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Glossary

bpf	Blows per foot
ft.	Feet.
in.	Inches
MHHW	Mean Higher High Water
MLLW	Mean Lower Low Water
N	Standard penetration distance
NAVD	North American Vertical Datum of 1988
OC	On Center
ODBC	Old Dominion Boat Club
Pt.	Point
psf	Pounds per square foot
$	United States Dollar(s)
USACE	U.S. Army Corps of Engineers
WSAP	Waterfront Small Area Plan

Executive Summary

The City of Alexandria is moving forward with the implementation of flood mitigation measures along the City's waterfront to minimize recurrent nuisance flooding. One flood mitigation measure is the construction of a new bulkhead with elevated walkway. The new bulkhead and elevated walkway will have a minimum elevation of 6 feet NAVD and span two segments of the waterfront. The south segment will extend from Point Lumley to the Torpedo Factory while the north segment spans the shoreline between the Commercial Docks at the City Marina to Founders Park.

A preliminary bulkhead design was developed during the schematic phase of the Waterfront Small Area Plan (WSAP) based on design criteria that included a 50-year service life, surcharge loads for vehicular and pedestrian uses, anchoring setbacks less than 40 feet from the shoreline and operational considerations for transient boating. A steel sheet pile bulkhead anchored with a continuous steel sheet pile deadman system was proposed based on a limited geotechnical investigation.

This evaluation was performed to update the preliminary bulkhead design based on new field investigations including topographic and bathymetric surveys and more detailed geotechnical investigations. Several anchoring systems were evaluated to restrain the steel sheet pile bulkhead including tie-rod and steel deadman systems, soil anchors and batter piles. The recommended bulkhead to advance to the preliminary design for the north segment is a batter pile bulkhead based on physical constrains associated with upland infrastructure and soil conditions. A batter pile bulkhead is also the recommended bulkhead design for the south segment; Point Lumley to the Torpedo Factory. A bulkhead retained by soil anchors may be utilized between the new ODBC site and King Street/IFS Park if unforeseen geotechnical or construction conditions are encountered.

1. Introduction

Nuisance flooding of Lower King Street, segments of North and South Union Street, and Strand Street have plagued the City of Alexandria (City) for many years, resulting in property damage and disruption of business. The nuisance flooding in these areas is primarily caused by elevated tide levels on the Potomac River backing up through existing storm sewer outfalls within low lying areas (< elevation 4 ft. NAVD) along the shoreline. Flooding from rainfall events also contribute to the nuisance flooding when higher river levels prevent water from draining through storm sewer inlets.

The City conducted an initial flood assessment in 2007 that evaluated three discrete flood events; nuisance flooding (elevation 4 ft. NAVD), intermediate flooding (elevation 8 ft. NAVD), and extreme flooding (elevation 10.2 ft. NAVD). A fourth studied flood event (elevation 6 ft. NAVD) was added during the initial mitigation strategy development. The report identified the frequency of occurrence (return period) of these studied flood events as shown in Table 1. Potential mitigation strategies were identified and summarized in terms of benefit and cost.

TABLE 1: STUDIED FLOOD EVENTS

Flood Event	Elevation (ft. NAVD)	Return Period (years)
Nuisance	4.0	1.5
6-ft. Flood (Elevated Walkway Alternative)	6.0	10
Intermediate	8.0	30
Extreme	10.2	100

In 2010, a follow up study was conducted to identify and rank flood mitigation measures for further consideration, with the goal of selecting a preferred mitigation measure. The outcome of the study were recommendations for implementation of several mitigation measures along the Alexandria waterfront, with an elevated walkway with integrated bulkhead recommended to protect the shoreline between Duke and Queen Streets. The top elevation of the elevated walkway was identified as 6 ft. NAVD; the maximum practical height based on topographic constraints. At this top elevation, the elevated walkway/bulkhead alternative mitigates frequent nuisance flooding.

Schematic design of the bulkhead component of the elevated walkway alternative was then performed in conjunction with the planning and design effort associated with implementation of the City's WSAP in 2014. A preliminary bulkhead alignment was identified and typical bulkhead sections were developed based on the WSAP program, the physical, environmental and regulatory constraints of the project site, and operation and maintenance requirements for the City.

This report discusses the outcome of an evaluation to refine the typical bulkhead alignment and sections shown in the schematic design phase documents based on more detailed field investigations.

2. Bulkhead Alignment

The deck elevation of the promenade in front of the Torpedo Factory and City Marina's Commercial Docks is approximately 7 ft. NAVD. Two bulkheads (concrete and steel sheet pile) define the edge of the promenade from the Torpedo Factory to the Commercial Docks and have assumed cap elevation between 6 feet and 7 feet NAVD based on available information from previous studies conducted by the City. The new bulkhead will be constructed in two segments between Duke and Queen Streets to connect to these existing bulkheads. One segment (south segment) extends from Pt. Lumley to the Torpedo Factory, a distance of approximately 1,185 ft. The second segment (north segment) extends 548 ft. from the Commercial Docks at the City Marina to the southeast corner of Founders Park.

The bulkhead alignment of the south segment was selected to provide a linear promenade along the shoreline, minimize conflicts between existing infrastructure/trees, and forego the need to remove existing shoreline structures. The new south shoreline will be, on average, 15 ft. riverward of the existing shoreline except at Waterfront Park, where the new bulkhead will be placed within 18 in. seaward of the existing bulkhead. Figure 1 shows the proposed alignment with respect to the existing shoreline features and the USACE regulatory bulkhead line. The proposed alignment of the south segment is referenced to the proposed buildout of upland and waterside infrastructure associated with WSAP as shown in Figure 2. Areas of shoreline excavation or fill placement to facilitate the new bulkhead are also highlighted in Figure 2. The proposed bulkhead will tie into the existing bulkhead on the north side of the peninsula at Pt. Lumley Park, which has a cap elevation of approximately 5 ft. NAVD. The Robinson Terminal South development to the south of Pt. Lumley Park has site grades higher than 6 ft. NAVD. Grading of the upland areas in Pt. Lumley Park will be performed to match the adjacent development and will provide closure to the flood protection provided by the bulkhead at this location.

The alignment of the bulkhead on the north segment was primarily based on providing sufficient land to support the planned pump station associated with the flood mitigation project and the extension of the promenade to Founders Park as shown in Figures 3 and 4. The existing bulkhead in front of the Charthouse Restaurant has a cap elevation of 4 ft. NAVD based on available surveys and studies conducted by the City and needs to be raised by 2 ft. to provide flood protection. There is insufficient room to raise the existing bulkhead in its present alignment and support the promenade. A new bulkhead will be placed along the riverside face of the fixed pier that parallels the bulkhead in this area. To the north of the restaurant, the bulkhead alignment extends into the river bisecting Pier E/F of the City Marina before meeting the existing bulkhead alignment at Pier G/H of the City Marina. The bulkhead alignment in this segment is, on average, 50 ft. riverward of the existing shoreline. The alignment of bulkhead from Pier G/H to Founders Park is based on program requirements identified in the WSAP. Figure 4 indicates the areas to be filled to support the new bulkhead.

BULKHEAD ALIGNMENT SOUTH SEGMENT - EXISTING CONDITIONS

LEGEND

- EXISTING BULKHEAD LINE (FROM USACE)
- EXISTING PIERHEAD LINE (FROM USACE)
- PROPOSED BULKHEAD (1185 LINEAR FEET)

40' 0' 40' 80'
SCALE: 1"=80'

FIGURE 1

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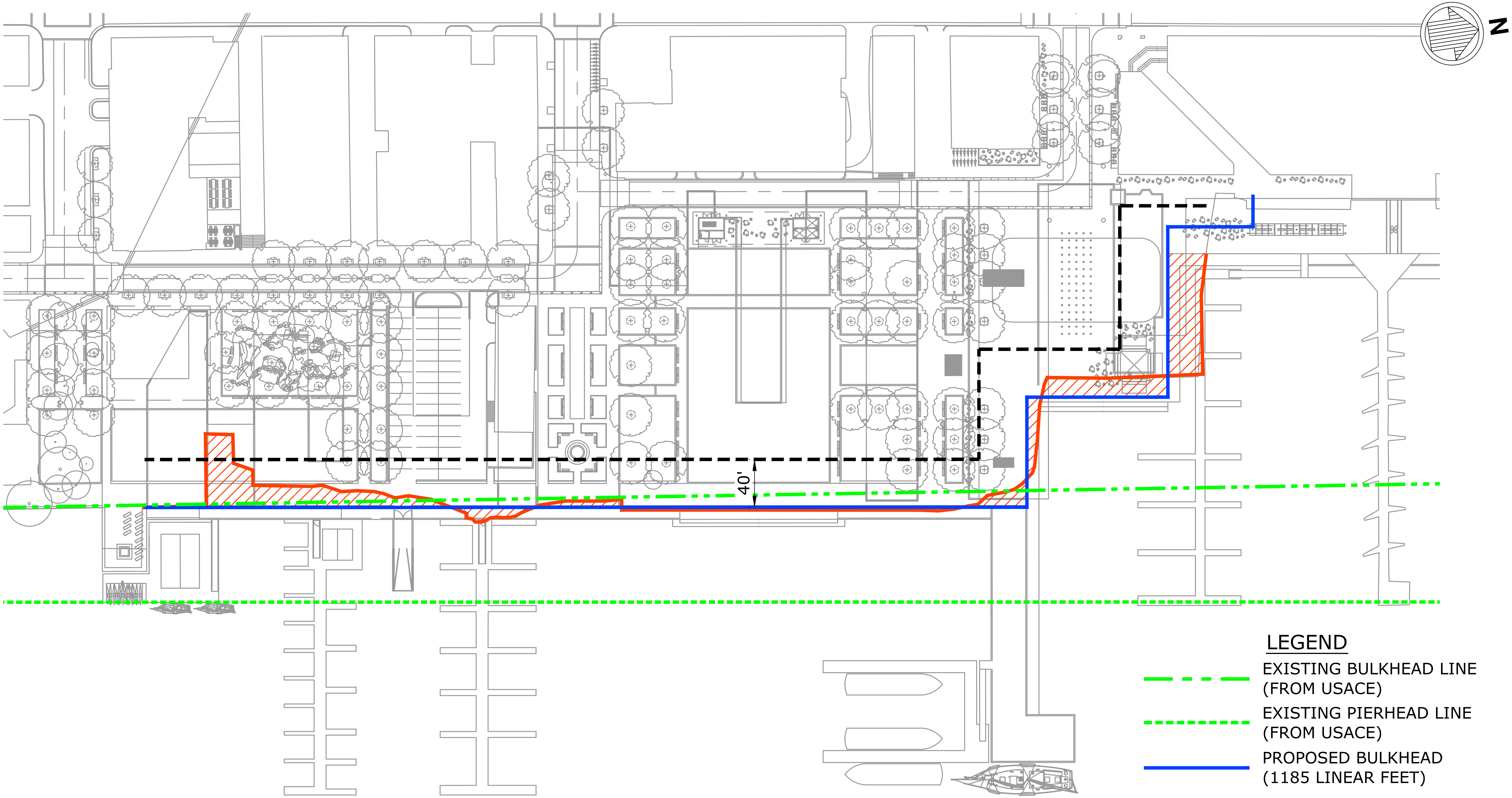
Q:\RA\9340\CADD_ACTIVE_EXHIBITS\FIGURE-1.DWG



LEGEND

- EXISTING BULKHEAD LINE (FROM USACE)
- EXISTING PIERHEAD LINE (FROM USACE)
- PROPOSED BULKHEAD (1185 LINEAR FEET)
- EXISTING SHORELINE
- APPROXIMATE EASEMENT
- FILL OR EXCAVATION

BULKHEAD ALIGNMENT SOUTH SEGMENT - WSAP INFRASTRUCTURE

FIGURE 2

40' 0' 40' 80'
SCALE: 1''=80'

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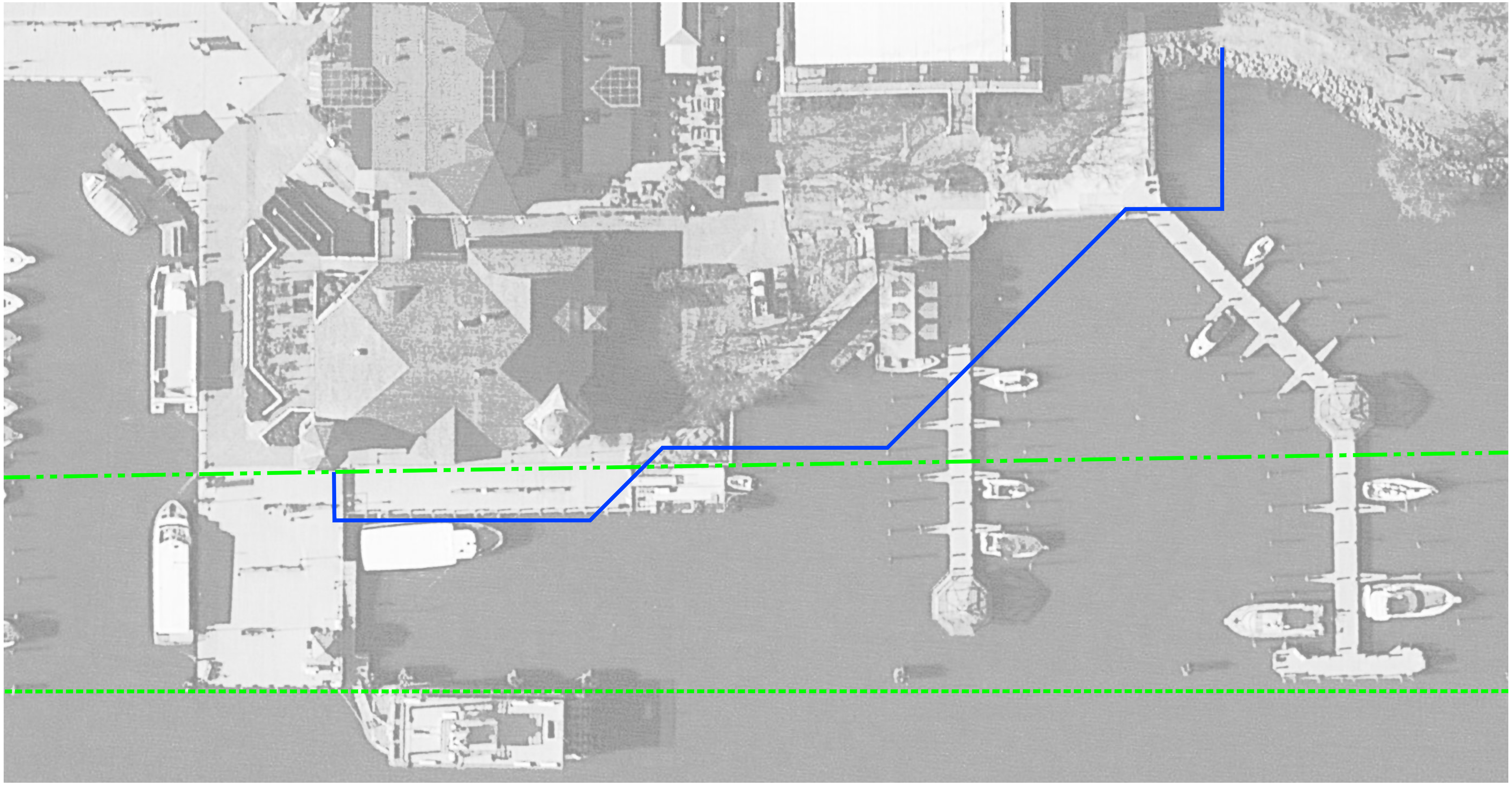
Q:\RA\9340\CADD_ACTIVE_EXHIBITS\FIGURE-2.DWG

N



BULKHEAD ALIGNMENT NORTH SEGMENT - EXISTING CONDITIONS

LEGEND

EXISTING BULKHEAD LINE (FROM USACE)

EXISTING PIERHEAD LINE (FROM USACE)

PROPOSED BULKHEAD (548 LINEAR FEET)

25' 0' 25' 50'

SCALE: 1"=50'

FIGURE 3

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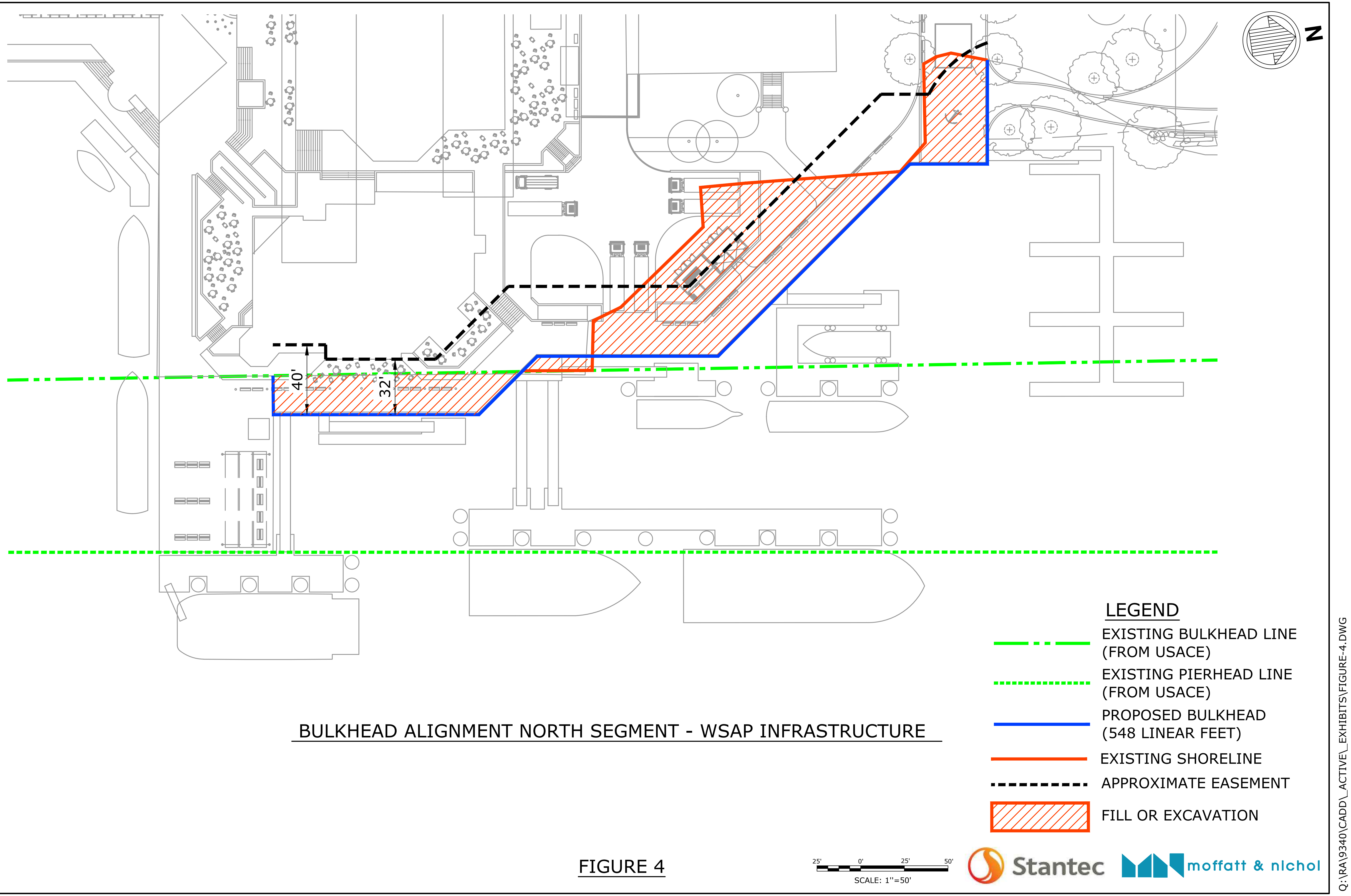


BULKHEAD ALIGNMENT NORTH SEGMENT - WSAP INFRASTRUCTURE

FIGURE 4

3. Preliminary Bulkhead Design (Schematic Phase)

3.1. Preliminary Geotechnical Investigation

AECOM (formerly URS Corporation) performed a limited geotechnical investigation along the waterfront in 2013 to collect and analyze soil conditions and provide recommendations for the construction of the two pump stations and bulkhead. Two subsurface soils borings were drilled, a south boring at Waterfront Park and a north boring on the east side of the building at 211 North Union Street. Existing fill material was encountered in the upper 13.5 to 18.5 ft. of the two borings and consisted of silty sands, clayey sands with gravel, and concrete fragments. Standard Penetration Test N-Values for this existing fill varied between 2 and 50 blows per foot (bpf). Alluvial soils, consisting of cohesive and granular soils were encountered below the fill to approximate elevation -59 ft. NAVD. Most of the cohesive material was comprised of soft silts with low N-values (< 7 bpf) and granular material with shared characteristics to that of the silts. Blow counts for this material ranged from 4 bpf to 45 bpf. Below elevation -60 ft. NAVD, Potomac Group alluvial soils consisting of clays and stiff clays with sand had N-values generally in the range of 18 bpf. The geotechnical report recommended that sheet pile or pile foundations for the bulkhead and pump stations be seated in compact soils found predominately below elevation -60 ft. NAVD. The report also recommend that ground vibrations during bulkhead installation be considered during the design phase to minimize potential impact on existing utilities and structures in the proximity of the proposed bulkhead. The report also recommended that additional geotechnical investigations be conducted during the design phase of the bulkhead.

3.2. Design Criteria

Design criteria for the bulkhead was based on preliminary geotechnical investigation and program requirements identified during the refinement of the WSAP. The bulkhead has to support emergency vehicle access along the promenade so the design surcharge load was increased. Dredging along the length of the bulkhead is also planned to facilitate boating access, so the bulkhead would be designed for the deeper water depth. An over-dredge allowance was also incorporated to accommodate variability in dredging methods.

A primary concern in the development of the bulkhead design criteria was the horizontal extent of the anchoring system. The area landward of the existing shoreline has been filled since the 1700's and there has been significant debris uncovered during excavation of areas to the south of the project site. Utility infrastructure, trees and buildings are also located less than 40 ft. landward of the proposed bulkhead alignment. A design criterion to limit horizontal extent of anchorage was added during the schematic design phase. A summary of the design criteria for the bulkhead is provided as follows:

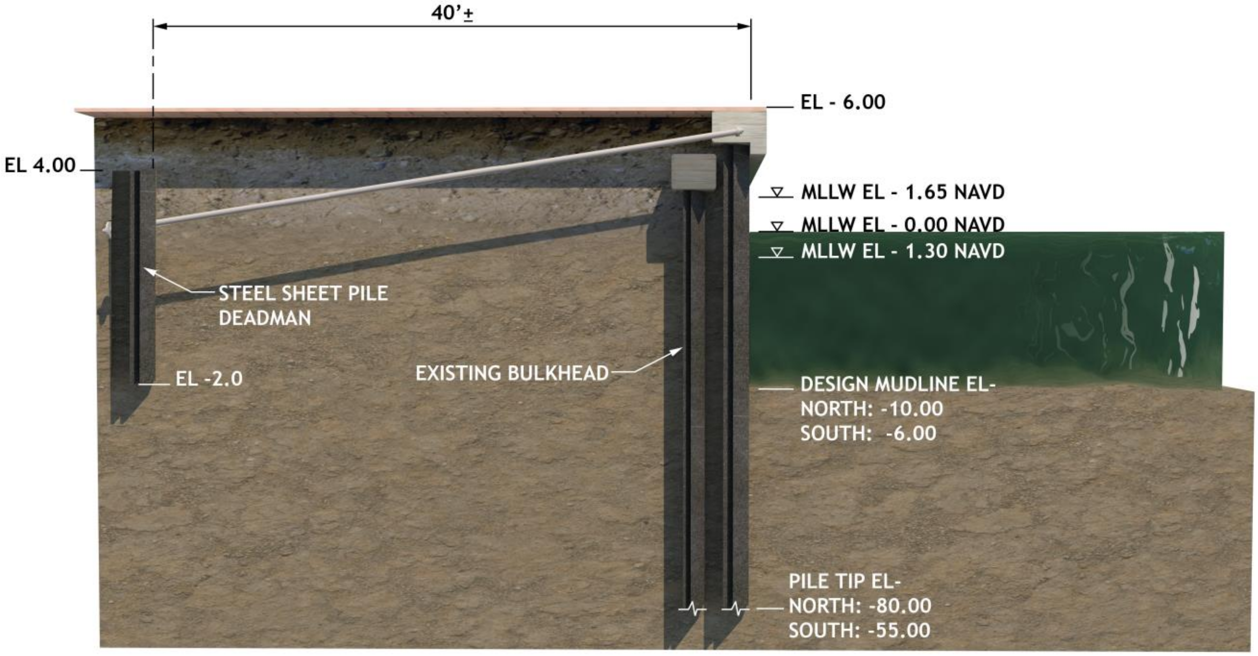
- 50-year design life;
- Surcharge Loads;
    - Live Load of 250 psf (approximately AASHTO HS-20 loading)
    - Construction Live Load of 250 psf
- Hydrostatic drawdown due to differential groundwater/surface water elevations;
- Boating Access: dredge elevation of – 6.0 ft. NAVD (-5 ft. MLW) on the south segment and -10 ft. NAVD (-9 ft. MLW) on the north segment with a 1-ft. over-dredge allowance;
- Minimize horizontal extent of bulkhead anchoring to less than 40 ft. landward of proposed alignment.
- Bulkhead to accommodate future WSAP marine infrastructure and boating access.

3.3. Preliminary Design

Based on the preliminary soil characteristics discussed in the geotechnical report and the aforementioned design criteria, a preliminary bulkhead design was developed during the schematic phase consisting of an AZ19 steel sheet pile bulkhead anchored with a continuous AZ12-700 steel sheet pile deadman for the entire south segment. The tip elevation of the sheet pile bulkhead in the south segment would extend, at a minimum, to elevation -55 ft. NAVD. The steel sheet pile deadman would be installed 40 ft. landward.

Water depths in the north segment of the proposed bulkhead are deeper, which necessitated the use of a combination king pile/steel pile bulkhead anchored with a continuous AZ12-700 steel sheet pile deadman. The minimum tip elevation of the combination type bulkhead in the north segment would be elevation -80 ft. NAVD, with the same 40-foot landward extent required for the anchoring system. The estimated cost per linear foot of bulkhead was $5,000 for the south segment and $8,000 for the north segment, respectively.

FIGURE 5: PRELIMINARY BULKHEAD DESIGN



4. Bulkhead Design Refinement

Additional field investigations were performed by Stantec and their consultant team for the flood mitigation project to assist in the design of bulkhead and other flood mitigation project components. These investigations included an updated bathymetric survey and a more in-depth geotechnical sampling program.

4.1. Expanded Field Investigation

4.1.1. Bathymetric Survey

Gahagan and Bryant Associates conducted a bathymetric survey in April 2016 along the Alexandria waterfront from Pt. Lumley to Founders Park. The survey indicated that water depths (at mean low water) ranged from 1.5 to 2.5 ft. (elevation -2.5 ft. to -3.5 ft. NAVD) along the majority of the south segment, with deeper water (9 to 10 ft. @ MLW) near the north termini of the bulkhead at the Torpedo Factory. The water depths in the north segment were approximately 10 to 12 ft. (elevation -10 ft. NAVD) since the alignment falls within the authorized maintenance dredge footprint for the City Marina. Dredging to elevation -6 ft. NAVD is proposed along most of the south segment to support transient and permanent boating facilities.

4.1.2. Geotechnical Investigations

A more extensive geotechnical field investigation was performed by Schnabel Engineering in August 2016. The field program consisted of drilling seven (7) new test borings, with three (3) of the borings located within 40 ft. of the shoreline. One boring drilled near Thompson's Alley in the north segment was advanced to 35 ft. below the ground surface. The two borings in the south segment were advanced 100 ft. below the ground surface.

The characterization of subsurface stratigraphy based on the three new borings indicate overall consistency with the subsurface stratums identified from the previous borings. The upper stratum is identified as fill, with a mixture of fine and coarse grained materials of generally low N-values. The fill layer is approximately 40 ft. thick, extending down to approximate elevation -38 ft. NAVD. The thickness of the fill layer is greater than the preliminary geotechnical investigation conducted by AECOM, which indicated a 20-foot layer of fill. Varying amounts of debris (wood, glass, and brick) were also encountered during drilling, indicating that it is highly likely that removal of debris may be required for installation of sheet piles and piles.

Below the fill is an approximate 20 to 25-foot-thick layer identified as the recent alluvium stratum. The alluvial stratum is a mixture of weak clays, silts, and clayey sand (fine and coarse grained material) that are loosely compacted and have low N-values (under 11 bpf). Below elevation -60 ft. NAVD, the Potomac Group stratum consists of medium to hard elastic silt and clay soils as noted in the previous investigation.

Schnabel provided engineering properties of the soil layers as input into the bulkhead design. These properties indicate weaker soils with higher clay content in the fill and alluvium stratums than previous characterizations. The weaker soils translate to a wider active zone of lateral earth pressure. The anchoring system for the bulkhead should be placed outside (landward) of this active zone, on the order of 70 to 80 ft., otherwise, the anchoring system will require long sheets or piles to compensate. The characteristics of the clayey soils also affects the passive lateral earth pressure zone on the seaward side of the bulkhead, increasing the embedment depth of the bulkhead.

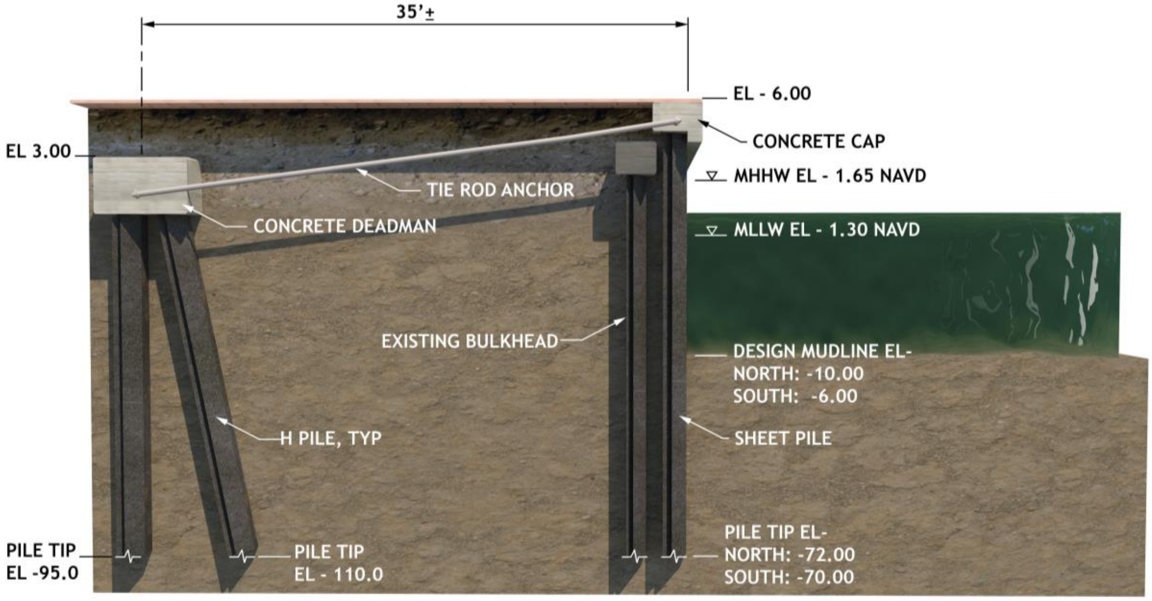
4.2. Alternative Bulkhead Designs

Since the primary concern during the schematic design phase was to limit the landward extent of the anchoring system to avoid impacts to existing tree canopy and utilities as well as proposed park and building infrastructure, alternative bulkhead designs were identified and assessed. The alternatives included designs that modified the anchoring system landward of the proposed bulkhead as well as those designs that placed the anchoring on the riverside face of the wall. Other design options were reviewed including the installation of a rock revetment on the riverside face of the bulkhead and replacement of soils behind the existing shoreline. The latter design options were assessed to reduce the horizontal extents of the anchoring system. All bulkhead alternatives were developed to meet the design criteria previously set forth, as well as maintain boating access to the waterfront.

4.2.1. Alternative 1 - Pile Supported Deadman Alternative

One alternative evaluated was a steel sheet pile wall anchored by a pile supported deadman located less than 40 ft. landward of the bulkhead. This deadman would lie within the active lateral earth pressure zone, necessitating steel H-piles that would extend to a minimum tip elevation of -95 ft. NAVD. The bulkhead itself would be comprised of 75- to 77- ft. long AZ14 or AZ24 sheet piles (south or north segment, respectively), connected to the deadman using a threaded steel tie-rod as shown in Figure 6. The steel tie-rods would be drilled through the existing bulkhead at Waterfront Park to facilitate connection. This anchoring system is not continuous, potentially allowing other pile supported structures to be constructed in the shared space. The disadvantage of this alternative is the long piles and the need to stabilize and dewater a trench to facilitate construction of the concrete cap associated with the deadman. The additional materials and the need to excavate and dewater elevates the unit cost of the wall in the south segment to approximately $7,000/ft. with the north segment at approximately $8,800/ft.

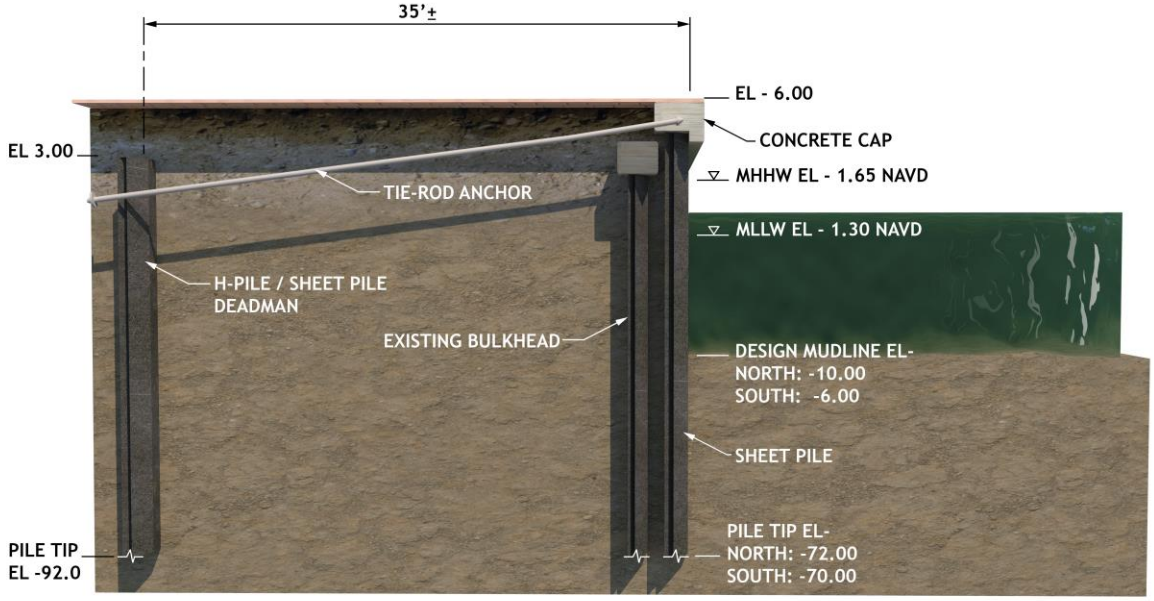
FIGURE 6: ANCHORED BULKHEAD (PILE SUPPORTED DEADMAN)



4.2.2. Alternative 2 - Tandem Wall Alternative

Figure 7 represents a tandem wall system where a continuous sheet pile deadman would be installed within 35 ft. of the new bulkhead face. This deadman is composed of two elements; steel H-piles spaced approximately 9 ft. OC that are interconnected with steel sheet pile. Since the deadman lies in the active lateral earth pressure zone, the tip elevation of the H-pile and intermediate sheet pile extends to elevation -92 ft. NAVD. The bulkhead would be composed of AZ14 or AZ24 sheet piles that have the same embedment depths as those for the pile-supported deadman alternative. The primary advantage of this anchoring system over the pile supported alternative is the potential for faster installation if debris is encountered. However, the additional material cost associated with long steel sheet piles increases the unit price of the wall to $12,500/ft. for the south segment and $14,000/ft. along the north segment.

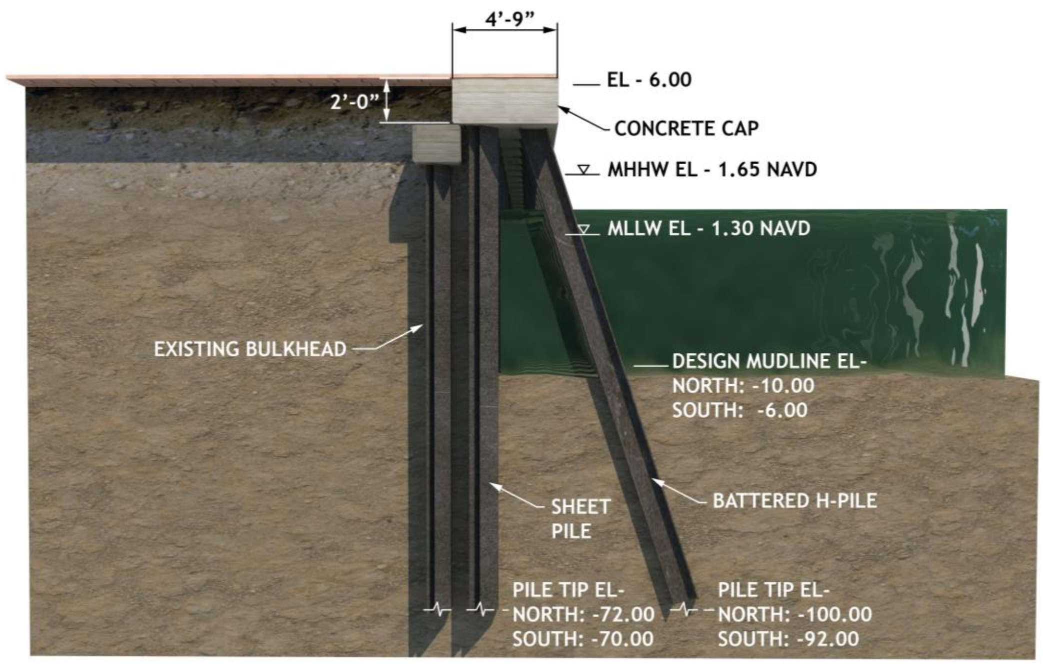
FIGURE 7: ANCHORED BULKHEAD (TANDEM WALL SYSTEM)



4.2.3. Alternative 3 - Batter Pile Bulkhead

In lieu of typical form of anchoring systems placed landward of the wall, batter piles placed on the seaward side of the wall would provide the lateral resistance for anchoring. The advantage of this anchoring system is its suitability to provide lateral resistance in weak soils while minimizing impacts to infrastructure landward of the wall. Figure 8 shows a typical batter pile bulkhead section.

FIGURE 8: BATTER PILE BULKHEAD



The design of steel sheet pile bulkhead is similar to the design of the pile supported and tandem bulkhead but with a 95 ft. long batter pile on a 1H:2V to 1H:4V angle spaced 9 ft. OC. The concrete cap of a batter pile wall will be wider by 1 to 2 ft. The anchoring system has a unique appearance as shown in Figure 9 that may contrast with some of the historical marine infrastructure along the Alexandria waterfront. A timber boardwalk planned as part of the WSAP to support boating access may be placed along the majority of the south segment and would mask most of the bulkhead as shown in Figure 10 and Figure 11.

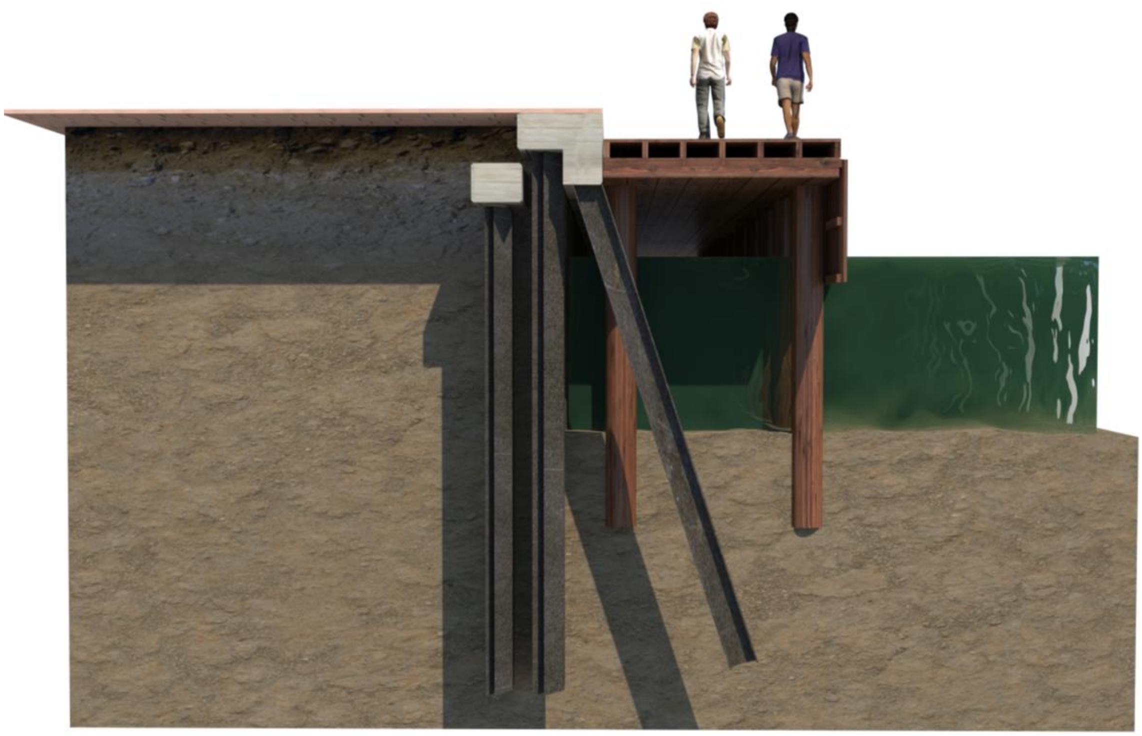
Boating access along the bulkhead in locations without the timber boardwalk would be accommodated by installing a timber mooring pile as shown in Figure 9 to provide adequate offset form the battered pile. The accumulation of river-borne debris along the waterfront is a constant maintenance concern for the City. The batter pile bulkhead design has the potential to trap smaller debris. To minimize the debris accumulation in front of the wall, a timber screen of similar appearance to the debris screen installed on the seaward face of the boardwalk shown in Figure 10 would be placed. This screen would also mask the batter piles.

The unit cost of the batter pile bulkhead is generally commensurate with the pricing of the bulkhead developed during the schematic design phase, with the unit cost for the south segment approximately $5,200/ft. and $7,000/ft. along the north segment.

FIGURE 9: TYPICAL BATTER PILE BULKHEAD INSTALLATION

FIGURE 10: BATTER PILE BULKHEAD WITH BOARDWALK

FIGURE 11: BOARDWALK WITH INTEGRATED DEBRIS SCREEN

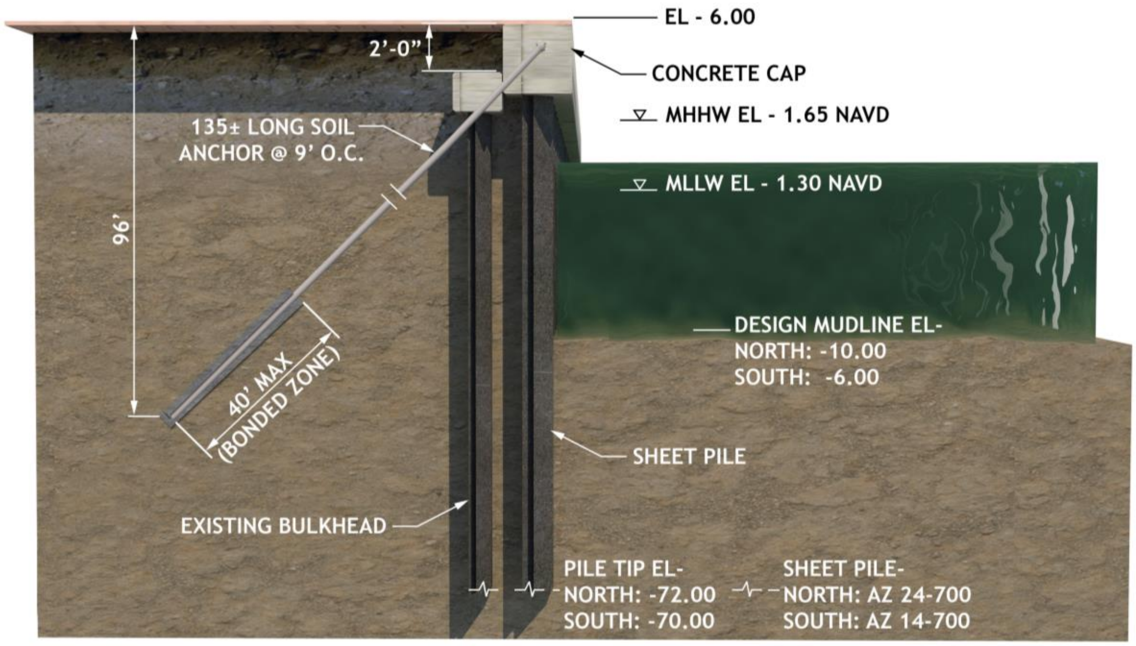


4.2.4. Alternative 4 - Soil Anchored Bulkhead

There are a few locations along the City's waterfront where installation of the anchored or batter pile bulkhead may be difficult due to construction access, proximity of buildings, and interaction with planned WSAP marine infrastructure. A bulkhead alternative restrained with deeply embedded soil anchors was developed to address shoreline segments with restricted access. Soil anchors would be installed on a steep angle (~45 degrees) into the stratum to restrain the system as shown in Figure 12. Installation of soil anchors consist of drilling a borehole from land or waterside into the ground, inserting a tendon, and injecting grout into the hole. The tendon is pre-tensioned and then connected to the wall through a structural concrete cap/wale. Schnabel recommends that the soil anchors extend a minimum 40 ft. into the Potomac Group stratum (below elevation -60 ft. NAVD) based on the soil conditions at the site. Based on this information, the soil anchors would be approximately 135 ft. long and spaced 9 ft. OC to provide sufficient restraint to the bulkhead. Soil anchors have a same service life to that of concrete and steel sheet pile deadman systems.

The steep installation angle of the soil anchors minimizes or avoids impacts to existing infrastructure and buildings that are near the bulkhead. The drilling process for anchor installation can also pass more readily through subsurface debris. However, the soil anchored bulkhead is generally not applicable to locations where the new bulkhead is significantly seaward (> 10 ft.) of the existing shoreline. This limitation is due to the potential settlement of the soil anchor as the underlying soils are compressed by the fill placed between the new bulkhead and the existing shoreline. The unit cost for the soil anchor is within 10 percent of the unit cost for the batter pile bulkhead, approximately $5,700/ft. for the south segment.

FIGURE 12: SOIL ANCHORED BULKHEAD



4.2.5. Alternative 5 - Design Modifications

Design modifications to reduce the size and depth of the bulkhead and associated anchoring system were also evaluated. One potential modification would consist of placing riprap in front of the wall to increase the passive force against the wall, thereby reducing the sheet pile and anchor lengths. A riprap revetment with crest elevation 1 ft. NAVD and toe elevation -4 ft. NAVD may reduce the tip elevation of the sheet pile to -50 ft. NAVD for bulkhead alternatives shown in Figures 6, 7, and 12. The riprap may be placed underneath the proposed boardwalk without compromising the ability for boats to berth alongside. The reduction in sheet pile length would be offset by the cost to place the rock. The primary benefit is the reduction in anchoring setback. The strength of the river sediment would need to be assessed to determine requirements for ground improvements to support the revetment.

Another design modification evaluated was the replacement of existing fill material behind the proposed bulkhead with light weight granular or flowable fill material. The replacement fill would reduce the size and length of anchoring system since its properties would reduce the active zone. The amount of existing fill to be removed may extend up to 50 ft. landward of the existing shoreline, at depths of 20 to 30 ft. minimum. The removal and replacement would require working in wet conditions and possibly impacting existing infrastructure and tree canopy. Based on discussions with Schnabel, the cost of replacing the fill may exceed the cost of engineering the bulkhead with existing soil conditions.

4.3. Recommended Bulkhead Alternative

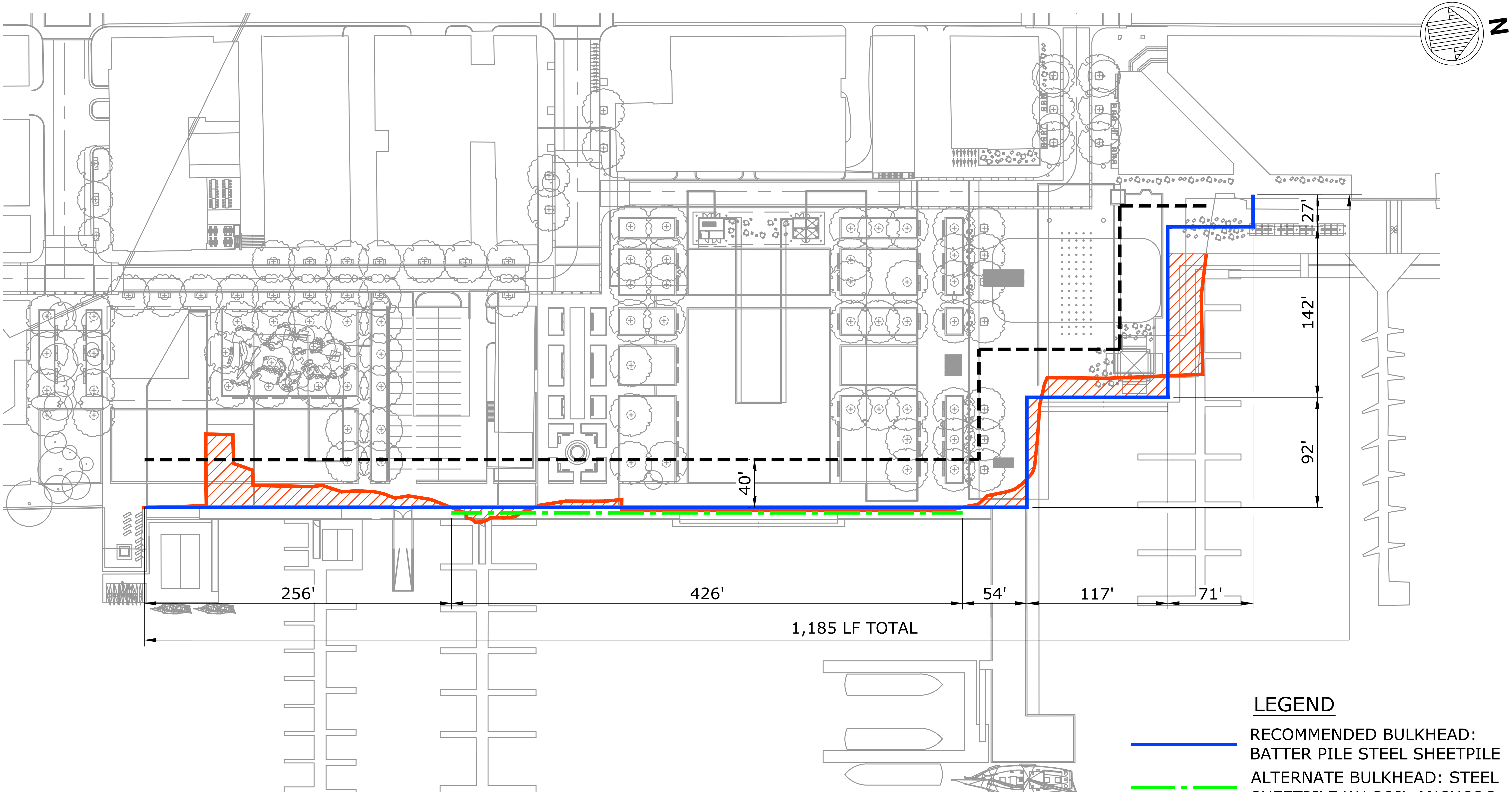
The bulkhead alternatives discussed in Section 4.2 generally satisfy the design criteria and program requirements. Alternatives 1 and 2 have higher construction costs due to larger material quantities and their more labor intensive installation methods. Of primary concern to the City is the potential need to excavate and dewater to install the anchoring system in Alternatives 1 and 2, the possibility of encountering debris that would require modifications to the planned design, and impacts to buildings that are less than 40 ft. from the proposed bulkhead. Replacement of soil behind the wall to reduce anchoring requirements as discussed in Alternative 5 would also require considerable excavation and dewatering; resulting in the same concerns as the deadman installation in Alternatives 1 and 2. The cost to replace soils, therefore, is anticipated to negate potential savings in anchoring costs. The same benefit-cost reasoning can be applied to the construction of the rock revetment.

Alternatives 3 and 4 address the City's concerns while meeting design and construction cost considerations. Alternative 3 (batter pile bulkhead) can be constructed along the entire waterfront, with potential modification to the batter pile installation procedure to account for the narrow construction corridor in front of the new ODBC building. The bulkhead restrained by the soil anchor (Alternative 4) is only applicable to the waterfront from 200 feet north of Pt. Lumley to King Street where there is minimal fill placed between the existing shoreline and the new bulkhead.

The recommended alternative for the north segment is the batter pile bulkhead (Alternative 3) as this bulkhead type is better suited to accommodate settlement of fill seaward of the existing shoreline while minimizing conflicts with the proposed pump station foundation. Fill will also be placed seaward of the existing shoreline in the south segment between Pt. Lumley and the new ODBC site and between King Street/ Fitzgerald Square Park; making the batter pile bulkhead the recommended alternative for the south segment. If unforeseen conditions are encountered in the south segment during the final design and construction stages; a narrow construction corridor precludes the installation of the batter pile wall, or connection to future WSAP infrastructure requires a flush bulkhead face, the soil anchored bulkhead (Alternative 4) may be installed in lieu of the batter pile wall from the new ODBC site to King Street/Fitzgerald Square Park. Figure 13 and Figure 14 indicate locations and limits of the recommended bulkhead alternative along the waterfront.

4.3.1. Bulkhead Installation and Phasing

The steel sheet piles and batter piles will most likely require an impact hammer (hydraulic or diesel) or vibratory hammer to drive them into the subsurface. This pile driving process produces vibrations and noises that may extend outside the project footprint. Vibrations produced by the pile driving operation may induce stresses in structures that could lead to damage, such as cracking of plaster and weaker mortar. Studies evaluating vibration impacts of hammer indicate that structural damage is generally eliminated within a 15 ft. radius of the vibration source. The vibrations become troublesome to people within a 50-ft. radius and perceptible to people within a 200 ft. radius.



LEGEND

- RECOMMENDED BULKHEAD: BATTER PILE STEEL SHEETPILE
- ALTERNATE BULKHEAD: STEEL SHEETPILE W/ SOIL ANCHORS
- EXISTING SHORELINE
- APPROXIMATE EASEMENT
- FILL OR EXCAVATION

RECOMMENDED BULKHEAD LOCATIONS - SOUTH SEGMENT

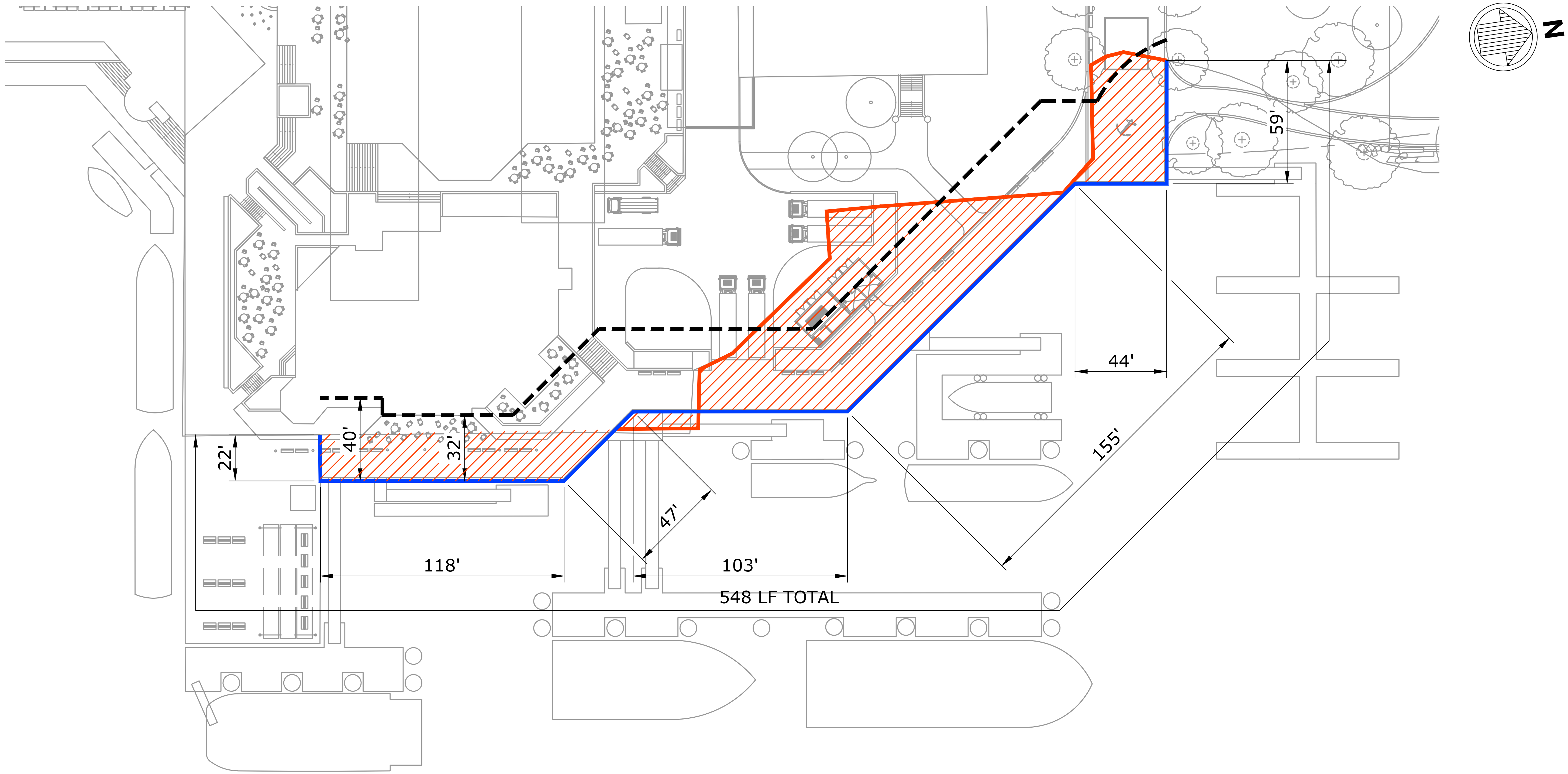
FIGURE 13

40' 0' 40' 80'
SCALE: 1"=80'

Stantec

moffatt & nichol

Q:\RA\9340\CADD_ACTIVE_EXHIBITS\FIGURE-13.DWG



LEGEND

- RECOMMENDED BULKHEAD: BATTER PILE STEEL SHEETPILE
- EXISTING SHORELINE
- APPROXIMATE EASEMENT
- FILL OR EXCAVATION

RECOMMENDED BULKHEAD LOCATIONS - NORTH SEGMENT

FIGURE 14

25' 0' 25' 50'
SCALE: 1"=50'

Stantec moffatt & nichol

Q:\RA\9340\CADD_ACTIVE_EXHIBITS\FIGURE-14.DWG

There are several ways to manage noise and vibration associated with the pile driving process. Education of people through dissemination of materials related to project schedule, nature of work, importance of work, and potential impacts of the work on them is a proactive step. Part of this educational process is to conduct pre-construction surveys of structures within a 200 to 300-ft. radius of the planned piling driving to quantify and assure people that noise and vibration does not lead to damage or physical harm. Monitoring is typically employed to demonstrate that work is below levels that may cause harm. Other management approaches may include limiting hours of pile driving operations and use of shrouds and noise abatement curtains.

Push-Press installation method is a technology developed to install sheet piles without the need for impact or vibratory hammer. Piles are statically pressed into the ground using previously pressed piles as anchorage to hydraulically jack the new piles into the ground. The use of static energy almost completely reduces vibrations and noise. This installation method requires a proprietary pieces of equipment which can lead higher construction costs, on the order of 15 to 30 percent.

Phasing of the bulkhead construction will most likely be required in coordination with the upland flood mitigation project. Phasing also minimizes disruption of businesses along the waterfront during the construction. At a minimum, two construction phases are envisioned; one for the north segment and one for the south segment. The south segment may further be split into two phases (three overall phases) depending on the timing of the pump station installation. The operation of the pump station is critical to avoid ponding of water behind the elevated walkway and bulkhead. The construction of the north segment will require sections of Piers E/F and G/H of the City Marina and associated marina utilities to be removed, effectively shutting down marina operations. By isolating the north segment into a separate phase, the City can benefit for continued marina operations while the south segment is constructed. Phasing the project does elevate the overall cost of the project since the City has to pay two mobilization costs of the contractor. There is also inefficiency due to potential selection of two different contractors for each phase and the associated start up curve that may lead to higher labor costs.

4.3.2. Bulkhead Maintenance

Maintenance of the bulkhead should be performed over the 50-year design life to maintain its integrity and function. Maintenance is separated into two types of work – recoating of the steel sheet pile and repair to the concrete cap and anchoring system as required. Inspection of the bulkhead should be performed on 5 year intervals starting at Year 15, when the sheet piles are typically recoated and the condition of the concrete cap is reviewed. Typically, repairs to the concrete cap from spalling and cracking start at Year 20. Subsequent maintenance cycles generally occur at 10-year intervals until Year 50 (i.e. Year 30 and Year 40). The following table (Table 2) summarizes a typical maintenance repair schedule. Maintenance and replacement costs based on future value of money at year performed based on a 3% industry average construction inflation factor is also shown in the table. Table 2 does not reflect the cost of inspections.

TABLE 2: BULKHEAD MAINTENANCE CYCLES

Maintenance Interval	Maintenance Item	Maintenance Cost (Future Value at Year Performed)
Year 15	Recoating of Sheet pile	$900,000
Year 20	Concrete Spall Repair	$150,000
Year 30	Recoating of Sheet pile and encapsulation of concrete cap.	$2,500,000
Year 40	Concrete Spall Repair	$1,140,000
Year 50	Bulkhead Replacement	$48,000,000

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