Memo

SUBJECT
Challenges to Constructing an On-Land Alignment
DRAFT CONFIDENTIAL

TO
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Neighborhood Strategies, NYCEDC

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Overview

This memorandum documents the key technical feasibility challenges associated with constructing a flood protection alignment entirely on-land. The memo builds upon the work presented at the prior Climate Coalition for Lower Manhattan (CCLM) #4 in early May and is in support of the upcoming CCLM #5 meeting on June 16th, 2021, where we will focus on the flood protection alignments that are most viable and opportunities to together shape a more resilient waterfront. After the CCLM #5 meeting, we will share a second memorandum that details the key technical findings associated with the alignments that were removed from further consideration and how the team arrived at the smaller subset of flood protection alignments that are most viable.

For the purposes of this memo, it is important to note that "feasible" is not only defined as technically implementable from an engineering standpoint, but also considers other important factors, such as cost, property ownership and jurisdiction, traffic implications, and ability to construct and/or retrofit when considered in the context of the existing urban fabric. Other key considerations, such as visual access to the waterfront and displacement of open space, are also critical to consider when determining where to site coastal defense and are being explored in greater detail in other workstreams of the project; as such, they are not covered here.

This memo identifies and analyzes key infrastructure constraints across the study area. A summary of the findings is discussed herein, organized based on above grade and subsurface conditions:

- Above Ground Conditions Across the Study Area
    - Building-level Adaptation
    - Street Raising
    - Deployable Measures
    - Siting Infrastructure Under the FDR Drive Viaduct
- Subsurface Conditions Across the Study Area
    - Interceptor and Conveyance Infrastructure
    - Oil-o-Static Lines
    - Subway Tunnels, Stations & Infrastructure
    - Battery Park Underpass

In addition, potential modifications to the FDR Drive Viaduct as they relate to opportunities to siting the coastal defense on-land is discussed before a reach-by-reach walk through of site conditions.

Floodwalls as the Preferred Coastal Defense Structure

While there are several potential types of flood risk protection structures, for the purposes of this evaluation and the discussion herein, floodwalls are considered the most viable solution given the performance (i.e., reliability) of the structure and the minimum above grade footprint. Coastal floodwalls are generally located landward of the normal high-water line to reduce damages from hurricane or other surge tides at an area-wide scale. Depending on the size of the wall and the soil conditions, floodwalls can reside on shallow foundations (bearing directly on soil) or deep foundations (pile-founded).[1]

When considering above ground and subsurface conditions, the typical floodwall typology is a T-wall shaped floodwall with a pile supported foundation, concrete footing, and concrete. This typology is consistent with neighboring resilience projects, including East Side Coastal Resiliency (ESCR), and considered a best practice based on US Army Corps Hurricane & Storm Damage Risk Reduction System (HSDRRS) Design Guidelines. A typical cross section is shown in Figure 1.

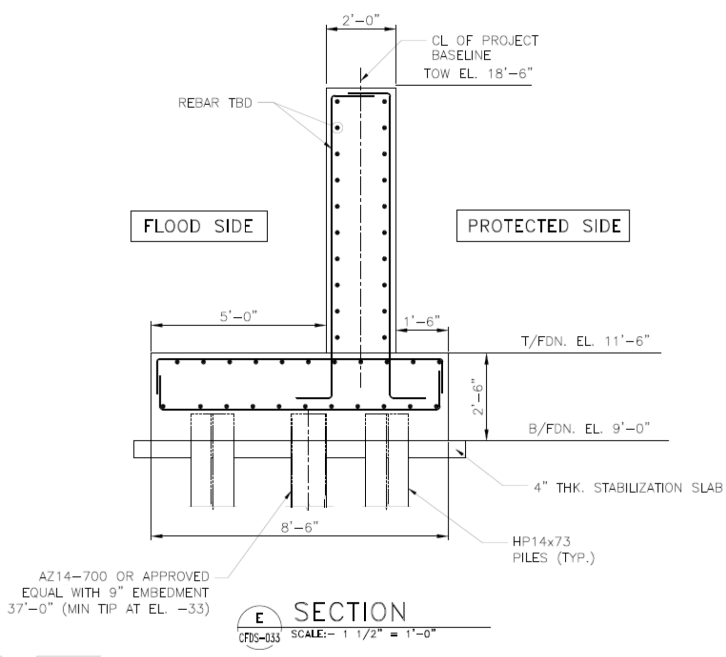

Figure 1: Example T-wall Cross Section

Floodwalls can take the shape of a T-Wall, I-Wall, or L-Wall. HSDRRS Design Guidelines recommend a height no greater than 4 feet for an I-Wall and no greater than 8 feet for an L-Wall, while a T-wall has no height restrictions. The wider foundation of the T-Wall permits it to be taller because it is more solidly embedded in the ground and

[1] While levees could be another suitable typology given the site conditions, they require a much larger footprint than flood walls which is generally not conducive to construction in a dense urban environment.

therefore can withstand forces farther away from its anchor point. A T-wall is also the preferred structure when considering impacts from barges and other floating objects. Based on existing grades and design flood elevations, the required wall height may be 15 feet or more in the project area. Given the design flood elevations and maritime activity within the study area, a T-wall is recommended.

The thickness of the T-wall stem is largely proportional to the storm tide elevations anticipated for the region and dependent upon barge or boat impacts and loads from wave action. The base is made as narrow as practicable but must be wide enough such that the wall does not slide, overturn, settle excessively, or exceed the bearing capacity of the foundation. The structural members are fully reinforced to resist applied moments and shears, including those from storm surge.

The width of the floodwall foundation is also largely proportional to the design loads. For example, a 15-foot-high floodwall may require a 15-foot-wide foundation to accommodate loads from wave action and other forces. T-walls can use several different foundation systems such as H-piles, pipe piles, drilled shafts, or micro piles, which allows for design flexibility. Pile type can be selected based on space limitations, site conditions, and subsurface conditions.

Space allocated to ensure proper operations and maintenance (O&M) of coastal defense structures (not just floodwalls) is also a key consideration. Best practice is to maintain 15 feet of clear access on either side of the floodwall, totaling a 30 to 35-foot maintenance corridor. Special considerations are needed wherever this corridor cannot be provided. As a result of these key dimensions, it is recommended that a minimum of 30-foot-wide corridor be considered to site the floodwall.

Design Criteria

Given the wave climate and existing site conditions, the design criteria for the Financial District and Seaport Climate Resilience Master Plan ("master plan") are different than neighboring projects, such as BMCR (Brooklyn Bridge to Montgomery Coastal Resiliency). These site conditions make it infeasible to site the coastal defense entirely on-land under present (2020s) conditions, and, as sea levels increase and design flood elevations become taller, the challenge to find clear, unobstructed space to site coastal defense becomes more complex. As a result, it is infeasible to entirely site the coastal defense on-land under both 2050s and 2100 sea level rise conditions, as described in greater detail within.

A few of the key drivers are noted below.

- **Sea Level Rise Projections:** Given the complexities associated with constructing even a portion of the project in-water, it is assumed that the timeline for implementation will be further into the future. As such, the Master Plan is utilizing 2100 sea level rise (SLR) projections based on the New York City Panel on Climate Change (NPCC). This is different than neighboring projects that are currently in construction or are anticipated to be over the next few years. These projects are instead employing a 2050s SLR projection from NPCC. The 2100 SLR projection is 75 inches, as compared to 30 inches in the 2050s.
- **Wave Climate:** The Financial District and Seaport neighborhoods have a larger significant wave height compared to other areas due to their relative location to the New York Harbor, with wave heights in the study area differing by as much as two feet.. As a result, the target design flood elevation and the types of coastal defense structures that can be utilized are different here than for other projects (e.g., Brooklyn Bridge-Montgomery Coastal Resilience or East Side Coastal Resiliency). In addition, as discussed in greater detail in later sections, depending heavily on deployable measures is not recommended in this area due to concerns over reliability and performance during wave conditions.

- **Existing Grade:** The Financial District and Seaport neighborhoods are very low-lying, with average grade elevations of approximately 7-8 feet NAVD88 and with low spots in the Seaport near 5 feet NAVD88. As a result, the area is highly vulnerable to daily high tides in the future. Our project seeks to protect the Financial District and Seaport neighborhoods from both daily tidal flooding and future coastal storms, which require different approaches. To protect against daily tidal flooding, we need to design to a constant (or "passive") level of flood protection that is always there to protect the Financial District and Seaport neighborhoods. While we recommend also providing a constant level of protection for coastal storms, the height of coastal defense required for these events is much higher than for daily tidal flooding. In some cases, reaching our design flood elevation for coastal storms will require selective use of deployable gates in areas where we are unable to build taller. However, for daily tidal flooding, which are much more frequent events, it is impractical to use deployable measures and a constant level of protection is needed.

A summary of the design criteria and corresponding target flood elevations is noted in the table below. All elevations are in feet NAVD88.

Design Flood Elevation (Coastal Storms)	2100 100-year storm	+23 ft to +26 ft
Passive Flood Protection (Tidal Flooding)	2100 Mean Monthly High Water [MMHW] + freeboard	+11 ft to +14 ft

Above Grade Conditions

One of the key challenges of the study area is the combination of lack of space due to the existing dense urban fabric and the low-lying topography resulting in tall coastal defense structures (i.e., 15 feet tall). As a result, finding clear, available space to site coastal defense within the study area is particularly challenge, with more details described herein.

Building-level Adaptation

This section discusses some of the key technical feasibility challenges associated with a building-level approach to coastal defense. However, aside from key technical feasibility concerns, it is important to note that a large portion of the study area will be vulnerable to regular tidal flooding late in the century, making a building-level approach not suitable. Tidal flooding will cause regular flooding of roadways and sidewalks that will render them impassable to cars and pedestrians. If the building cannot be accessed on a regular basis, it loses its importance as a structure even if damage to the structure is avoided. Finally, building-level adaptation will leave many critical systems, including utilities, outside of the alignment, requiring independent hardening measures.

From a technical feasibility standpoint, building level adaptation in the study area is primarily constrained by the height of the design flood elevation and the lack of necessary foundation space due to the large number of buildings and utilities leaving little space unobstructed. The red areas, shown in Figure 2, illustrate the difficulty of integrating the necessary height that needs to be achieved by the flood protection with the existing buildings. Key considerations when considering building-level adaptation for the study area include:

- **Foundation Requirements:** In addition to the portion visible above ground, any flood protection structure, including building level adaptation, would have significant foundation requirements which will be challenging to site between building foundations, subway infrastructure, and other subsurface infrastructure.
- **Use of Deployable Measures to Maintain Access:** Building level flood protection would require significant use of deployable measures to maintain connections between the street, sidewalk, and buildings. Ground raising would be necessary in conjunction with deployable measures to meet the project goal of preventing daily tidal inundation: deployable measures alone would not meet the project goal because the ground elevation would be too low. In Figure 2, numerous openings and entrances give a glimpse into the sheer number of deployable measures that would be needed.
- **Wave Loads & Building Impacts:** The structures closest to the waterfront are not designed to handle the load cases created by storm surges and wave action. With building-level adaptation, the outer walls would be required to bear the brunt of these loads, which could compromise the structural integrity of the building. Other options such as having “sacrificial” first floors would be very challenging to retroactively implement; building-level adaptations of this nature are generally more applicable for new construction or for a single building rather than an entire study area.
- **There are also concerns with accessibility, O&M, ownership, liability, and governance.** If a building becomes part of the line of defense, the building’s owner would now be required to maintain the building in accordance with best flood management practice guidelines established by the Federal government. This could limit future modifications to the building. Building access points also are potential weak points in the system and could create flood pathways which could impact other buildings in the area. Additionally, building-level adaptation on private property would create a dependence on private property owners to provide critical flood protection and emergency response to the neighborhood.

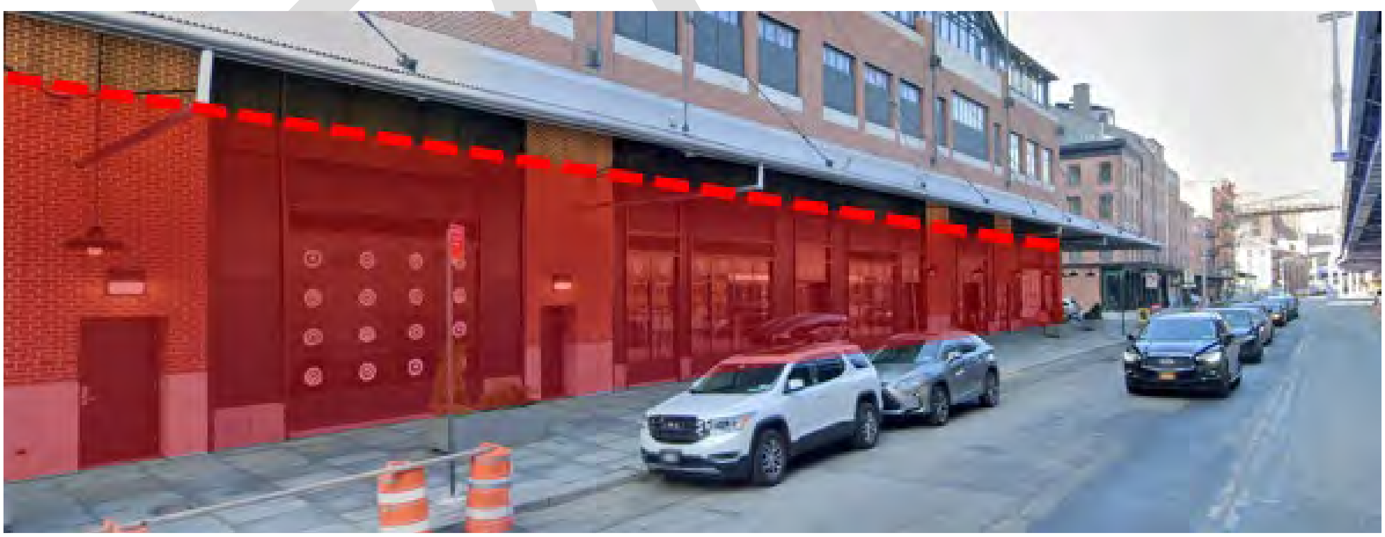

Figure 2: Height of building-level interventions

Street Raising

While street raising has several precedents, most street raising projects are aimed at improving drainage or mitigating sea level rise, not providing coastal defense. Several factors make street raising a non-viable option for most of the project area:

- **Height of intervention**: The height of interventions necessary in this project area would make the implementation of raised streets as coastal defense particularly challenging: street or sidewalk raising is only recommended in the study area where the existing grade is within four (4) feet of the DFE (i.e., closer to tiebacks).
- **Disruption to street grid**: Raising streets to the target DFE would also have significant impacts to the existing street grid and connections; in contrast to FiDi-Seaport, many locations in which streets are raised are those where there is little existing development around the raised streets.
- **Subsurface implications:** Street raising would result in additional cover placed on subsurface infrastructure, increasing the loads on subsurface utilities, and making long-term operations and maintenance more challenging. Relocation of subsurface infrastructure and new access points (e.g., manholes, etc.) would be required.
- **Independent flood protection still needed**: Independent flood protection structures with foundations would need to be integrated into the raised roadway; this will prove particularly challenging for our project due to underground infrastructure and limited horizontal space underneath roadways available for foundations. Where the existing grade is near the DFE, the need for horizontal space could be reduced by using I-walls instead of T- or L-walls. However, this condition is rarely present in the project area.

Deployable Measures

For the purposes of this memo, deployable measures refer to any feature that requires activation prior to providing the full level of protection (i.e., design height). Deployable measures could include “just-in-time” systems such as Tiger Dams or Hesco Barriers, plank-type systems, “flip-up” gates such as FloodBreak system, as well as steel roller or swing gates. In urban areas, some deployable components are typically needed to maintain access.

- **Deployment Frequency:** The primary consideration for any deployable measure is the deployment frequency of the system. Each system requires resources to plan and execute each deployment, rendering frequent deployment burdensome. Within the study area, daily tidal flooding will be a concern under future sea level rise conditions making deployable systems impractical here. As such, our recommendation is that there be a minimum elevation for a completely passive system designed to +11 feet NAVD88 and that deployable measures would be used in conjunction with raising the edge. This would ensure that deployable measures would only be utilized on an infrequent basis for coastal storms rather than twice daily for tidal flooding.

- **Just-in-time measures:** Just-in-time measures, pictured in Figure 3 and Figure 4, have limited application in the study area. Several limitations to just-in-time systems include:
    - **Height limitations**: Most just-in-time systems have height limitations that would be exceeded in most of the study area due to low surface elevations and high design flood elevations.
    - **Wave and load impacts**: Most just-in-time systems have limited capacity for wave and impact loads, both of which could be substantial in the study area.

- **Deployment lead time**: Just-in-time measures require a long lead time to deploy, making installing area wide protection time consuming and potentially impractical.
- **Reliability**: Just-in-time measures are less reliable than passive systems since they require substantial resources to plan and execute deployment. Additionally, failure of individual components could lead to system wide failure.

For these reasons, use of just-in-time measures is not recommended for this project, except for use for interim tie-back measures as part of a phased project plan.

Figure 3: A woman walks by temporary water-filled tubes (Tiger Dams) in Lower Manhattan during Tropical Storm Isaias. (Source: Shannon Stapelton/Reuters)

Figure 4: Filling metal-reinforced containers (HESCO Barriers) with dirt in preparation for Tropical Storm Isaias near South Street in Lower Manhattan. (Source: G.N.Miller/NYPost)

- **Plank-type systems:** Plank-type systems, pictured in Figure 5, have greater applicability within the study area. Considerations for this type of system include:
  - **Robustness:** These systems are more robust, which means they have better wave and impact load capacity and more ability to reach the design flood elevation.
  - **Deployment lead time:** These systems require substantial time and resources to deploy.
  - **Foundation requirements:** Plank-type systems have foundation requirements similar to a T-Wall (see Floodwall discussion above).

While a plank-type system could be a reasonable choice for some gate and crossing applications, the deployment time and effort renders area-wide use of this type of system impractical.

Figure 5: Plank-type system installed at Verizon Telecommunications, 140 West Street, NYC

- **Flip-up gates**: Flip-up gates, pictured in Figure 6, have limited application in the study area. Considerations for this type of system include:
  - **Robustness:** These systems are more robust than just-in-time measures, which means they have better wave and impact load capacity and more ability to reach the design flood elevation.
  - **Foundation requirements:** Foundations also tend to be wider than the other solutions since they need to encompass the full height, plus edge beams and mechanical systems.

  As with the plank-type system, flip-up gates could be used (in combination with raised grades) for some gate and crossing applications in the study area; however, due to the low-lying elevation throughout most of the study area, as well as the wave climate compared to elsewhere in Lower Manhattan, these measures are recommended for use only sparingly in this project area and in concert with raising the edge to a constant, passive level of protection to address future daily tidal flooding.

Figure 6: Activated flip-up barrier protecting entranceway. (Source: PS Flood Barriers)

- **Roller and swing gates**: Roller and swing gates provide robust access with a good track record of successful deployment. These systems would be a preferred choice for access points and crossings. However, these systems are not intended for area-wide use due to the same concerns noted for flip-up gates: due to the low-lying elevation throughout most of the study area, as well as the wave climate compared to elsewhere in Lower Manhattan, these measures are recommended for use only sparingly in this project

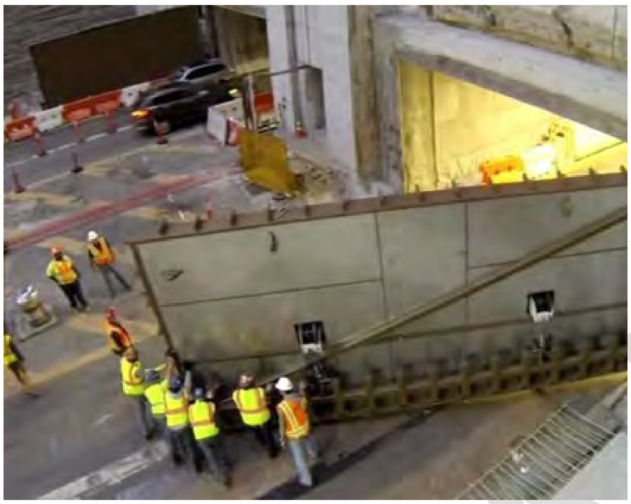

Figure 7: Swing-hinged gate at Hugh L. Carey tunnel entrance

Figure 8: Over-head trolley roller gate at Bay Park WWTP.

In some areas we still need to use deployable measures to maintain at grade access across the study area. However, given the wave forces in the area, as well as the foundation requirements and need for on-site storage, passive measures, such as levees and floodwalls, are recommended.

Alignment under the FDR Drive Viaduct

This section documents some of the key design aspects that were considered when evaluating the feasibility of constructing deployable and permanent members beneath the FDR Drive Viaduct in the study area.

To complete this analysis, design drawings for BMCR (BK-Bridge Montgomery Coastal Resiliency) dated December 6th 2019 were consulted. The BMCR design includes flip up gates, totaling approximately 2700 linear feet (LF) along the alignment. For comparison with the conditions in the project area, the Consultant Team evaluated flip up gate capabilities relative to each project's high-level requirements and constraints (BMCR is designed to protect against a 100-year storm in the 2050s).

In addition to deployable measures, the Consultant Team evaluated the feasibility of constructing a permanent measure – a floodwall – beneath the FDR Drive Viaduct. In both instances, the result of the analysis suggests that there is limited ability to construct beneath the FDR Drive Viaduct in the study area because of both vertical and horizontal clearances beneath the roadway. More information is provided below.

Vertical Clearance

The height of the intervention needed to protect the study area from the 100-year storm in both 2050s and 2100 poses significant challenges to the vertical clearance under the FDR Drive Viaduct. The "top of wall" elevation of the flood protection could range from 21ft NAVD88 to 23ft NAVD88 (2050s and 2100, respectively), with the space needed for wave runup reaching 26ft NAVD88 in 2100. Additionally, a 5-foot offset from the bottom of the FDR Drive Viaduct is required by state DOT. Due to the difficulty of future modification to an under the FDR alignment, we would likely recommend a top of wall elevation of 23ft NAVD88 to limit overtopping. Figure 9 shows the overlay of the elevation of the FDR viaduct and the various vertical constraints. As demonstrated in the graphic, there is insufficient clearance under the FDR to accommodate the flood defense system along the entire alignment except for a stretch of about 750 feet between Piers 11 and 15. Even where vertical clearance allows for some type of flood protection to be located under the FDR Drive, several factors still pose significant challenges to the successful implementation of such an alignment:

- **Ensuring critical assets are protected**: Placing an alignment of this height underneath the FDR would not protect the eastern support columns for the highway, exposing them to wave and impact loads during coastal flood events and would also increase the exposure of the entire superstructure to salt spray. The increased exposure to salt spray would likely increase maintenance for the highway support structure.
- **Maintaining waterfront access**: Waterfront access would not be able to be maintained via up-and-over measures with an alignment under the FDR Drive. Not only would configuring the up-and-over be a challenge, but there is insufficient clearance under the FDR superstructure for the height of the alignment plus the height of a person going over it. Additional detail on the limitations of deployable measures to provide waterfront access are discussed in later sections.
- **Increased technical complexity**: To connect the section where vertical clearance allows for an alignment under the FDR to the neighboring section of alignment, a transfer from outboard alignment to inboard alignment and back to outboard alignment would be required. This necessary connection adds technical complexity to the alignment and would add cost without increasing the benefits of the flood defense system.

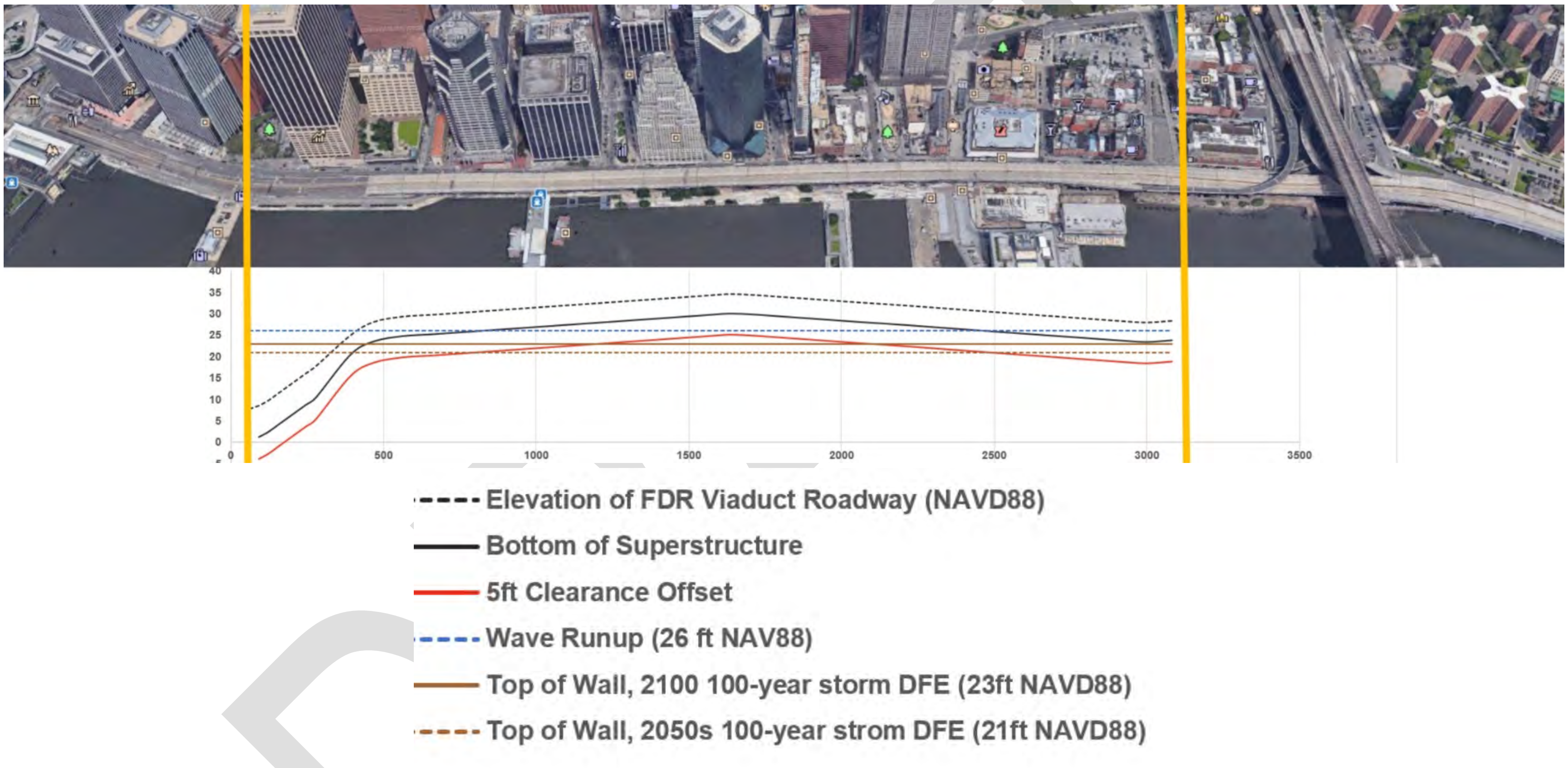

Figure 9: FDR Vertical Clearance Challenges

Horizontal Clearance

In addition to vertical clearances, limited horizontal space presents challenges to construction under the FDR Drive Viaduct. Table 1 and Figure 10 summarize the approximate horizontal dimensions under the FDR Drive Viaduct in our study area. Considering the required offset from the FDR Drive footings, only 13 feet of horizontal space is available under the FDR Drive Viaduct.

Table 1: Approximate Horizontal Dimensions Under the FDR Drive

Dimension	Approximate Measurement
Between FDR footing column clearance offsets	13 ft
Between FDR footing columns	23 ft
Between FDR footing column centerlines	35 ft
Subgrade footing column	15 ft x 12 ft
Offset from FDR footing column	5 ft

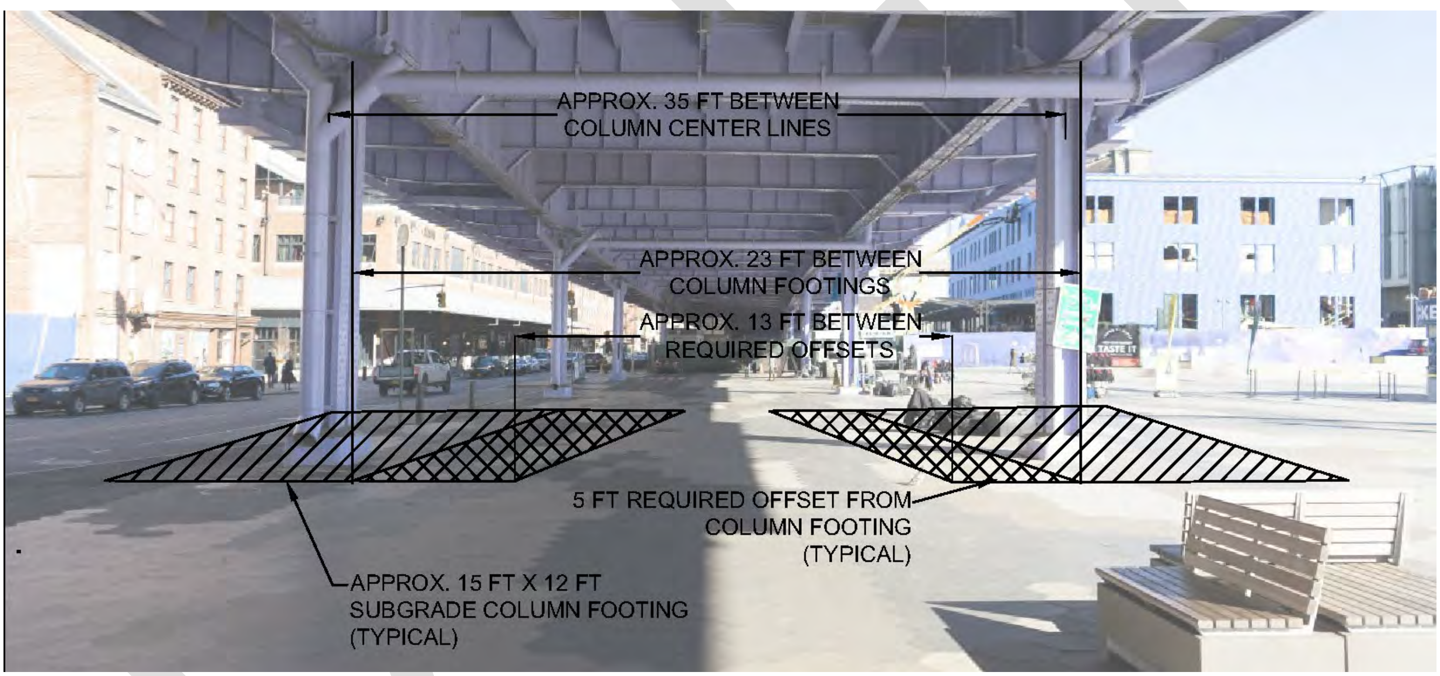

Figure 10: Approximate FDR Drive Dimensions (from BMCR)

Flip-Up Gates (Figure 11)

One option that was considered was the use of flip-up gates and whether there was sufficient available space to site on-land. A spatial analysis concluded that there was not sufficient horizontal clearance to house a flip-up gate that reaches the target DFE of 23ft NAVD88. Rather, the space is limited to a gate of +19ft NAVD88, which is insufficient in both 2050s and 2100 sea level rise conditions.

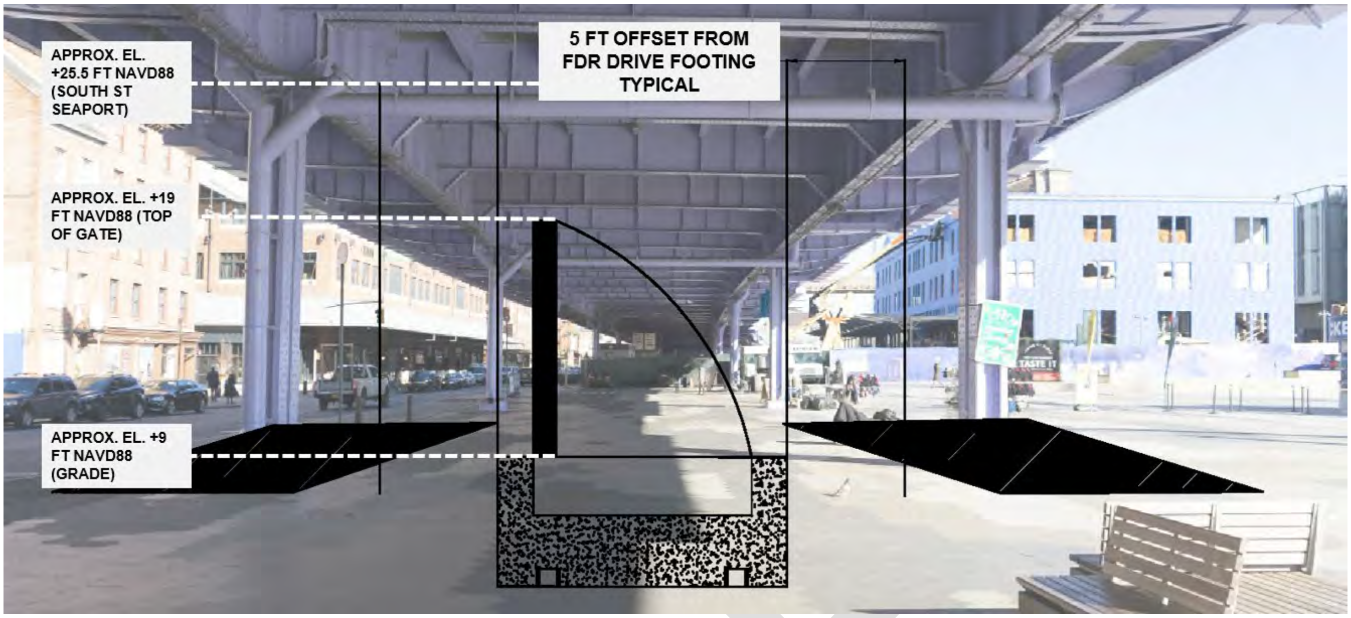

Figure 11: Flip-Up Gate Under the FDR

Providing Passive "Constant" Protection

Due to low ground elevations in the area, there is not enough space from the facades of the buildings on South Street to the mid-point under the FDR (where the flood protection measure would be) to achieve the necessary passive level of protection. With a ground elevation of about 6ft NAVD88 (lower at times), a passive DFE of 11ft NAVD88, and a horizontal distance of approximately 90 ft, achieving passive protection by raising the road would not be possible because the road slope would be above the acceptable upper limit of 5% (1:20 slope for universal access).

Subsurface Conditions

Another key challenge of the study area is the numerous below-grade utilities and subsurface critical infrastructure, further complicating the ability to site coastal defense and the associated foundations within the study area. A description of the key elements is provided herein.

Interceptor

The interceptor is a large sewer (108" diameter) which during dry weather receives flow from sanitary or combined sewers and during storms receives additional stormwater. The interceptor will pose several challenges to siting coastal infrastructure including inability to move the interceptor without constructing a new interceptor, DEP access requirements, and the strong recommendation to site the interceptor on the dry side of the flood protection to reduce risk. Each of these points is described in greater detail below and is illustrated in Figure 12, Figure 13, and Figure 14.

- **The interceptor cannot be moved without constructing a new interceptor:** At 108" (9 feet) wide, the interceptor is the largest piece of stormwater infrastructure in the area. As a result of its size, it cannot be easily accommodated elsewhere due to space limitations. Furthermore, taking the interceptor offline, even temporarily, would require bypass structures and present a significant undertaking due to the critical function it serves in carrying both wet and dry weather flows to the Manhattan Pump Station.

- **DEP has many access and offset requirements:** DEP will likely require large offsets from the interceptor, reaching 10-15 feet for piles. This offset requirement would likely limit the ability to construct foundations under the FDR or on South Street. Bridging structures will likely be required in locations where the interceptor must be crossed by any part of the alignment. Additionally, there is a risk of interference with implementation if DEP needs to unearth their assets while construction is underway – given the duration of implementation, this risk could be notable.
- **Siting the interceptor on the flood side will expose the system to inundation** and would require extensive floodproofing measures such as backflow preventers, sealed manholes, tide gates, and vent seals. The more drainage and sanitary infrastructure located outside the line of protection, the more complicated implementation becomes, creating situations of higher risk which also require more O&M. Some of these floodproofing measures will still be required around outfalls and future pump stations but minimizing the need for these floodproofing measures is key.

Due to these constraints, our alignment must be sited **at least 15 feet to the east of the interceptor** and incorporate necessary floodproofing measures where needed.

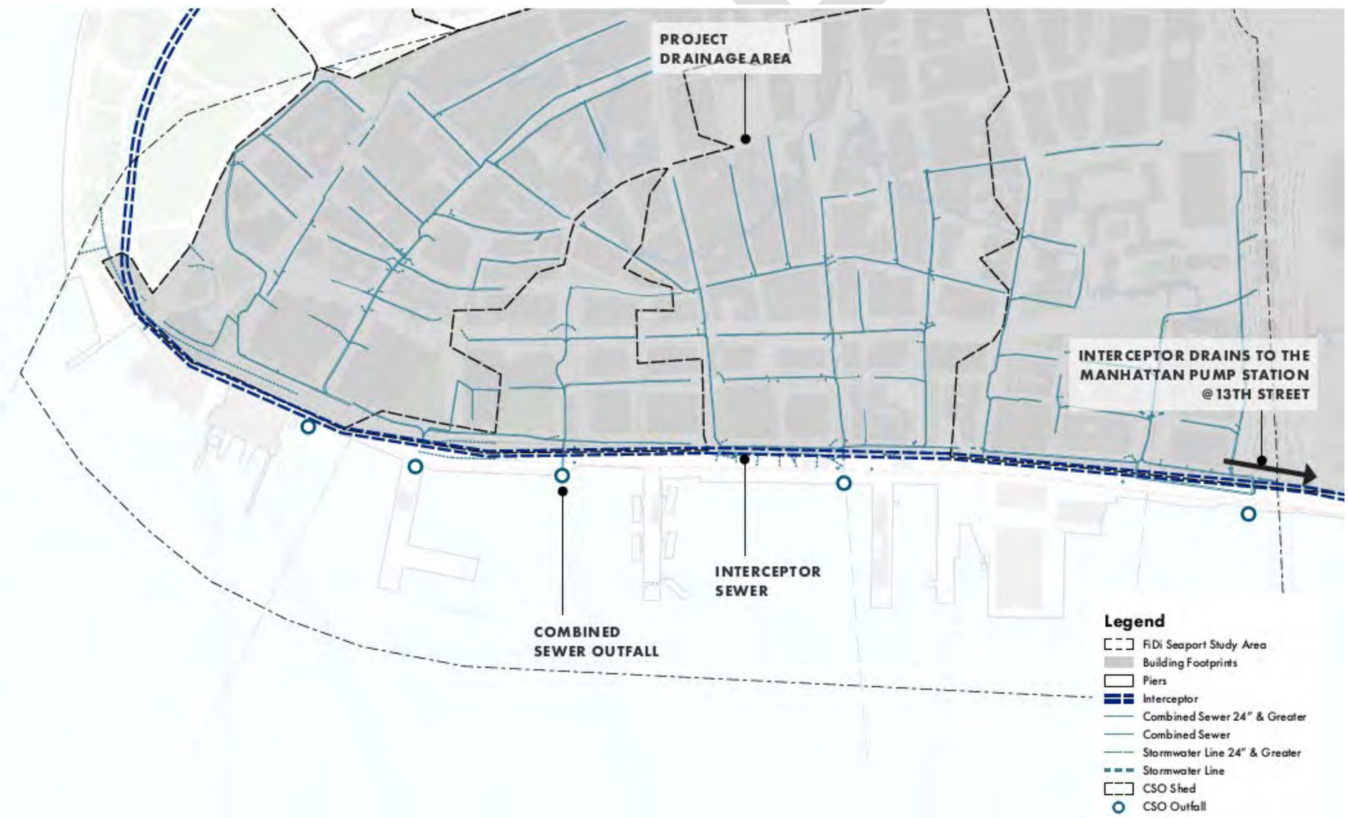

Figure 12: Location of interceptor in the study area

Oil-o-static

The Con Edison oil-o-static line is an underground high transmission electric line that is kept cool by oil. As noted in Figure 13 and Figure 14, the oil-o-static line runs from approximately Pier 17 to the northern boundary of the study area. It cannot be easily moved due to the critical function it provides for the electric grid in Lower Manhattan. While it could potentially be crossed if adequate heat proofing measures are put in place, it would require special attention to ensure sufficient heat dissipation.

The oil-o-static is located inboard of the interceptor; due to our requirement to build outboard of the interceptor, significant interference with the oil-o-static is not expected. Any need to cross the oil-o-static line could be handled like East Side Coastal Resiliency (i.e., crossing at a nearly 90-degree angle).

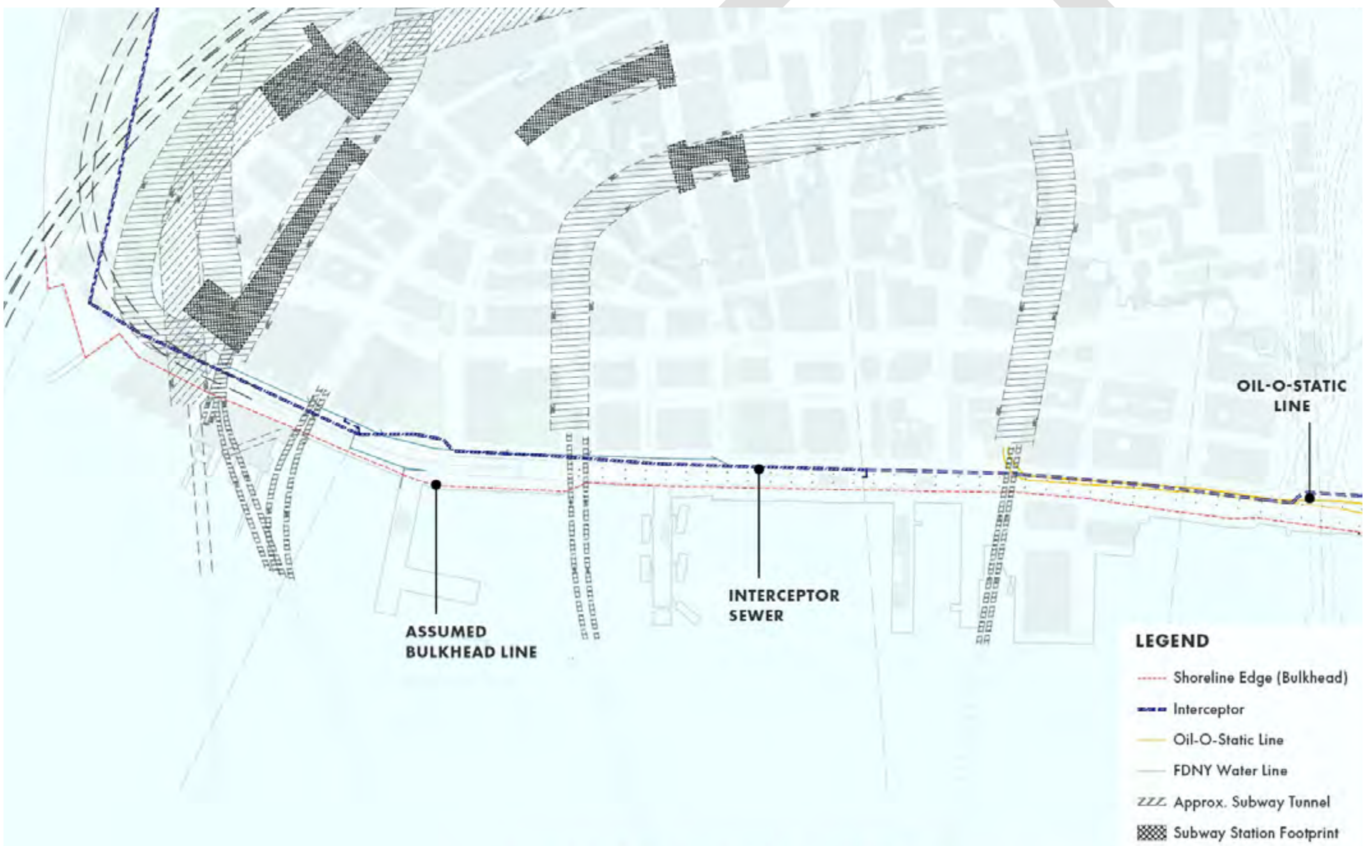

Figure 13: Location of oil-o-static line in the study area

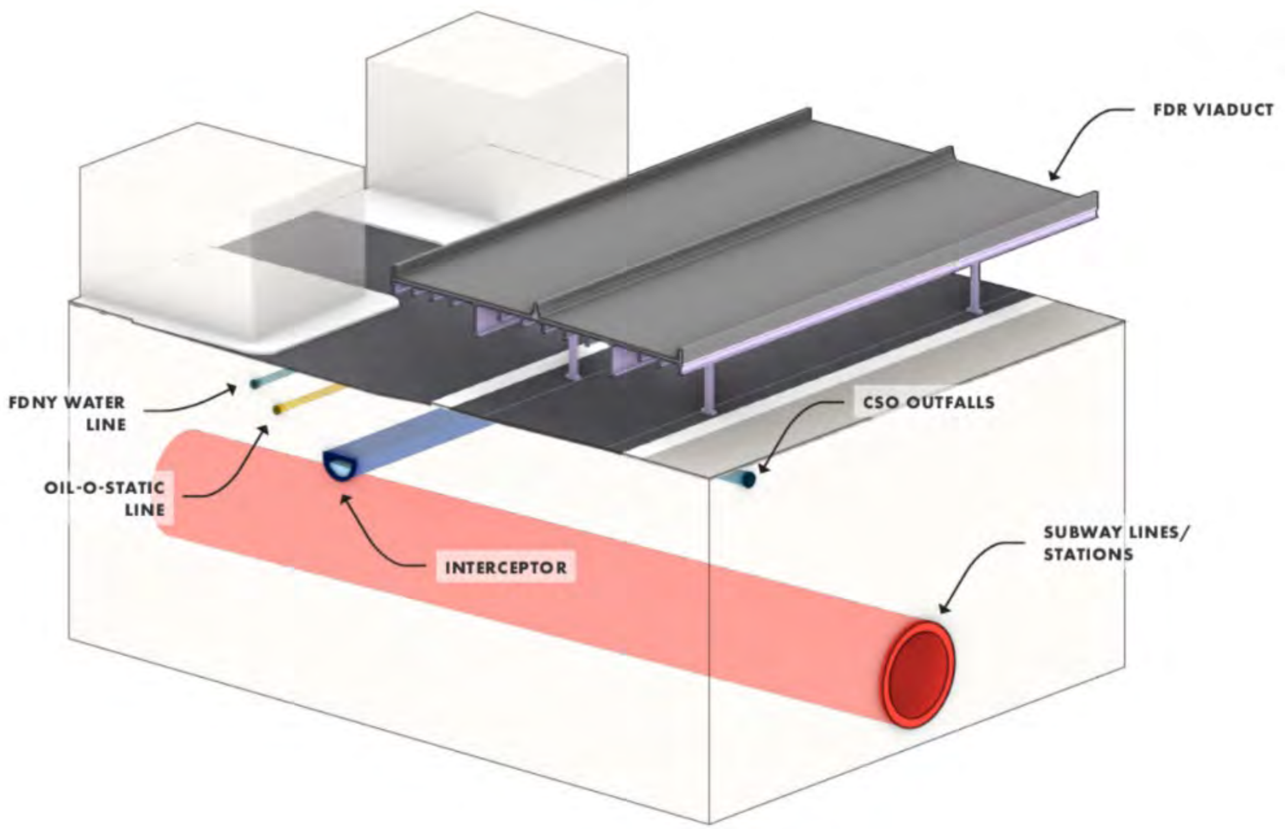

Figure 14: Arrangement of subsurface infrastructure in the study area

Subway Tunnel, Stations, & Infrastructure

The Metropolitan Transportation Authority (MTA) has requirements for construction work near and above subway tunnels with the intent to limit any additional loading on the tunnels. Factors which influence loads on existing tunnels include depth of the tunnel below grade and nature of the subsurface material. **It is assumed that subway tunnels will not be relocated or altered for this project.**

- **Fill on subway tunnels:** Fill on top of subway tunnels is highly discouraged, with any exceptions requiring substantial analysis. On other flood protection projects (and for other applications) the typical solution is to "bridge across" the subway tunnel. An illustrative example of lines of influence, which additional loads must remain clear of, is shown in Figure 15.
- **Loads on subway tunnels:** The MTA determines a "zone of influence" around each subway tunnel. The zone of influence starts at an offset from the bottom of the tunnel and extends up to the ground surface at an angle determined by the soil conditions. For example, tunnels in bedrock have a much steeper (therefore smaller) zone of influence than tunnels in soft soils. No new loads are allowed above the zone of influence line. Piles or drilled shafts may be used to transfer loads to below the zone of influence. For a

pile supported T-Wall, the piles would need to extend below the zone of influence as they approach the tunnel, then span (or bridge) across the top of the tunnel using a system of beams that minimize any load transfer onto the tunnels. As the cost and complexity of the bridging structure is related to the span of the structure (approximately a squared function – proportional to span^2), the span distance is usually minimized by crossing the tunnel at a right (90 degree) angle.

- **Floodproofing subway tunnels:** Tunnels also provide a flood pathway into interior areas and any openings outside of the line of defense would require seals or flood proofing. Subway tunnels which extend under the East River or which are located below the groundwater table must be watertight, designed for hydrostatic pressure, and maintained to keep their watertightness. While we assume that subway tunnels and stations above the groundwater table are generally designed to prevent the entry of water, they may not be designed to withstand hydrostatic pressure and buoyancy forces or maintained to be substantially watertight.

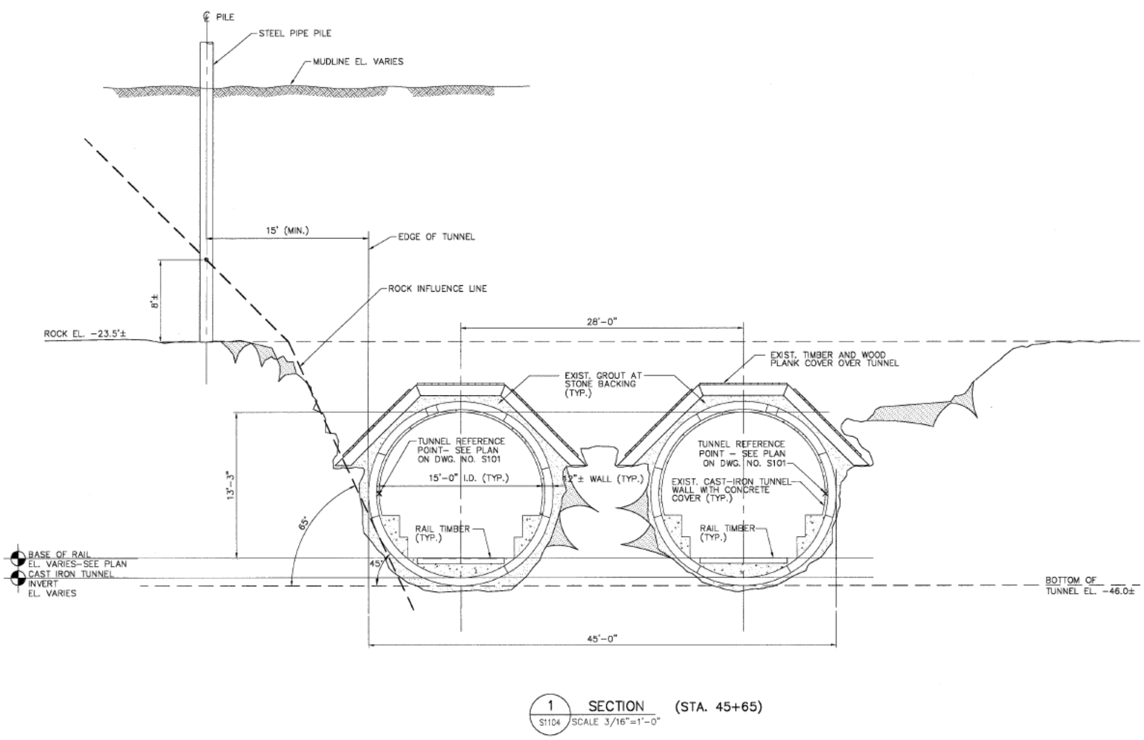

Figure 15: Illustration of subway tunnel influence line from Whitehall Ferry Terminal as-builts

South Ferry Loop

Per discussions with MTA, **the South Ferry Loop is used regularly and cannot be decommissioned or moved**. The South Ferry Loop presents several challenges for area-wide flood defense. First, the South Ferry configuration makes crossing the tunnel at 90 degrees difficult – multiple crossings or long spans would likely be required. Moreover, the South Ferry Loop is very close to the surface, presumably above the groundwater table. As the tunnel is very close to the surface, and the flood wall will pass directly over the top of the tunnel, the tunnel would effectively become part of the seepage barrier for the system, as well as a penetration through the line of defense. If any portion of the tunnel is located on the flood side of the alignment, it was assumed that it would require extensive floodproofing, structural retrofit, or reconstruction to meet performance standards appropriate for an integral flood protection component and to prevent it from becoming a flood pathway into the protected area. These modifications would likely require taking the tunnel out of service for an extended period. For these reasons, it would be highly preferred to have the tunnel on the protected side of the line of defense.

Whitehall and South Ferry Subway Stations

The Whitehall and South Ferry subway stations cannot be moved. Like the South Ferry Loop, the Whitehall and South Ferry subway stations present several challenges for area-wide flood defense. They are located very close to the surface and the size and configuration would require long, expensive spans. While the stations have undergone flood proofing, they were not designed nor are being maintained to resist the hydrostatic and uplift pressures associated with being an integral component of a flood defense system. For these reasons, as well as to maintain access, the stations should be on the protected side of the line of defense. If any portion of the stations were to be located on the flood side of the alignment, we have assumed that it would require extensive structural retrofit or reconstruction to meet performance standards appropriate for an integral flood protection component and to prevent it from becoming a flood pathway into the protected area. These modifications would likely require taking the stations out of service for an extended period or otherwise disrupt normal operations.

Figure 16: Whitehall and South Ferry Stations (Source: MTA)

Battery Park Underpass

While the Battery Park Underpass (BPU) could be leveraged and incorporated into the flood protection, doing so will be a complex undertaking and will likely require significant modifications to the structure and to traffic patterns. Additional coordination will also be needed with Battery Park City Authority (BPCA) to ensure that the underpass does not serve as a flood pathway in either direction. We are studying different pathways by the Battery Park Underpass, including:

- **Crossing the BPU**: While crossing the BPU (pictured in Figure 18) is technically feasible and likely necessary to complete a tie-in to higher ground at the southern end of the alignment, it remains challenging. Shallow depth of the tunnel and any crossing angle that is not perpendicular adds complexity to this crossing. Crossing the underpass at 90 degrees is most preferred and most feasible.
- **Location of the BPU with relation to the line of defense**: If the tunnel is on the flood side of the line of defense, the flood pathway through the tunnel *to* the West side would still need to be addressed. With the BPU on the dry side of the alignment, the flood pathway through the tunnel *from* the West side still needs to be addressed; the timing of this mitigation will depend on BPCA resiliency projects and could prove a challenge to the independent utility of the alignment.
- **Incorporating the BPU into the line of defense**: Incorporating the BPU into the line of defense, such as placing a floodwall above or along the centerline of the underpass (pictured in Figure 17), may be possible but would require some level of demolition and reconstruction with likely significant service disruptions to traffic. Repurposing the structure itself, such as relying on the existing outer wall or center divider, to be part of the flood alignment would require significant structural modifications or reconstruction. These modifications or reconstruction would likely include new foundation support, structural reinforcement of the tunnel, and waterproofing; these measures would result in significant service interruptions to traffic, to above ground uses, and to adjacent uses.
- **"Around" the BPU:** The current thought process is to build an independent flood defense structure "around" the BPU, utilizing the BPU alignment as a convenient pathway for the line of defense. This would still require some structural modification to the tunnel and would likely result in the loss of one lane of traffic, as well as traffic disruptions during construction.

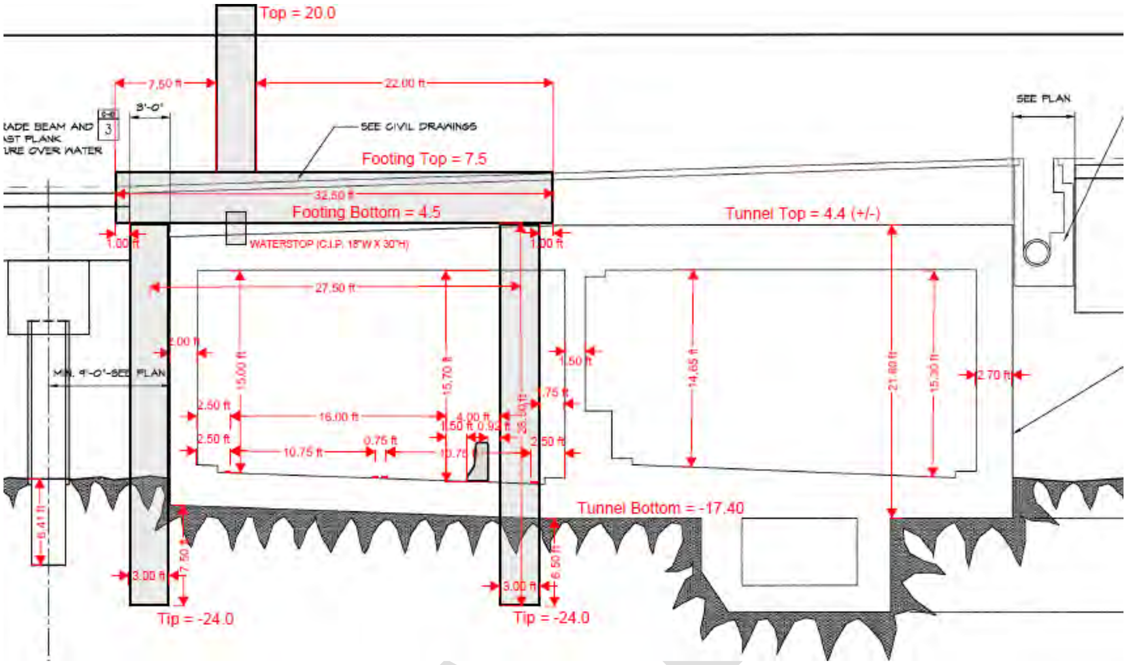

Figure 17: Schematic of potential modifications to the BPU needed to incorporate flood defense (representative cross section of BPU; not intended for design)

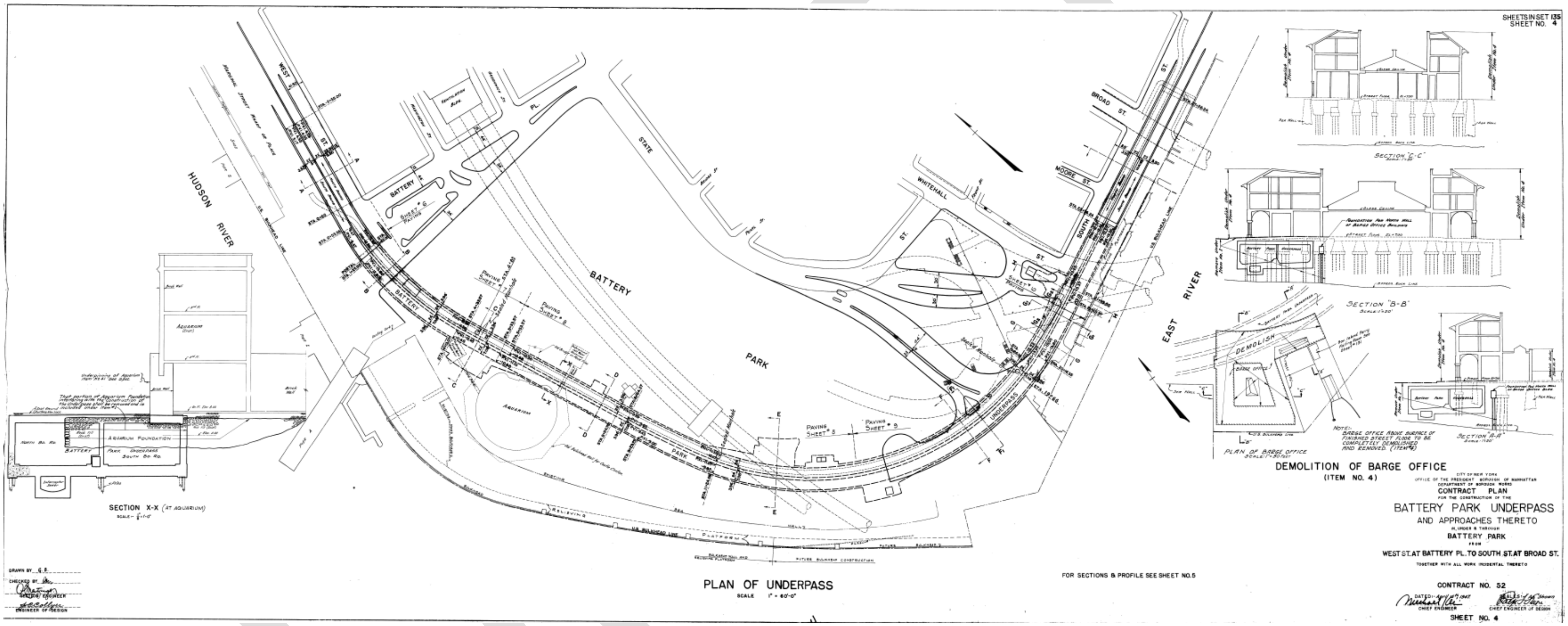

Figure 18: Plan of Battery Park Underpass from as-built documents

Potential FDR Drive Viaduct Modifications

In early phases of the project, the project team examined several FDR Drive Viaduct configurations that had the potential to create additional space available on-land to site flood protection. Structural feasibility and traffic implications were also analyzed.

From discussions with EDC, the Mayor's Office of Climate Resiliency (MOCR) and New York City Department of Transportation (NYCDOT), the team established that the FDR Drive Viaduct is a critical regional connection between the BPU and the Brooklyn Bridge: the project must maintain this connection in some form. Traffic volumes in Manhattan and on this section of the FDR Drive Viaduct have reduced in the last several decades, consistent with the City's OneNYC sustainability goals. Feedback from NYCDOT and NYSDOT indicates an openness to "right-size" the section of the FDR south of the Brooklyn Bridge to an at-grade, non-limited-access road.

It is important to note that while replacing the elevated FDR Drive Viaduct with an at-grade boulevard within our study area (a length of about half of a mile), would afford some additional space on-land to site coastal defense, it is insufficient to site the entire coastal defense system on-land while maintaining access to key maritime & waterfront uses. Rather, taking down the FDR Drive Viaduct provides only an additional ±35 feet of space on-land to construct the project, which is insufficient to site the coastal defense entirely on-land.

Traffic Scenarios

Both current and future traffic volumes were considered in the development of potential alternatives, as described below:

- **Current traffic volumes**, as well as representative past volumes, are show in Figure 19 and Table 2.

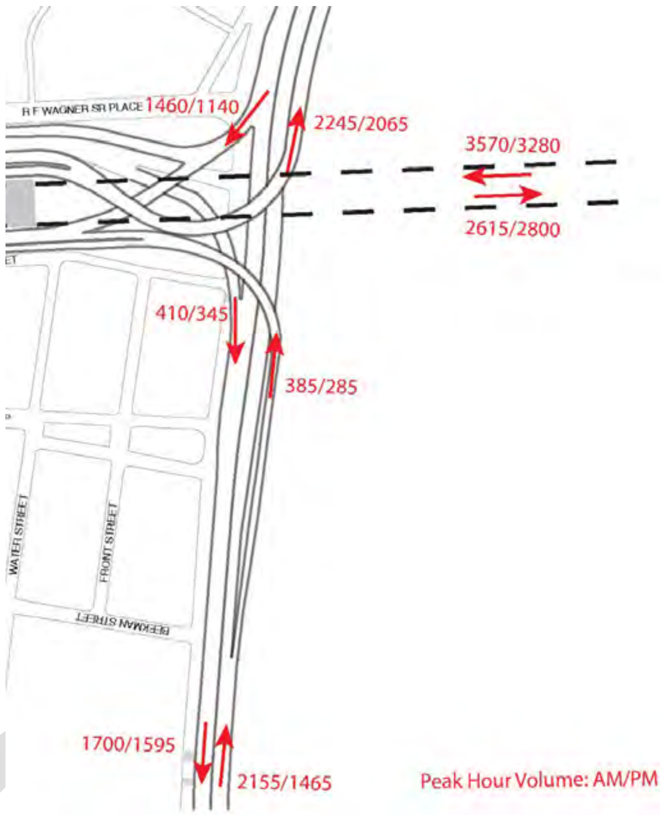

Figure 19: 2019 Traffic Volumes (AM/PM)

Table 2: Traffic Volumes Change 2002-2019 (AM/PM)

Direction	2002 Volumes	2019 Volumes
Northbound	2570 / 2300	2155 / 1465
Southbound	2400 / 2050	1700 / 1595

- **Future traffic volumes**: To test traffic implications, the team developed three scenarios for future traffic volumes on the FDR Drive. The Conservative Scenario assumes 2019 traffic volumes would continue. The Medium Scenario assumes a 35 percent reduction in traffic volumes, and the Optimistic Scenario assumes a 70 percent reduction in traffic volumes. These vehicle volumes are outlined in Table 3.

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Table 3: Future Traffic Volumes Scenarios

FDR Drive Vehicle Volumes

				2050			2100		
		2002(4)	2019(5)	Conservative	Mid	Optimistic	Conservative	Mid	Optimistic
Southbound	Exit 2 (exits)		1,460	1,460	949	438	1,460	913	365
	Pearl St On-Ramp		410	410	267	123	410	256	103
	Elevated (south of bridge)	2,400	1,700	1,700	1,105	510	1,700	1,063	425
	Exit 1 (exits)	1,002		1,002	651	301	1,002	626	251
	Exit 1 (entries)	-		-	-	-	-	-	-
	Batt. Underpass	1,398		1,398	909	419	1,398	874	350
Northbound	Exit 2 (exits)		385	385	250	116	385	241	96
	Pearl St On-Ramp + BK Bridge		2,245	2,245	1,459	674	2,245	1,403	561
	Elevated (south of bridge)	2,500	2,155	2,155	1,401	647	2,155	1,347	539
	Exit 1 (exits)	350		350	228	105	350	219	88
	Exit 1 (entries)	100		100	65	30	100	63	25
	Batt. Underpass	2,750		2,750	1,788	825	2,750	1,719	688

(4) Lower Manhattan FDR Drive At-Grade Study, 2002

(5) NYCDOT Volume Counts October, 2019

All options were developed using the Conservative Scenario as a baseline starting place for analysis. To maintain the current volumes on the FDR Drive, one lane in either direction is sufficient if it is limited access. Two lanes in either direction is needed if signalized intersections are introduced, with a potential fifth center turn lane where left turns are permitted.

Trough & Tunnel

Two variations for replacing the FDR Drive as limited-access highway below-grade with one lane in either direction were explored: a trough, where the roadway would be below grade and constructed through cut and cover, and a tunnel, where the roadway would be below grade in a bored tunnel. The trough option could be either mostly on-land, taking up space where the elevated FDR Drive is today, or located outboard. The tunnel would most likely be located outboard, as would it face conflicts with existing subgrade utilities both on-land and nearshore. While a trough option could maintain the traffic connections between the Brooklyn Bridge and FDR Drive, the tunnel option would likely have to bypass the Brooklyn Bridge interchange. Both options could provide additional space to site the coastal defense on-land but were deemed infeasible due to considerations described below.

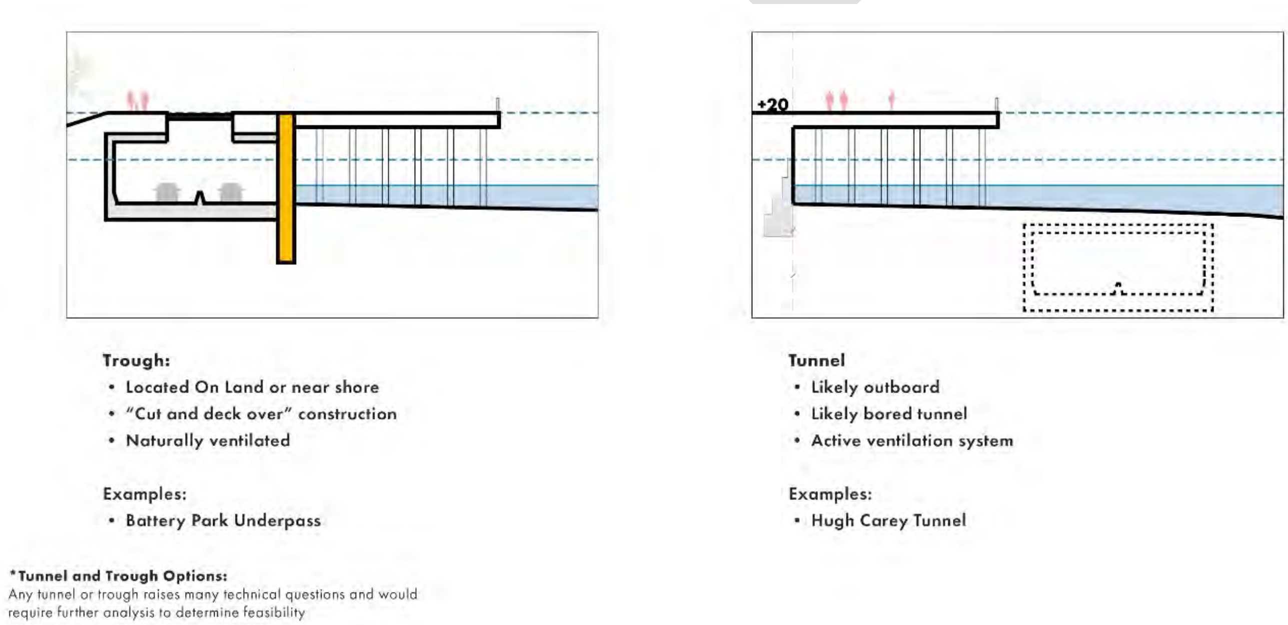

Figure 20: Trough and Tunnel Definition

As shown in Figure 20, the on-land trough option would not eliminate the need to go into the water as it would need to be elevated enough to avoid sub-grade conflicts, be able to connect to the existing elevations of the Battery Park Underpass and the Brooklyn Bridge, and provide sufficient headroom for ventilation; additional figures and configurations evaluated for the FDR Drive are presented in Appendix A. While the tunnel option would provide additional space on-land to construct the coastal defense, it would not eliminate the need to go into the water to site coastal defense while maintaining access to maritime functions (and the tunnel would be constructed in-water, outboard of the existing bulkhead). Both options also present additional engineering challenges:

- **Existing subway tunnels**: Regardless of whether the project is on-land or in-water, subway tunnels (such as the 2/3 tunnel) will need to be crossed with bridging structures. The tunnel and trough options will increase the complexity of crossing the subway tunnels.
    - A tunnel would need to pass under the existing subway tunnels. This would be dependent on an acceptable roadway slope being achieved to go under the 2/3 tunnel and connect to the Battery Park Underpass (BPU) above the 4/5 tunnel.
    - A trough would need to go over the top of the 2/3 tunnel, placing the top of the trough at roughly 13ft NAVD88, which is 7 feet above the existing grade. This would still require significant grading to create an up and over and maintain waterfront access.
- **Cost**: Scaling the projected cost for the Gateway Tunnel project ($11.6B) by length, the tunnel option would cost $3.5B alone, not factoring in the cost of coastal defense.
- **Need to avoid BMB**: Assuming the tunnel would be offshore (see Figure 28), it would need to tie back into land north of the Battery Maritime Building (BMB), before the FDR transitions from at-grade to subsurface. Realigning with the BPU would require avoiding disturbances to the BMB, resulting in some complex alignment issues. The tunnel cannot be under the maritime uses and therefore must go around them. Additionally, as mentioned above, the road grade needed to tie back into the BPU at an acceptable roadway angle is not within the acceptable range; it is not possible to realign an outboard tunnel or trough with the BPU while avoiding conflict with the BMB, which is a historic structure.
- **Subsurface infrastructure conflicts**: An onshore trough would require siting and constructing new oil-o-static and interceptor lines outside of the trough alignment and removing the existing lines prior to construction. A tunnel would also require siting and constructing new oil-o-static and interceptor lines outside of the tunnel alignment and removing the existing lines prior to construction (for some distance) at the northern tie-in location.

Additional figures and configurations evaluated for the FDR Drive are presented in Appendix A.

At-grade Roadway

The team also explored several options for how the FDR Drive elevated structure could be replaced with an at-grade roadway, where the FDR Drive would be combined with South Street into a single roadway.

- **At-grade boulevard**: This option would provide two travel lanes in either direction with left-turn lanes at key intersections (for a total width of approximately 61 to 63 feet) and could accommodate current traffic volumes.
- **At-grade street**: This option would provide one travel lane in each direction.
- **Reduced one-way**: This option would divert northbound traffic to other routes (primarily Water Street).

The at-grade street and reduced one-way options cannot accommodate current traffic volumes but are expected to operate at marginally acceptable levels of service under the Medium Scenario (35% reduction) and at acceptable levels of service under the Optimistic Scenario (75% reduction). Note that these projections are based on assumed traffic volumes and lane capacities and not on detailed evaluations using traffic analysis software.

Figure 21: Roadway Configurations

Transforming the FDR viaduct to an at-grade boulevard (two travel lanes / each direction) creates an additional 25 to 55 feet of clear space for flood protection (see Figure 30); however, this is still insufficient to site coastal defense while maintaining access to the waterfront. The at-grade street (one travel lane / each direction) provides additional space to site coastal defense (50-85 feet) but as noted above, would create significant vehicle level-of-service impacts with existing traffic volumes and therefore is not recommended.

Key Takeaways

As a result of the technical analyses completed to date, the Arcadis Team has determined that it is not practicable to site the coastal defense on-land for most of the study area. Key takeaways include:

- **FDR Drive:** Most notably, the FDR Drive – both its above ground and below grade components – presents a significant challenge throughout a large portion of the study area (Reaches B through D). This limits the unobstructed, available space on-land to construct and maintain coastal defense structures. While there is a limited stretch of approximately 750 feet between Piers 11 and 15 where a coastal defense structure could be sited based on vertical clearances, a transfer from an outboard alignment to an inboard alignment and back to outboard alignment would be required, adding technical complexity to the alignment and cost without increasing the benefits of the flood defense system. In addition, physical and visual access to the waterfront must also be considered in evaluating the practicability of these structures. If the FDR Drive viaduct is transformed into an at-grade roadway, this could create 25-55ft of clear space on-land, but this would not be enough space to site coastal defense while maintaining access to the water. Rather, citing the coastal defense infrastructure on land would effectively create a wall at the water's edge, disconnecting the maritime functions and waterfront from the neighborhood and upland.
- **Limited Use of Deployable Measures:** There are numerous technical challenges that limit the applicability of deployable measures within the study area – from foundation requirements to wave loads, to concerns over O&M, ownership, liability, and governance. In addition, it is important to note that a large portion of the study area will be vulnerable to regular tidal flooding late in the century making deployable systems impractical. As such, our recommendation is that deployable measures are used sparingly throughout the site – limited to only where necessary to limit cover over subway tunnels or provide access to historic structures – and to be used in concert with raising the edge to a minimum constant elevation of +11 feet NAVD88.
- **Critical Infrastructure:** It is recommended that the coastal defense remain outboard of numerous critical utilities and transportation infrastructure – the interceptor, subway tunnels and stations, and oil-o-static lines. Siting critical infrastructure on the flood side would leave the system exposed to damage during

storm events and could provide pathways for interior flooding. Any critical system on the flood side would require extensive floodproofing measures to ensure that each individual system, and coastal defense system overall, is safeguarded during storm events.

Reach by Reach Analysis

This section walks through the on-land option studied across each reach (or “sub-area”), as shown in Figure 22. This memo captures the options evaluation analysis as of spring 2021.

- **Reach A** has key maritime assets and ferry terminals, including the Whitehall Ferry Terminal and the Battery Maritime Building.
- **Reach B** is the longest stretch of the project and houses the heliport and Pier 11, as well as the transition of the FDR from at-grade to elevated viaduct.
- **Reach C** has the historic, low-lying South Street Seaport district as well as Pier 17, which houses the newly reconstructed Tin building.
- **Reach D** is where the project ties back to higher ground, adjacent to the Brooklyn Bridge.

These unique considerations across each reach determine what is technically feasible when deciding how and where to place the coastal defense system.

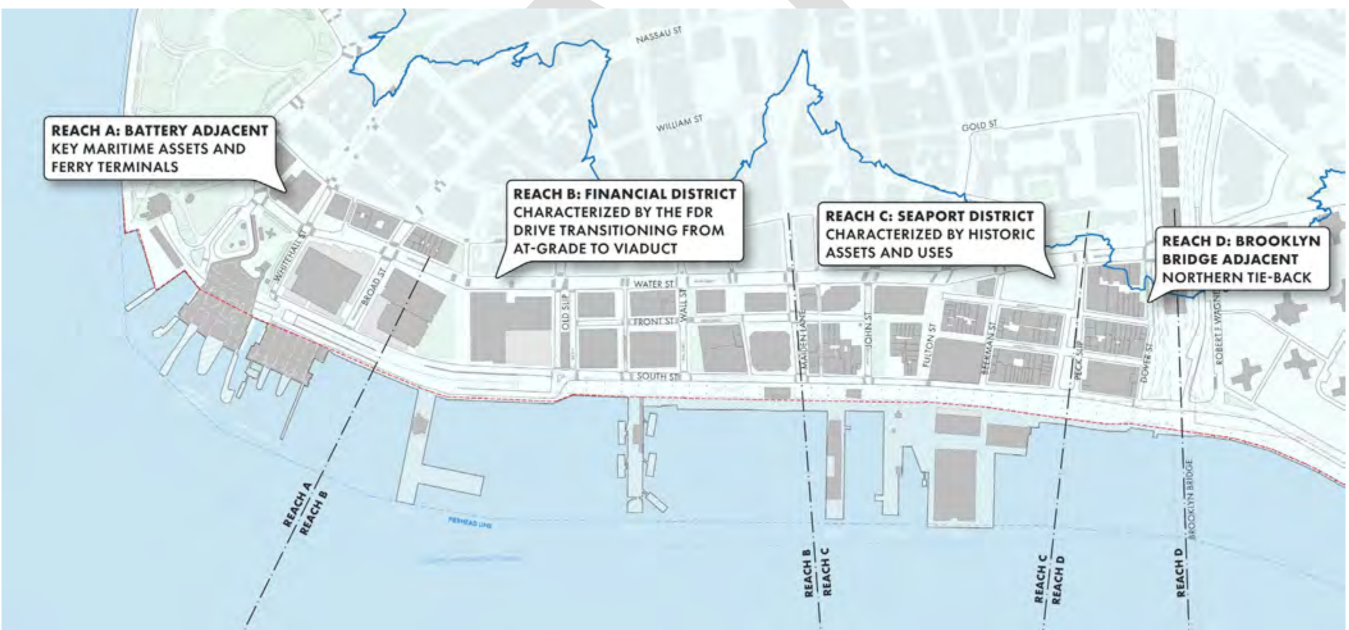

Figure 22: Study area overview

Reach A

In Reach A of our study area, the key considerations determining how our coastal defense is integrated into the waterfront include:

- Maintaining Staten Island Ferry service at the Whitehall Ferry Terminal (WFT)
- Preserving the Battery Maritime Building (BMB), a historical landmark

- Navigating a complex system of underground infrastructure, including the Battery Park Underpass, subway stations, and subway tunnels

Two on-land options were analyzed in this reach (Figure 23):

- Inland of the Battery Park Underpass (BPU)
- Along the Battery Park Underpass

The flood protection alignment must also tie into higher ground in this area, with different options still under review.

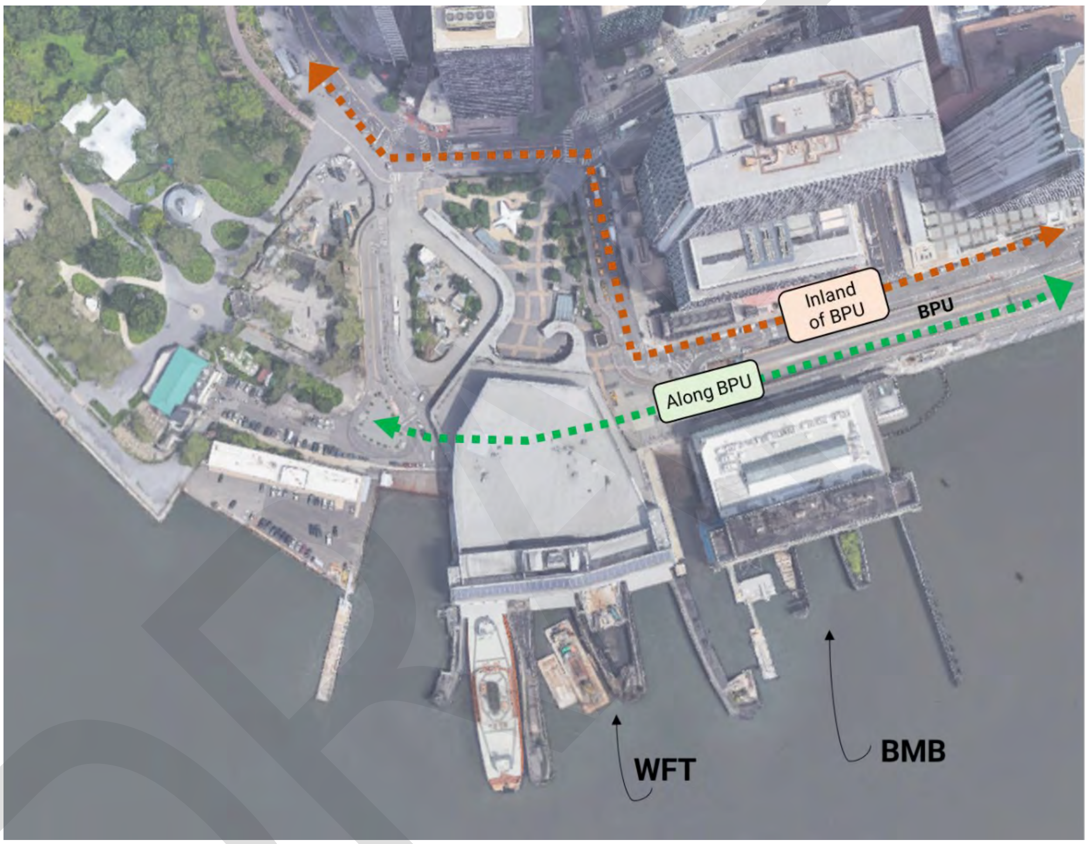

Figure 23: Reach A Alignments

Inland of the Battery Park Underpass (BPU)

An option inland of the Battery Park Underpass would aim to avoid direct impacts to both the Whitehall Ferry Terminal and the Battery Maritime Building. To achieve this, the coastal defense system would have to be integrated with adjacent building podiums north of South Street and across through Peter Minuit Plaza. With several subway tunnels (4/5 train, R/W train), the South Ferry Loop, and subway station (Whitehall Station) underneath the plaza, this option would encounter significant technical obstacles underground. An overview of the subsurface infrastructure in Reach A is shown in Figure 24.

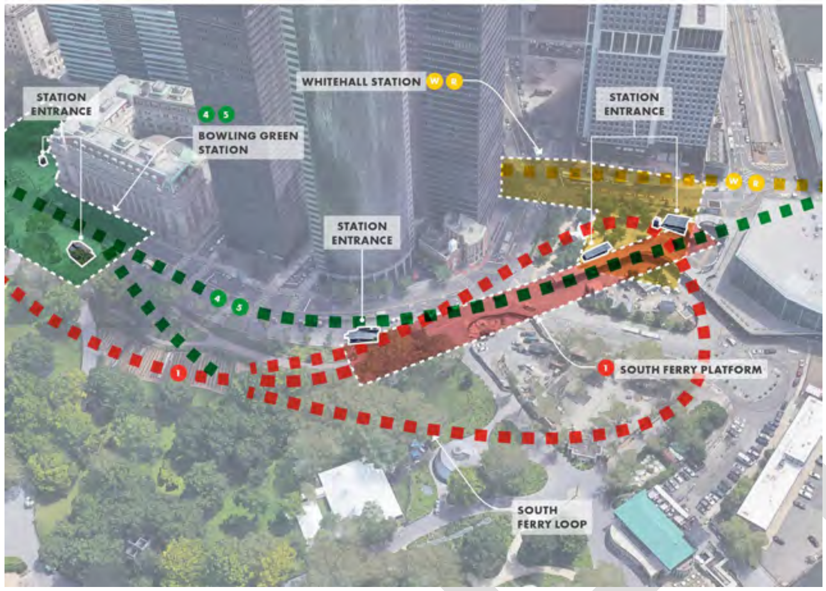

Figure 24: Overview of key subsurface infrastructure in Reach A

This alignment option precludes us from achieving our target design flood elevation for regular tidal flooding. The Battery Park Underpass, subway stations, and critical maritime infrastructure would remain vulnerable under this approach. Tidal flooding will also create issues with high deployment frequency of gates or other deployable measures. Every deployable system requires resources to plan and execute each deployment, rendering frequent deployment challenging and impractical.

Additional technical challenges that preclude this alignment are described in further detail below:

South Ferry Loop: Per discussions with MTA, the South Ferry Loop is used regularly and cannot be decommissioned or moved. The South Ferry Loop presents several challenges. First, the South Ferry configuration makes crossing the tunnel at 90 degrees difficult–multiple crossings or long spans of bridging structure would likely be required. Moreover, the South Ferry Loop is less than 5 feet from the surface in some locations, presumably above the groundwater table. If any portion of the tunnel is located on the water side (floodable side) of the coastal defense system, it would require extensive floodproofing, structural retrofitting, or reconstruction to meet performance standards and to prevent it from becoming a flood pathway into the protected area by other means. These modifications would likely require taking the tunnel out of service for an extended period. Overall, any alignment that impacts the South Ferry Loop would impact MTA operations, have significant feasibility concerns, and add significant costs to the project beyond the core resilience work. For these reasons, it would be highly preferable to have the tunnel on the protected side of the line of defense.

Whitehall and South Ferry Subway Stations: The Whitehall and South Ferry subway stations cannot be moved. Like the South Ferry Loop, the Whitehall and South Ferry subway stations present several challenges. They are located very close to the surface and their sizes and configurations would require long, expensive spans. While the stations have previously undergone floodproofing, they were not designed to resist forces associated with being an integral component of a flood defense system. For these reasons, as well as to maintain access, the project aims to protect subway stations. If any portion of the stations were to be located on the water side of the coastal defense system, it would require extensive structural retrofitting or reconstruction to meet performance standards and to prevent it from becoming a flood pathway into the protected area by other means.

These modifications would require taking the stations out of service for an extended period or otherwise disrupt normal operations.

This option would also rely heavily on use of deployable gates as well as selective building-level flood protection measures to maintain access to streets and buildings. Building-level measures in this area are constrained by the sheer height of the target design flood elevation and the lack of necessary foundation space due to the dense urban fabric of the area. Key considerations are described in *Building-level Adaptation*.

Along the Battery Park Underpass

One option is to place the coastal defense along the Battery Park Underpass, which could take a multitude of forms, as described earlier in *Battery Park Underpass*:

- Incorporating the Battery Park Underpass into the line of coastal defense
- Repurposing the structure itself
- Build an independent flood defense structure "around" the Battery Park Underpass

For the segment of Reach A along the Whitehall Ferry Terminal, following the Battery Park Underpass would not require any shoreline extension. However, this option would require partial or full reconstruction of the Whitehall Ferry Terminal, both of which require further study to understand technical & cost feasibility and practicability. The Whitehall Ferry Terminal would still be located on the water side of the flood protection alignment, which would leave it vulnerable to flooding and require additional building-level measures for the structure to be protected.

For the segment of Reach A along the Battery Maritime Building, following the Battery Park Underpass would allow impacts to the historic structure to be greatly minimized. It would leave the Battery Maritime Building on the water side of the coastal protection system, requiring additional building-level measures to protect the structure. In addition, the coastal defense system would obscure views of and reconfigure access and connections to the first floor of the Battery Maritime Building's South Street façade. This option is under further study.

Reach B

In Reach B of our study area, the key considerations determining how our coastal defense is integrated into the waterfront include:

- Maintaining maritime and ferry services, as well as access to and from for all users
- Understanding the role and function of the FDR Drive viaduct in relation to placing coastal defense infrastructure
- Crossing subway stations, tunnels, and other underground infrastructure

On-Land Option

In Reach B, it is infeasible to implement an on-land alignment because it would not accomplish our project goals:

- **We cannot achieve our passive level of flood protection underneath the FDR.** With a ground elevation of about 6ft NAVD88 (lower at times), a passive DFE of 11ft NAVD88, and a horizontal distance of approximately 90 ft, achieving passive protection by raising the road would not be possible because the road slope would be above the acceptable upper limit of 5% (1:20 slope for universal access).

- **The wave climate prohibits relying heavily on deployable measures in this area.** Given the taller wave heights in the FiDi-Seaport study area (as compared to projects further north along the East River), depending heavily on deployable measures is not recommended due to concerns over reliability and performance. Additionally, the Financial District and Seaport neighborhoods are very low-lying, with average grade elevations of approximately 7-8 feet NAVD88 and with low spots in the Seaport near 5 feet NAVD88. As a result, the area is highly vulnerable to daily high tides in the future. For daily tidal flooding, which are much more frequent events, it is impractical to use deployable measures.
- **Horizontal and vertical clearances preclude deployable measures from being located here.** Additional detail about this item can be found in *Alignment under the FDR Drive*.

Reach C

In Reach C of our study area—the most vulnerable area in the study area due to low-lying elevations in the Seaport District—the key considerations determining how our coastal defense is integrated into the waterfront include:

- Protecting and preserving the historic South Street Seaport District
- Understanding the role and function of the FDR Drive in relation to placing coastal defense infrastructure
- Crossing subway stations, tunnels, and other underground infrastructure

On-Land Option

This option studies the feasibility of an entirely on-land alignment through Reach C following the existing shoreline. With the FDR Drive as-is, there is not sufficient clearance between the FDR Drive, the existing shoreline, and the Tin building's foundations to place our coastal defense infrastructure with its foundation requirements, as pictured in Figure 25. It is also infeasible to run an alignment under the FDR Drive here due to the reasons described in *Alignment under the FDR Drive.*

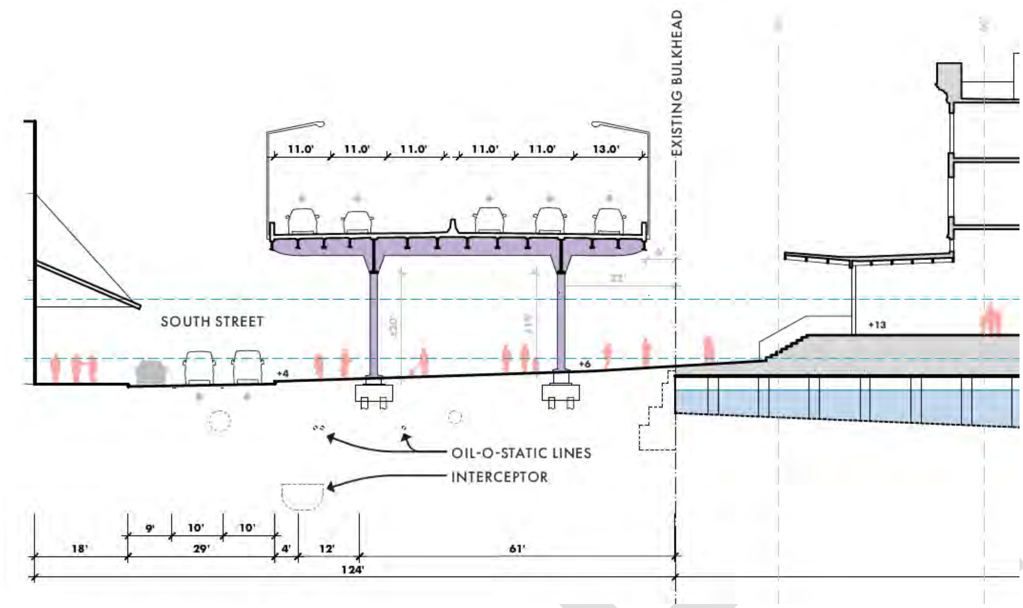

Figure 25: There is only about 6ft of clearance between the FDR Drive Viaduct and the existing bulkhead near the Tin Building.

Reach D

In Reach D of our study area, the key considerations determining how our coastal defense is integrated into the waterfront include:

- Understanding traffic connections to and from the Brooklyn Bridge
- Understanding the role and function of the FDR Drive in relation to placing coastal defense infrastructure.

In Reach D, the project team is still evaluating the technical feasibility of an entirely on-land coastal defense system following the existing shoreline. While this section of the project area still has constraints such as the FDR Drive Viaduct and underground utilities, the intertidal habitat and proximity of the Brooklyn Bridge Piers adds additional complexity to citing the flood protection alignment. Additionally, there are no maritime transportation functions that must be maintained in this area, potentially allowing a different approach to waterfront access. For example, in this reach, it may be feasible to site the maintenance access to the flood protection and continuous waterfront access on the water side of the alignment. This approach will continue to be studied, with additional hydrodynamic modeling & aquatic sampling and testing to inform the design.

* * * * * * * * *

Appendix

The studies located in this appendix provide a full picture of all previously analyzed options.

Figure 26 illustrates the on-land trough option. The subsurface infrastructure, particularly the subway tunnel crossings, located where the through would go renders this option impractical. Additionally, the tunnel entrance would likely block off Peck Slip and the feasibility of the interchange with Brooklyn Bridge would need to be studied.

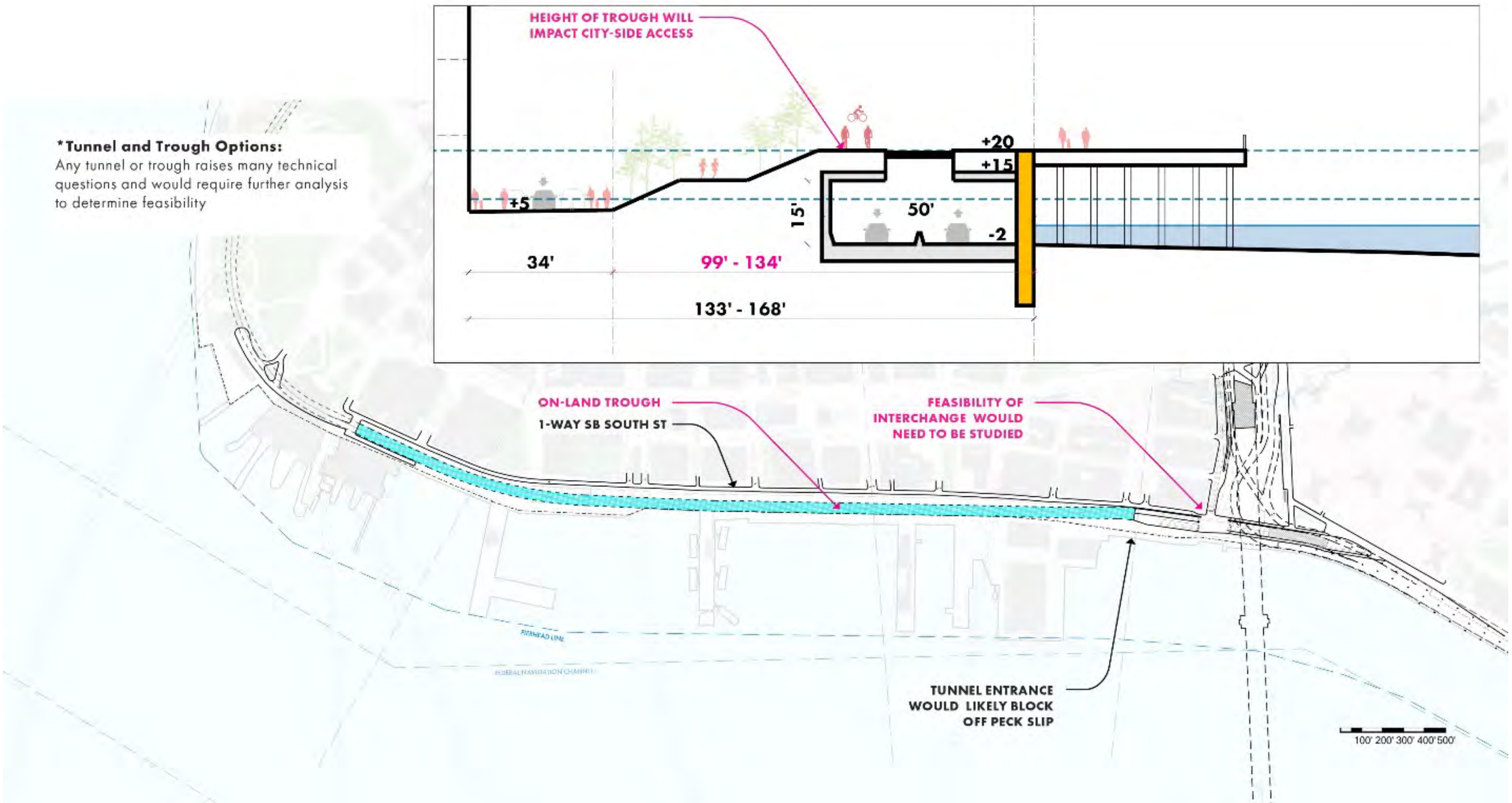

Figure 26: On-land Trough

Figure 27 illustrates the in-water trough option. This option does not reduce the amount of in-water space needed to complete the project; rather, it likely increases it. Additionally, the feasibility of the interchange with Brooklyn Bridge would need to be studied.

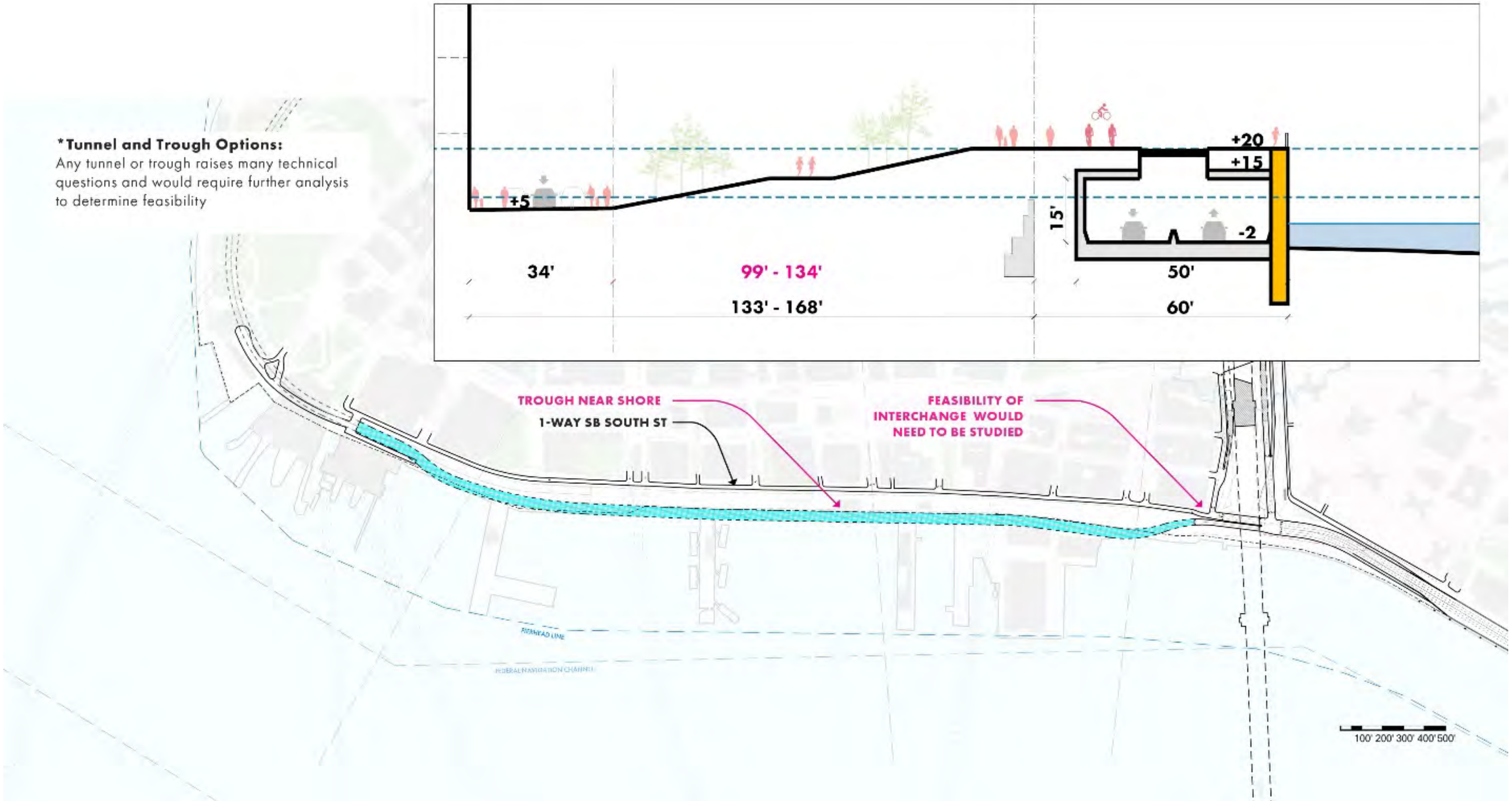

Figure 27: In-water trough

Figure 28 illustrates the outboard tunnel option. These tunnels would conflict with subway tunnels. Furthermore, it's unclear how they would work with the Brooklyn Bridge.

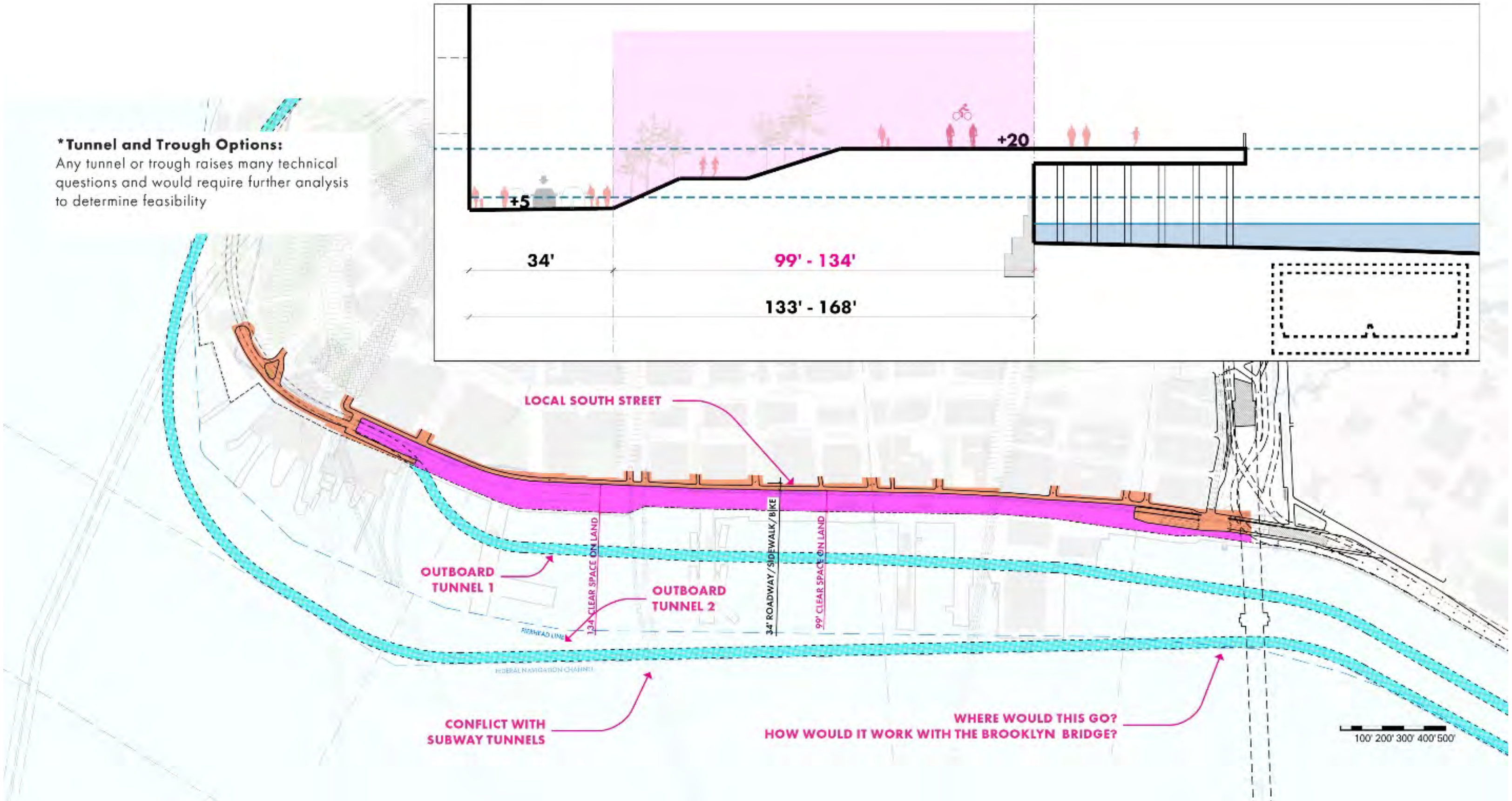

Figure 28: Outboard tunnel

Figure 29 illustrates the at-grade street option with the battery park underpass repurposed. While this option makes on-land space available, it cannot accommodate current traffic volumes, so is deemed non-viable.

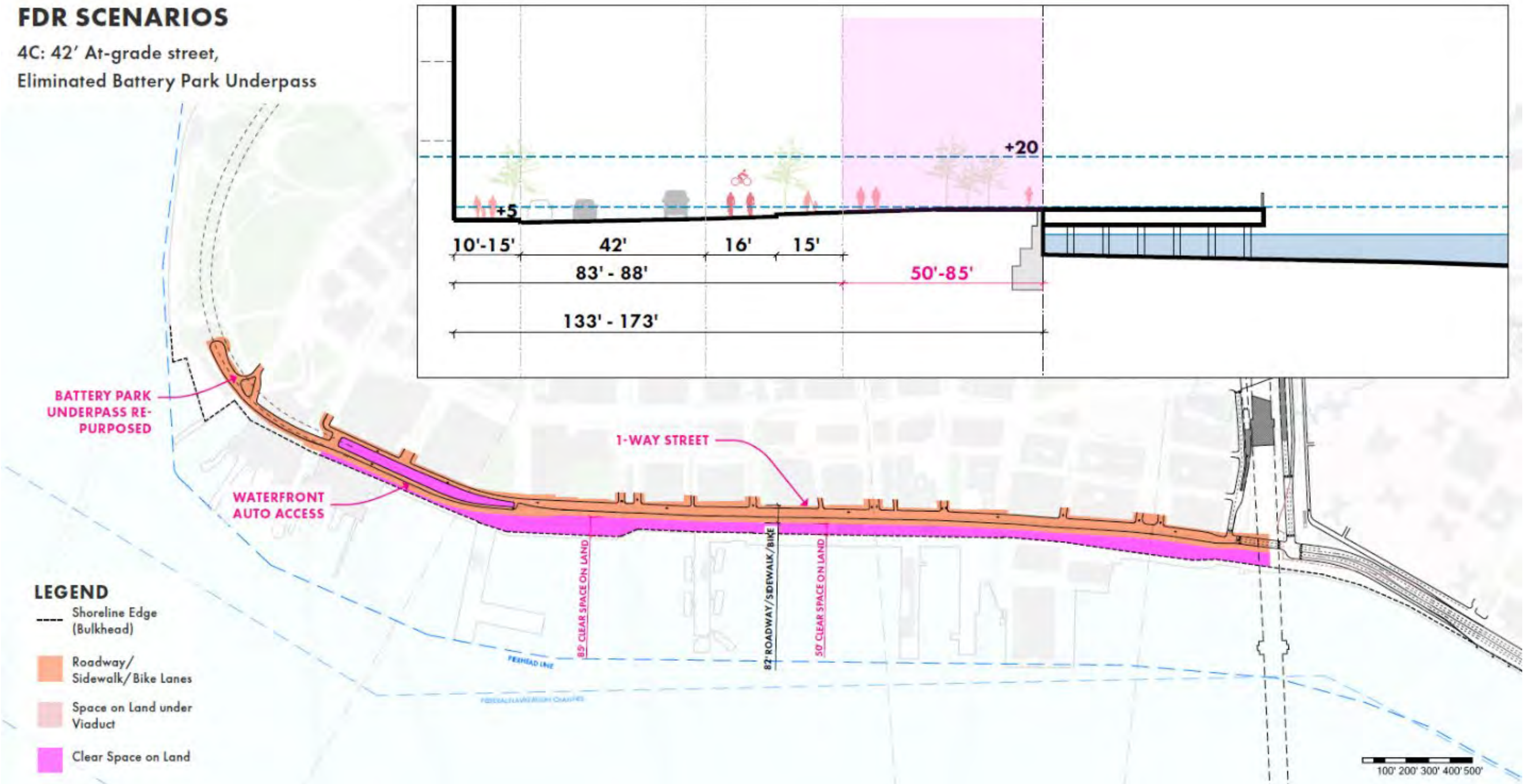

Figure 29: At-grade street

Figure 30 illustrates the at-grade boulevard option. This option makes on-land space available and can accommodate current traffic volumes.

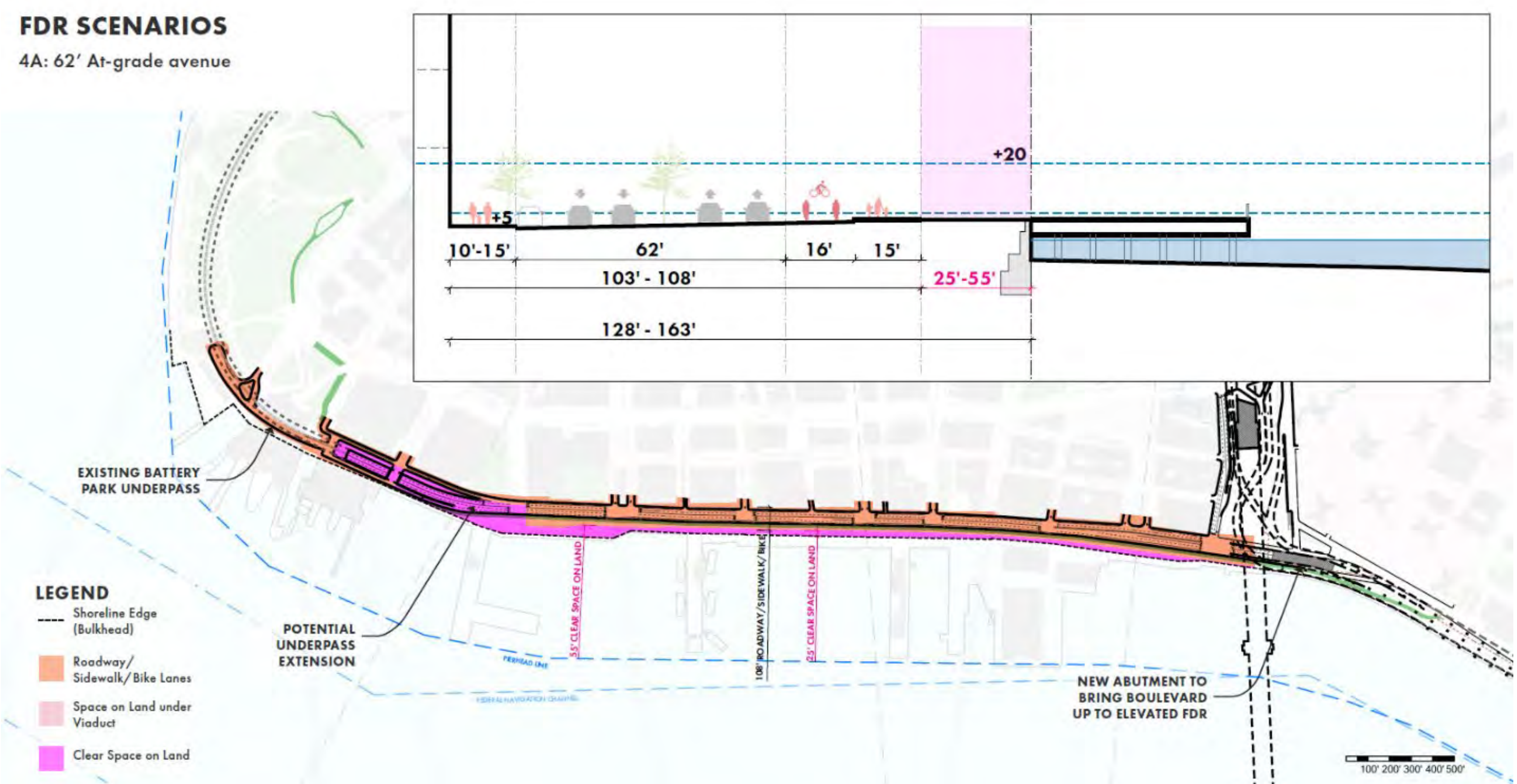

Figure 30: At-grade boulevard