City of Alexandria, Virginia
Waterfront Implementation

Technical Memorandum 7
BULKHEAD EXISTING CONDITION ASSESSMENT

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COMMONWEALTH OF VIRGINIA
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Contents

Appendices

Tables

Figures

Abbreviations

Carollo	Carollo Engineers
City	City of Alexandria
ft	feet
LF	linear feet
M	million
Project	Waterfront Implementation Project
TM	technical memorandum

Technical Memorandum 7

BULKHEAD EXISTING CONDITION ASSESSMENT

1.1 Purpose

The Potomac River is a regular source of flooding in Old Town Alexandria. The City of Alexandria's (City's) Waterfront Implementation Project (Project) aims to mitigate riverine flooding as part of a larger, comprehensive flood mitigation investment. Previous planning efforts considered various engineered solutions and elevations between 4.0 and 10.2 feet (NAVD88). A cost-benefit analysis recommended a new floodwall and new elevated walkway at elevation 6.0 feet to be considered in the 2012 Waterfront Small Area Plan (URS 2010). These concepts were carried forward and the 2018 Stantec Master Storm Water Management Plan recommended a 6.0 feet level of protection to eliminate more regular flooding occurrences and maintain waterfront access.

Collectively, this technical memorandum evaluates and recommends alternative shoreline protection solutions. Following review of the previous studies and reports as prepared to develop the Baseline Project, Carollo Engineers (Carollo) explored alternative bulkhead solutions to reduce the overall cost. Value engineering offered new structural (hard) and landscape (soft) design strategies while on-site findings provided new insights into the condition of the bulkhead. This was followed by a site visit with Olin to integrate new solutions within the Waterfront Small Area Plan framework.

These findings supported the development of a riverine flood protection solutions for the Performance-Based and Cost-Based option.

1.2 Project Baseline Bulkhead

Per the Baseline Project, the bulkhead is a critical component to the Waterfront Small Area Plan because it provides flood mitigation while creating a consistent and continuous promenade along the Waterfront. A summary of the Baseline Project's Bulkhead Alignment, Design, and Cost is summarized below.

1.3 Bulkhead Alignment

Variations of the existing shoreline and all existing bulkhead sections will be replaced with a new 2,200 linear feet (LF) bulkhead. The new bulkhead will be built to an elevation of +6.0 feet (ft) NAVD88 (Moffatt & Nichol 2017).

Figure 1 shows the existing (red) and proposed (blue) bulkhead alignment according to the *Bulkhead Design Manual* (Olin 2018). Overall, the new bulkhead alignment seeks to simplify and straighten the shoreline. The alignment helps reduce dead zones of stagnant water and eliminate areas for significant debris collection. It also improves the shoreline experience by removing waste concrete and abandoned boat launches. Lastly, the proposed alignment will have federal regulatory impacts due to the construction activities in the Potomac, including filling, dredging, excavating and realigning the bulkhead line due east.

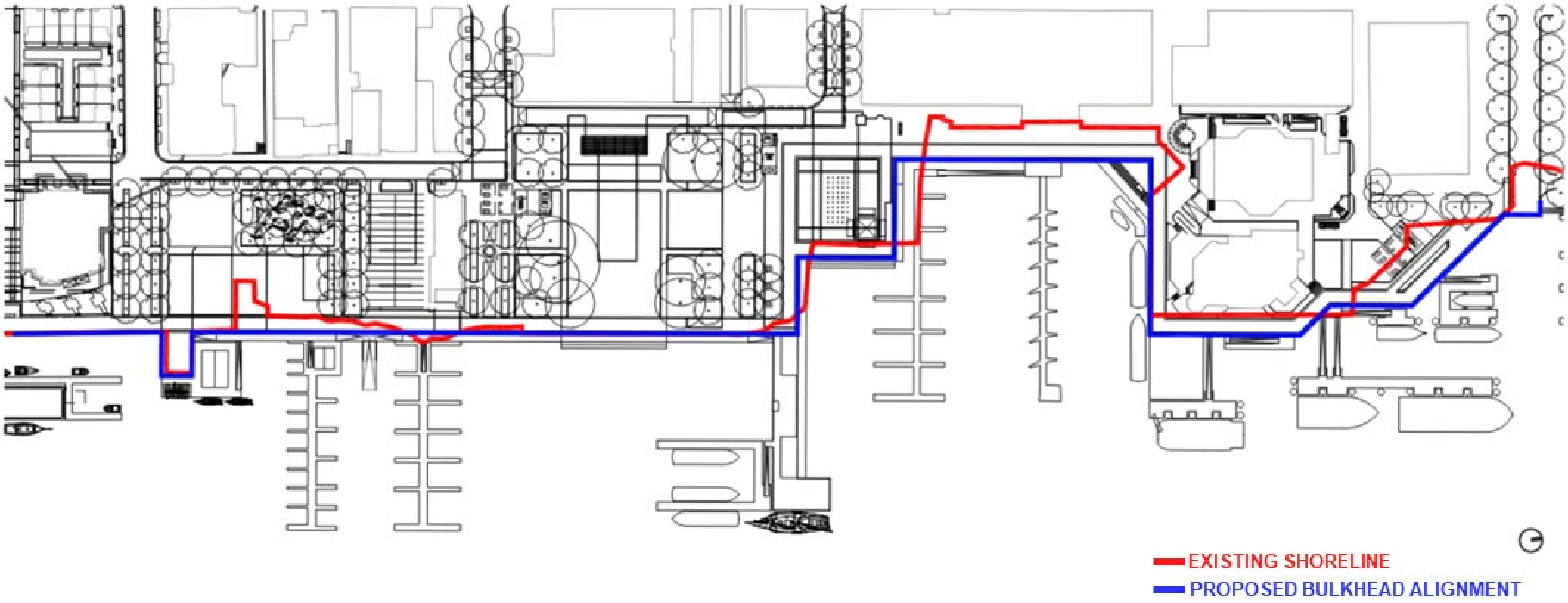

Figure 1 Existing and Proposed Bulkhead Alignment

1.3.1 Bulkhead Design

Figure 2 shows the proposed bulkhead system as documented in the *Bulkhead Design Manual*. This structural design was selected for the new 2200 LF length of bulkhead.

The battered H-pile is located on the seaward side of the wall, spaced 9.0 feet on center, to provide lateral resistance for anchoring. Vertical sheet piles are located at the traditional land/water interface. The system is capped with a 4-foot 9-inch wide reinforcing concrete bulkhead cap. At the Torpedo Factory, this new bulkhead is located on the seaward side of the existing bulkhead, preventing existing bulkhead removal, with spacing varying from 18 inches to several feet between the new and old bulkhead depending on section.

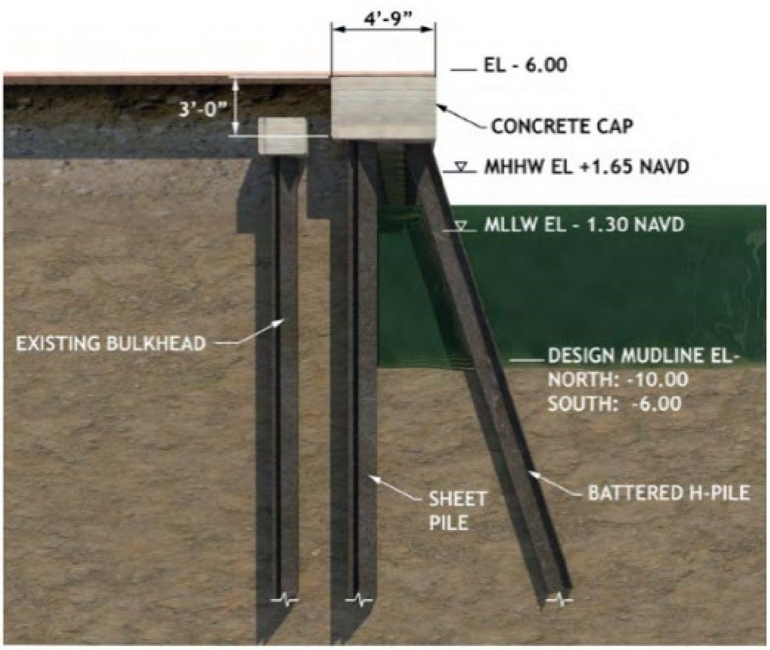

Figure 2 Baseline Bulkhead Design

1.3.2 Bulkhead Cost

The structural bulkhead represents the single largest component of the Baseline Project cost, accounting for almost 40 percent of the Direct Costs of the project, or $30 million (M) of $80M total direct costs (Carollo 2020). In comparison to the 2019 Cost Estimate Budget Update, the structural bulkhead represents an overall 8 percent cost increase as documented in the Project Narrative (Carollo 2020). The Baseline Bulkhead Design (Figure 2) represents the most costly flood protection solution; however, in-house structural resources coupled with landscape architectural input from Olin were incorporated to develop value engineered solutions.

1.4 Project Baseline Evaluation for Value Engineering

Initially Carollo performed a value engineering assessment on the structural bulkhead design in an effort to reduce overall project costs. The following elements of the project baseline bulkhead were reviewed:

- Option 1: Reuse and Repair Bulkhead.
- Option 2: Replace Existing Bulkhead.

A Go/No-Go assessment was completed with the results detailed in Table 1 and Table 2.

For all considered options, Carollo assumed that the entire length of bulkhead would provide +6.0 ft of protection. A Phase II Geotechnical Investigation, inclusive of structural/marine visual bulkhead assessment and subsurface sampling, testing, and analysis, will follow the issuance of this technical memorandum. The Go/No-Go assessment offered scoping suggestions for the forthcoming work to ultimately provide feasible design parameters that will be carried forward to the Basis of Design. Therefore, strategies and their associated cost savings included herein are contingent on MRCE's Phase II Geotechnical Investigation.

1.4.1 Option 1: Reuse and Repair Bulkhead

In review of the previous bulkhead condition assessment studies, Carollo assumed that the existing support elements and bulkhead can be reused specifically in the area noted as 'existing wall replacement length' per Figure 3 (Stantec 2020) in order to optimize areas of reuse and repair. As documented in *Design Optimization Report,* Carollo assumed that approximately 765 LF of the total 2,360 LF proposed in the baseline design had the potential for reuse and/or repair (Carollo 2021). As shown in Table 1, the reuse and repair of existing bulkhead strategy could provide some cost savings to the project. Details on the feasibility for bulkhead reuse following Carollo's on-site investigation are discussed later in this document.

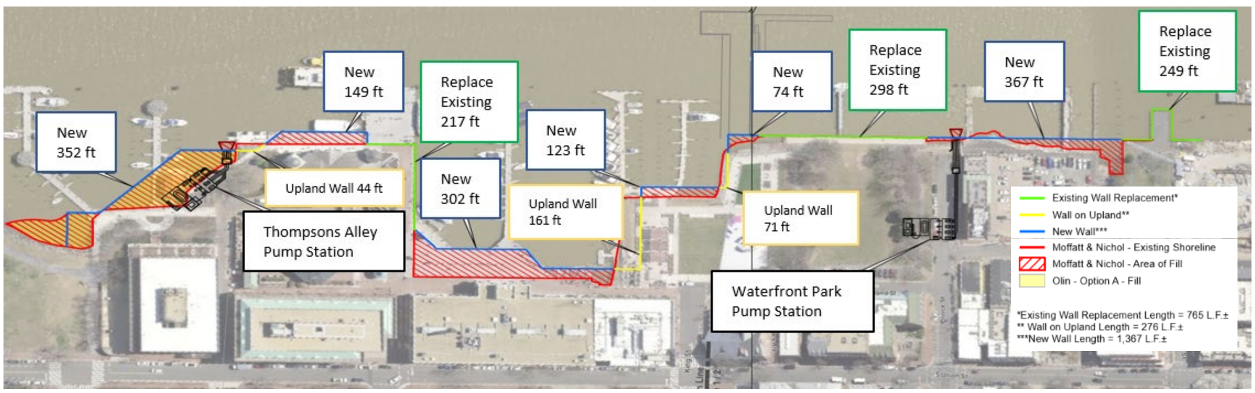

Figure 3 Bulkhead Reuse Assessment South Sections (Stantec 2020)

Table 1 Bulkhead Value Engineering Summary

Strategy		Total Cost Savings(1)	Go/No-Go
General	Specific		
Reuse and repair additional support to existing piles and raise concrete cap	Install battered H-piles and raise cap	$5-$9M (7-13%)	Go
	Install helical tiebacks	$12M-$17M (18-25%)	Go
	Install lightweight cellular concrete fill	$12M-$17M (18-25%)	Go

Note:
(1) Per Carollo's 2020 OPCC, the total bulkhead cost escalated to year 2024 (mid-point construction) is approximately $67M.

Figure 4 illustrates the three options considered in Table 1. Each conceptual detail references the Project Baseline bulkhead design and is edited accordingly.

- **Option 1A: Support existing cap with battered H-piles and raise cap**:
  - This option removes the sheet pile, as proposed for the new bulkhead, and assumes the H-piles effectively support existing bulkhead. The concrete cap is raised up to El. +6.0-ft.
- **Option 1B: Add helical tie-backs**:
  - This option requires additional coordination with existing and proposed utilities along the bulkhead to confirm the helical anchor alignment will not pose any conflicts. In addition, vibration prevention and monitoring are required during construction. The concrete cap is raised up to El. +6.0-ft.
- **Option 1C: Add lightweight cellular concrete fill**:
  - This option reduces soil lateral loads imposed onto the existing bulkhead with the use of lightweight cellular concrete fill. The concrete cap is raised up to El. +6.0-ft.

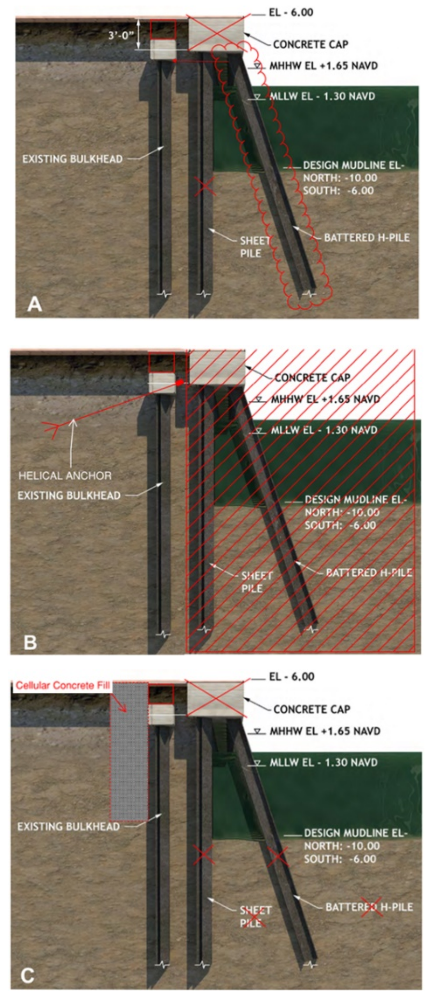

Figure 4 Bulkhead Alternatives

In April 2021, Carollo conducted a bulkhead (visual) condition assessment recommended that all options proceed for further evaluation and consideration under MRCE's Phase II Geotechnical Investigation.

1.4.2 Option 2: Replace Existing Bulkhead

Under the replacement strategy, Carollo assumed that the entire length of the bulkhead is not in reusable condition. While this strategy would not require a new bulkhead condition assessment, the options presented below require further evaluation under Phase II Geotechnical Investigation by MRCE. As shown in Table 2, the replacement of the existing bulkhead strategy could provide up to 25 percent in cost savings.

Table 2 Bulkhead Value Engineering Summary

Strategy		Total Cost Savings(1)	Go/No-Go
General	Specific		
Replace alternative more cost-effective support elements	Recommended improvements	$2-$5M (3-7%)	Go
	Secant piles	$13M-$17M (19-25%)	Go
	Slurry wall	$16M-$20M (24-30%)	No-Go

Note:
(1) Per Carollo's 2020 OPCC, the total bulkhead cost escalated to year 2024 (mid-point construction) is approximately $67M.

Figure 5 illustrates the three options considered in Table 2. Each conceptual detail references the Project Baseline bulkhead design and is edited accordingly.

- **Option 2A: Recommended improvements for the Baseline Project**:
  - This option carries forward the Baseline Bulkhead Design per Figure 2. However, an additional geotechnical exploration may result in reduced pile length, and thus, offer some overall cost savings.
- **Option 2B: Secant Piles**:
  - This option is a one-step process that relies on the use of concrete, rather than steel, for the new bulkhead support system. The sheet pile and battered H-pile system is replaced with a new concrete secant pile. It is also proposed to reduce the total width of the bulkhead from 4 ft-9 in to 3 ft-6 in.
- **Option 2C: Slurry Wall**:
  - This option is a one-step process that relies on the use of concrete, rather than steel, for the new bulkhead support system. The sheet pile and battered H-pile system is replaced with a new slurry wall. It is also proposed to reduce the total width of the bulkhead from 4 ft-9 in to 3 ft-6 in.

Carollo recommended that options (2A) and (2B), per Figure 5, proceed for further evaluation and consideration; option (2C) – Slurry Wall – was not recommended since it is not a typical or proven supporting method for this application.

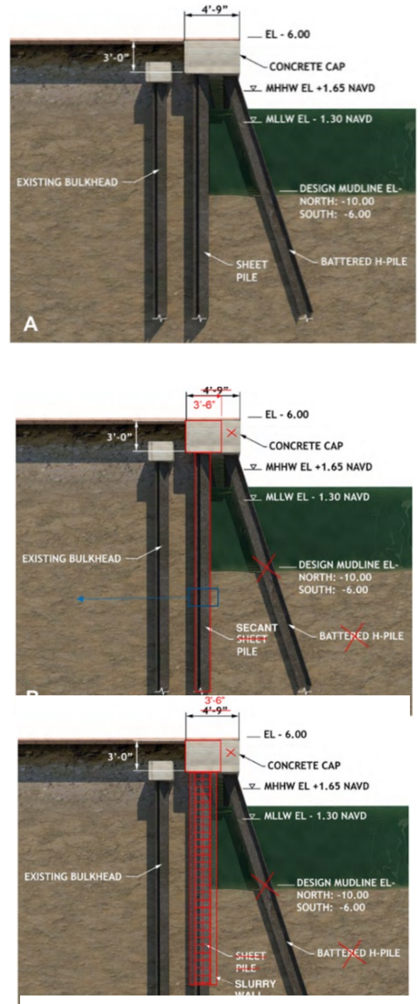

Figure 5 Bulkhead Alternatives

1.4.3 Option 3: Alternative Solutions

Carollo explored bulkhead alternatives that could provide the same level of flood protection but maximize use of the existing shoreline alignment, and thus, reduce regulatory impacts and overall project cost. This includes shoreline deployable barriers, building deployable barriers, and landscape-based barriers. These options could be incorporated in lieu of the new bulkhead or in concert with the new bulkhead in discrete segments along the Waterfront.

1.4.3.1 Shoreline Deployable Barriers

Shoreline deployable barriers were evaluated for their ability to retain the floodwater as well as preserve the promenade, waterfront views, and greenspace while providing riverine flood protection. Investigated shoreline deployables include:

- Flood Barriers (passive and active barriers).
- Seawall Barriers (passive and active barriers).
- Floodbreak Free View Barriers (passive barriers).
- Self-Closing Flood Barriers (passive barriers).
- Hinged Flood Barriers (passive and active barriers).

All shoreline flood barriers require independent structural foundations and are slightly recessed behind the existing bulkhead. When recessed, the barrier could service as the promenade walkway. During storm or flooding conditions the barriers would be deployed.

Upon preliminary assessment, two options that continued for further evaluation were Floodbreak FreeView Barrier (Figure 6) and the Fenex Floodproof Glass Barrier (Figure 7).

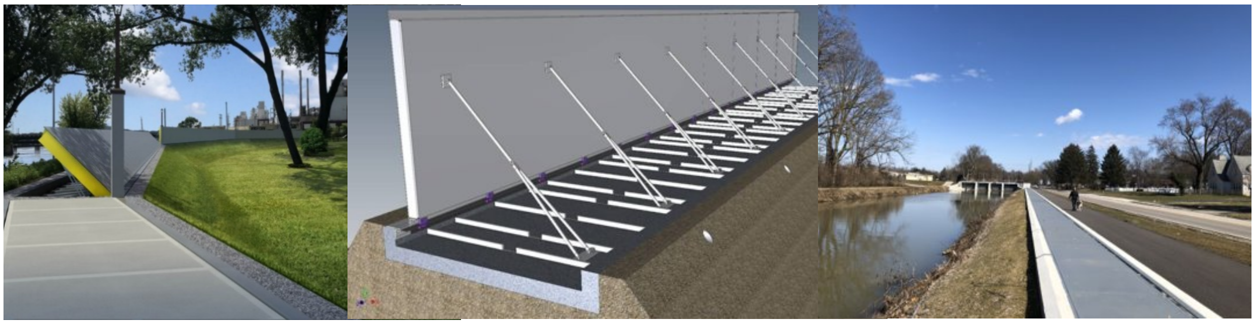

Figure 6 Shoreline Deployable Barrier, Floodbreak FreeView Barrier

Ultimately, Carollo's detailed coordination with the FloodBreak manufacturer as well as Olin led to a *no-go* decision.

First and foremost, the barrier has the capability to operate passively (automatic/self-deploying) or actively (manual/human intervention required) flood barrier; project references confirmed active deployment is the preferred option. To accommodate for the anticipated optional modes, barrier costs must account for the hydraulic lifts and external hydraulic pumping unit. Regular maintenance and deployment responsibility would likely reside with the end-user, e.g., City's Department of Transportation and Environmental Services. Preliminary community feedback from Spring 2021 shared a preference towards a fixed barrier in order to reduce risk of failure.

Additionally, the construction of the barrier would require a two foot excavation, at minimum, in order to accommodate the foundation and drainage pipe, but could be higher depending on structural calculations and whether support piles would be required. Considering the anticipated costs of site disturbance along the Waterfront, this option did not appear to be as cost-effective as initially anticipated.

During a site visit, Olin offered landscape-oriented feedback. Given the current shoreline configuration, a seamless integration of the FloodBreak barrier may be challenging. Two major challenges included how to tie in the barrier with other shoreline protection strategies and the limited opportunity for installation since much of the promenade is not a straight-line path.

For all these reasons, the FloodBreak FreeView Barrier was not integrated into the various Project Alternatives.

Figure 7 Shoreline Deployable Barrier, Fenex Floodproof Glass

The Fenex Floodproof Glass Barrier in Figure 7 was initially considered a viable option because it was a fixed barrier with the ability to be integrated with the *Common Elements Plan* such that the handrails could provide structural support. This option would also maintain the aesthetics desired and not require mechanical or personnel to deploy when flooding conditions occurred. However, this solution was also considered a no-go.

Further coordination with the manufacturer confirmed this is a brand-new solution and the project team was hesitant to implement without any previous project success.

From initial site walks, the Torpedo Factory to Chart House appeared the most suitable location considering the extent railing and straight line alignment. However, following a site visit with Olin, the team struggled to conceptualize how the barrier could provide a consistent aesthetic across the Waterfront if only a portion was planned to accommodate the floodproof glass solution.

Lastly, the latest topographic survey by Gordon (2022) confirmed the Torpedo Factory was above the level of flood protection and may be an area to defer riverine investments in the short-term depending on available funds (Carollo 2022).

For all these reasons, the Fenex Floodproof Glass was not integrated into the various Project Alternatives.

1.4.3.2 Building Deployable Barriers

Building-level protection was considered including deployable barriers across doors, windows, louvers, etc. These solutions would not support the downsizing of stormwater protection but could be an alternative to riverine flood protection (while accepting the flooding of parkspaces) and/or a "belt-and-suspenders" approach to stormwater. Some investigated building deployable barriers include:

- Stop Log Flood Shields (active barriers).
- Hinged Flood Barriers (active barriers).
- Removable Flood Gate Barriers (passive barriers).
- Sliding Flood Barriers (active barriers).

As noted above, most of the options require active, or manual, deployment, and therefore, require on-site storage and staffing resources to deploy in advance of a storm. Major concerns for building-level implementation included challenging integration with Old Town's historic aesthetic, building's ability (or lack thereof) to handle structural loading due to construction material/design, and spatial limitations to provide storage (as applicable) for barriers. These reasons coupled with the community preference for fixed riverine flood protection resulted in a *no-go* decision.

1.4.3.3 Landscape-Based Barriers

Landscape-based barriers can provide riverine flood protection at a fraction of the cost, in comparison to new bulkhead construction. Some examples of landscape-based solutions include a ha-ha wall, staircases, ADA accessible ramps, and planter boxes. Gradual grading – in streets or parkspaces – may also offer protection and could be integrated into the Waterfront Plan. A "ha-ha wall" can have many variations in design (as shown in Figure 8) and implementation, i.e., can be installed along the Waterfront adjacent to the promenade or further recessed behind parkspace. In all cases, the integration of a ha-ha wall or other landscape-based barrier will reduce site disturbance activities, e.g., excavation, hauling, fill and grading, and utilize the existing waterfront alignment to avoid dredging and/or fill operations in the Potomac. An alignment that orients the ha-ha wall further land will allow the parkspace to flood under certain river elevations but protects the commercial and residential areas along the Strand or Union Street (and due west) with the barrier. A further inland may increase maintenance costs since debris could get washed up onto the parks during these tidal events.

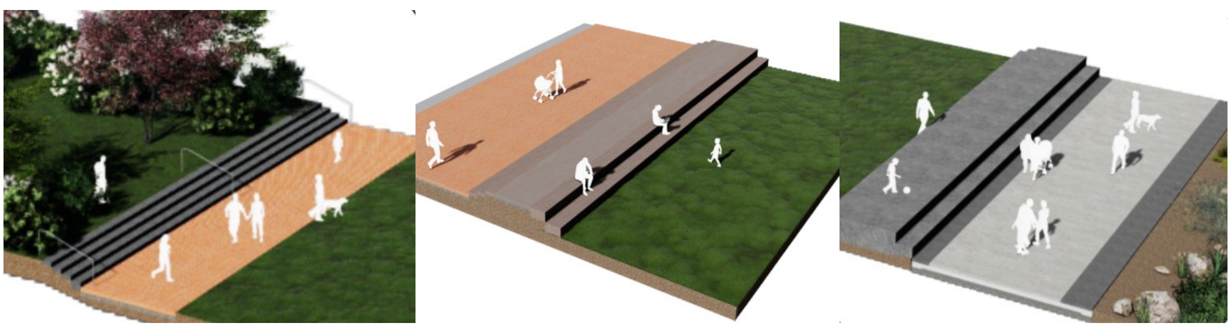

Figure 8 Ha-Ha Wall Concepts

1.5 Existing Conditions of Waterfront Infrastructure

Carollo performed a visual inspection of the bulkhead on April 21st, 2021, to assess the existing condition. The site visit demonstrated a wide-ranging bulkhead condition from Duke to Queen Street. Figure 9 calls out various inspected locations with photos summarizing key observations and findings.

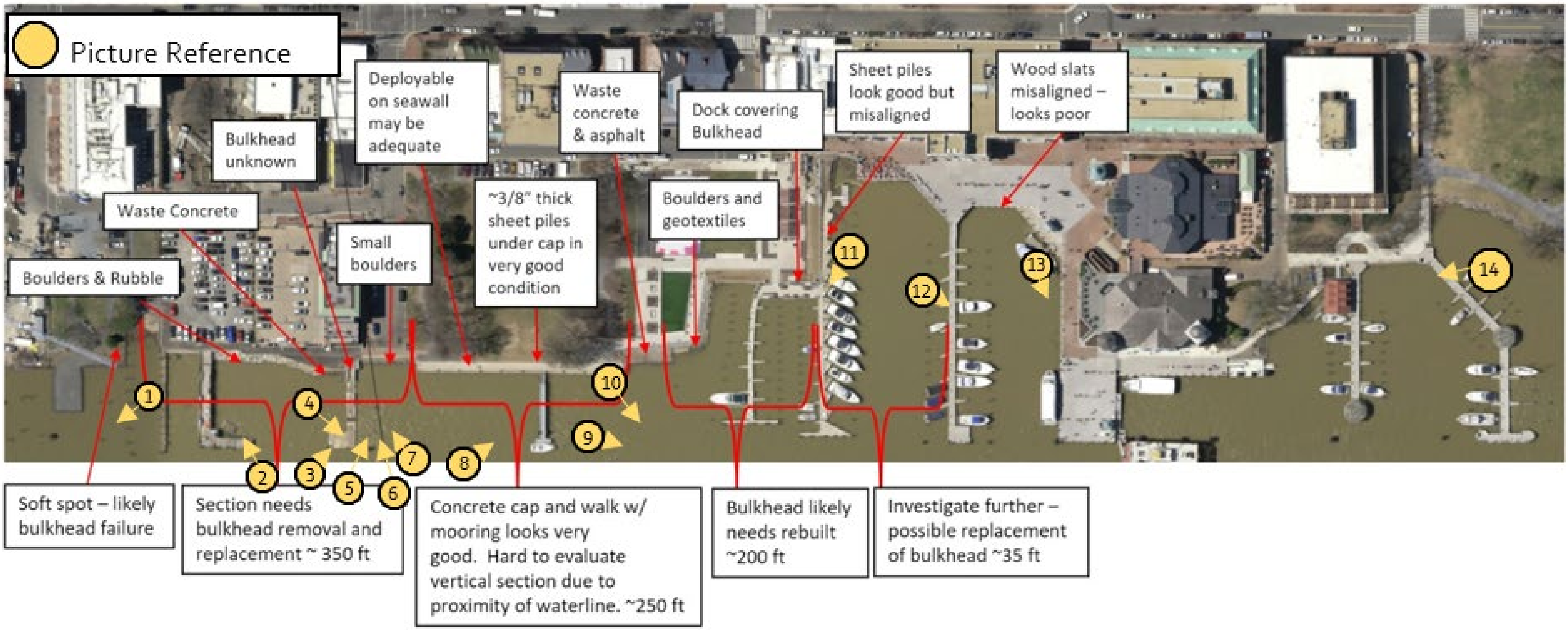

Figure 9 Carollo Visual Inspection with Photo Angle References

Photo 1 – Point Lumley Soft Spot (likely bulkhead failure)

Photo 2 – Point Lumley Boulders and Rubble

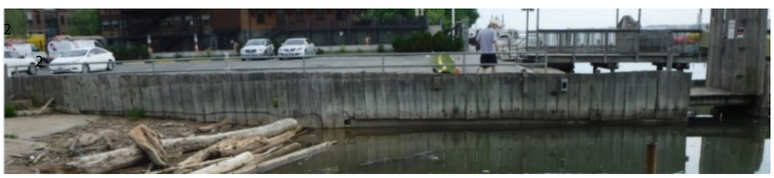

Photo 3 – Point Lumley Boat Slip (significant debris accumulation)

Photo 4 - Old Dominion Boat Club

Photo 5 – Unknown Bulkhead and Small Boulders

Photo 6 - Prince Street

Photo 7 - Waste Concrete and Boulders

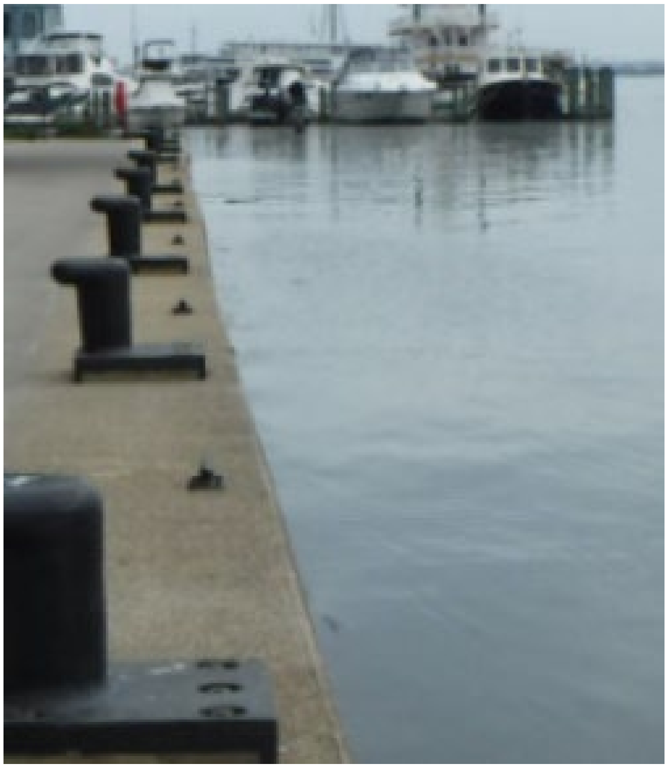

Photo 8 – Waterfront Park Concrete

Photo 9 – Waterfront Park Concrete (cap and walk-in, good condition)

Photo 10 – King Street Square – Waste Concrete and Asphalt

Photo 11 – Marina Sheet Piles (in fair condition)

Photo 12 – Marina Wood Slats (in poor condition)

Photo 13 – Marina Wood Slats

Photo 14 – End of Bulkhead at Founder's Park

This site visit helped the team understand the feasibility of integrating the Project Baseline, Value Engineering and Alternative Solutions together. While some segments of the bulkhead are in visibly poor condition that necessitate either a new bulkhead per the Baseline or VE approach to reconstruct or repair, there are other segments in good condition that may benefit from a landscape barrier. Recognizing that marine construction, and associated bulkhead structural supports, are the significant cost drivers, a riverine solution capable of integrating both bulkhead and landscape-based barriers may offer a more cost-effective investment.

1.6 Initial Conditions Recommendations

Following the April 2021 Site Visit, Carollo's structural engineer outlined the following solutions in order to reuse as much of the shoreline alignment as possible and integrate alternative flood protection solutions (Figure 10). These recommendations were further coordinated with Olin – who provided input on landscape-based barriers – and with the City and community members for stakeholder feedback. Based on this feedback and as discussed in the *Alternative Solutions* section above, the proposed addition of a glass flood barrier or other deployables along the Waterfront was removed from consideration.

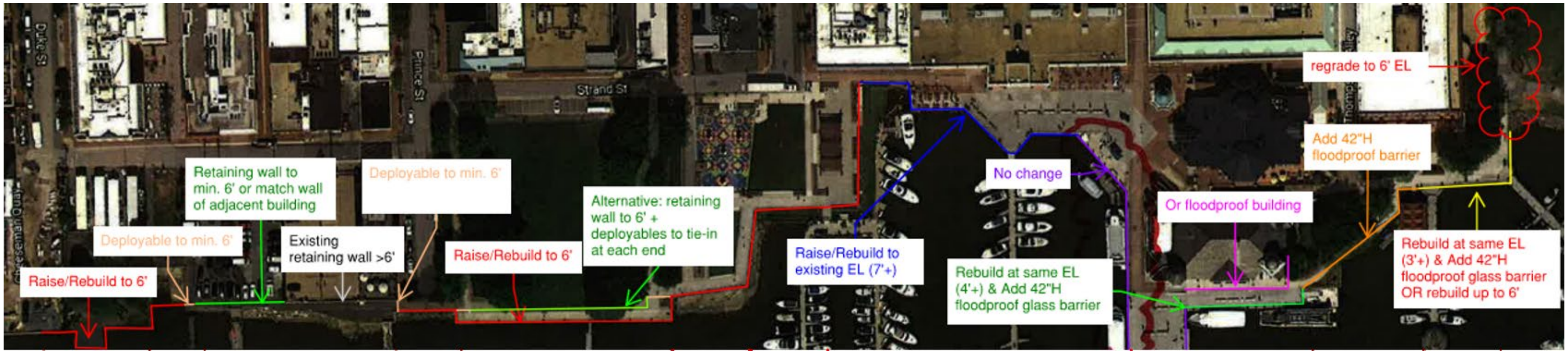

Figure 10 Carollo Structural Engineer Floodproofing Assessment

Per the Alexandria Waterfront Study (Olin, July 2021), Carollo worked with Olin to integrate structural visual assessments and landscape design to develop more cost-effective alignments. Significant changes in comparison to the Project Baseline include reuse of existing bulkhead segments, where applicable, and efforts to maintain current shoreline and reduce regulatory impacts. The team prepared two alignments which differed based on the preference to provide protection at the Potomac River versus at the Strand (or further inland to permit flooding along the promenade and parkspaces). However, both alignments seek to integrate the flood protection strategy with the priorities of the Small Area Plan. Therefore, these concepts also illustrate a new promenade, creation of new parks along the Waterfront, and a straight-line alignment for flood protection.

The alignment options, as shown in Figure 11, include multiple means of flood protection including sections of new bulkhead, grading and shoreline realignment as described below. The two alignments primarily differ along Point Lumley, Waterfront Park and King Street Square, and Thompsons Alley.

Figure 11 Value Engineering Solutions Providing El. +6.0 ft Flood Protection at the River and at the Strand with Landscape-Based Flood Barriers

The following is a general description of each segment of the Waterfront. Segments that do not explicitly differentiate between the alignments in Figure 11 are assumed to be consistent. Refer to *Appendix A: Bulkhead Section Detail* for location details for the bulkhead segments described below.

- **Robinson Terminal:** No change since area is outside of the scope of work.
- **Duke Street End Garden**: Use existing bulkhead with an extension (concrete cap) to El. +6.0 ft. Additional grading is required between Strand Street and the bulkhead.
- **Point Lumley Park:** Fill is required to realign shoreline to create a continuous promenade extending from Duke Street to Prince Street, which will be supported by a new bulkhead. A ha-ha wall is used for flood protection, at the Waterfront or closer to the Strand, assuming the new bulkhead is built at or around the existing shoreline elevation (approx. +4.0 ft).

- **Waterfront Park:** The existing shoreline alignment would be maintained with a new promenade. A ha-ha wall would be positioned adjacent to the promenade, at the Waterfront, or at the Strand. For either alignment, some grading changes are proposed from the top of ha-ha wall to/from Waterfront Park.
- **King Street Square:** The existing shoreline alignment would be maintained with a new promenade. A ha-ha wall is used for flood protection either at the Waterfront or Strand Street. Regardless of ha-ha wall alignment, additional riprap may be necessary to stabilize the shoreline.
- **Torpedo Factory Bulkhead:** New bulkhead under the assumption that existing bulkhead is in poor condition and cannot be repaired. This is based on the visual condition of the Torpedo Factory Wharf which is constructed of timber piles and framing (Michael Baker 2013) and is in poor condition on the water side. The wood slats are an architectural feature and existing bulkhead condition visual inspection needs to be performed by divers[1].
- **Thompsons Alley:** Fill is required to realign the shoreline to create a continuous promenade which will be supported by a new bulkhead. Bulkhead to be constructed to El. +6.0 ft to provide Waterfront protection or to a lower elevation coupled with a ha-ha wall for more inland protection. A further assessment of this area is needed to ensure appropriate space is allocated for the Thompsons Alley Pump Station (PS).
- **Queen Street End Garden:** Fill is required to realign the shoreline to create a continuous promenade which will be supported by a new bulkhead. Bulkhead to be constructed to El. +6.0 ft to provide Waterfront protection or to a lower elevation coupled with a ha-ha wall for more inland protection.

Some project stakeholders, including members of the Flood Mitigation Subcommittee, shared a preference for the "River" alignment shown in Figure 11. Carollo also favored an alignment closer to the Waterfront because it would reduce maintenance following an overtopping event. Excess debris from the Potomac consistently piles up on the Waterfront, so a solution that physically keeps logs and other debris in the Potomac will help the City recover faster following an extreme high tide event. Therefore, the River Alignment depicted in Figure 11 was the selected strategy for Project Performance Alternative. The associated cost is provided in the following section.

In preparation of a Cost-Based Alternative, Carollo worked with Olin to prepare a fully landscape-based flood barrier solution. Under this scenario, the Project reused the existing promenade and shoreline alignment to provide flood protection at the Waterfront or at the Strand. It does not depict any shoreline stabilization efforts that may be needed due to the visibly poor condition in certain areas. The solution uses a combination of ha-ha walls, planter boxes, grading changes, ramps, etc. and was ultimately presented to the Flood Mitigation Subcommittee in October 2021. The alternative was well received with preference towards Waterfront protection. The slides have been modified in Figures 12 and 13 to depict only the landscape flood protection alignment. A copy of the relevant slides is included at the end of the technical memorandum (TM). Both alignments assume that the Thompsons Alley Pump Station can be relocated to the Queen Street end garden as depicted in Figures 12 and 13.

[1] The 2013 Bulkhead Condition Assessment was unable to obtain construction documents or other record information related to the bulkhead sections but did perform underwater and underdeck inspections. This report noted the poor conditions of the Torpedo Factory Wharf and the satisfactory condition of the concrete bulkhead.

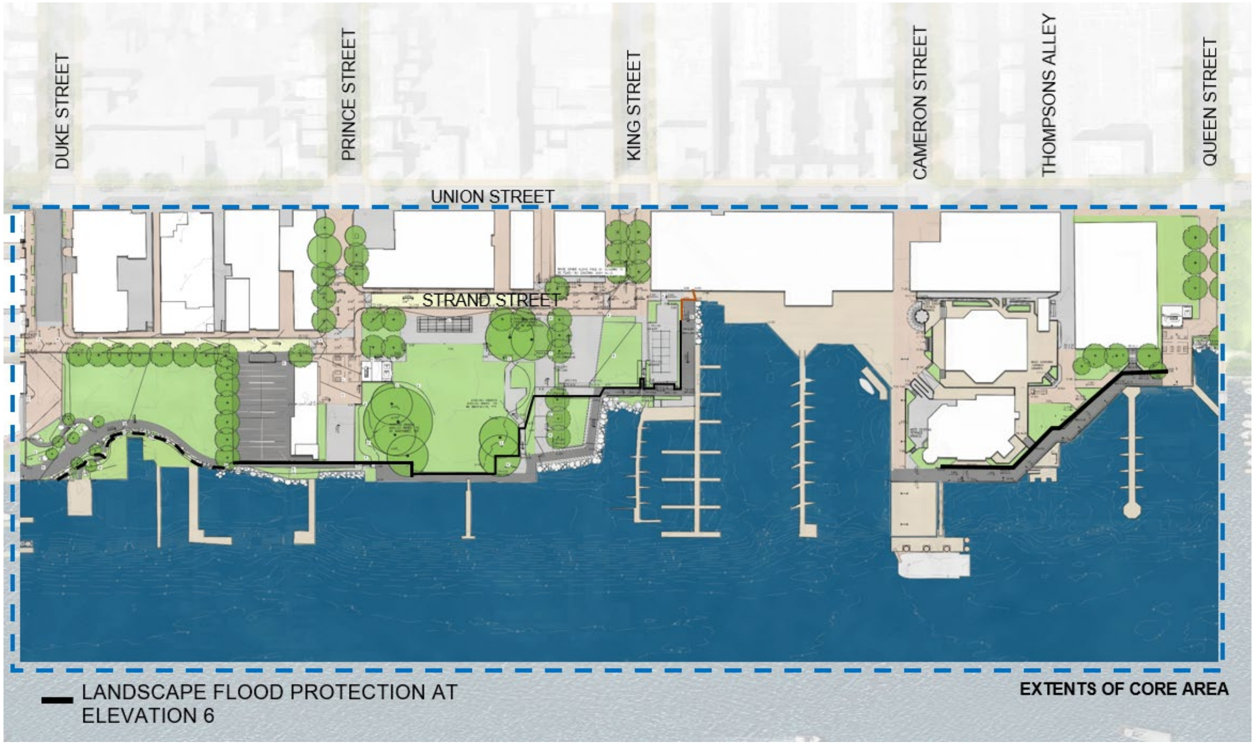

Figure 12 Landscape Flood Protection at the Waterfront and Maintaining Shoreline Alignment

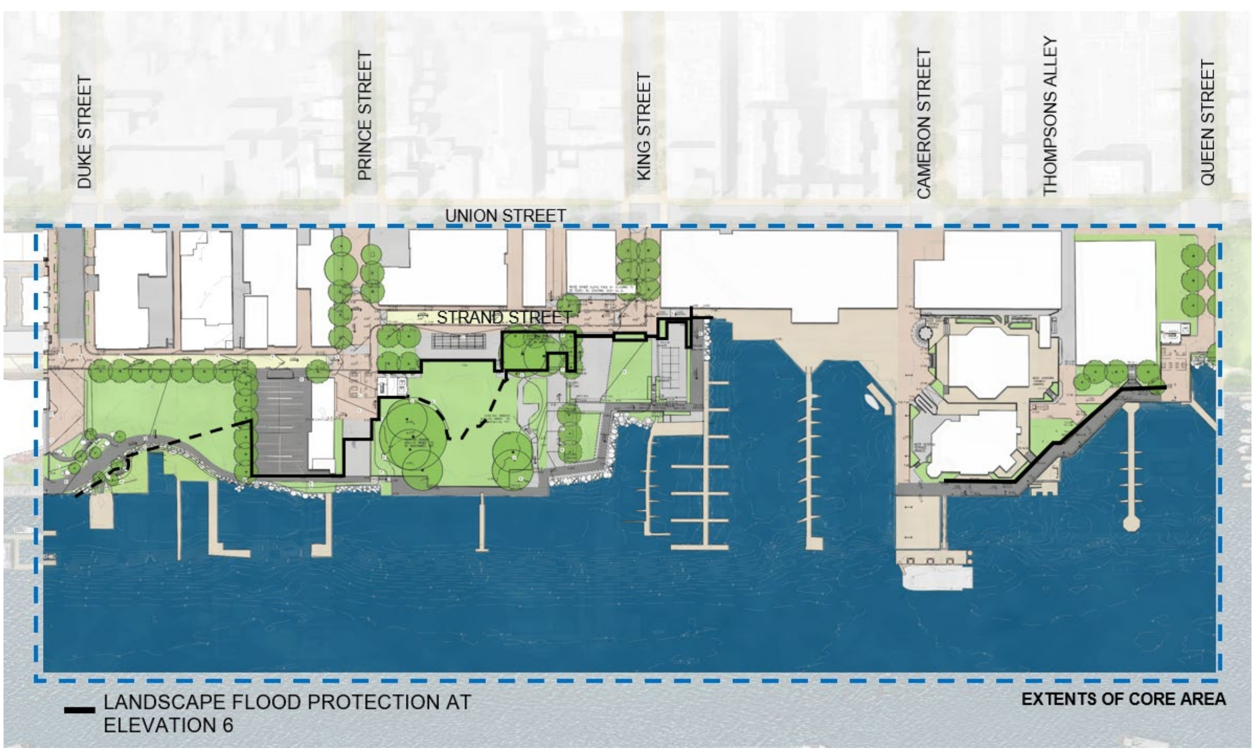

Figure 13 Landscape Flood Protection at the Strand and Maintaining Shoreline Alignment

1.7 Cost

Carollo prepared Class 4 direct construction cost estimate for the Baseline Project (Carollo 2020) and modifications as proposed in this memorandum with support from Olin. The cost basis for the Baseline Project is summarized in Table 3 per the *Bulkhead Design Manual* (Olin 2018). **The Baseline Project bulkhead, as described in Table 3, total direct cost is approximately $30M**.

Figure 11 and the use of a bulkhead and landscape-based barrier was carried forward as a Project Performance Alternative. **At this level of conceptual design, Carollo estimates that the alternative shown in Figure 11 would provide riverine flood protection equal to the Baseline while reducing the project cost by over 50 percent to a total direct cost at approximately $12M.** Table 4 bulkhead pricing uses the Baseline Project structural design (per Table 3), however, the overall bulkhead length is reduced to 660 LF. The landscape-based protection assumes a consistent ha-ha wall for protection with a unit cost of approximately $13 SF (at a 1 ft high) for a non-reinforced brick. The Geotechnical Design Memorandum will further refine the bulkhead and landscape-based barrier cost and will supersede the cost estimates provided herein.

Table 3 Design Parameters for the Baseline Project Structural Bulkhead

Parameter	Basis
Design elevation	6 ft NAVD
Construction means	Battered H-pile (113 ft depth), 9 ft on-center, with sheet pile (100-110 ft depth)
Design mudline elevation	North: -10.00 NAVD; South: -6.00 NAVD
Cap	4 ft-9 in wide reinforced concrete cap with dowel connection to adjacent paving slab
Length	2,200 LF

Note:
Adapted from 2019 Bulkhead Technical Design Manual (Olin).

Table 4 Value Engineered Hardscape and Landscape Based Riverine Flood Protection

Description	Length	Cost	Total Direct Cost
Battered H-Pile with Sheet Piling	660 LF	$12M	$12M
Landscape Based Protection	925 LF	< $50k	

Cost estimates were not prepared for the fully landscape-based design (Figures 13 and 14). While a fully landscape-based solution is expected to be less than a hybrid strategy, further subsurface investigation and analysis is needed and will be documented in the Geotechnical Design Memorandum.

1.8 Conclusions and Recommendations

Based on the evaluation presented, next steps include the following:

- A visual inspection of the bulkhead by Mueser Rutledge Consulting Engineers' in-house marine and geotechnical designers.
- A comprehensive subsurface investigation along the Waterfront including geotechnical and environmental testing and analysis.

Collectively these efforts will help the team determine appropriate and cost-effective structural support methods and construction materials for repairing, reusing and reconstructing the bulkhead. Additionally, this work will inform any refinements to the Preferred Project Alternative and advise on preferential investments to bulkhead segments, if and when funding becomes available.

Carollo will also seek the landscape and permitting input to evaluate and refine the Preferred Project Alternative. Landscape input will ensure the balance of hardscape and landscape flood protection is well integrated and connected to, from, and along the Waterfront. An understanding of the local regulatory environment and the expected impacts of various bulkhead alignments and design may inform the recommended path forward.

For further information on riverine flood protection design, data collection and analysis, please refer to the following documents. Documents are listed in chronological order of work performed:
Bulkhead Condition Site Walk Memorandum dated February 14, 2022.

- Geotechnical Data Report (MRCE 2022).
- Geotechnical Design Memorandum (MCRE).
- Conceptual Design Report (Carollo 2023).

1.9 References

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12. Olin Partnership Ltd. July 2021. *Waterfront Study Draft.* Philadelphia, PA.
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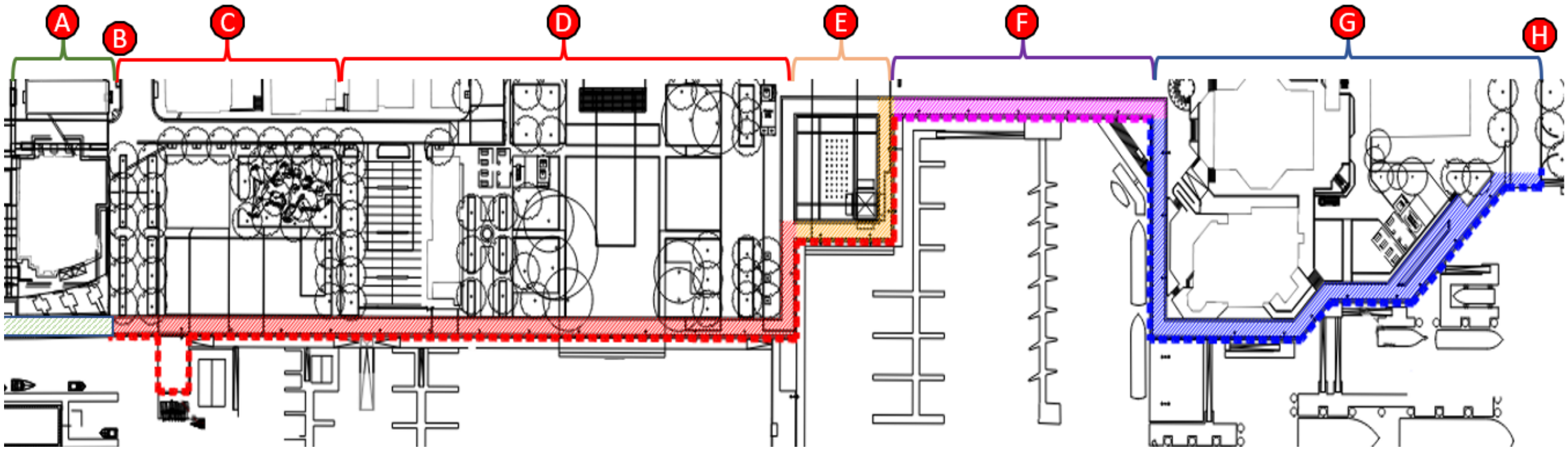
Appendix A
BULKHEAD SECTION DETAIL



A. **Robinson Terminal**
B. **Duke Street End Garden**
C. **Point Lumley Bulkhead**
D. **Waterfront Park Bulkhead**
E. **King Street Bulkhead**
F. **Torpedo Factory Bulkhead**
G. **Thompsons Alley Bulkhead**
H. **Queen Street End Garden**

Appendix B

EXCERPT SLIDES FROM THE FLOOD MITIGATION SUBCOMMITTEE OCTOBER 4TH UPDATE MEETING

Waterfront Implementation Project

Update to Waterfront Commission Flood Mitigation Subcommittee

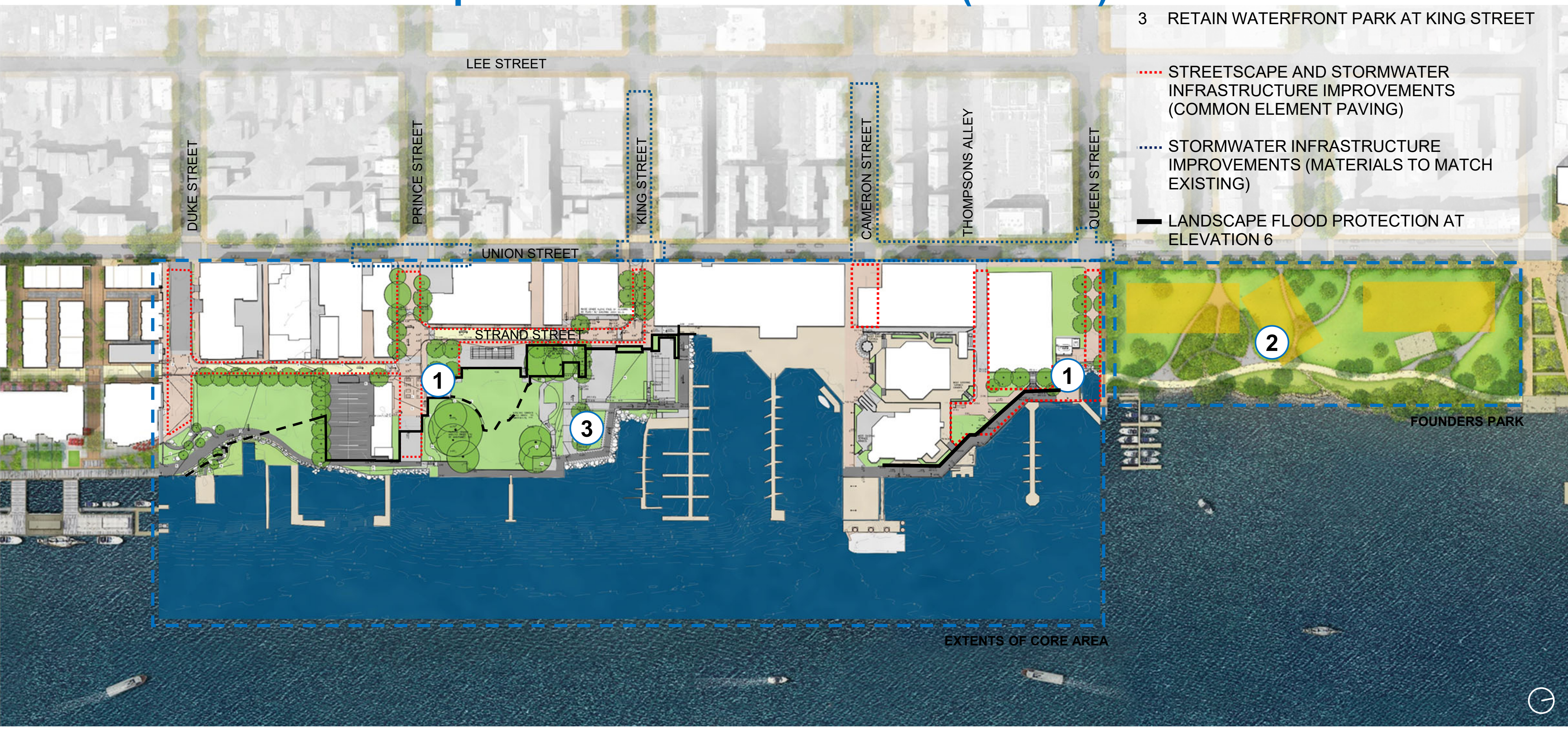
October 4th, 2021

Terry Suehr, PE, PMP
Department of Project Implementation, Director
Matthew Landes, PLA, ISA
Department of Project Implementation, Division Chief / Waterfront Program Manager

Cost-Based Alternative

// Cost Based Option - 1

Add-On A: Landscape Based Flood Protection (Strand)



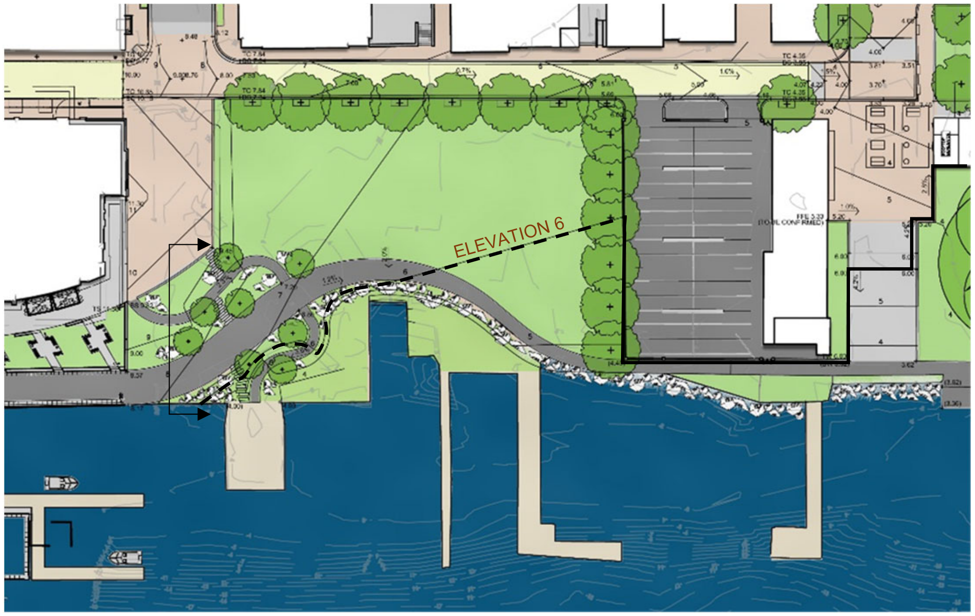
// Cost Based Option - 1

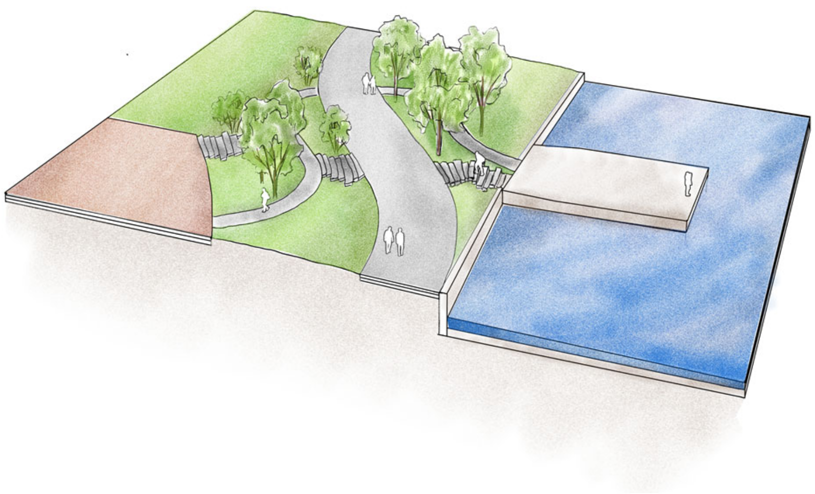
Add-On A: Landscape Based Flood Protection (Strand)

Point Lumley Park Improvements

- Extension of green space with new hardscape and landscape improvements
- New waterfront promenade
- Connection to Robinson Landing and Waterfront development to the north

KEY PLAN



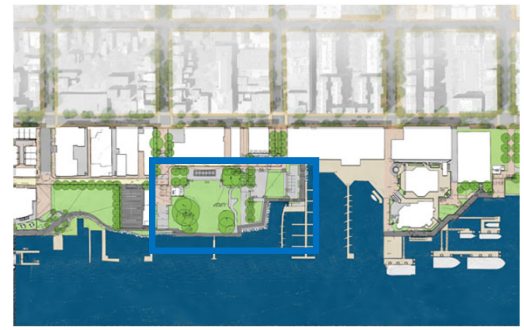


// Cost Based Option - 1

Add-On A: Landscape Based Flood Protection (Strand)

Waterfront Park and King Street Sq Improvements

- Incorporates stairs, ramps, and ha-ha walls
- Pump station



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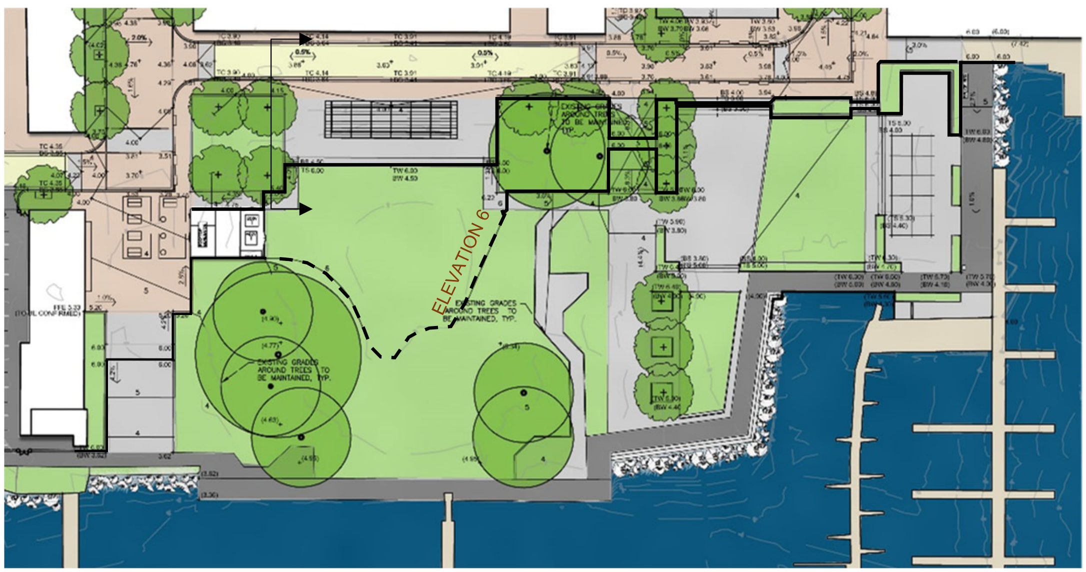
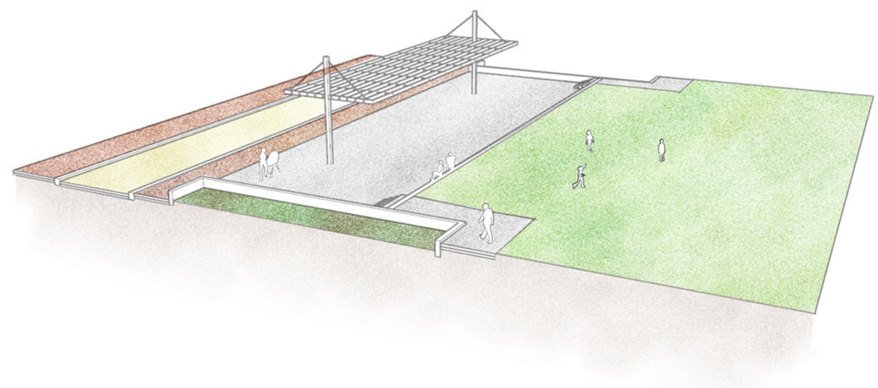




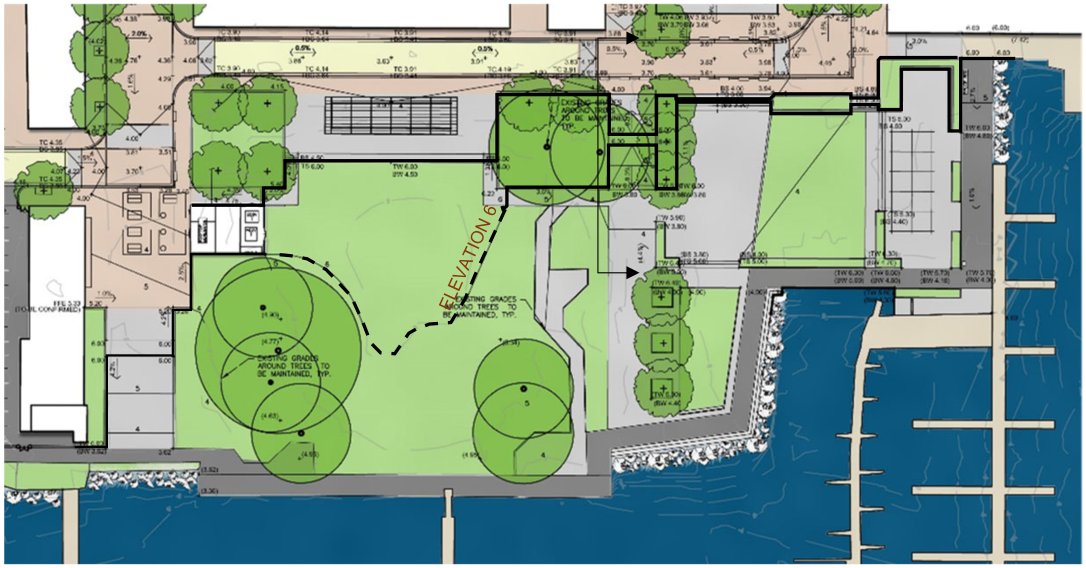
// Cost Based Option - 1

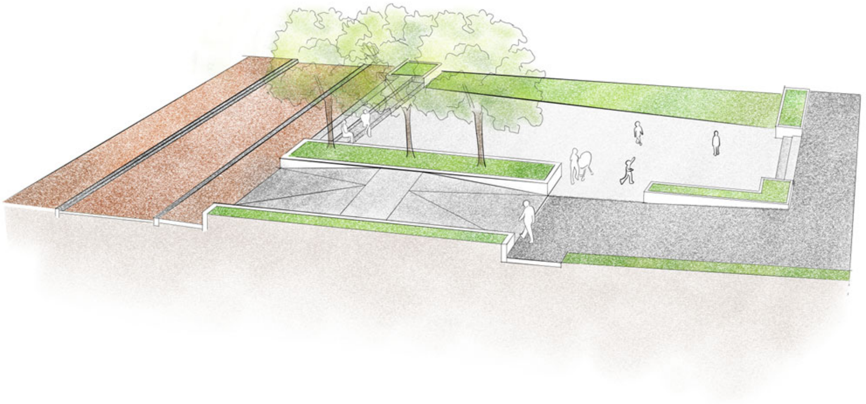
Add-On A: Landscape Based Flood Protection (Strand)

Waterfront Park and King Street Sq Improvements

- Incorporates stairs, ramps, and ha-ha walls
- Pump station

KEY PLAN





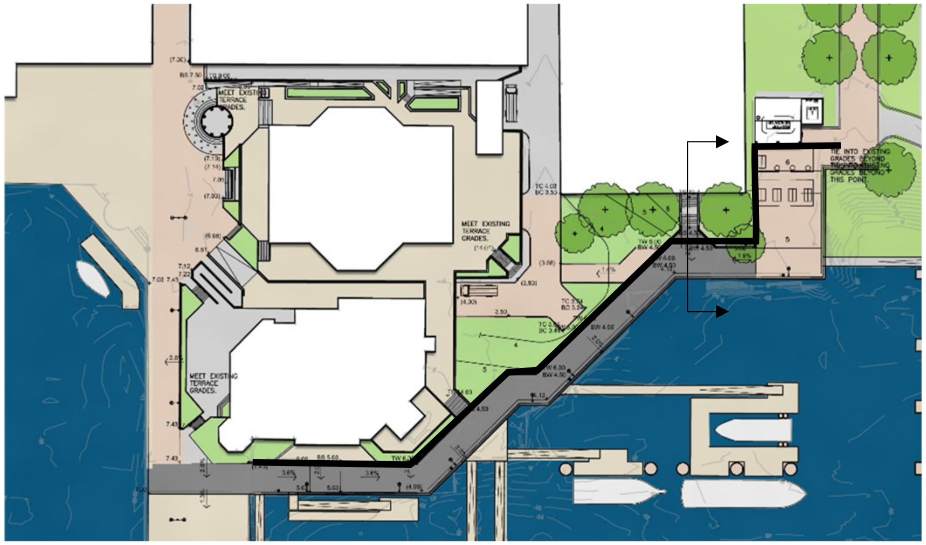
// Cost Based Option - 1

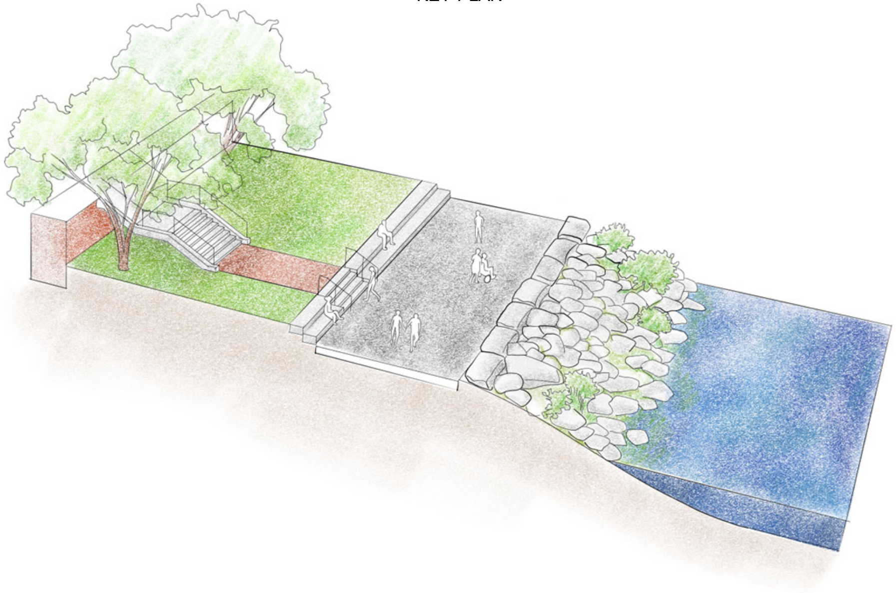
Add-On A: Landscape Based Flood Protection (Strand)

KEY PLAN

Thompsons Alley Improvements

- Ha-ha wall to promenade
- Pump Station
- Maintain existing waterfront promenade





// Cost Based Option - 1

Add-On B: Landscape Based Flood Protection (River)

LANDSCAPE ELEMENTS PROVIDE 6' ELEVATION FLOOD PROTECTION

LEGEND

1 PUMP STATION

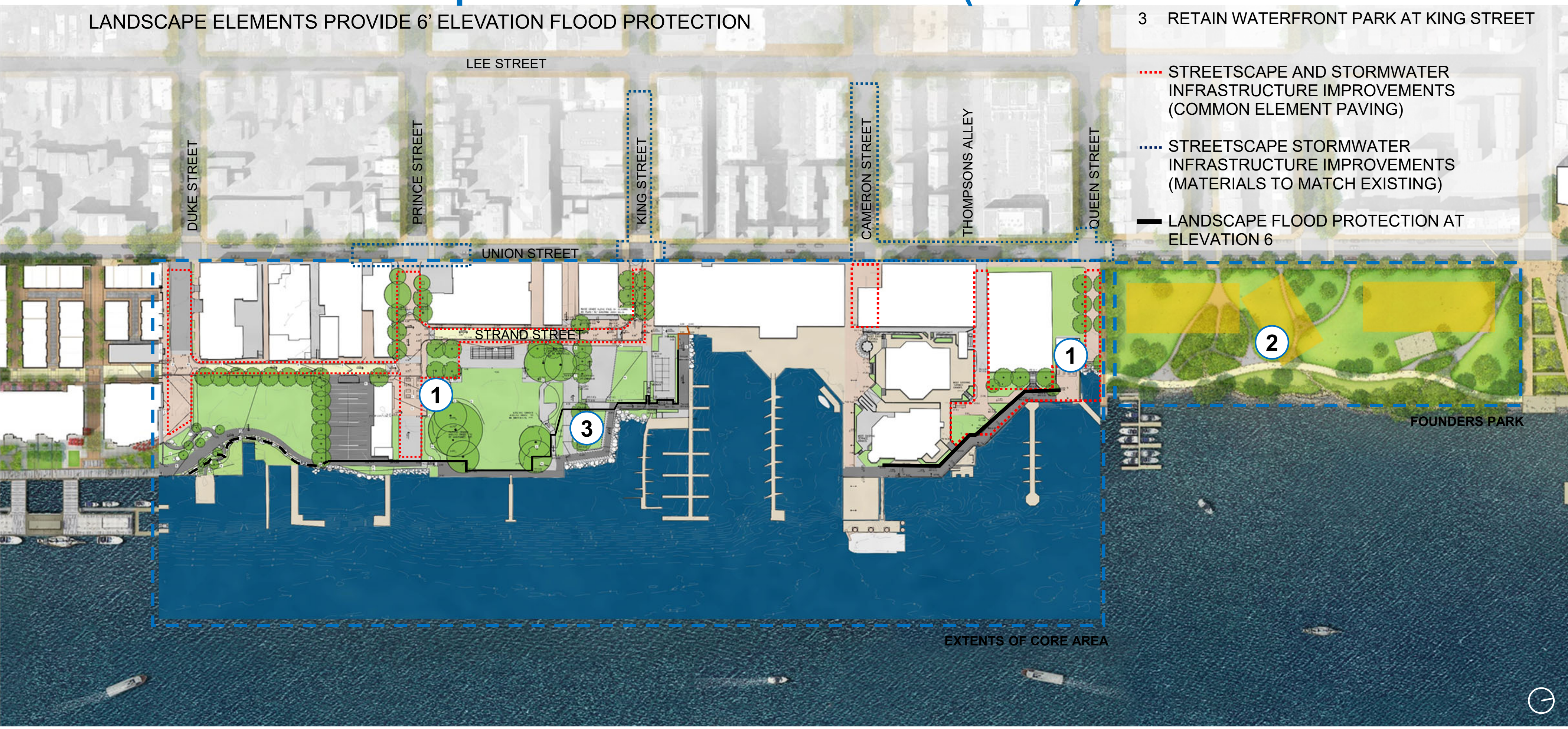
2 UNDERGROUND STORMWATER DETENTION CHAMBERS

3 RETAIN WATERFRONT PARK AT KING STREET

STREETSCAPE AND STORMWATER INFRASTRUCTURE IMPROVEMENTS (COMMON ELEMENT PAVING)

STREETSCAPE STORMWATER INFRASTRUCTURE IMPROVEMENTS (MATERIALS TO MATCH EXISTING)

LANDSCAPE FLOOD PROTECTION AT ELEVATION 6



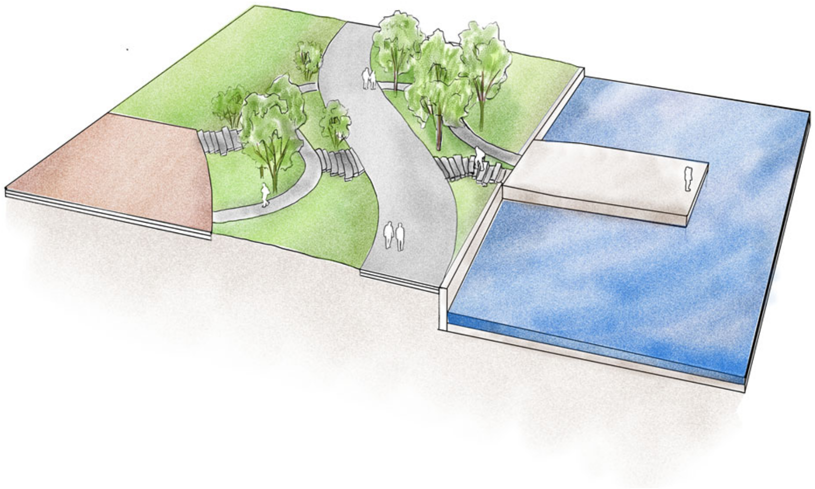
// Cost Based Option - 1

Add-On B: Landscape Based Flood Protection (River)

Point Lumley Park Improvements

- Extension of green space with new hardscape and landscape improvements
- New waterfront promenade
- Connection to Robinson Landing and Waterfront development to the north

KEY PLAN



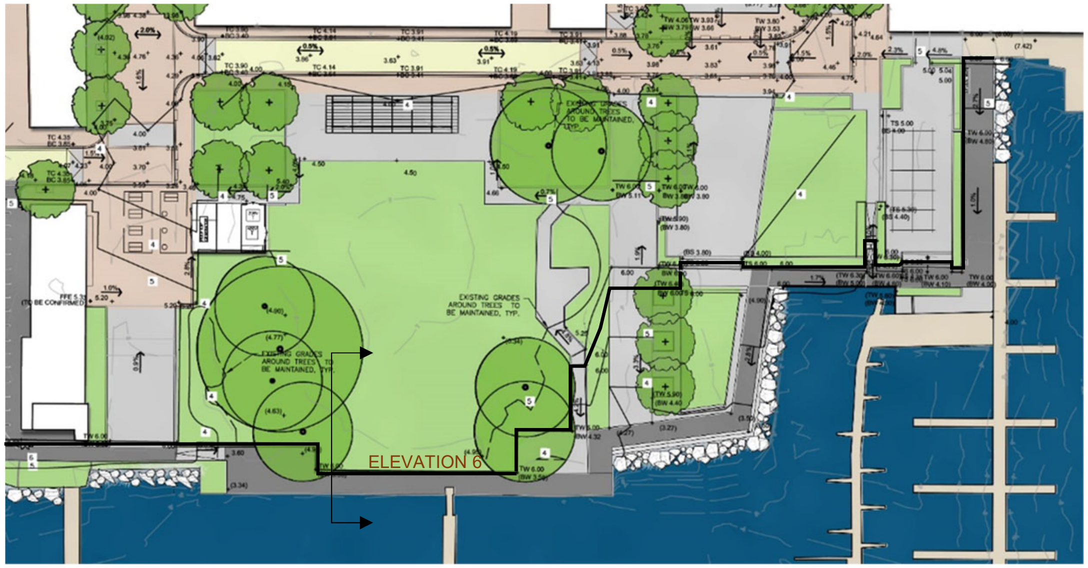
// Cost Based Option - 1

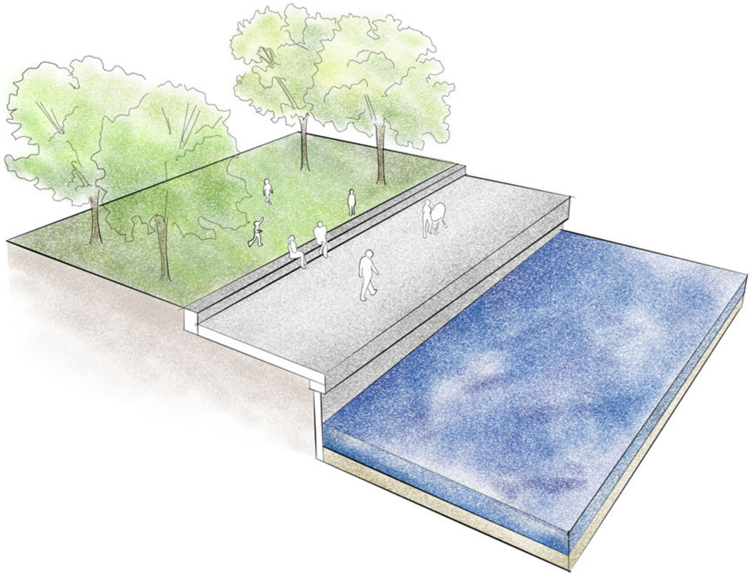
Add-On B: Landscape Based Flood Protection (River)

Waterfront Park and King Street Sq Improvements

- Stairs, ramps, and ha-ha walls
- Pump Station
- Maintain current waterfront promenade

KEY PLAN





Performance Alternative A

Prioritizes flood protection in the form of streetscape and stormwater infrastructure improvements, pump stations, and overtopping protection at El. +6ft with a 20' wide promenade along the water's edge

// Performance Alternative A

LEGEND

1 PUMP STATION

2 UNDERGROUND STORMWATER DETENTION CHAMBERS

3 RETAIN WATERFRONT PARK AT KING STREET

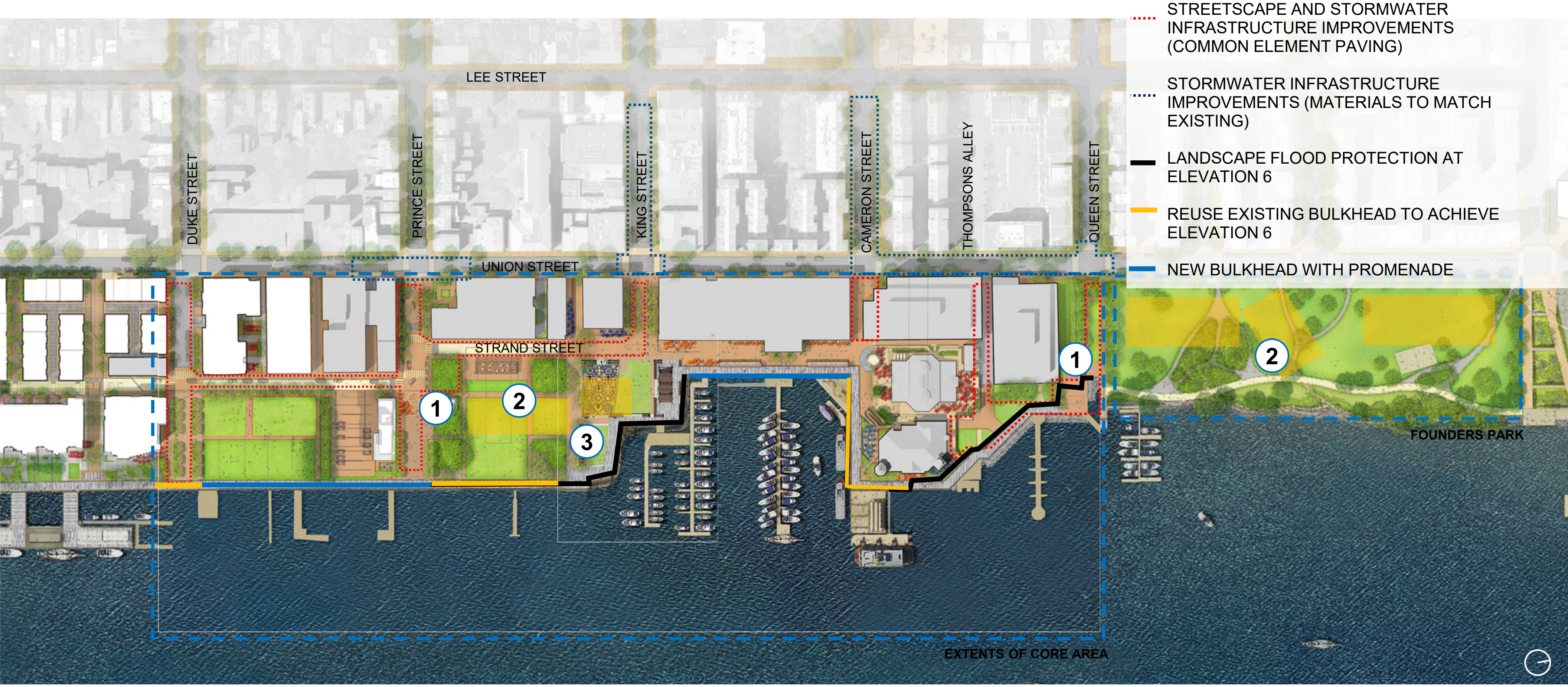
STREETSCAPE AND STORMWATER INFRASTRUCTURE IMPROVEMENTS (COMMON ELEMENT PAVING)

STORMWATER INFRASTRUCTURE IMPROVEMENTS (MATERIALS TO MATCH EXISTING)

LANDSCAPE FLOOD PROTECTION AT ELEVATION 6

REUSE EXISTING BULKHEAD TO ACHIEVE ELEVATION 6

NEW BULKHEAD WITH PROMENADE

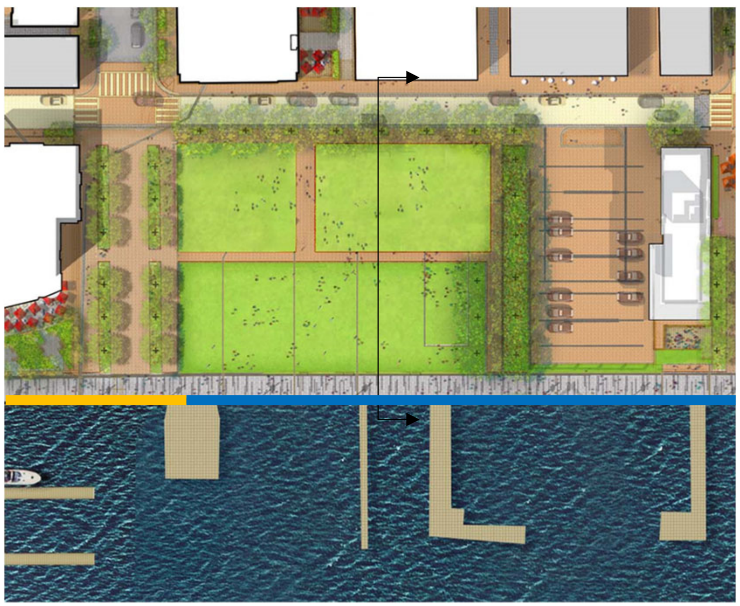


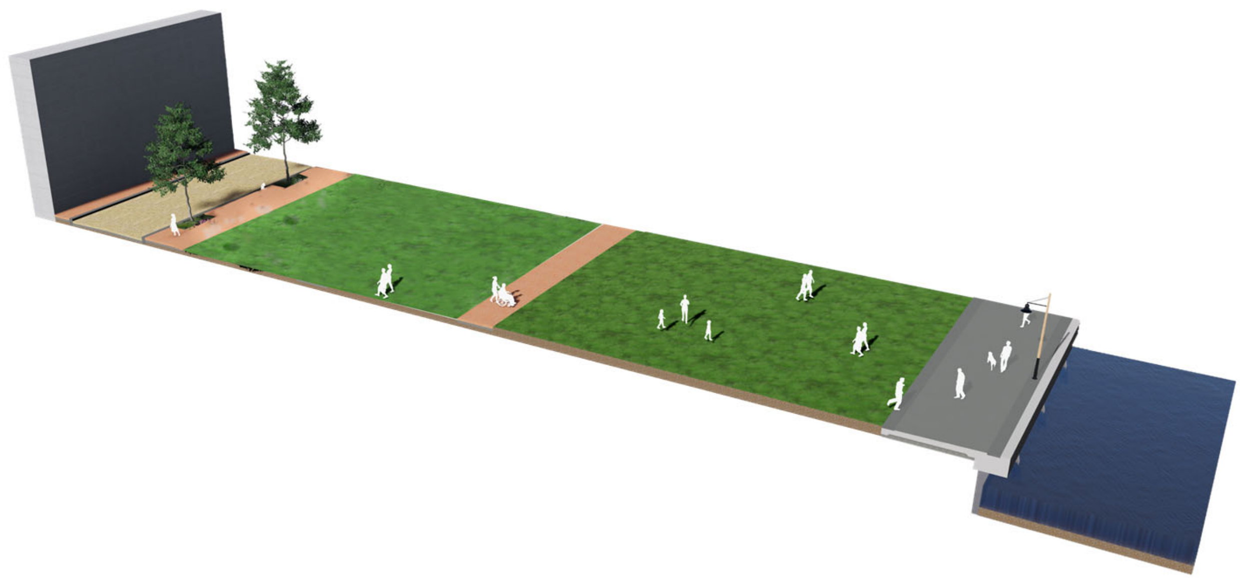
// Performance Alternative A

Point Lumley Park Improvements

- Extension of greenspace with new hardscape and landscape improvements
- New bulkhead and 20-ft wide promenade with pavers
- Connection to Robinson Terminal South and rest of waterfront new development

KEY PLAN



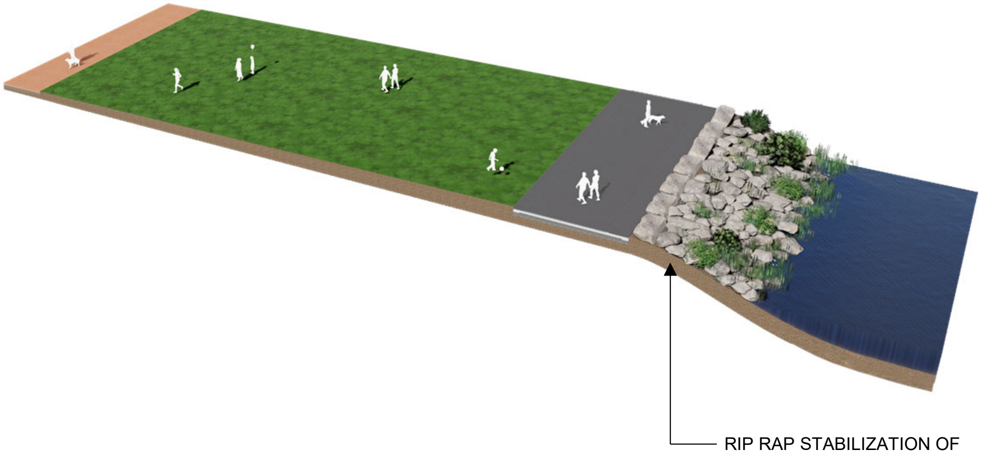


// Performance Alternative A

Waterfront Park and King St Square Improvements

- Pump Station at 60% capacity reduction
- New 20-ft wide promenade with pavers
- Riprap promenade edge at King St Square
- Concealed stormwater chambers

KEY PLAN



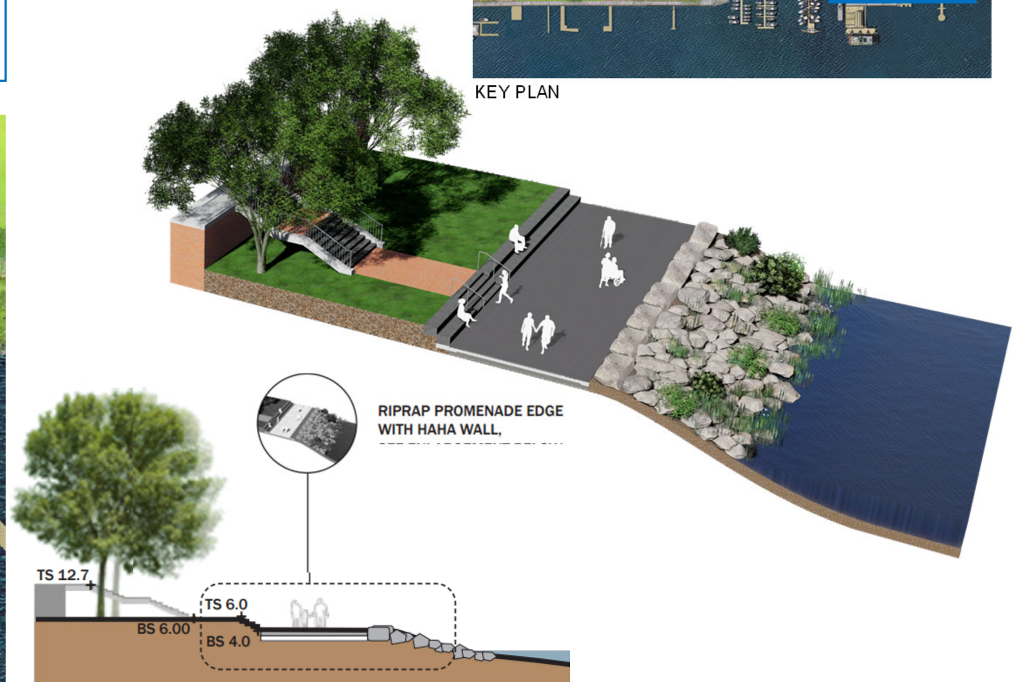
RIP RAP STABILIZATION OF PROMENADE EDGE

// Performance Alternative A

Thompsons Alley Improvements

- Ha-ha wall to new 20-ft wide promenade with pavers
- Pump Station at 95% capacity reduction and at least a 15% footprint reduction

KEY PLAN



SECTION A