depth and determine the vertical extent of the elevated PAH levels, the Town of Blue Hill dug four test pits in October 2016 (Figure C-3). The Town's contractor placed timber mats across the harbor at low tide and used an excavator to dig 4 to 9-foot-deep test pits at predetermined locations. USACE personnel were on-site to describe the lithology of the pit walls and subsample the sediment in two-foot horizons for PAH analysis. Results from this analysis are presented in Appendix F and show the extent of PAH contamination is limited to the upper two feet of the harbor sediments.

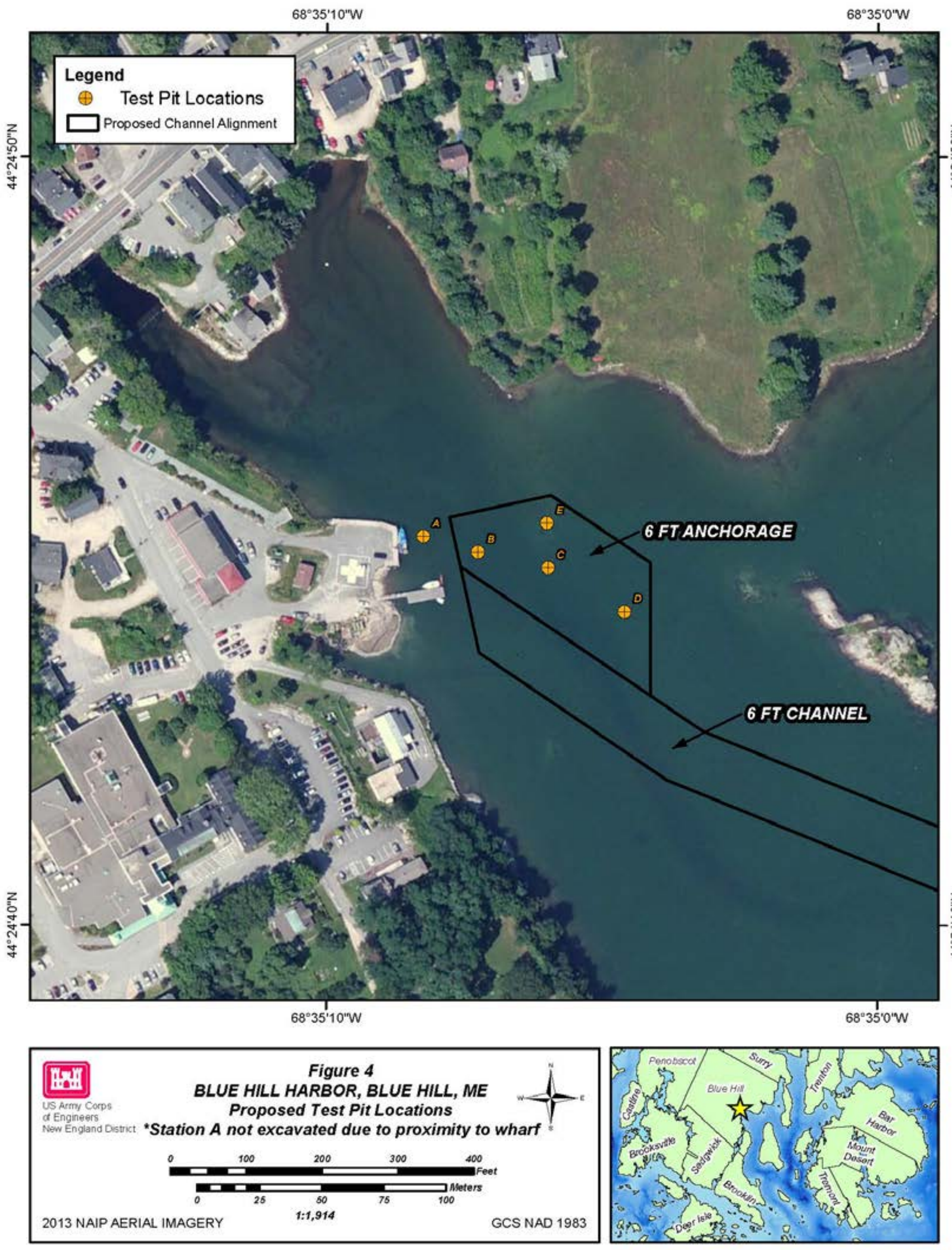


Figure C-3 - 2016 Test Pit Locations

Sediment Sampling and Analysis

During the October 23, 2016 sampling event, USACE personnel described each sediment core in the field and composited the length of each individual core for analysis of grain size, total solids, and water content. Additionally, USACE composited the core samples according to the plan outlined in the SAP for chemical analysis of the contaminants of concern (COC). Grain size results are presented in Table C-1. For more information on the chemical analysis, refer to Appendix F.

Table C-1 - Grain Size Analysis

Sample ID	% Cobble	% Gravel	% Coarse Sand	% Medium Sand	% Fine Sand	% Total Fines	% Moisture
A	0.1 (U)	0.1	2.2	6.6	21.6	69.5	55.3
B	0.1 (U)	0.1 (U)	1.7	3.5	7.4	87.4	51.2
C	0.1 (U)	1.1	1.9	4.9	12.1	80	54.5
D	0.1 (U)	4.4	13.2	34.8	35	12.6	19.6
E	0.1 (U)	1.8	8.8	26.7	37.9	24.8	33.2
F	0.1 (U)	5	14	30.6	29.8	20.6	26.8
G	0.1 (U)	45.9	12.4	16.7	16.2	8.8	21.4
U = Non-detected analytes are reported as the RL and qualified with a “U”.							

These samples indicate that the unconsolidated materials (non-ledge) in the proposed improvement areas consist of clayey silts, sands, and silty sands with the exception of the small area of ledge found in the proposed 8-foot area, all materials within the areas proposed for dredging are expected to be removable by a typical mechanical bucket dredge.

3.0 Channel and Turning Basin Design

The existing commercial fleet consists of 50 boats. The design vessel used for the channel design has a 5-foot draft, 40-foot length, and a 14-foot beam.

Channel Width

Until 2006, the U.S. Army Corps of Engineers channel design focused on dividing the channel into a maneuvering lane and a bank clearance lane. Appropriate widths were determined for each lane separately. However, the Engineering Manual, EM 1110-2-1613 was updated in 2006 and suggests this method is no longer appropriate. Rather than break the channel into separate lanes, the Corps now focuses on the channel as a whole. The new method states that the total channel width calculations should incorporate six factors: traffic pattern (one-way or two-way), design ship beam length, channel cross section shape, current speed and direction, quality and accuracy of aids to navigation, and variability of channel and currents. In a harbor with this volume of traffic and boats entering and leaving the channel at the same time of day, design for two-way traffic is essential. The width of a channel is measured at the design depth between the bottoms of the side slopes. This channel is considered to be a "trench" type channel, as opposed to a canal or shallow type channel. The passing of two powered vessels in a generally open waterway with adequate safe clearance between them, and between each boat and the channel boundary or bank, would require a width of about 4 to 6 times the vessel beam. With the largest boats having a beam of 14 feet, this equates to a channel width of about 80 feet. See EM Table 8-3 below.

EM 1110-2-1613 (dated 31 May 06)
Table 8-3 Two-Way Ship Traffic Channel Width Design Criteria

	Design Ship Beam Multipliers for Maximum Current, Knots		
	0.0 to 0.5	0.5 to 1.5	1.5 to 3.0
Channel Cross Section - Constant Cross Section, Best Aids to Navigation			
Shallow	5.00	6.00	8.00
Canal	4.00	4.50	5.50
Trench	4.50	5.50	6.00

Applying these factors for Blue Hill, ME resulted in the following channel design.

	Vessel Beam (ft)	x	Factor	=	Channel Width (feet)
Trench	14		5.50		77

"Approach Channels: A Guide for Design", a June 1997 report for the Permanent International Association of Navigation Congresses (PIANC) provided another method for determining channel width. This approach was deemed slightly more conservative than the EM 1110-2-1613 approach discussed above. However, due to the location of Blue Hill Harbor and the protection provided within the inner harbor, the EM-1110-2-1613 approach is satisfactory.

Channel Depth

Channel depth "should be adequate to safely accommodate ships with the deepest drafts expected to use the waterway" according to the EM 1110-2-1613. This statement not only addresses the physical characteristics of the design vessels, but the future use economic projection. The physical concerns include the draft of the vessel and its operability when underway. Vessels will ride deeper in the water than when at berth. The term for this is "squat." Ships are also impacted by the wave conditions and tend to roll, pitch, or heave. The EM provides technical guidance related to design depth for larger commercial vessels. The Blue Hill Harbor fleet is relatively small and protected within the inner harbor. Therefore, a channel depth between 5 and 8 feet was analyzed with 1-foot of over depth taken into consideration.

Channel Turn Configuration

In order to avoid ledge outcrops within the harbor, the channel alignment required a few turns rather than a straight line to the outer harbor. An initial design for a channel turn can be developed from the factors used in Table 8-4 of the EM. These factors are derived from empirical tests and serve as a starting point for the channel turn configurations and are presented below in Table 8-4.

EM 1110-2-1613 (dated 31 May 06)
Table 8-4 Recommended Channel Turn Configurations

Defection Angle, Deg	Ratio of Turn Radius/Ship Length	Turn Width Increase Factor (*Ship Beam)	Turn Type
0-10	0	0	Angle
10-25	3-5	2.0-1.0	Cutoff
25-35	5-7	1.0-0.7	Apex
35-50	7-10	0.7-0.5	Curved
>50	>10	0.5	Circle

The only deflection angle for the inner harbor design greater than 10 is 13.85 degrees and the ratio of turn radius/ship length is 4.5 at that point. Therefore, there was an additional 70 feet added to the channel width (turning area only) to allow for a safe cutoff turn within in the channel.

Turning Basin

The EM also provides guidance for turning basins in deep draft navigation projects. The EM recommends providing a turning basin 1.2-1.5 larger than the channel width. However, because this is not a deep draft project and taking into consideration the needs of the town, the proposed turning basin is 160 feet long and 80 feet.’ wide, shown on Attachment A.

4.0 Quantity Estimates

Quantities of material to be dredged from the proposed navigation improvement area were calculated by comparing the existing bottom surface defined by the hydrographic surveys and subsurface explorations to a design bottom surface with side slopes of 1 vertical to 3 horizontal. The data was imported into a MicroStation file and through the InRoads program, a digital terrain model was created for both the existing surface and the design surface. The amount of material to be dredged was then calculated by comparing the two surfaces. A one-foot allowable over depth was calculated for ordinary material to account for dredging tolerance. Table C-2 is a summary of that work.

Table C-2 - Channel Quantities

Channel Quantities and Areas							
	Area (SF)	Required Depth (Feet)	Required Depth Suitable Quantity (CY)	Over-Depth Quantity (CY)	Total Quantity (normal material + over depth), CY)	Contaminated Quantity (Upper 2 Feet) (CY)	Total Material to be Removed (CY)
Plan A	309,970	5	37,979	11,850	49,829	10,591	60,420
Plan B	326,700	6	49,829	12,530	62,359	10,591	72,950
Plan C	346,810	7	62,359	13,220	75,579	10,591	86,170
Plan D	367,490	8	75,579	24,516	100,095	10,591	110,686
*If 9 feet of material are dredged due to 1-foot of over depth, the area to be dredged rises to 389,670 ft^2.							
Revised Plan B with Modified Channel Bend Width							
Plan B		6	48,650	12,250	60,900	10,600	71,500

5.0 CAD Cell for Contaminated Material

Results from the sediment analysis are presented in Appendix F and show the extent of PAH contamination is limited to the upper two feet of the harbor sediments, which is approximately 10,600 cubic yards of material. This information prompted the team to design a 525-foot by 150-foot CAD cell (bottom footprint is 470 feet by 140 feet) to relocate and consolidate the contaminated material. The CAD cell depth design is -9 feet MLLW and the top of the 3-foot wide cap will be -2-feet MLLW. Due to the limits of the 2012 bathymetric survey, the existing surface to be dredged to accommodate the CAD cell was estimated to be -2 feet MLLW. The quantity of material to be removed to create the CAD cell is approximately 19,500 cubic yards. Refer to Attachment A for CAD cell placement within Blue Hill Harbor.

6.0 Disposal Area

Knowledge of the nature of the material to be removed and the quantity of material enables an examination of potential disposal alternatives for the dredged material. The mixed nature of the dredged material, including cobbles, sands, silt and clay, the potential for small boulders, make use of a cutterhead pipeline dredge or other form of hydraulic plant such as a hopper dredge, impractical. The distance from shore to the dredge areas precludes use of a land-based dragline. Use of a barge-mounted bucket dredge and scows is the only feasible option for removal of the material.

A potential new site was investigated in State waters close to Bass Harbor near the mouth of Blue Hill Bay in the Eastern Passage. The site in the Eastern Passage is located about 6 miles from Bass Harbor in about 330 feet of water. The site in the Eastern Passage is close enough to Blue Hill to enable the work to be completed within the allowable dredging and disposal window in a single dredging season with only one scow.

7.0 Future Maintenance Costs

Project annual costs must include an annualized estimate of the cost of maintaining the project over the period of analysis. Since the proposed project is limited to dredging, the only annual maintenance cost is periodic maintenance dredging of the improved areas to their recommended depth. It is estimated that maintenance dredging of the improved areas would be required once during the project life, if at all. For purposes of this study, an annual shoaling rate of 0.5 percent has been incorporated into the annual cost of the alternatives.

8.0 Sea Level Change Analysis

Based on ER 1100-2-8162 and EP 1100-2-1, USACE studies must consider future rates of sea level change (SLC) to account for the potential impacts of climate change. Due to the uncertainty associated with future sea level change, USACE policy is to look at three scenarios of sea level change and investigate impacts to project feasibility. The three sea level change scenarios are illustrated by curves representing the low (historic) rate of SLC at the project site, an intermediate rate (modified NRC Curve I), and a high rate of SLC (modified NRC Curve III). All three local SLC curves include the global (eustatic) sea level rise rate (approximately 1.7 mm/year) as well as vertical land movement. These rates were calculated using the USACE Sea Level Change Calculator (Version 2019.21) (https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html). The tool uses the closest NOAA tide station with an adequately long water level record to determine the historical trend. The historical trend is then used with a formulation provided in the EP to determine the intermediate and high rates of change.

The Bar Harbor, ME station (NOAA 8413320) was used to approximate changes in sea level rise for Blue Hill Harbor from 2022 to 2122. This time range includes both anticipated project economic life and the planning horizon. The historic rate of sea level rise at Bar Harbor is 0.00742 feet/year (1947 to 2019). Sea level is expected to rise between 0.59 feet and 2.97 feet by 2072 and between 0.96 feet and 7.23 feet by 2122 from the 1992 midpoint of the present National Tidal Datum Epoch (1983-2001). Sea level change for each of the three scenarios is presented in Figure C-4 and Table C-3.

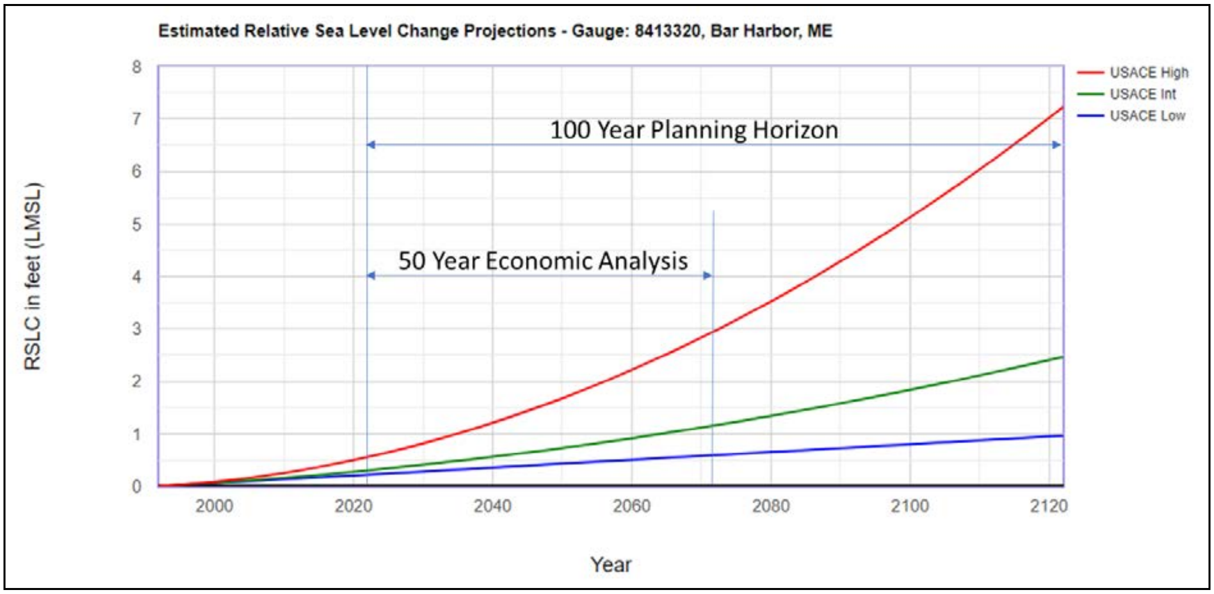


Figure C-4. Sea Level Change Projections at Bar Harbor, ME

Table C-3. USACE Sea Level Change Rates – Future Scenarios

Year	Low RSLC (Feet)	Intermediate RSLC (Feet)	High RSLC (Feet)
2072	0.59	1.16	2.97
2122	0.96	2.47	7.23
Note: Sea level change values are relative to the base year of 1992 which corresponds to the midpoint of the current National Tidal Datum Epoch of 1983-2001			

Increases in sea level will deepen the existing channel and proposed improvements, resulting in safer vessel transits with greater under-keel clearance. However, sea level change is expected to impact landside infrastructure on or access to the town wharf over time. To assess the wharf’s vulnerability to sea level change, projected changes in sea level were added to existing water levels to evaluate if sea level rise will impact landslide infrastructure on or access to the wharf over the project’s 50-year economic life and the 100-year planning horizon. Mean Higher High Water (MHHW) was selected to evaluate high water levels that are projected to occur daily. The 99% Annual Exceedance Probability (AEP) (1-year Annual Recurrence Interval) storm surge at Mean High Water (MHW) was used to approximate an annual storm event or nor’easter. The MHHW and 99% AEP surge at MHW levels for the years 2072 and 2172 are provided in Table C-4 for each scenario.

Table C-4. Projected Water Surface Elevations – Future Scenarios

Year	Scenario	MHHW (FT, NAVD88)	99% AEP Surge at MHW (FT, NAVD88)
2072	Low	5.93	7.42
	Intermediate	6.50	7.99
	High	8.31	9.80
2122	Low	6.30	7.79
	Intermediate	7.81	9.30
	High	12.57	14.06

The town wharf, situated at the head of the harbor, consists of a pile bulkhead on its north and east sides, boat ramp, floating dock, and parking. The wharf and bulkhead elevations are approximately 8 feet NAVD88 (13.8 feet MLLW). As shown in the oblique imagery in Figure C-5 and the topographic LiDAR surface in Figure C-6, the wharf is lower in elevation than Water Street, from which it can be accessed by two routes. The wharf elevation is highest at its northern end where parking is available landward of the bulkhead. The parking area to the south, adjacent to the boat ramp, is approximately 1-foot lower and is more susceptible to inundation by high water levels.

Figure C-5. Oblique Imagery of Town Wharf

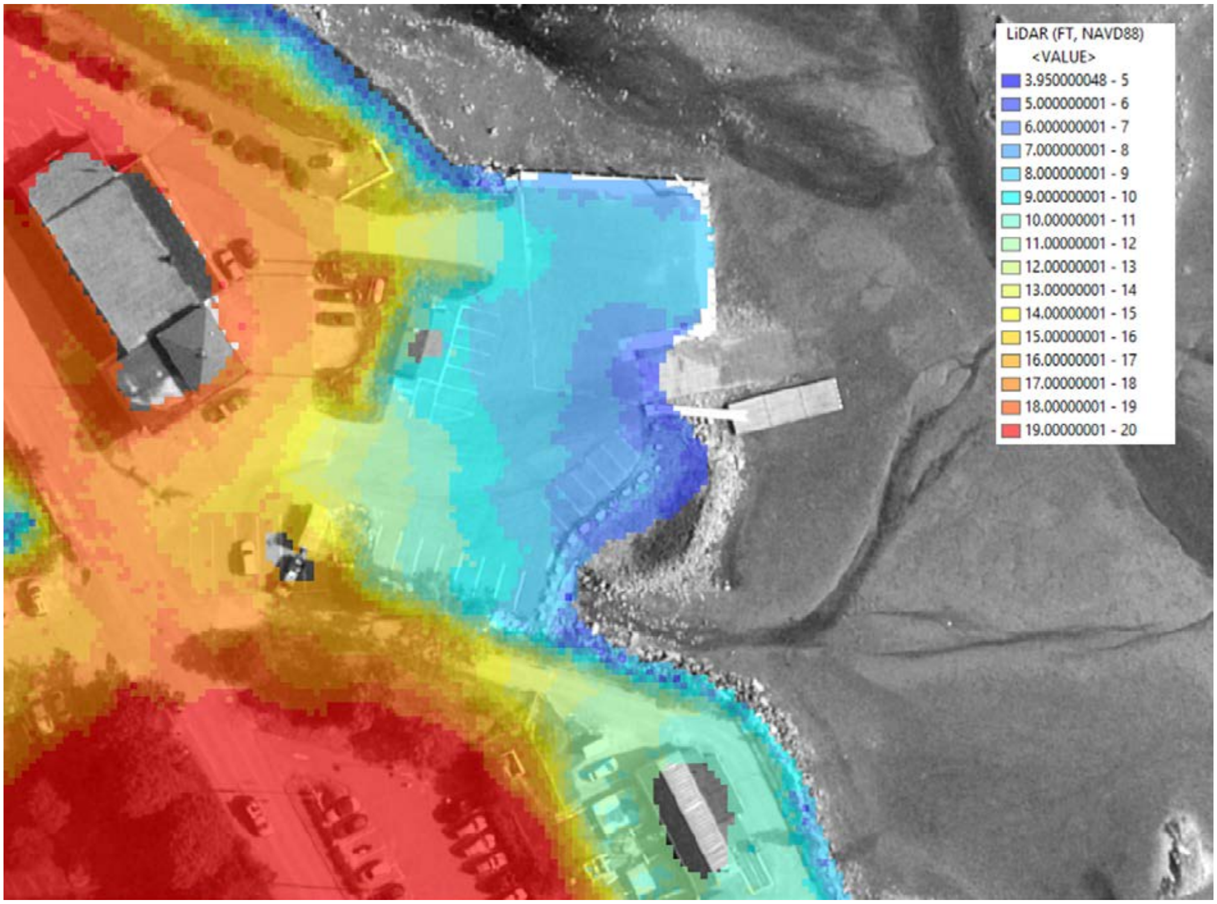


Figure C-6. Topographic LiDAR Coverage of Town Wharf

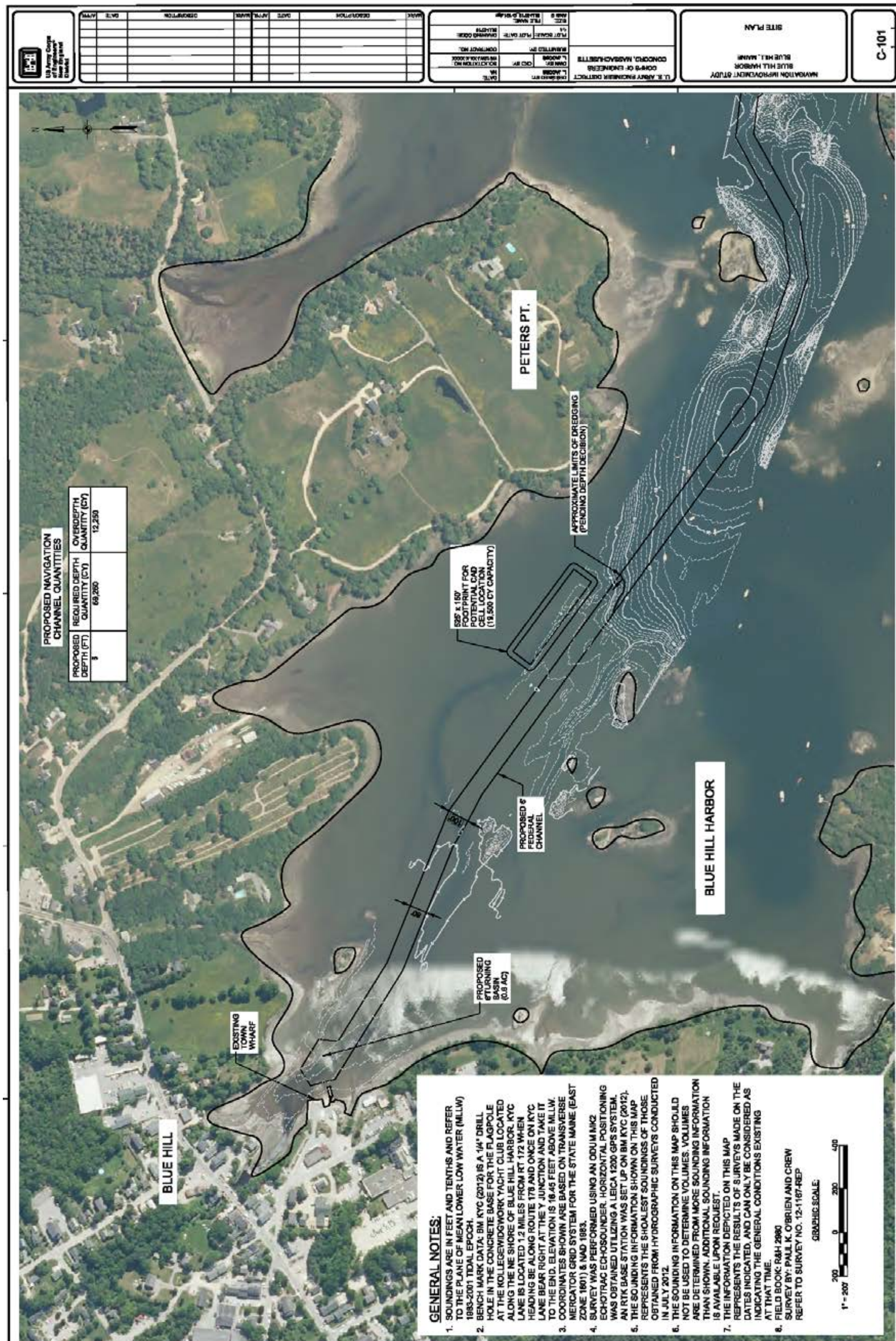
A comparison of the wharf elevation, approximately 8 feet NAVD88 (13.8 feet MLLW), to the projected water levels in Table C-4 shows that the wharf is not projected to be impacted by MHHW alone under the low and intermediate SLC scenarios through 2072. However, wharf access will be affected under the high SLC scenario as MHHW is projected to exceed the wharf elevation at the tail end of the 50-year period of economic analysis in 2068. The 2072 MHHW lines for the three SLC scenarios are shown in Figure C-7.

Figure C-7. MHHW Inundation Limits for 2072 SLC Scenarios

Looking out to 2122, the wharf will again not be exceeded by MHHW alone under the low and intermediate SLC scenarios. However, as shown in Figure C-8, the inundation at MHHW under the high SLC scenario will make the entirety of the town wharf inaccessible. If a higher sea level scenario is realized, the town will need to make improvements to the wharf area to maintain its access across the tidal cycle.

Figure C-8. MHHW Inundation Limits for 2122 SLC Scenarios

Attachment A – Recommended Plan



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