Appendix A

COASTAL RESOURCE AREAS TECHNICAL MEMORANDUM

June 28, 2023

Katie Moniz
Senior Project Manager
Fort Point Associates,
31 State Street, 3rd Floor
Boston, MA 02109

Resource Area Delineation – Bass River District Resilience Plan

Dear Ms. Moniz,

On February 27th, 2023, a Woods Hole Group Professional Wetland Scientist (PWS) and a Woods Hole Group Coastal Scientist conducted a coastal resource area delineation along the Bass River shoreline in Beverley, Massachusetts. The survey extended from the west side of the tidal basin south of Elliot Street and continued downstream along the eastern Bass River shoreline to the dock located at the end of Marshall Court (Figure 1).

Coastal resource areas surveyed in the field included coastal bank, coastal beach, salt marsh, and rocky intertidal shore. Where present, vertical buffer (armored sections) of coastal bank were differentiated from sediment source (unarmored) banks. The extents of all coastal resource areas observed on-site were surveyed using a Trimble R8 survey-grade Real-Time Kinematic (RTK) Global Positioning System (GPS) at sub-centimeter accuracy in both horizontal and vertical datums. RTK-GPS data were collected in the Massachusetts State Plane-Mainland NAD83 (horizontal) and NAVD88 (vertical) datums, in units US survey feet. Land Subject to Coastal Storm Flowage was also mapped and detailed in this report using data from the FEMA Flood Map Service Center.

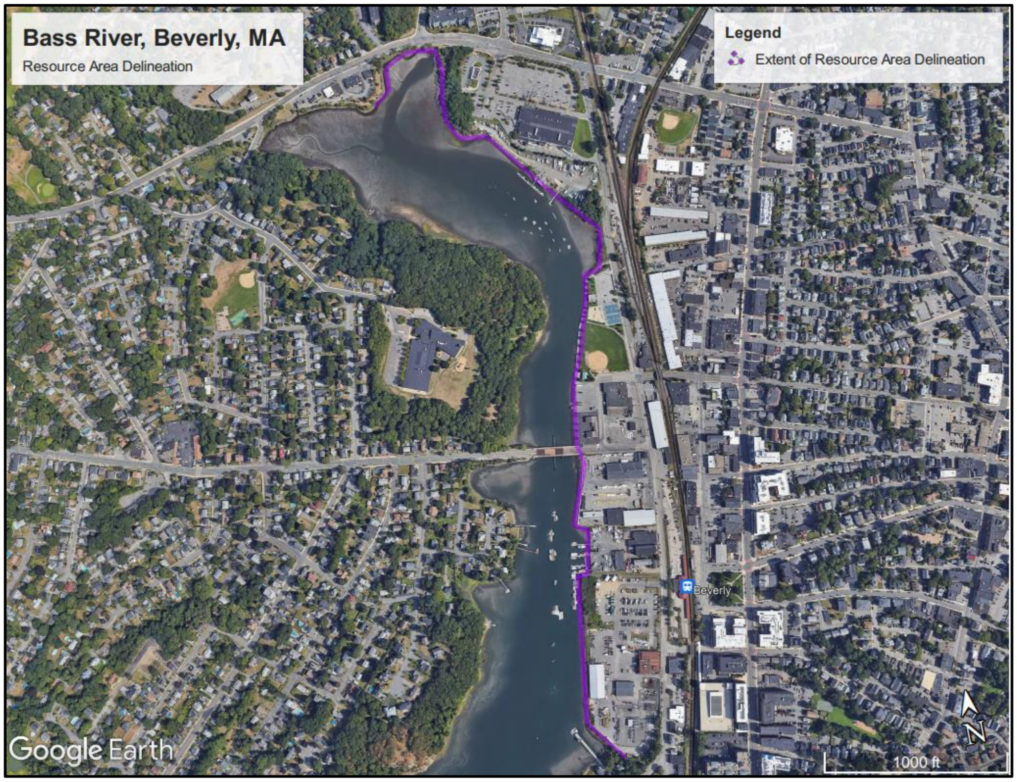


Figure 1. Extent of resource area delineation.

Given the length of shoreline included in the project area (5,367 linear feet), the delineation was divided into (3) discrete sections – the **upstream basin** section, extending from Elliott Street to the southern edge of the Stop-and-Shop parking lot, the **boatyard** section, extending from the boatyard abutting Stop-and-Shop to the Miles McPherson Youth Center, and the **River Street** section, extending along highly developed shoreline south to Marshall Ct. Figures illustrating the extent of resource areas delineated in each of the (3) sections are included in Figures 2-4. Descriptions of each resource area are included in the following sections.

Figure 2. **Resource areas delineated along the shoreline of the upstream basin section.**

Figure 2. **Resource areas delineated along the shoreline of the boatyard section.**

Figure 3. **Resource areas delineated along the shoreline of the River Street section.**

Coastal Bank

Coastal banks are defined at 310 CMR 10.30 as:

> "the seaward face or side of any elevated landform, other than a coastal dune, which lies at the landward edge of a coastal beach, land subject to tidal action, or other wetland".

The toe of the coastal bank in the study area was delineated based on where there is an abrupt change in topography (steeper than 10:1) within land subject to coastal storm flowage and immediately landward of a beach, salt marsh, or rocky intertidal shore. Approximately 5,310 linear ft of coastal bank was delineated in the study area, of which about 3,840 linear ft is non-sediment source (armored) coastal bank.

The coastal bank around the upstream basin was comprised of industrial fill, brick, concrete waste, and some fine-grained sands and silts, which conveyed to the adjacent coastal beach and mudflat located seaward of the bank. Active erosion was observed along the west side of the upstream basin abutting Starbucks (Figure 4). Only minor erosion was observed along most of the coastal bank along the northern shoreline of the upstream basin abutting Elliott St. – except where the bank had eroded all the way back to the concrete roadway abutment immediately landward of the culvert connecting Bass River to Shoe Pond (Figure 5). Along the east side of the upstream basin, actively eroding coastal bank was observed along the entirety of the public space abutting Stop-and-Shop (Figure 6). Given the poor quality of the coastal bank substrate around the upstream basin, only limited amounts of native and invasive vegetation were observed growing on the landform. Species observed along this section of shoreline included native black cherry (*P. serrotina*), eastern red cedar (*J. virginiana*), black oak (*Q. velutina*), high tide bush (*B. halimifolia*), and poison ivy (*T. radicans*), and invasive Asiatic bittersweet (*C. orbiculatus*), and black locust (*R. pseudoacacia*). Many native and invasive trees along the coastal bank in the upstream basin were severely undercut, putting the bank at risk of slumping and further erosion. Only sparse grasses and perennial species were observed.

Figure 4. Industrial material eroding from the coastal bank on the west side of the upstream basin.

Figure 5. **Coastal bank erosion extending landward to the roadway abutment along Elliott St.**

Figure 6. **Industrial material eroding from the coastal bank on the east side of the upstream basin.**

Coastal Bank, cont'd

Further south, the boatyard section of shoreline included both sediment source (actively eroding) and non-sediment source (armored) coastal bank. Immediately seaward of the boatyard, a sloping rock revetment and bulkhead armored the landform (Figures 7-8). South of the boatyard and associated coastal engineering structures, unarmored sections of coastal bank have eroded all the way back to McPherson Dr., encroaching on the roadway side slopes just north of the Miles McPherson Youth Center (Figure 9-10). Vegetation observed along this unarmored section of shoreline mirrored that observed around the upstream basin – including severely undercut trees along McPherson Dr., increasing the vulnerability of the roadway side slope.

Figure 7. Bulkhead adjacent boatyard ramp. Photo taken facing north.

Figure 8. Sloping rock revetment seaward of boatyard. Photo taken facing south.

Figure 9. **Eroded coastal bank and undercut trees immediately seaward of McPherson Dr.**

Figure 10. **Eroded coastal bank along McPherson Dr. Photo taken facing north towards boatyard.**

Coastal Bank, cont'd.

The entirety of the coastal bank from the north end of Innocenti Park south to Marshall Ct. (the southern extent of the delineation) was heavily developed and armored with a combination of sloping rock revetments, vertical bulkheads, sheeting, bridge abutments, and seawalls (Figures 11-12).

Figure 11. Seawall along Innocenti Park shoreline. Photo taken facing south.

Figure 12. Rock revetment north of the Bridge Street bridge. Photo taken facing south.

Salt Marsh

Salt marsh is defined at 310 CMR 10.32 as:

> "a coastal wetland that extends landward up to the highest high tide line, that is, the highest spring tide of the year, and is characterized by plants that are well adapted to or prefer living in, saline soils. Dominant plants within salt marshes typically include salt meadow cord grass (*Spartina patens*) and/or salt marsh cord grass (*Spartina alterniflora*), but may also include, without limitation, spike grass (*Distichlis spicata*), high-tide bush (Iva frutescens), black grass (Juncus gerardii), and common reedgrass (*Phragmites*). A salt marsh may contain tidal creeks, ditches and pools."

The salt marsh in the study area was delineated in areas subject to the highest spring tide based on the presence of salt marsh vegetation species and peat that may contain rhizomes and other subsurface plant material. Approximately 3,920 sf of salt marsh was delineated in the study area.

The upstream basin contained two distinct fringing peat salt marshes located immediately landward of the coastal bank (roadway side slope) along Elliott St. The seaward face of both marsh platforms was heavily armored with riprap ranging in size from 1-3', forming a manmade sill (Figures 13-14). The fringing marshes in the upstream basin were vegetated with smooth cordgrass (*S. alterniflora*), which dominated low marsh areas, and salt marsh hay (*S. patens*), which dominated high marsh areas (Figure 15). A narrow strand of high tide bush (*B. halimifolia*) occupied the narrow strand along the landward edge of the salt marsh and the toe of the coastal bank. Evidence of salt marsh vegetation dieback and degraded peat were observed along the seaward extents of both marsh platforms.

Downstream, another small area of salt marsh was delineated at the extreme north end of the boatyard (Figure 16 & 17). This marsh contained the same vegetation species as found in the upstream basin area. Three other small areas of salt marsh were observed downstream of the boatyard's concrete boat ramp (Figure 18). These three salt marsh areas showed the most severe evidence of dieback, degradation, and active erosion with large, unvegetated sections of the marsh sloughing off onto the beach.

Figure 13. Fringing, rock-sill-supported salt marsh on the north shore of the upstream basin.

Figure 14. Fringing, rock-sill-supported salt marsh on the north shore of the upstream basin.

Figure 15. Interface between high marsh *S. patens* (left) and low marsh *S. alterniflora* (right).

Figure 16. Fringing salt marsh seaward of the boatyard. Photo taken facing east.

Figure 17. Fringing salt marsh seaward of the boatyard. Photo taken facing north.

Figure 18. **Fringing salt marsh (left) and degraded marsh platform (right). Photo taken facing south.**

Rocky Intertidal Shore

Rocky intertidal shores are defined at 310 CMR 10.31 as:

> " naturally occurring rocky areas, such as bedrock or boulder-strewn areas between the mean high water line and the mean low water line."

The rocky intertidal shore in the study area was delineated within areas between mean high and mean low water based on sediment size and the dominant presence of plants and animals that are specially adapted to live in the tidal environment. Approximately 6,600 sf of rocky intertidal shore was delineated in the study area.

Rocky intertidal shore extended along most of the northern shoreline of the upstream basin where intermittent boulders were strewn seaward of the coastal bank and fringing salt marsh (Figure 19). Within the rocky intertidal shore, cobbles exceeding 1' in diameter were subject to daily tidal inundation and were occupied by various species of macroalgae. (Figure 20). Per the Massachusetts Coastal Zone Management Office Coastal Manual, it is important to note that while manmade coastal engineering structures sometimes meet the definition for rocky intertidal shore, they are not able to meet the performance standards of the resource area and therefore, are not delineated as such (Figure 21). Only boulder strewn areas with stable cobble seaward of the manmade structures were mapped as rocky intertidal shore. To that end, no additional rocky intertidal shore was mapped south of the northern basin.

Figure 19. Rocky intertidal shore (in orange), seaward of the salt marsh sill. Photo taken facing east.

Figure 20. Macroalgae attached to cobbles and boulders within rocky intertidal shore.

Figure 21. **Manmade sloping rock revetment with boulders and attached macroalgae does not meet performance standards for rocky intertidal shore.**

Coastal Beach

Coastal beach is defined at 310 CMR 10.27 as:

> "unconsolidated sediment subject to wave, tidal and coastal storm action which forms the gently sloping shore of a body of salt water and includes tidal flats. Coastal beaches extend from the mean low water line landward to the dune line, coastal bank line or the seaward edge of existing man-made structures, when these structures replace one of the above lines, whichever is closest to the ocean."

The coastal beach in the study area was delineated within areas landward of the mean low water line where sediments were observed to have been primarily reworked by waves and tides. Tidal flats, which were not specifically delineated, are present from the seaward of the edge of the delineated coastal beach to the mean low water line. Approximately 31,640 sf of coastal beach was delineated in the study area.

Around the entire shoreline of the upstream basin, a narrow coastal beach was delineated between the coastal bank, salt marsh, and/or rocky intertidal shore and the edge of the mudflat (Figure 22-23). The beach along the northern, terminal end of the upstream basin consisted of fine sediments mixed with gravel and industrial fill, overlain with mud (Figure 24). Just downstream along the eastern shoreline of the upstream basin, the landward edge of beach was comprised of coarser sand, gravel, and fill, becoming muddier along the seaward edge (Figure 25). Substantial amounts of eroded fill from the coastal bank had been conveyed to the coastal beach, evidence of ongoing erosion of the landform. Given the poor quality of the beach sediments, no vegetation was observed growing out of the beach platform.

Coastal beach delineated within the boatyard section of shoreline was somewhat gravellier than areas located further upstream (Figure 26). However, the beach still became muddy along the seaward edge, where mudflat was omnipresent (Figure 27). No coastal beach was delineated along the heavily armored River Street section of shoreline.

Figure 22. **Coastal beach (left), transitioning to coastal bank (right) along the western shore of the upstream basin. Photo taken facing south.**

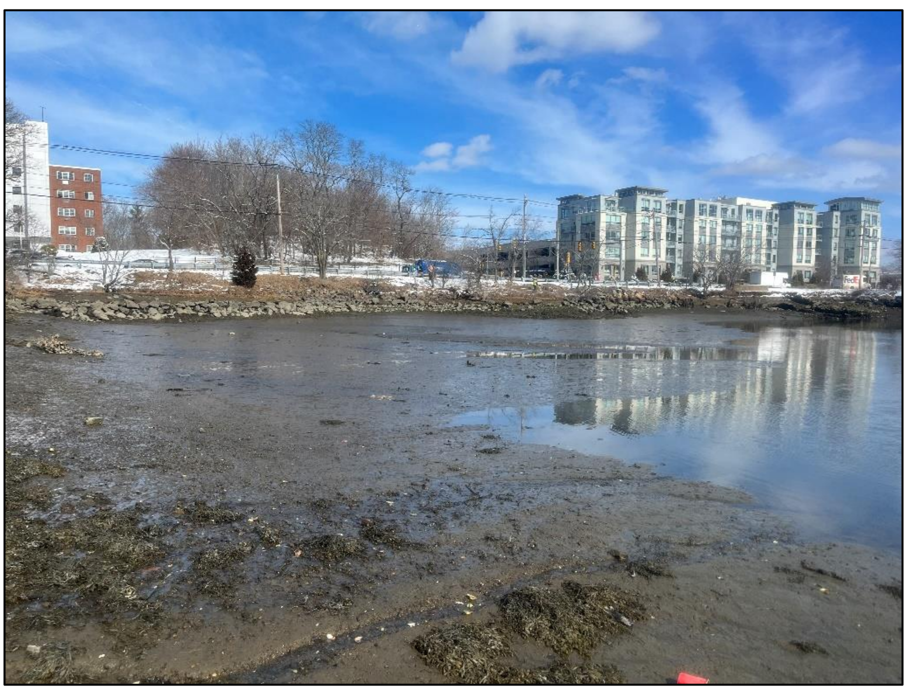


Figure 23. **Coastal beach along the western shoreline of the upstream basin. Photo taken facing north.**

Figure 24. **A veneer of mud overlaying fine-grained sediments and gravel along the seaward edge of the coastal beach.**

Figure 25. **Coastal beach between mudflat and coastal bank along the eastern shoreline of the upstream basin. Photo taken facing north.**

Figure 26. Gravellier substrate downstream of the boatyard boat ramp.

Figure 27. Coastal beach seaward of eroding coastal bank along McPherson Dr. Photo taken facing south.

Land Subject to Coastal Storm Flowage

Land subject to coastal storm flowage is defined at 310 CMR 10.04 as:

> " land subject to any inundation caused by coastal storms up to and including that caused by the 100-year storm, surge of record or storm of record, whichever is greater."

The land subject to coastal storm flowage in the study area was delineated based on the Special Flood Hazard Area boundary shown on the current effective FEMA Flood Insurance Rate Maps.

Land subject to coastal storm flowage (LSCSF) extended throughout the study area, extending up to the Base Flood Elevation (10.0') of the site (Figure 28). As a result, LSCSF also encompasses all the resource areas that were observed on site.

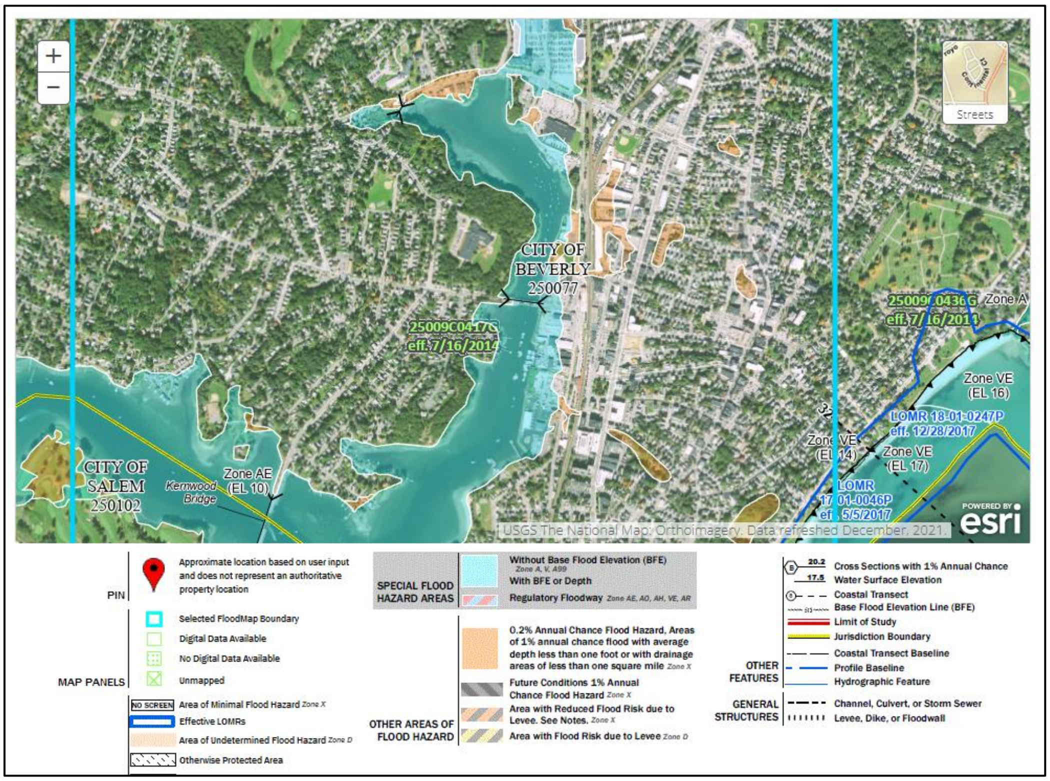


Figure 28. Extent of AE and VE Zones within the vicinity of the study area.

Natural Heritage Estimated & Priority Habitat and Massachusetts Division of Marine Fisheries Shellfish Suitability Areas

No Estimated or Priority Habitat for Rare or Endangered Species was identified within the study area by the Massachusetts Natural Heritage and Endangered Species Program (Figure 29). However, a significant portion of the study area was identified as spawning and settlement habitat for soft-shell clam (*Mya arenaria*) (Figure 29). No live shellfish were observed during the delineation, though some shell hash was observed along the coastal beach.

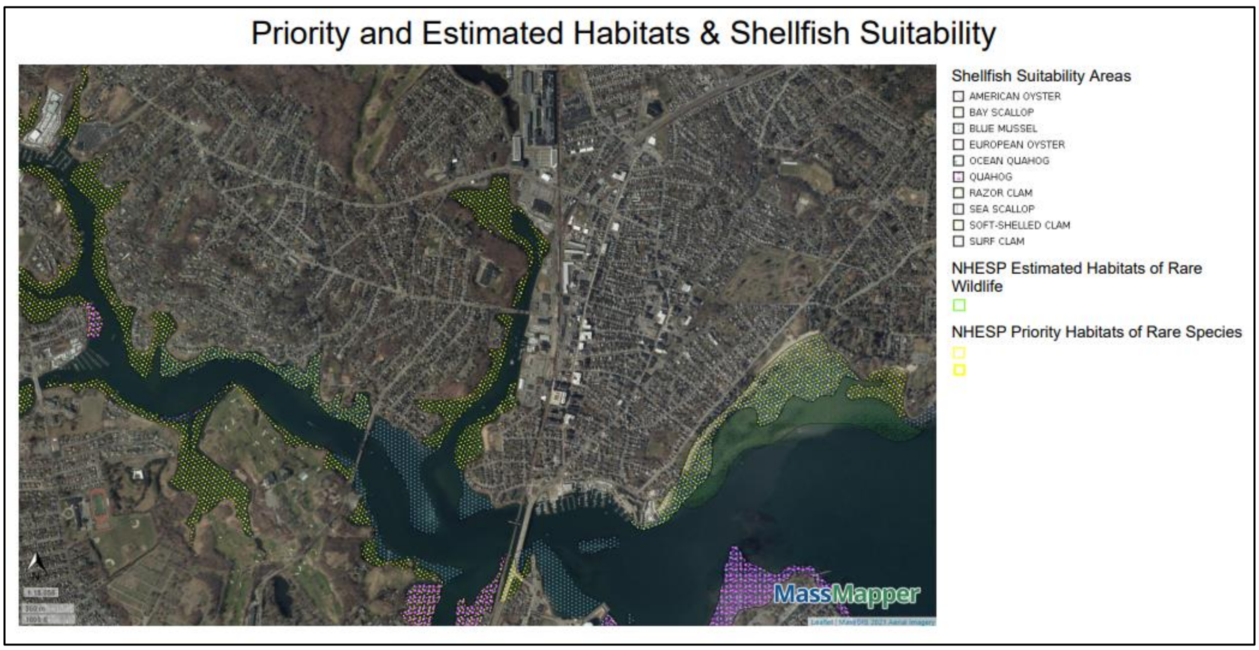


Figure 29. NHESP & Shellfish Suitability habitat adjacent to the Bass River study area.

If you have any questions or require any further information, please do not hesitate to contact me directly at 508-495-6272 or via email at afinkle@woodsholegroup.com

Sincerely,

Adam Finkle
Coastal Scientist, PWS, CERP

Appendix B

FLOOD INTERVENTION PERFORMANCE MODELING MEMORANDUM

TECHNICAL MEMORANDUM

Sent by Electronic Mail

DATE June 26, 2023 **JOB NO.** 2022-0026

TO Katie Moniz
Director
Fort Point Associates
kmoniz@fpa-inc.com

FROM Nasser Brahim
Senior Climate Resiliency Specialist
nbrahim@woodsholegroup.com

Grace Medley
Coastal Scientist
gmedley@woodsholegroup.com

Beverly Bass River District-Wide Resilience Interventions – Performance Modeling

Introduction:

Woods Hole Group utilized the Massachusetts Coast Flood Risk (MC-FRM) to verify the performance and assess potential impacts associated with the conceptual strategies developed for the Bass River District Resilience Study, in Beverly, Massachusetts. In addition to focusing on the overall performance of the proposed adaptations under both present and future climate change conditions, this evaluation also included influences of the proposed conceptual interventions on flood extents, and highlights areas where the conceptual interventions could be improved in order to mitigate flooding.

The following technical memorandum serves to summarize the results of the performance modeling. This includes an analysis of flooding extents and water surface elevations under a series of future return-period storm events for existing and proposed conditions. This analysis also included assessment of potential localized increases in water surface elevations and velocities in the vicinity of the proposed conceptual interventions.

Proposed Resiliency Adaptations

Performance modeling involves the virtual construction of the proposed conceptual interventions into the MC-FRM domain, select return-period storm scenarios within the model, and assessing hydrodynamic changes (water levels, velocities, etc.) between existing and proposed conditions. For this project, the conceptual district-wide flood interventions for “Elevate the District” and “Revitalize the District” were applied to the modeling grids, and modeled results were used to inform the changes in the flood extents of three 1% AEP storm events (2030, 2050 and 2070). In addition, a conceptual intervention for roadway raising, independent of other district-wide conceptual flood interventions, we applied and modeled as another option for the City to consider going forward. Figures 1-3 present the approximate alignment of coastal flood infrastructure, raised properties, and elevated roadways that that were applied to the hydrodynamic modeling grid.

Figure 1: Approximate raised road elevations, raised property elevations, and coastal flood infrastructure alignments applied to the modeling domain for the "Elevate the District" conceptual district-wide flood intervention (elevations in NAVD88).

Figure 2: Approximate combination of coastal flood infrastructure and elevation of land with a continuous crest elevation applied to the modeling domain for the “Revitalize the District” conceptual district-wide flood intervention (elevation in NAVD88).

Figure 3: Approximate raised road elevations applied to the modeling domain for raising roadway rights-of-way and publicly accessible waterfront path (elevations in NAVD88).

Performance modeling using MC-FRM

The MC-FRM is a high-resolution, probabilistic flood risk model created specifically to assess physics-based, coastal forced, flooding conditions under present and future climate conditions for the entire coast of Massachusetts. The model uses a two-way coupled version of the Advanced Circulation (ADCIRC) and Unstructured Simulating Waves Nearshore (UnSWAN) models to fully simulated a variety of storm conditions (e.g., tropical and extra-tropical cyclones, etc.). The MC-FRM incorporates the state standard sea level rise conditions over time as presented by Massachusetts Coastal Zone Management and Resilient MA (https://resilientma.mass.gov/changes/sea-level-rise). Storm intensification due to climate change is also incorporated within the MC-FRM 2050 and 2070 time horizons. The model has, and is currently, being used for numerous coastal planning and design projects throughout Massachusetts and is recommended by the Commonwealth of Massachusetts *Climate Resilience Design Standards* as the basis for resilient coastal design.

The MC-FRM provides a probabilistic distribution of water levels for locations throughout Massachusetts based on thousands of storms. From these thousands of storm events, individual storms corresponding closely to specific return-periods water surface elevations can be selected to evaluate the performance of flood resiliency projects. For this modeling effort, three representative storms, under three different climate horizons were simulated for existing conditions (existing elevations) and proposed conditions (with the proposed development constructed) withing the MC-FRM framework.

The peak stillwater levels at this particular location (associated with these storm events) are listed in Table 1.

Table 1. Peak water levels utilized for the performance modeling.

Storm Event Case (Annual Exceedance Probability)	Return Period	Climate Horizon	StillWater Level (ft, NAVD88)
1%	100-year	2030	10.0
1%	100-year	2050	11.5
1%	100-year	2070	13.5

Results of Performance Modeling: Extent of Flooding

"Elevate the District" Conceptual District-wide Flood Intervention

The "Elevate the District" conceptual district-wide flood intervention features a series of coastal flood infrastructure alignments, raised property, and raised roadway alignments to mitigate flooding in the near-term and long-term timeframe. In the 2030 timeframe (Figure 4), the "Elevate the District" conceptual district-wide flood intervention will mitigate flooding to the singular properties raised to >10 ft NAVD88 during the 1% storm. These properties consist of the most critical area of the utility substation, potential redevelopment sites along Margin Street, and the site of the McPherson Youth Center. The "Elevate the District" conceptual district-wide flood intervention eliminates storm surge flooding behind elevation 10 ft NAVD88 coastal flood infrastructure, that will protect existing commercial/industrial properties adjacent to River, Bridge, and Margin Streets during the 1% AEP storm scenario in 2030, though these sites may experience localized impacts from wave overtopping. Sites and buildings that are not elevated or protected by coastal flood infrastructure (the rest of the utility site and buildings, Bass Haven Yacht Club) will be exposed to flooding, though building floodproofing and preparedness actions envisioned in the "Elevate the District" conceptual district-wide flood intervention may limit the impacts of associated flooding.

In the 2050 timeframe (Figure 5), the 10 ft NAVD88 coastal flood infrastructure at existing commercial/industrial properties adjacent to River, Bridge, and Margin Streets are inundated during the 1% storm event, leaving these properties vulnerable to storm surge flooding. Building floodproofing and preparedness actions envisioned in the "Elevate the District" conceptual district-wide flood intervention may limit the impacts of associated flooding. Individual properties that are built to an elevation of greater than 11.5 feet (utility substation critical area, the potential redevelopment site that spans Bridge Street and Margin Street, and McPherson Youth Center site) avoid flooding in the 2050 1% storm scenario. Finally, during the 2050 1% AEP storm event, the raised roadway infrastructure in combinations with a potential redevelopment site at Bridge Street to Margin Street block a key flood pathway that would otherwise send floodwaters down Federal Street into a low-lying inland neighborhood area.

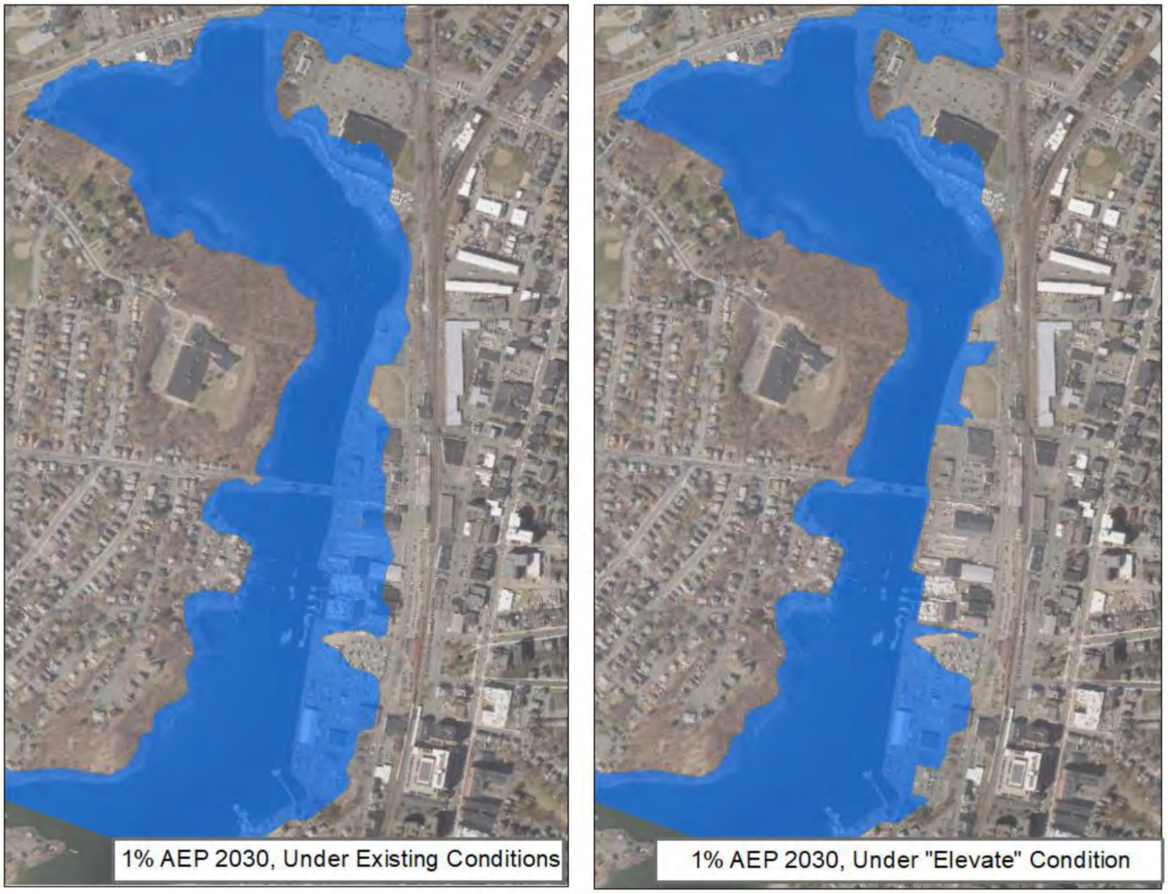


Figure 4. Flood extents for the 1% AEP storm event for existing (Left Panel) and with the proposed intervention in place (Right Panel) under the 2030 climate horizon for the “Elevate the District” conceptual district-wide flood intervention. Shades of blue indicate areas where flooding is expected to occur.

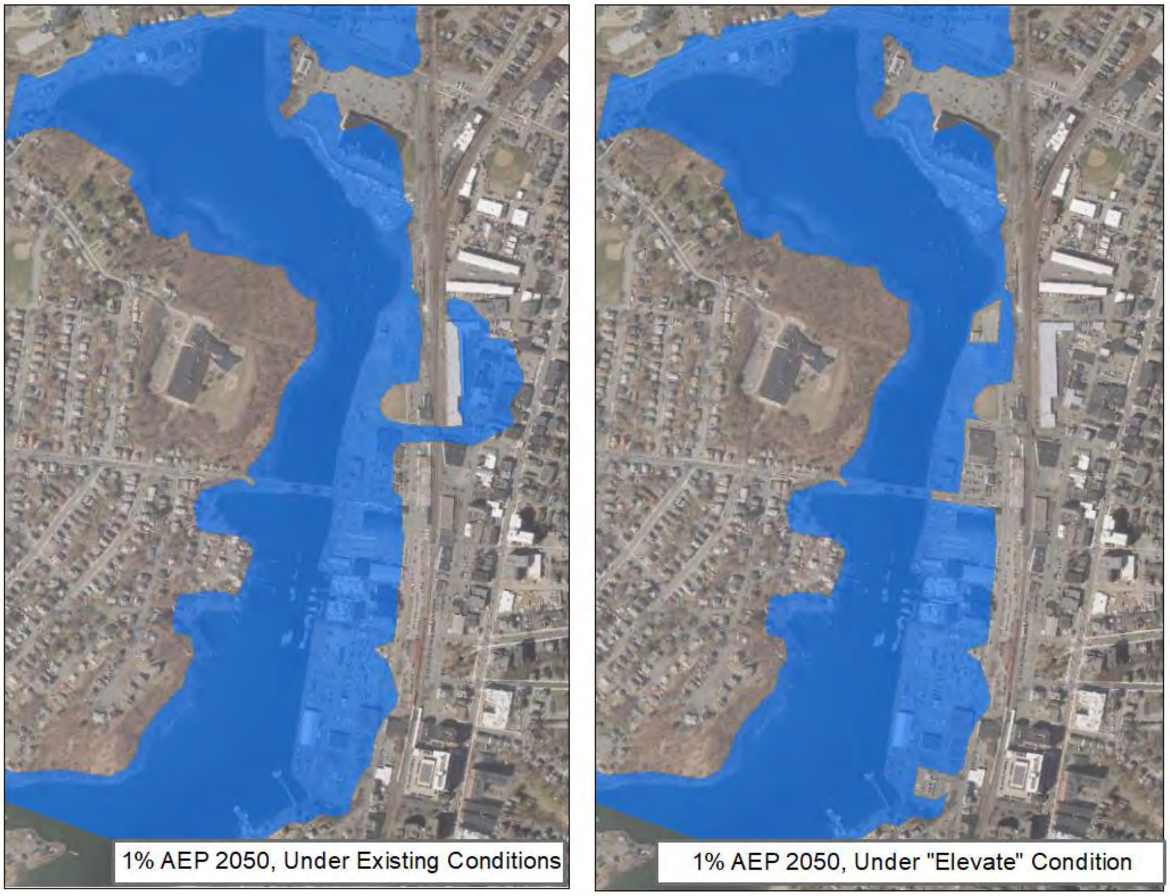


Figure 5. Flood extents for the 1% AEP storm event for existing (Left Panel) and with the proposed intervention in place (Right Panel) under the 2050 climate horizon for the "Elevate the District" conceptual district-wide flood intervention. Shades of blue indicate areas where flooding is expected to occur.

"Revitalize the District" Conceptual District-wide Flood Intervention

The "Revitalize the District" conceptual district-wide flood intervention features a combination of coastal flood infrastructure and elevation of land, with a continuous crest elevation of 13.5 feet, along the Bass River District waterfront. These alternatives will effectively eliminate flooding to the waterfront extending from the utility substation site, north to the grocery store site in both the 2050 (Figure 6) and 2070 (Figure 7) 1% AEP storm events. It is important to note that this scenario would need to wrap around the corner of Elliott Street and McPherson Drive in order to mitigate flooding to the grocery store site in both the 2050 and 2070 1% AEP storm events.

In the updated concepts presented at the June 13, 2023 Public Forum #2, the "Revitalize the District" conceptual district-wide flood intervention showed a lower waterfront buffer area at 12.5 ft NAVD88, and properties landward of the buffer area raised to more varied elevations. Individual properties that are raised to an elevation of >11.5 ft NAVD88 would be protected from flooding during the 1% AEP event in 2050, and properties that are raised to an elevation of >13.5 ft NAVD88 would be protected from flooding during the 1% AEP event in 2070.

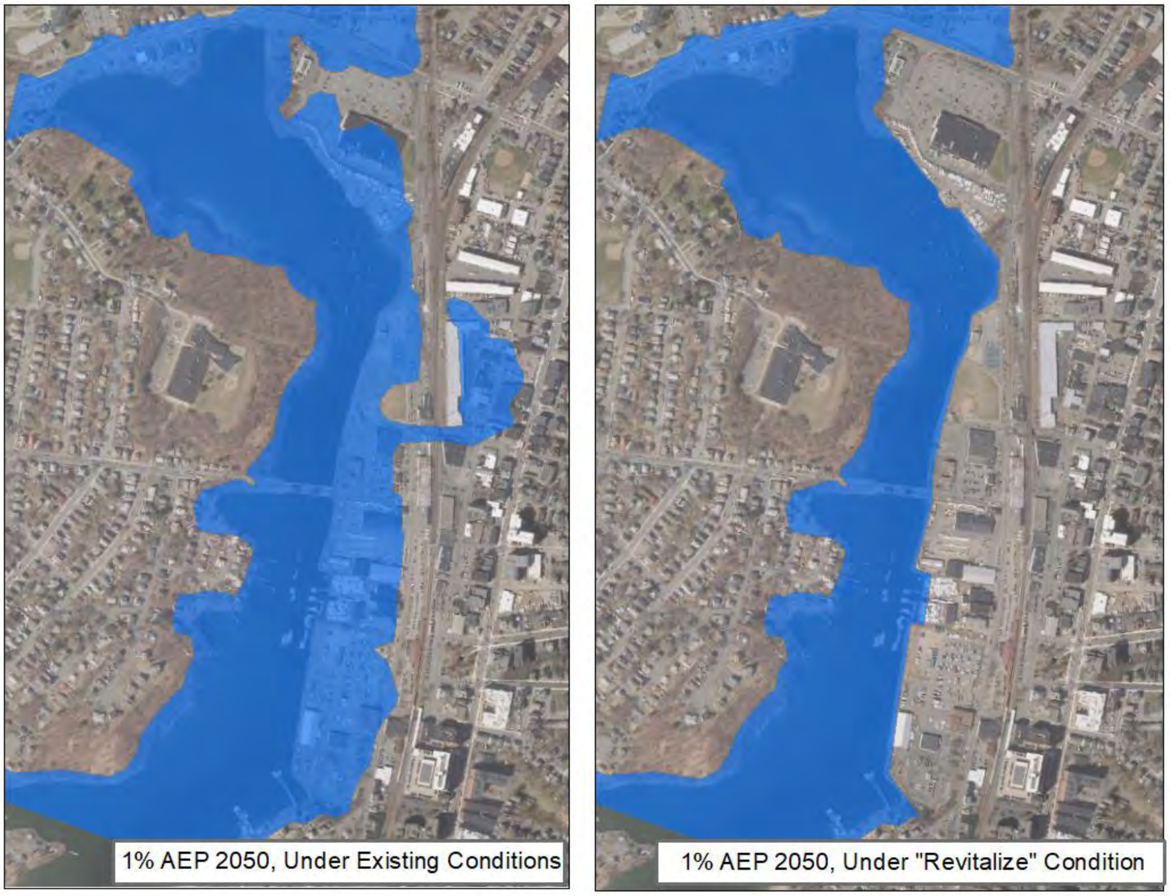


Figure 6. Flood extents for the 1% AEP storm event for existing (Left Panel) and with the proposed intervention in place (Right Panel) under the 2050 climate horizon for the “Revitalize the District” conceptual district-wide flood intervention. Shades of blue indicate areas where flooding is expected to occur.

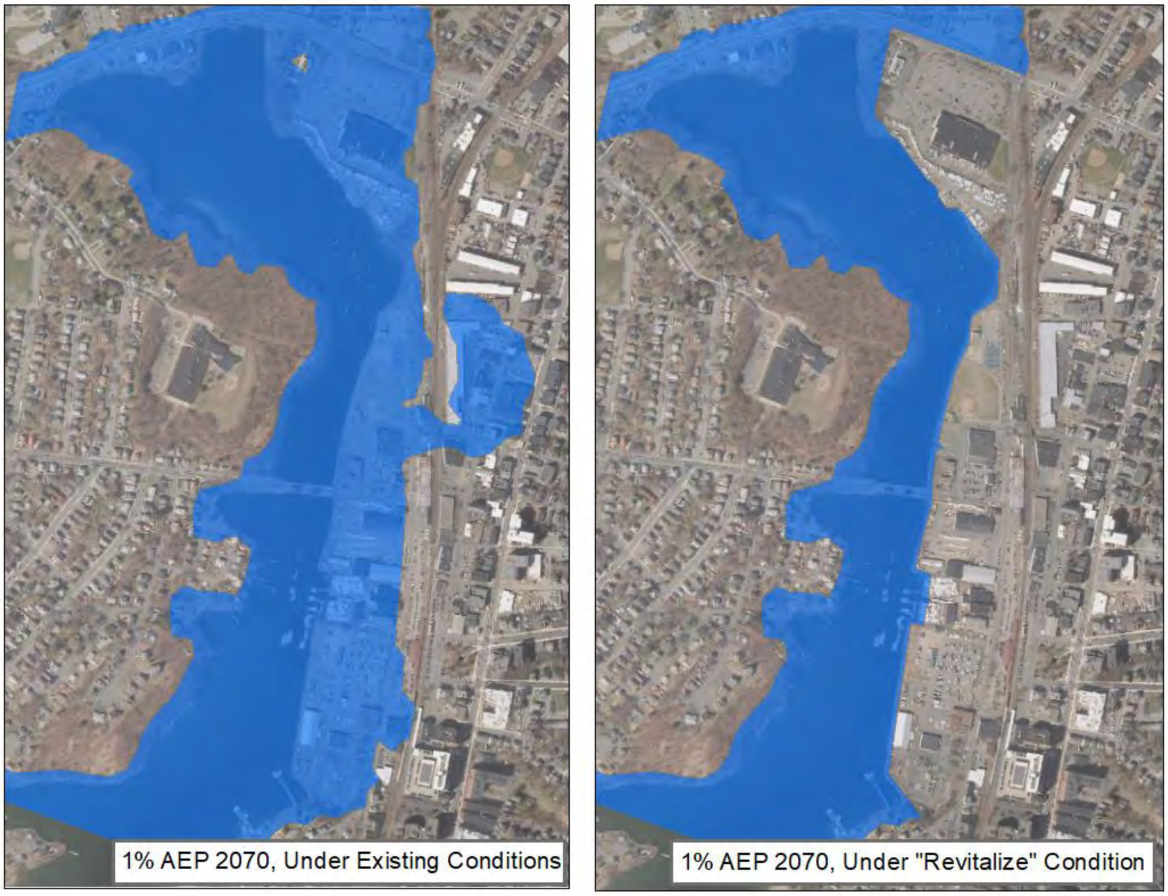


Figure 7. Flood extents for the 1% AEP storm event for existing (Left Panel) and with the proposed intervention in place (Right Panel) under the 2070 climate horizon for the "Revitalize the District" conceptual district-wide flood intervention. Shades of blue indicate areas where flooding is expected to occur.

Consideration for Road Raising Interventions in the District

Road raising within the District is another option to protect transportation infrastructure (and the access/egress it provides) and block key flood pathways during the 2050 (Figure 8) and 2070 (Figure 9) 1% AEP storm events. This is accomplished by raising public roadways or public access paths to a crest elevation of 13.5 ft NAVD88. This effectively protects all transportation infrastructure within the District, in both the 2050 and 2070 1% AEP storm events. It also blocks the key flood pathways in the 2050 1% AEP storm event, eliminating flooding down Federal Street and Pleasant Street underpasses as well as the flood pathway impacting the existing grocery store. In the 2070 1% AEP storm event, it blocks all except the flood pathways impacting the existing grocery store.

While flooding is mitigated in 2050 for the existing grocery store coming from the south, a main takeaway from the 2070 1% AEP result is that raising the publicly accessible waterfront access path seaward of the grocery store does not mitigate flooding of the grocery store site in the 2070 1% AEP storm event, due to flanking along Elliott Street from the north and west. The conceptual road raising intervention, much like the extension to the "Revitalize the District" conceptual district-wide flood intervention, would need to wrap around and continue along Elliott Street in order to mitigate flooding to the grocery store site in both the 2050 and 2070 1% AEP storm events.

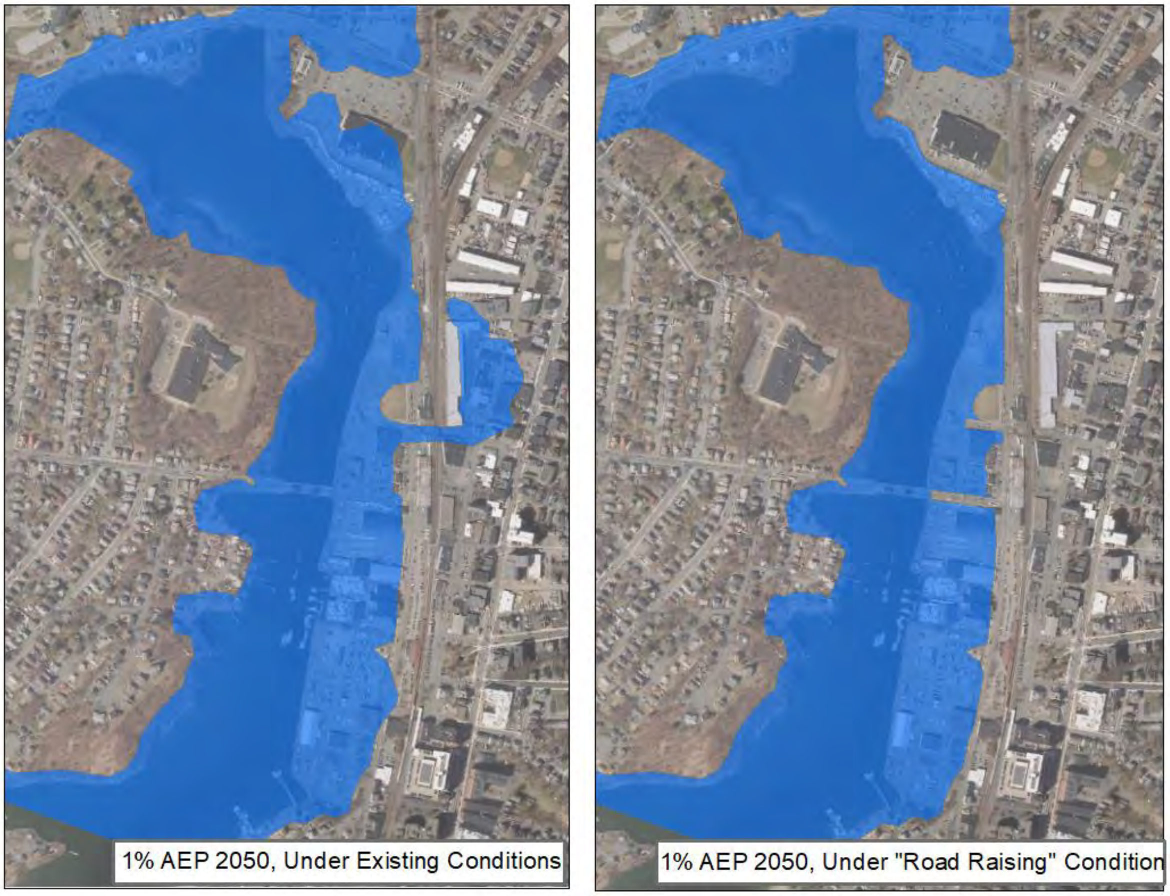


Figure 8. Flood extents for the 1% AEP storm event for existing (Left Panel) and with the proposed intervention in place (Right Panel) under the 2050 climate horizon for the “Road Raising” conceptual district-wide flood intervention. Shades of blue indicate areas where flooding is expected to occur.

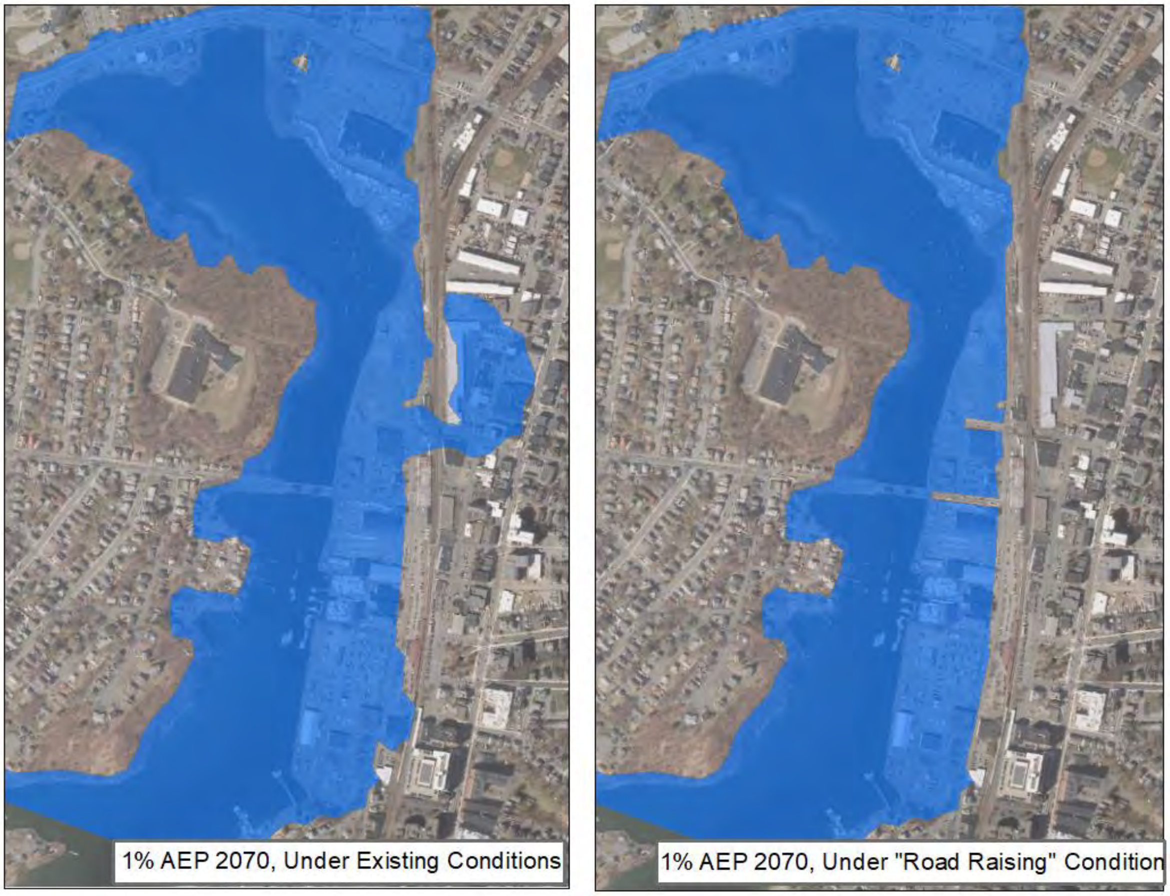


Figure 9. Flood extents for the 1% AEP storm event for existing (Left Panel) and with the proposed intervention in place (Right Panel) under the 2070 climate horizon for the "Road Raising" conceptual district-wide flood intervention. Shades of blue indicate areas where flooding is expected to occur.

Results of Performance Modeling: Redirected Floodwaters and Velocity Increases

As flood waters flow inland and interact with infrastructure (both existing and proposed), various patterns and potential redirection of flow magnitudes, directions, and volumes can occur. Proposed infrastructure can function as a barrier to flow, which can potentially alter the flow patterns and modify flow velocities and flow volumes in the vicinity of these changes. Redirected flood waters that cause additional flooding to adjacent neighborhoods will be shown through modeled results as a localized increase in the water surface elevation in areas adjacent to the project implementation site. Impacts to neighboring properties in the form of redirected flood waters were investigated for the "Revitalize the District" conceptual district-wide flood intervention, during the 1% AEP storm event in 2070 (Figure 10). "Revitalize the District" was chosen for this analysis because it involves the largest amount of flood protection and volume displacement, and the 1% AEP event in 2070 was chosen because it was the largest storm event considered.

Modeled results indicate that during the 1% AEP event in 2070 with the "Revitalize the District" conceptual district-wide intervention implemented, there are no localized increases in water surface elevations, and therefore no redirected flood waters to the neighborhoods adjacent to the District or across the Bass River. The assumption is made that results of flow redirection are the most extreme during the largest events, and if no difference is calculated in the largest of the events between existing and proposed water surface elevations, no differences will be observed in events of lesser magnitude.

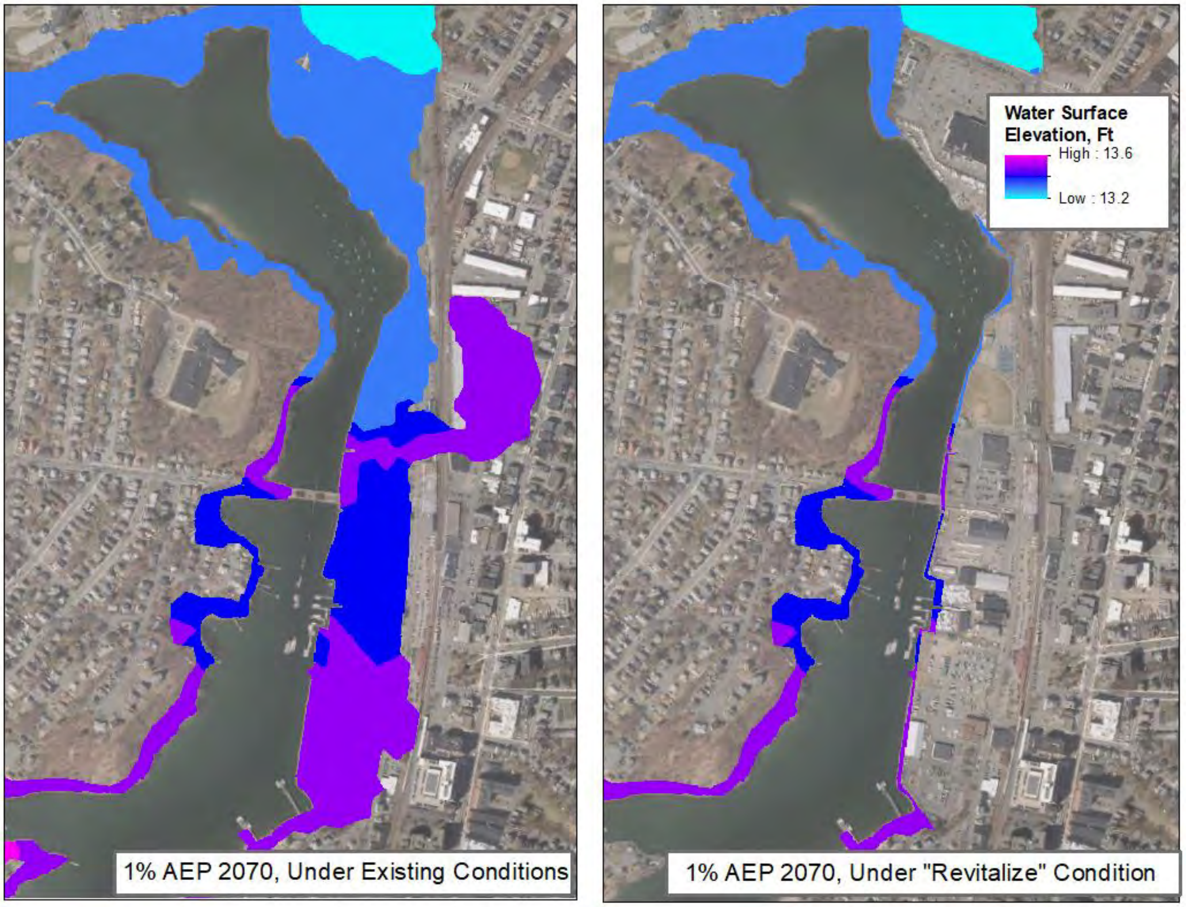


Figure 10: Water surface elevations for the 1% AEP in 2070. The left panel represents existing conditions, and the right panel represents conditions with the "Revitalize the District" conceptual district-wide flood intervention implemented. Water surface elevations above Mean High Water (MHW) are shown in this figure, considering overland flooding only.

With the "Revitalize the District" conceptual intervention in place during the 2070 1% AEP event, there exists the potential for an increase in velocities in narrow sections of the Bass River (Figure 11). These increases in flow, occurring before and after the storm peaks, have the potential to occur due to the redirection and channelization of flood waters as they flood and recede. The regions featuring the most significant flow increases are pinch points in the Bass River, where water channelizes as it interacts with the elevated waterfront. Modeled impacts include up to a 1 ft/s increase in velocities at the Bridge Street crossing, just over a 1 ft/s increase in water velocity in the pinch point of the river, adjacent to Innocenti Park and just over a 1 ft/s increase at the head of the Bass River, at Elliott Street. It should be noted that the model considers the alignment to be in the form of a vertical structure, which would cause a conservative estimate in the velocity increases. Velocity increase estimates and the consequences of changes in velocity would need further investigation during future design and permitting phases, and should account for the actual proposed design's material type, slopes, and toe elevations. Future improvements to the Bridge Street bridge should consider appropriate safety factors to account for potential future changes.

Figure 11: Velocity increases (in feet per second) for the "Revitalize the District" conceptual district-wide flood intervention implemented during a 1% AEP storm event in 2070.

Conclusions

MC-FRM was utilized in order to gauge the performance of a series of conceptual district-wide interventions to increase the resilience of the Bass River District, in Beverly MA, to coastal flooding. Based on the performance modeling results and analysis, key findings include:

- The "Elevate the District" conceptual district-wide flood intervention eliminates storm surge flooding behind elevation 10 ft NAVD88 waterfront coastal flood infrastructure during the 1% AEP storm scenario in 2030, but the coastal flood infrastructure will not protect these properties during the 2050 1% AEP scenario. Individual properties that are raised to an elevation of >10 ft NAVD88 are protected from flooding during the 1% AEP event in 2030, and properties that are raised to an elevation of >11.5 ft NAVD88 are protected from flooding during the 1% AEP event in 2050. Raised roadway infrastructure in combination with the potential redevelopment site at

Bridge Street to Margin Street block a key flood pathway that would otherwise send floodwaters down Federal Street into low-lying inland neighborhood areas.

- The “Revitalize the District” conceptual district-wide flood intervention effectively eliminates flooding in the Bass River District in both the 2050 and 2070 1% AEP storm events by raising sites and/or constructing coastal flood infrastructure to form a continuous barrier at 13.5 ft NAVD88, extending from the utility substation site, north to the grocery store site. Individual properties that are raised to an elevation of >11.5 ft NAVD88 are protected from flooding during the 1% AEP event in 2050, and properties that are raised to an elevation of >13.5 ft NAVD88 are protected from flooding during the 1% AEP event in 2070.
- The district-wide road raising flood interventions block key flood pathways that occur in the 2050 and 2070 1% AEP storm events and protects and maintains the accessibility to travel the roadways that are raised during these scenarios. The raised publicly accessible waterfront access path conceptual intervention would need to wrap around and continue along Elliott Street in order to mitigate flooding to the grocery store site in the 2070 1% AEP.
- With the “Revitalize the District” conceptual district-wide flood intervention implemented, there are no measurable effects (i.e., increases in flood extents or elevations) of re-directed flood waters to neighboring properties on or across the Bass River during the 2070 1% AEP event.
- With the “Revitalize the District” conceptual district-wide flood intervention in place during the 2070 1% AEP event, there exists the potential for an increase in velocities in narrow sections of the Bass River adjacent to the project site. Further investigation should be undertaken in future design and permitting phases. Future improvements to the Bridge Street bridge should consider appropriate safety factors to account for potential future increases in velocities.

Appendix C

COASTAL FLOOD MAPS

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED PRESENT FLOOD PROBABILITY

TETRA TECH | WOODS HOLE GROUP

0 500 1,000 1,500 2,000 Feet

N

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected Present Flood Probability

- 0.1%
- 0.2%
- 0.5%
- 1%
- 2%
- 5%
- 10%
- 20%
- 25%
- 30%
- 50%
- 100%

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2030 FLOOD PROBABILITY

TETRA TECH

WOODS HOLE GROUP

0 500 1,000 1,500 2,000 Feet

N

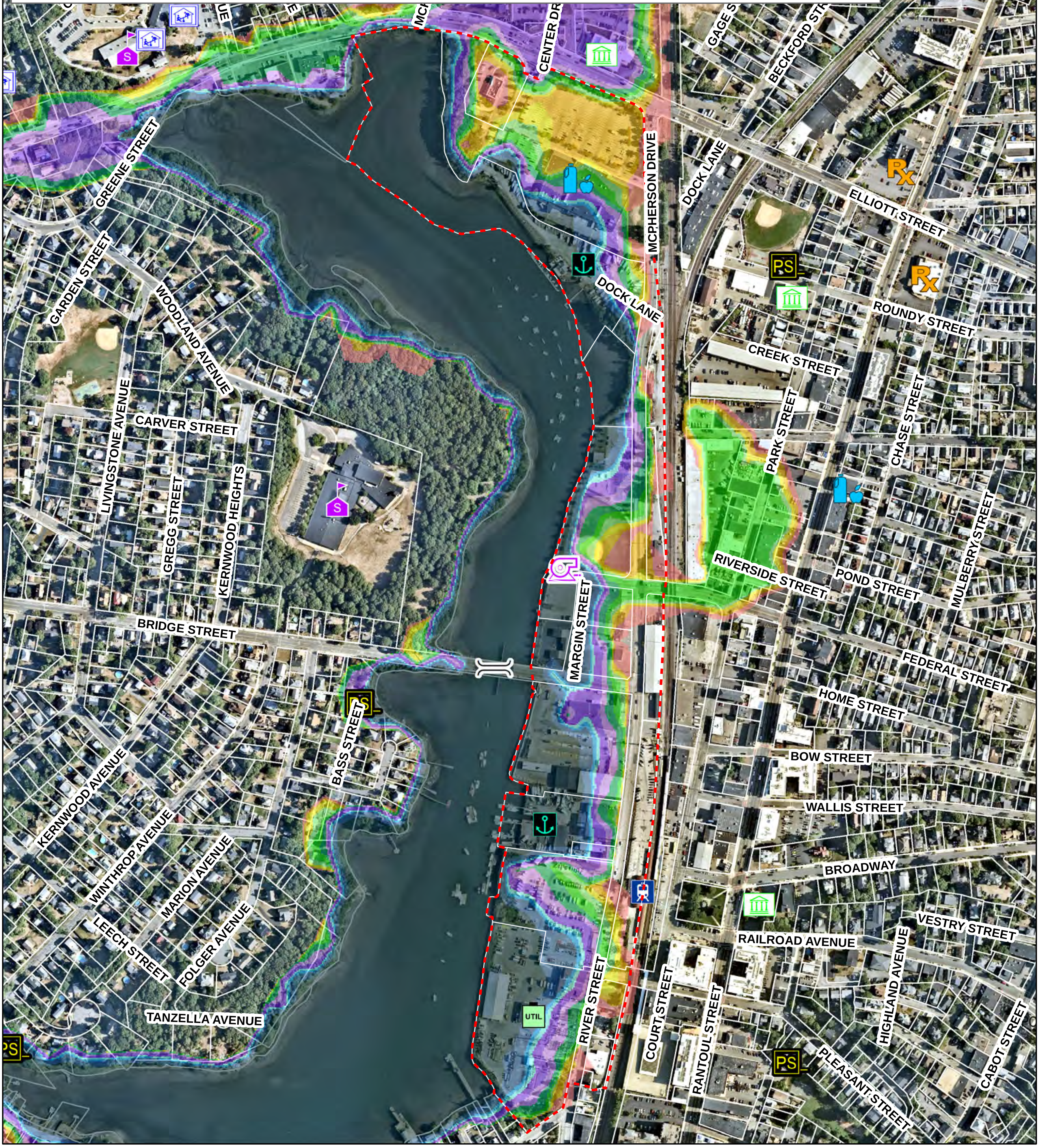
Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2030 Flood Probability

0.1%	10%
0.2%	20%
0.5%	25%
1%	30%
2%	50%
5%	100%

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2050 FLOOD PROBABILITY



TETRA TECH

WOODS HOLE GROUP

Legend

Beverly Bass River District	Pharmacies
Bridge	School
Child Care Facilities	Sewer Pump Station
Church	Storm Pump Station
Cultural Resource	Supermarket
Government	Train Station
Marina	Utility

Projected 2050 Flood Probability

0.1%	10%
0.2%	20%
0.5%	25%
1%	30%
2%	50%
5%	100%

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2070 FLOOD PROBABILITY

TETRA TECH

WOODS HOLE GROUP FOR EARTH, FROM SPACE A CLS COMPANY

0 500 1,000 1,500 2,000 Feet

N

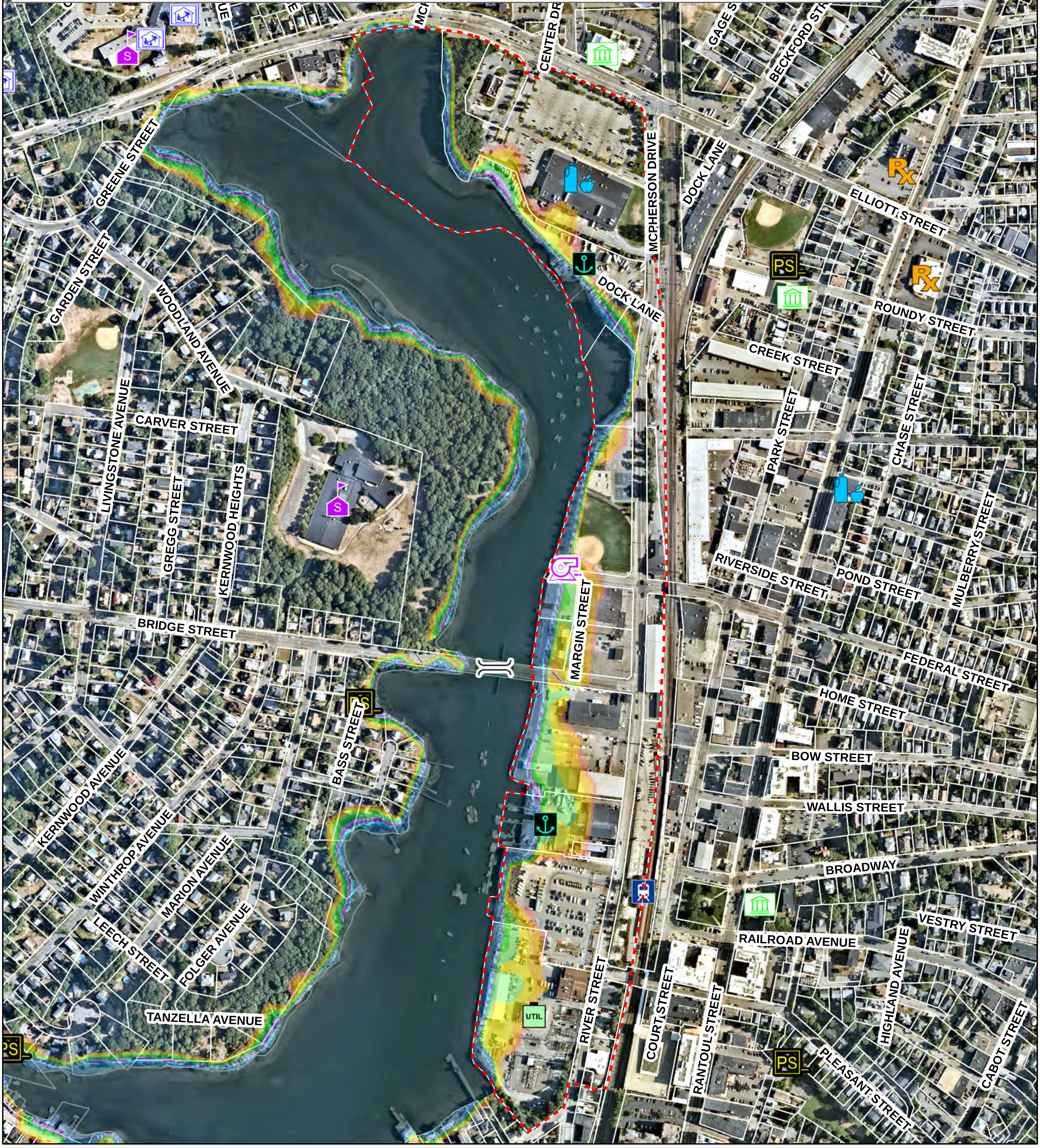
Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2070 Flood Probability

- 0.1%
- 0.2%
- 0.5%
- 1%
- 2%
- 5%
- 10%
- 20%
- 25%
- 30%
- 50%
- 100%

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED PRESENT 1% FLOOD DEPTH



TETRA TECH

WOODS HOLE GROUP

0 500 1,000 1,500 2,000 Feet

N

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected Present Flood Depths (1%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2030 1% FLOOD DEPTH

TETRA TECH

WOODS HOLE GROUP

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2030 Flood Depths (1%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2050 1% FLOOD DEPTH

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2050 Flood Depths (1%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2070 1% FLOOD DEPTH

TETRA TECH

WOODS HOLE GROUP

0 500 1,000 1,500 2,000 Feet

N

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2070 Flood Depths (1%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED PRESENT 0.5% FLOOD DEPTH

TETRA TECH

WOODS HOLE GROUP

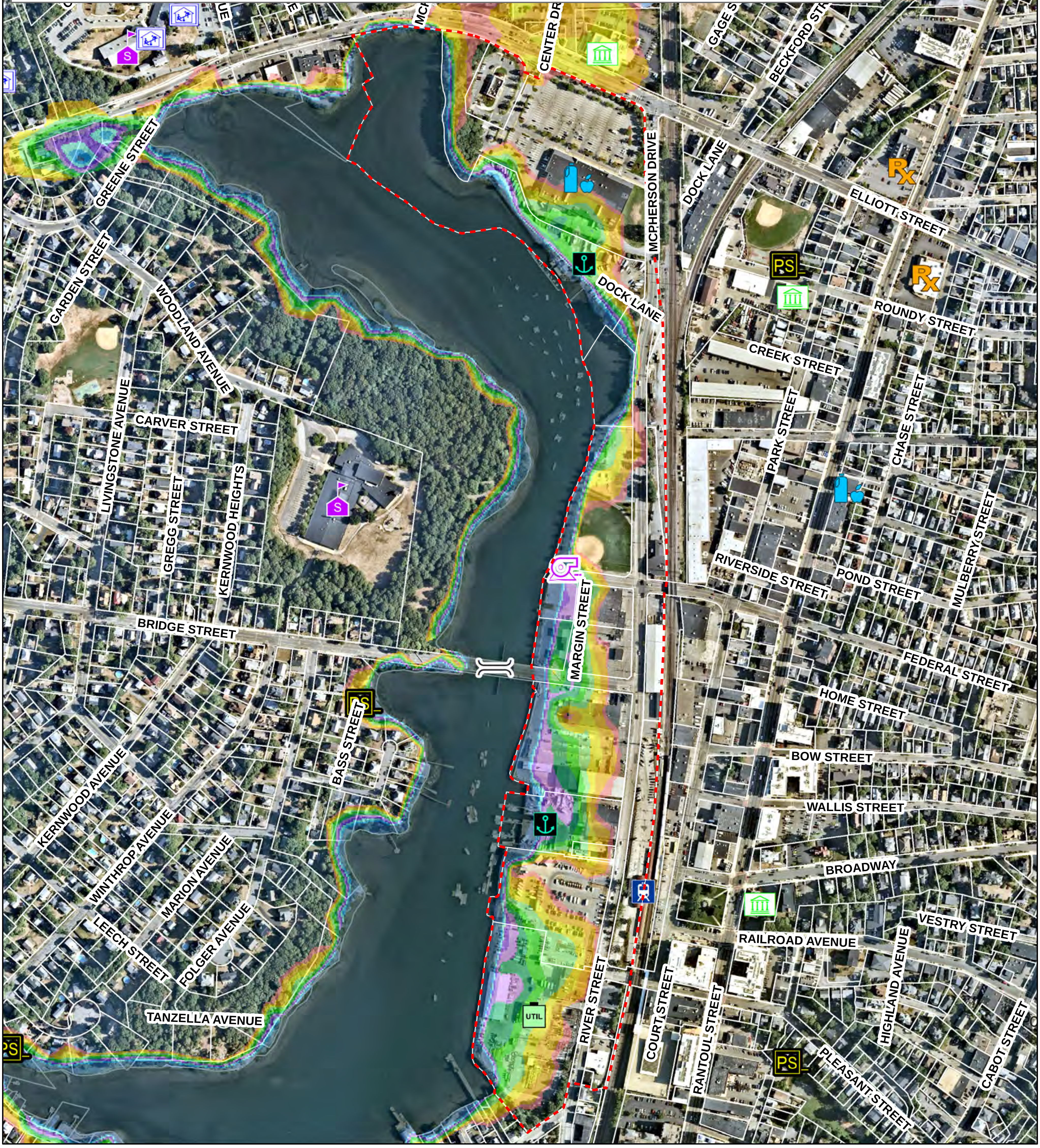
Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected Present Flood Depths (0.5%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2030 0.5% FLOOD DEPTH



TETRA TECH

WOODS HOLE GROUP

0 500 1,000 1,500 2,000 Feet

N

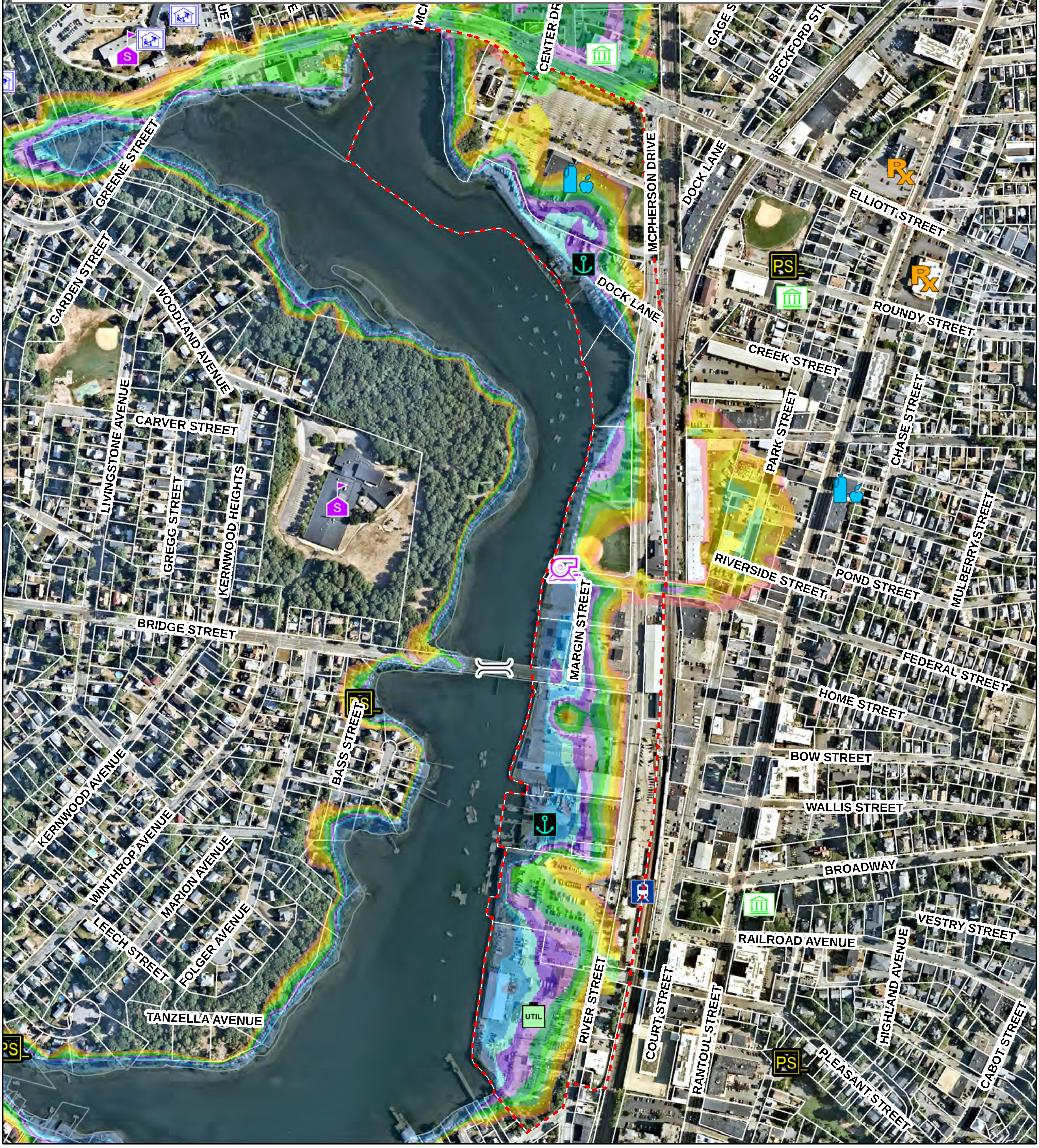
Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2030 Flood Depths (0.5%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2050 0.5% FLOOD DEPTH



TETRA TECH | WOODS HOLE GROUP

0 500 1,000 1,500 2,000 Feet

N

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2050 Flood Depths (0.5%)

0.5 ft	3.5 ft
1 ft	4 ft
1.5 ft	4.5 ft
2 ft	5 ft
2.5 ft	10 ft
3 ft	>10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2070 0.5% FLOOD DEPTH

TETRA TECH

WOODS HOLE GROUP

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2070 Flood Depths (0.5%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED PRESENT 0.1% FLOOD DEPTH

TETRA TECH

WOODS HOLE GROUP

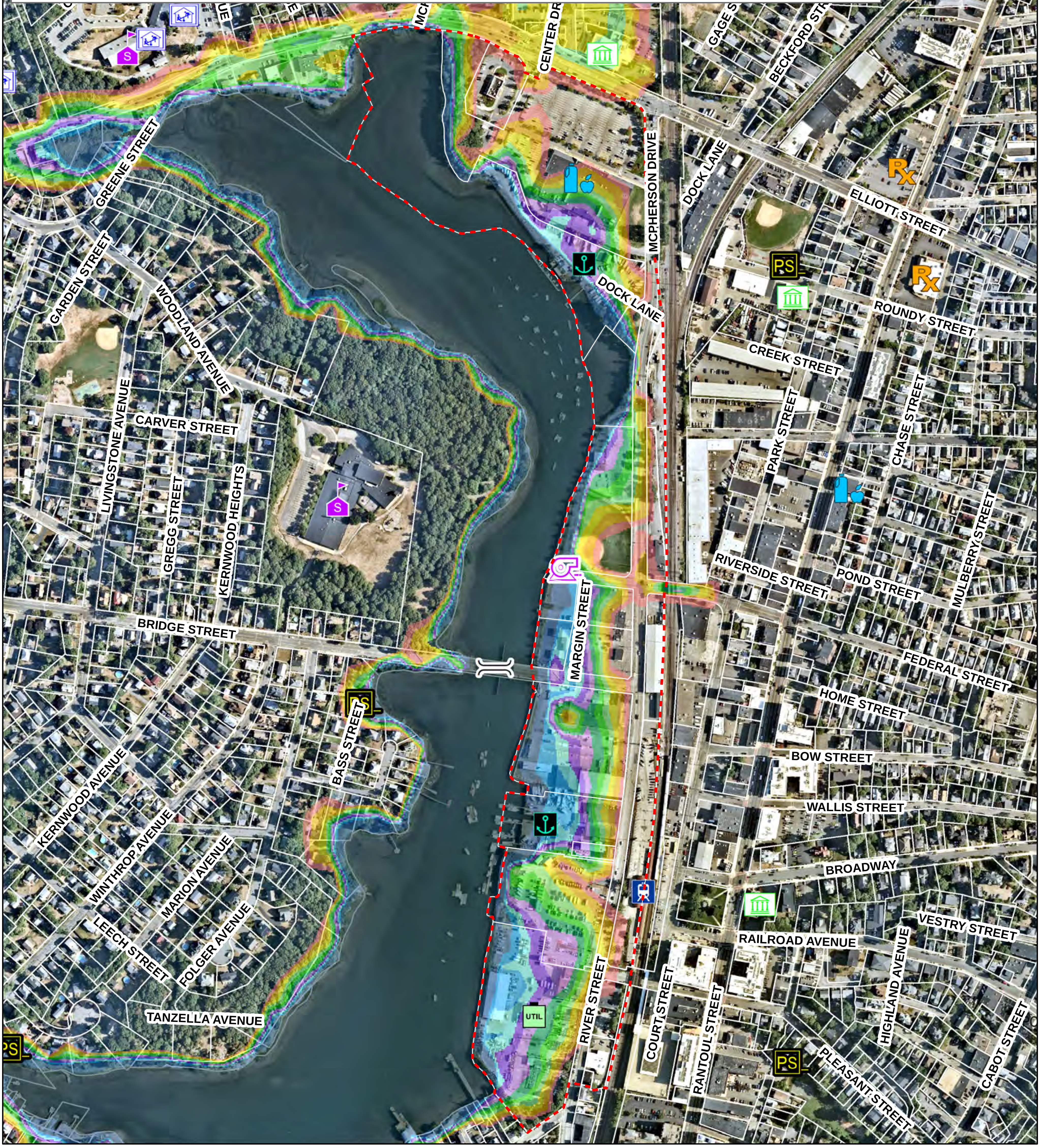
Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected Present Flood Depths (0.1%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2030 0.1% FLOOD DEPTH



TETRA TECH

WOODS HOLE GROUP

0 500 1,000 1,500 2,000 Feet

N

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2030 Flood Depths (0.1%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2050 0.1% FLOOD DEPTH

TETRA TECH

WOODS HOLE GROUP FOR EARTH, FROM SPACE A CLS COMPANY

0 500 1,000 1,500 2,000 Feet

N

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2050 Flood Depths (0.1%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2070 0.1% FLOOD DEPTH

TETRA TECH

WOODS HOLE GROUP

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2070 Flood Depths (0.1%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

Appendix D

WATER SURFACE ELEVATIONS AND MAX WAVE CREST ELEVATIONS

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
2050 WATER SURFACE ELEVATION

TETRA TECH

WOODS HOLE GROUP

0 500 1,000 1,500 2,000 Feet

N

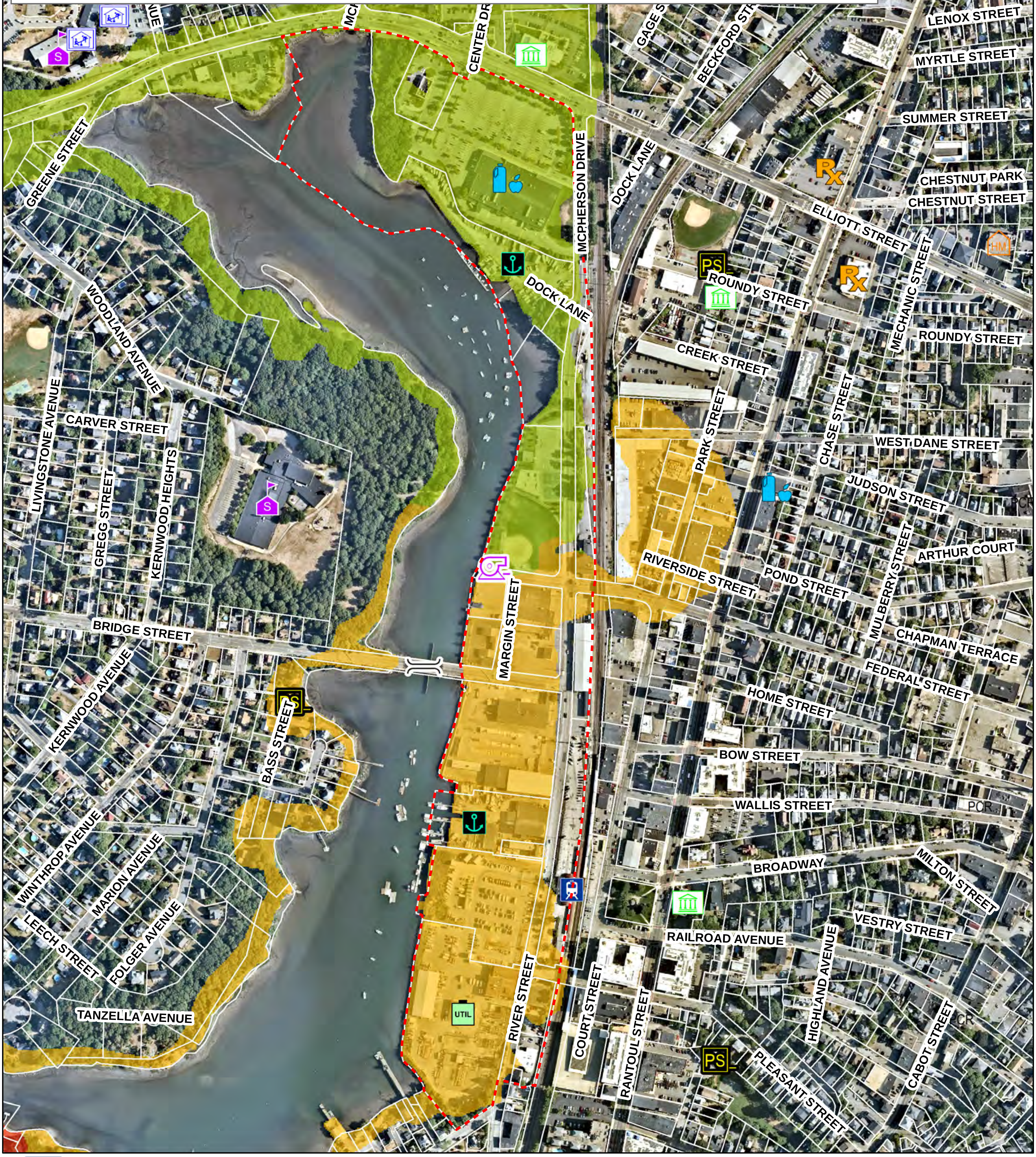
Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- HM Hazmat
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- UTIL Utility

Water Surface Elevation (2050)

- 11.6
- 11.8

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
2070 WATER SURFACE ELEVATION



0 500 1,000 1,500 2,000 Feet

N

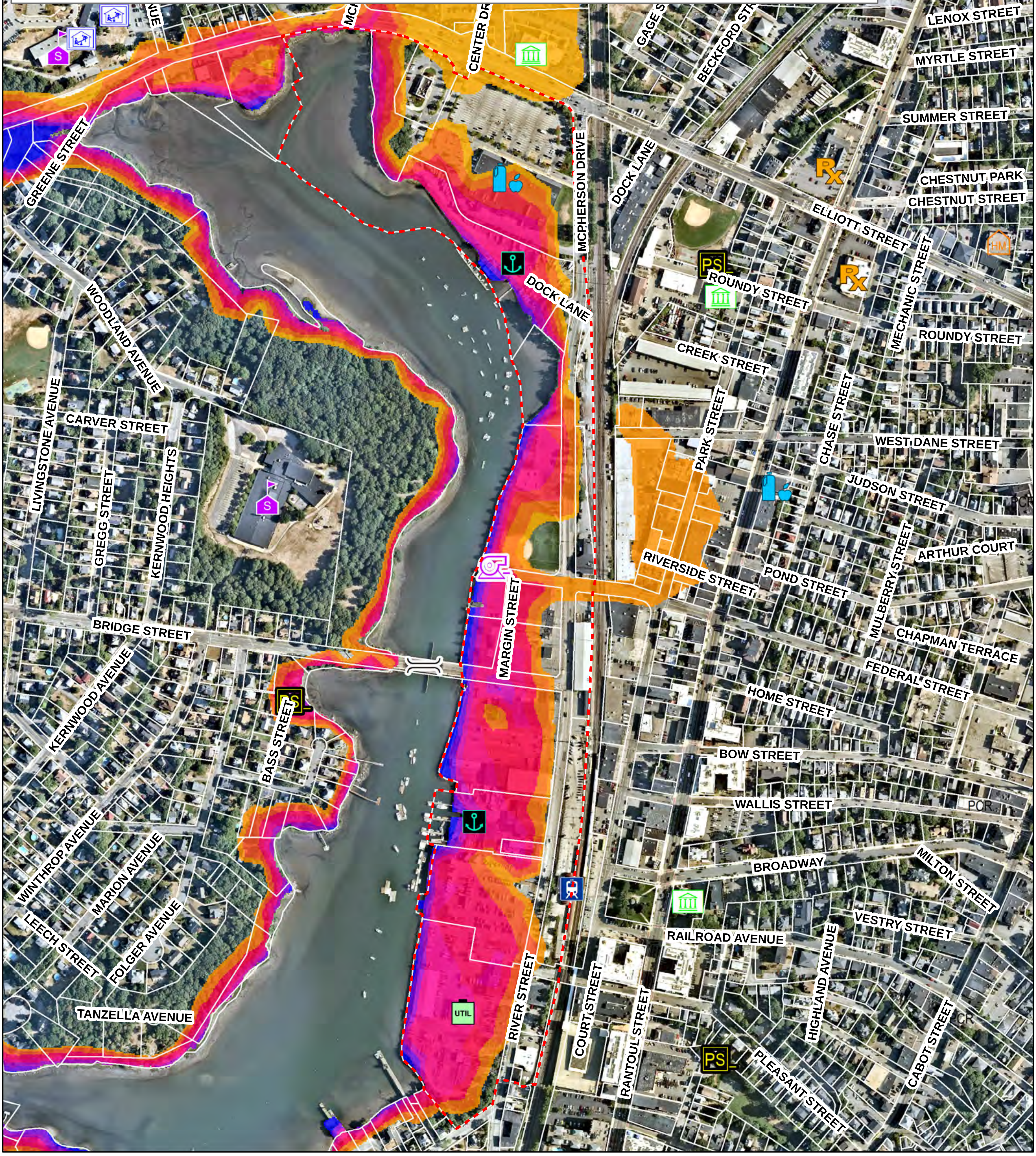
Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Hazmat
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Water Surface Elevation (2070)

- 13.4
- 13.6
- 13.9

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
2050 MAX WAVE CREST ELEVATION



TETRA TECH
WOODS HOLE GROUP

0 500 1,000 1,500 2,000 Feet

N

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Hazmat
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Design Flood Elevation (2050)

11.3	12.5
11.6	12.8
11.8	12.9
12.1	13.2
12.2	13.4
12.3	13.7
12.4	14.3

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
2070 MAX WAVE CREST ELEVATION

0 500 1,000 1,500 2,000 Feet

N

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- Cultural Resource (PCR)
- Government
- Hazmat
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Design Flood Elevation (2070)

13.1	14.6
13.5	15.0
13.8	15.1
14.1	15.3
14.3	15.4
14.4	15.8
14.5	16.2

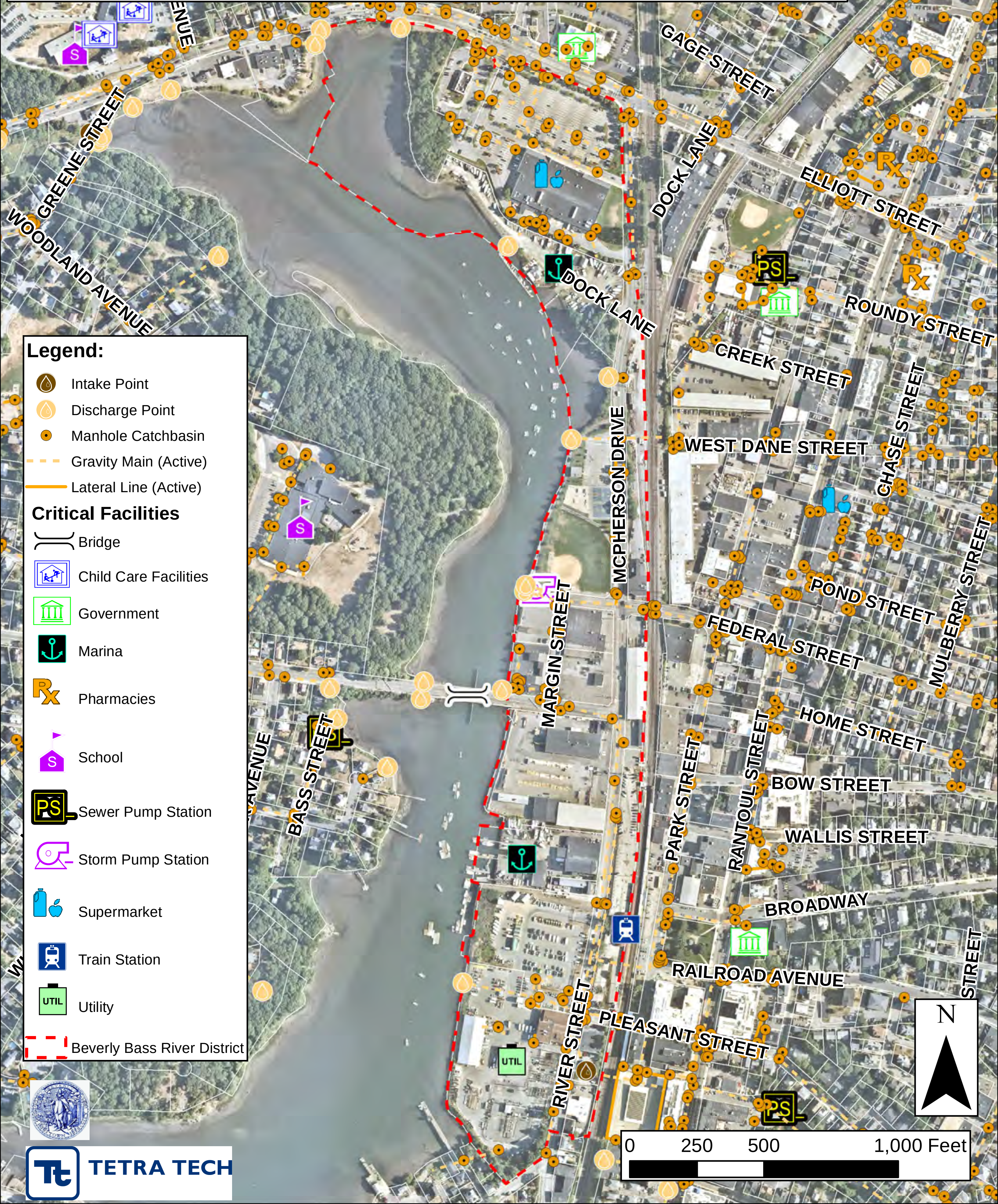
Appendix E

UTILITY INFRASTRUCTURE MAPS

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
EXISTING SEWER PIPE INFRASTRUCTURE MAP

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN EXISTING WATER PIPE INFRASTRUCTURE MAP

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
EXISTING STORM DRAIN UTILITY INFRASTRUCTURE MAP



Appendix F

MARGIN STREET PUMP STATION TECHNICAL MEMORANDUM

To:	Lisa Chandler, City of Beverly Engineering Department
Cc:	Katie Moniz, Tetra Tech
From:	Robert Parsons, Tetra Tech
Date:	June 28, 2023
Subject:	City of Beverly MVP Action Grant – Bass River District Resilience Plan Margin Street Stormwater Pump Station

1. Overview and Background

The City of Beverly (the "City") contracted Tetra Tech ("Tt") to perform a resiliency evaluation of the Bass River District, see **Figure 1** for reference, and most notably the Margin Street Stormwater Pump Station (the "Pump Station") located on Margin Street adjacent to Innocenti Park. The Pump Station is approximately 20 feet ("ft") from the bank of the Bass River and vulnerable to flooding from sea level rise and storm surge. The Pump Station serves to dewater an approximate 130-acre area of the City and was designed and constructed to address current (and historic) flooding issues. The impacts from sea level rise will stress the importance on the continued operation of the Pump Station and protection of the surrounding area.

The intent of this task is to understand the impacts of flooding based on results of the inundation model for present day and the future years of 2030, 2050, and 2070 in the vicinity of the Pump Station. These models are located in **Appendix A**. Further, this will allow the City to approximate impacts of flooding to the area if the Pump Station was rendered inoperable. Tt is also providing recommendations for short term and long-term protective measures based on the results of the inundation modeling. The task included various steps as outlined below, including data collection and site visit, documentation of existing conditions, modeling results and recommendations.

2. Data Collection

a. Records Provided by the City

Tt reviewed the following materials provided by the City:

- City of Beverly, Massachusetts Report on Storm Drainage, 1970
  - Prepared by Camp, Dresser and McKee ("CDM")
- Chase Street Drainage Area Investigations, 1999
  - Prepared by CDM
- Contract for Chase Street Drainage Area Improvements, 1999
  - Prepared by CDM
- Contract for Margin Street Pump Station, 1999
  - Prepared by CDM
- Margin Street Pump Station Chapter 91 Waterway license application, 1999
  - Prepared by CDM
- Margin Street Pump Station Full Plan Set, 1999
  - Prepared by CDM
- Margin Street Pump Station Revision to RAM Plan, 2000

    - Prepared by CDM
- Margin Street Pump Station Phase 1 Report, 2001
    - Prepared by CDM
- O&M Manuals for Pump Station Parts, 2003
    - Prepared by CDM
- AutoCAD drawings for Margin Street Pump Station

For the purposes of this report, Tt utilized the 1970 Storm Drainage Report prepared by CDM for hydrologic conditions. For the purposes of establishing the existing condition of the Pump Station, Tt utilized both design and record drawings from the late 1990's also prepared by CDM. It is understood that the 1970 drainage report was utilized to inform the design of the Pump Station, although there does appear to be some data gaps and design criteria missing between the report and the constructed pump station. Tt also understands that there was not a basis of the design report prepared as part of the 1990's design of the Pump Station.

b. Site Visit

Tt and the City conducted a site visit on February 7, 2023, to document the existing conditions of the Pump Station and adjacent area. See **Figures 2 and 3**, Existing Conditions Photographs.

3. Original Recommended Pump Station Design

a. Pump Station

In the 1970 Storm Drainage Report produced by CDM, a stormwater pump station was recommended with the capacity for runoff from a 130-acre drainage catchment area. The 10-year design storm events resulted in a pumping capacity of 110,000 gallons per minute (gpm) with a total dynamic head of 10 ft. The recommended pump station included three pumps, two 36-inch 25,000 gpm axial flow propeller pumps, and one 42-inch 60,000 gpm axial flow propeller pump. The proposed pump station locations were at the foot of West Dane Street just east of the railroad embankment, and the extension of West Dane Street just west of the railroad, north of Innocenti Park. The two proposed pump station locations are shown in **Figure 4**. Note that the current Pump Station is located at the south-west corner of Innocenti Park.

The proposed pump station would be automatically operated, with low tide discharge by gravity through a 60-inch reinforced concrete pipe ("RCP") under the railroad embankment. High tide and high runoff discharge would be achieved by a sluice gate that automatically diverted storm flows through a coarse bar screen to the pumping station wet well. An automatic sensing device would activate the pumps, and a diesel engine is used during electrical failure with a pumping capacity of 60,000 gpm.

b. Historical Contributing Drainage Area, Critical Facilities, and Infrastructure

The 1970 Storm Drainage Report details five designated principal drainage areas as shown in **Figure 5**. The Pump Station is located on the designated line between Areas B and C, depicted as a red star in **Figure 5**. Area B encompasses 90 acres that drains the Cabot Street area which includes the low area between Cabot Street and Chapman Street and Area C covers 40 acres that drains to an outlet discharging to the Bass River at Federal Street. The complete drainage area is 130 acres.

4. Margin Street Pump Station Existing Conditions

a. Margin Street Pump Station

The Pump Station is located on the east side of the Bass River, north of Bridge Street. A locus map of the Pump Station is provided in **Figure 1**. The Pump Station was constructed between 1999 and 2001 to alleviate stormwater flooding from adjacent commercial and residential neighborhoods, as described in Section B below. The Pump Station was completed concurrently with the Chase Street Drainage Improvement Project.

The Pump Station is located in the Federal Emergency Management Agency ("FEMA") Flood Zone AE, where the Base Flood Elevation ("BFE") has been determined. The BFE at the Pump Station is located at Elevation (El.) 10 NAVD88, as reflected in the current version of the FEMA Flood Insurance Rate Map (FIRM) Community Panel 25009C0417G (effective July 16, 2014). See **Figure 6**. This zone indicates areas that have at least a 1% annual chance of being flooded, but where wave heights are less than 3 ft. All projected flood inundation models for years 2030, 2050, and 2070 suggest that much of the drainage area associated with the Pump Station may be inundated by coastal floodwaters with a depth of 5 ft or more by 2070. The inundation model results are located in **Appendix A.**

The Pump Station consists of a 4-ft by 6-ft concrete culvert that conveys stormwater via gravity to the Bass River, with a discharge invert at 3.08 ft Beverly City Base Datum ("BCB") (-3.21 ft NAVD88). A record site plan of the Pump Station is shown in **Figure 7**. The gravity box culvert transverses through a concrete junction box which ties into the wet well of the Pump Station through a 4-ft by 8-ft concrete culvert. Based on the contract documents prepared by CDM, the flow into the Pump Station is controlled by sluice gate with the positions controlled by either a manual setting (open or close) or an automatic ("auto") setting. The auto setting's position for the sluice gate will open when the high-level alarm or high high-level alarm is detected at two sensors located in a drainage manhole that is located in an upstream gravity line on Federal Street, beneath the Massachusetts Bay Transportation Authority ("MBTA") Railroad Bridge. The elevations of the two high-level alarm and high high-level alarm sensors are 12.14 ft BCB (5.85 ft NAVD88) and 13.06 ft BCB (6.77 ft NAVD88) respectively in the railroad bridge manhole.

The wet well consists of four pumps each with a 30-inch discharge. The outlet of each discharge pipe into the Bass River is approximately El. 7.75 ft BCB (1.46 ft NAVD88). The discharge pumps were designed with a capacity up to 17,000 gpm with a total dynamic head of 10 ft. The operations of the discharge pump are summarized below in **Table 1.**

Table 1 – Discharge Pumps Operation Levels

Discharge Pump	Start Elevation (ft)		Stop Elevation (ft)	
	BCB	NAVD88	BCB	NAVD88
High High-Level Alarm	10.50	4.21	N/A	
Pump 1	5.00	-1.29	2.75	-3.54
Pump 2	5.50	-0.79	3.25	-3.04
Pump 3	5.75	-0.53	3.75	-2.54
Pump 4	6.00	-0.29	4.25	-2.04
Low Low-Level Alarm	N/A		2.75	-3.54

b. Existing Drainage Area, Critical Facilities, and Infrastructure

For the purposes of this analysis, Tt assumed that the 1970 Drainage Analysis Report prepared by CDM established the correct design criteria, specifically that 130 acres are tributary to the drainage collection system and ultimately the Pump Station. Refer to **Figure 5** for the delineation extent of the designed drainage area.

To protect the critical facilities in the designed drainage area, the Pump Station needs to remain operable at all times, especially during flooding events. The Pump Station's critical infrastructure that is vulnerable to damage from flooding includes:

- Electrical panel and switches
- Emergency generator
- Other electrical equipment; transformers, wiring

5. Historical and Existing Pump Station Conditions

a. Tide Level Conversion

The critical tide level elevation adopted for the 1970 Pump Station design was 12.5 ft BCB. Tide levels in Beverly, MA have changed substantially since 1970 and are now commonly referenced through the North American Vertical Datum of 1988 ("NAVD88"). Tide level datum conversions were calculated to represent both the 1970 and 2020 tide level elevations in the same vertical datum for direct comparison purposes. The 2020 tide elevations are detailed in Mean Sea Level (MSL) through the NOAA Tides & Currents Database at Beverly Harbor, MA.

Converting to the NAVD88 datum involves subtracting 6.286 ft from the original BCB Datum values in the Report. The 2020 NAVD88 tide data for Beverly Harbor, specifically at the mouth of the Bass River, are shown in **Table 2** below. The MSL tide datum is converted to NAVD88 by subtracting 0.31 ft to the MSL values, which is the datum elevation conversion for Boston, MA. This datum conversion is provided by the Massachusetts Office of Coastal Zone Management (CSM). The percentage change between 1970 and 2020 tide levels are calculated as well in **Table 2**.

Table 2 – Vertical Tide Datum Conversions in feet (1970, 2020)

Datums	1970 BCB	1970 NAVD88[1]	2020 MSL	2020 NAVD88[2]	1970 to 2020 % Change NAVD88
Critical	12.50	6.21			
MHW	10.50	4.21	4.43	4.12	2% decrease
MSL	5.53	-0.76	0.00	-0.31	59% increase
MLW	1.00	-5.29	-4.50	-4.81	9% increase

[1] BCB can be converted to NAVD88 by using a conversion factor of -6.286-ft.

[2] MSL can be converted to NAVD88 by using a conversion factor of 0.31-ft.

The 1970 Storm Drainage Report was generally accurate in relation to the Mean High Water ("MHW"), Mean Sea Level ("MSL"), and Mean Low Water ("MLW"). Therefore, it can be said that the critical tide level adopted for design was and still is appropriate at 6.12 ft NAVD88 for 2020. Following projected 2030, 2050, and 2070 sea level rise models, the relative MSL is expected to rise in Beverly MA. **Table 3** details the projected relative MSL for Boston, MA over the next 75 years. This data is provided by the

Massachusetts Executive Office of Energy and Environmental Affairs ("EEA") Sea Level Rise Projections (NE CASC) for the Boston, MA tide gauge location. The relative MSL data was last updated February 25, 2023.

Table 3 – Relative mean sea level (ft NAVD88) for Boston, MA

Scenario	Probabilistic Projections	2030	2050	2070
Intermediate	Unlikely to exceed (83% probability) given a high emissions pathway (RCP 8.5)	0.7	1.4	2.3
Intermediate – High	Extremely unlikely to exceed (95% probability) given a high emissions pathway (RCP 8.5)	0.8	1.7	2.9
High	Extremely unlikely to exceed (99.5% probability) given a high emissions pathway (RCP 8.5)	1.2	2.4	4.2
Extreme (Maximum physically plausible)	Exceptionally unlikely to exceed (99.9% probability) given a high emissions pathway (RCP 8.5)	1.4	3.1	5.4

As detailed in **Table 2** above, the 2020 MSL for the Bass River is -0.31 ft NAVD88. The maximum projected MSL is 5.4 ft in 2070 under an extreme scenario. This is an increase in sea level of 5.09 ft NAVD88. Therefore, assuming a direct proportionality between the MSL and critical tide level adopted for design, the new 2020 design sea level should be 11.3 ft NAVD88. Therefore, a new critical tide level adopted for design is required for 2030, 2050, and 2070 sea level rise projections.

b. Pump Station Capacity Conversion

The 1970 Storm Drainage Report calculated the design stormwater runoff through the Weather Bureau Technical Paper 40 (TP-40), which has since been replaced by National Oceanic and Atmospheric Administration Atlas 14 (NOAA 14). The duration of the design storm event was not detailed in the Report; therefore, 5-min storm event with a 25-year return period is simulated using the NOAA 14 Point Precipitation Frequency (PF) estimates for the Pump Station location. Refer to **Appendix B** for the NOAA 14 results.

The average precipitation intensity estimate is approximately 9.5 in/hr (6.10 – 10.9 in/hr) to simulate the peak rainfall intensity during a 50-year event. This average precipitation intensity estimate also corresponds to the NOAA 14 Applicable Design Criteria for a 2070, 50-year design storm at a 2% flood depth located at the Pump Station. Employing the Rational Method detailed in the Report, the runoff is calculated through $\mathrm{Q} = \mathrm{CiA}$, with "C" being the coefficient of runoff (0.95 was chosen as a conservative measure to represent a high impervious drainage area), "i" the average intensity rainfall (8.17 in/hr rain), and "A" the area of the basin (130 acres of drainage areas B and C combined).

$$\mathrm{Q\ (cfs)} = 0.95 * 8.17\ \frac{\mathrm{in}}{\mathrm{hr}} * 130\ \mathrm{acres} = 1{,}009\ \mathrm{cfs}$$

The pump station capacity is the conversion of cfs to gpm through the conversion rate of 1 cfs = 449.13 gpm.

In comparison to the originally proposed capacity of 110,000 gpm, using updated rainfall intensity projections, the Pump Station appears to be operating at 30% of stormwater runoff in the present day, which correlates to approximately 38.36 acres. These calculations would need to be confirmed as recommended below.

Note that the Pump Station's collection system is driving how much stormwater enters the system, not the rainfall intensity. This calculation exercise is performed to show the worst-case scenario for reference and future possible design considerations. For future Pump Station design considerations, future projected tidal elevations of the Bass River have been calculated for 2030, 2050, and 2070 projections by the Woods Hole Group, Inc. (WHG). The tide elevation fluctuations are calculated under a time series of approximately one month under each projected year. These tide elevation values will be used for future Pump Station design and analysis.

6. Anticipated Flood Elevations Based on Modeling

WHG provided updated flood risk maps and data for the Beverly Bass River District. The data was derived from the MC-FRM model including design flood elevations and tidal benchmark elevations for the 2030, 2050 and 2070 time horizons. **Table 4** below is a comparison of elevations of the critical Pump Station features versus estimated flood elevations.

Table 4 – Flood Modeling Results

Pump Station Critical Feature		**Present**	**2050**	**2070**	
Description	**Feature Elevation in ft[1] (NAVD88)**	**Flood Elevation[2] (NAVD88)**	**Flood Elevation[3] (NAVD88)**	**Flood Elevation[3] (NAVD88)**	**MHHW[4]**
Door Threshold	9.15	10.0	11.9	13.7	9.4
Louver Sill	9.80	10.0	11.9	13.7	9.4
Bottom of Emergency Generator	9.50	10.0	11.9	13.7	9.4
Bottom of Electrical Panel	9.50	10.0	11.9	13.7	9.4
Top of Force Main Valve Chamber (exterior)	7.65	10.0	11.9	13.7	9.4
Bottom of Exterior Transformer	8.85	10.0	11.9	13.7	9.4

[1] Elevations provided on City records are referenced in BCB, where MSL=-5.53. The elevations presented in Table 4 are converted to NAVD88;
[2] Current FEMA BFE
[3] Projected 1% Annual Chance Flood Extent with Sea Level Rise;
[4] Mean Higher High Water Line approximation circa 2070 or later

7. Assessment

The Pump Station will become increasingly vulnerable to flooding impacts due to sea level rise and increasing storm frequency and intensity, which could impede its ability to pump drainage runoff from portions of the City during storm events. In order to prevent significant flooding and damage due to projected sea level rise, Tt recommends consideration to short, mid and long-term mitigation measures to protect the Pump Station and its surrounding drainage area.

8. Recommendations

Tt has developed preliminary recommended site improvements that will be refined and presented to the City via workshops as part of follow-up design mitigation tasks. Tt evaluated measures to determine if critical components of the Pump Station can remain operational during future storm events. It is the opinion of Tt that the City consider short term measures for flood-proofing the Pump Station to mitigate the effect a flood will have on the Pump Station and its ability to operate efficiently. Should the City consider long term measures, Tt recommends reinforcing the Pump Station with a wall to ensure water never reaches the structure, redesigning the structure to elevate it such that it will be located above the current sea level rise projection elevations, and relocating the Pump Station inland and outside of the flood zone and direct influence of future sea level rise associated with the Bass River. Any recommendations for pump station upsizing or increased capacity should also consider the stormwater collection system capacity and its ability to convey stormwater to the existing or improved Pump Station. Additional work may be required to increase the capacity of the stormwater collection system to meet objectives. Future communication is recommended to analyze the multiple options detailed below, as well as confirm the City's priorities regarding the Pump Station.

a. Short-Term Recommendations (0–5-year timeframe)

- i. Prepare an update to the 1970 CDM Drainage Report. The focus of this update could be on either the Bass River District or the Pump Station tributary. The results of this update can be used for future mitigation projects. This update would also consider related MS4 and green infrastructure initiatives such as attenuating stormwater on individual development sites or larger scale attenuation at municipally owned facilities similar to that of historic detention basin projects in North Beverly. Develop new and modify existing stormwater management requirements to accommodate various flood mitigation measures.
- ii. Floodproof key aspects of the Pump Station such as providing watertight doors, manholes, louvers, and other elements. Conduct inspection on exisitng waterproof hatches for seal deterioration and leakage and replace hatches based on inspection results.
    1. Flood Risk America (FRA) flood panels are recommended for doors and louvers, and floodproof hatches. Tt recommends products from Floodproofing such as their Floodproofing FRA Flood Panel or the Flood Panel Super Flood Log. Note that the Floodproofing FRA Flood Panels are already installed in the Beverly Water Street Pump Station. For deployable barriers, Tt recommends products such as the Muscle Wall or the Diluvium. The specification sheets are detailed in **Appendix C**.
- iii. Deploy temporary flood mitigation systems such as an inflatable barriers and temporary walls around the Pump Station. These measures require advanced notice for staff to deploy, monitor and disassemble after an event.
- iv. Other considerations:
    2. Flooding could cause interruption in the emergency generator natural gas supply. Consideration should be given to elevate the generator and electrical panel and/or change the fuel supply to diesel. Diesel is considered to be more reliable for short term disruptions.

b. Mid-Term Recommendations (5–20-year timeframe)

- i. Confirm the current capacity of the existing pump station and determine if equipment upgrades can be made without significant modifications to the superstructure. This would maximize the Pump Station capacity by replacing mechanical and electrical equipment as needed.

ii. Upon confirming current capacity, construct an addition to the existing pump station that would serve to dewater the contributing area under more extreme conditions. For instance, the addition of a larger wet well and additional pumps will provide additional pump station capacity under more severe future projected conditions.
iii. Install flood walls around the building, construct a permanent berm around the existing pump station. If completed, the limits of the flood wall would consider not only the existing footprint, but also any potential pump station expanded footprints. Limitedly raise critical equipment inside the Pump Station.
iv. Proceed with implementation of updated stormwater regulations specific to low impact development ("LID"), green infrastructure, and stormwater attenuation.

c. Long-Term Recommendations (20+ year timeframe)
i. Construct a new pump station to an alternate location upland of the existing station, perhaps in Innocenti Park near the intersection of McPherson Drive and Federal Street.
ii. Consider other large scale infrastructure projects such as storage conduits and/or storage tanks in public/municipally owned land.

The long-term recommendations represent the costliest options in terms of associated costs with potential land acquisition, pump modeling, pump capacity, and viability.

Beverly, Massachusetts

Figure 1
Locus Map
Source: USGS, 2023


Photo 1: Ground Mounted Transformer

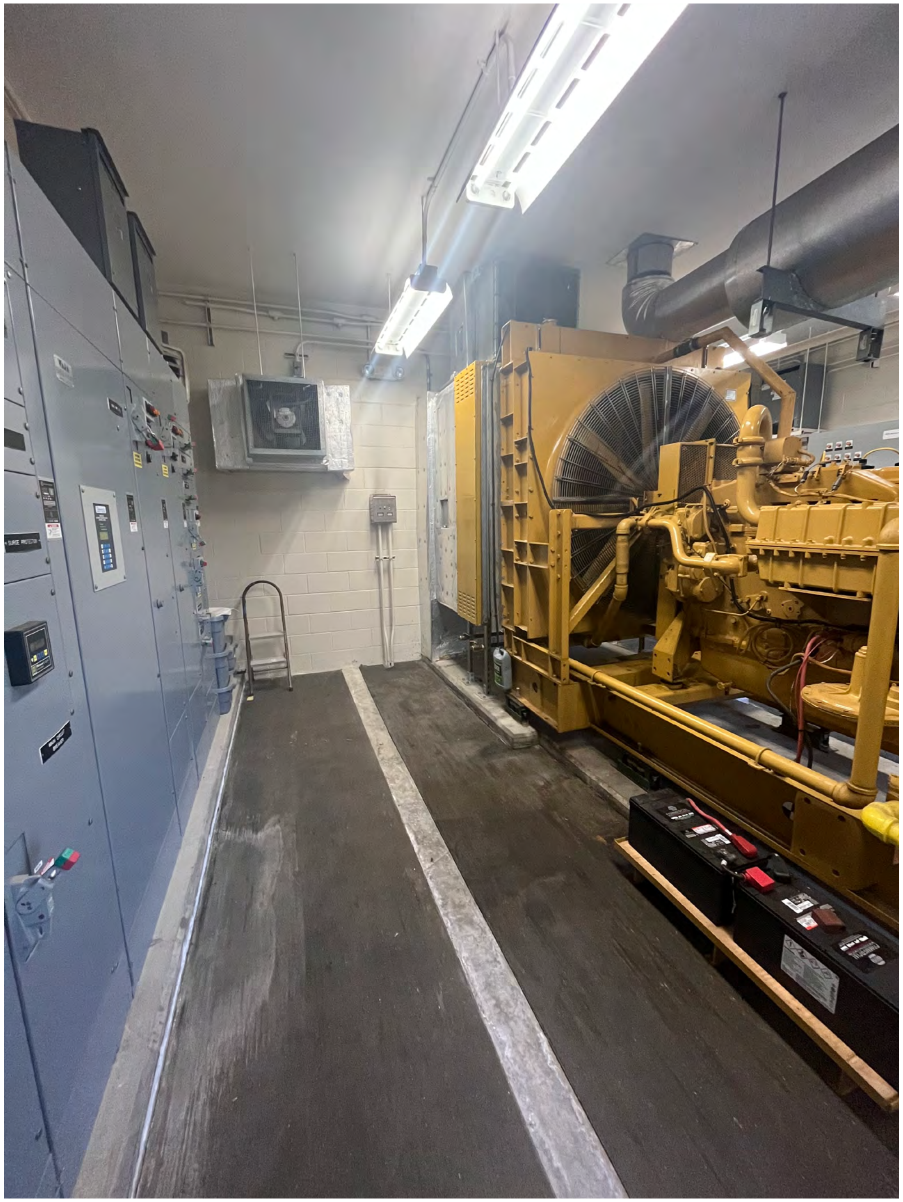


Photo 2: Emergency Generator & Electrical Panel

Figure 2
Existing Conditions Photographs
Source: Tetra Tech, 2023

Photo 3: Pump Well Hatches (4)

Photo 4: Pump Station next to Bass River

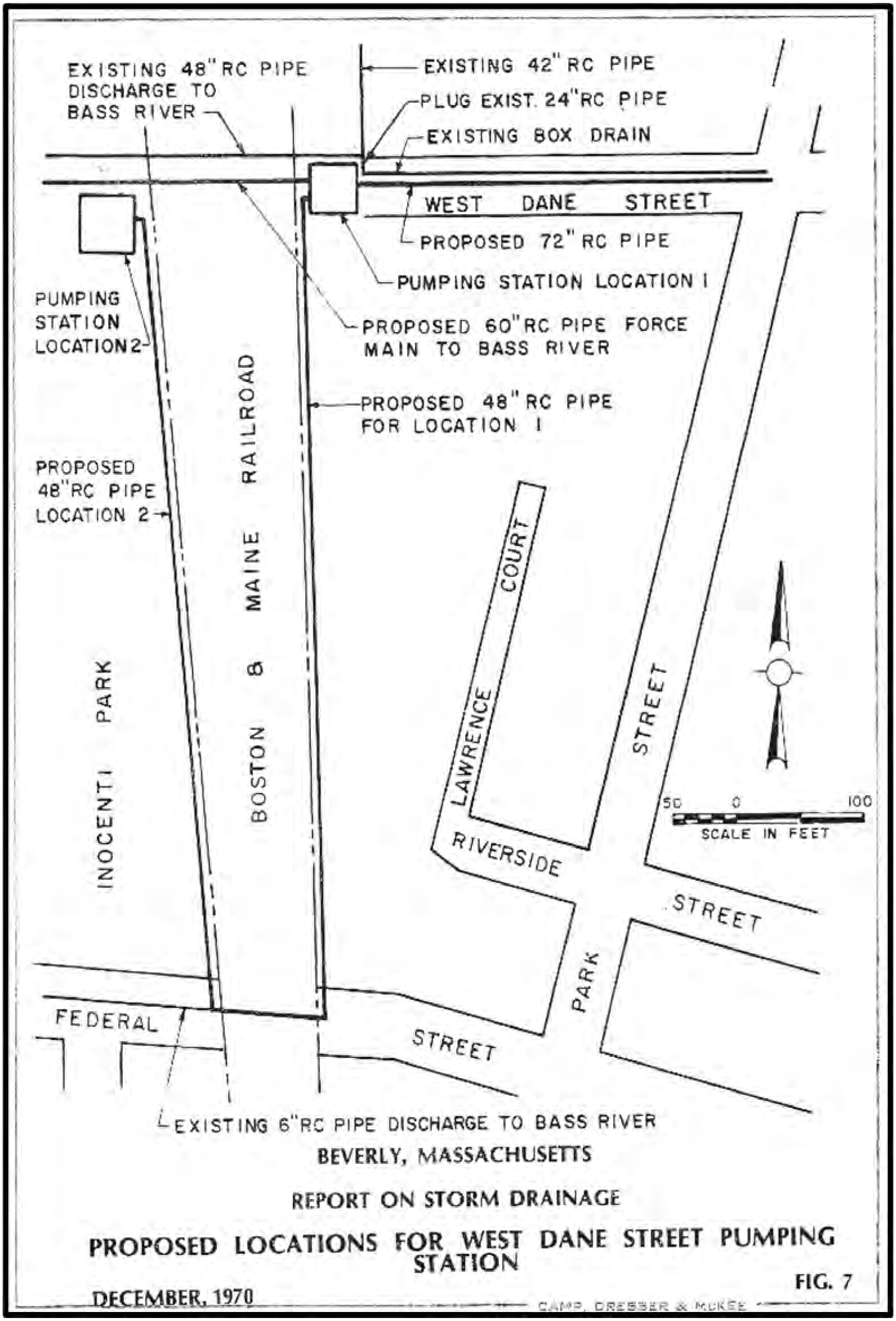


Figure 4
1970 Storm Drainage Report Proposed Pump Station Locations
Source: CDM, 1970

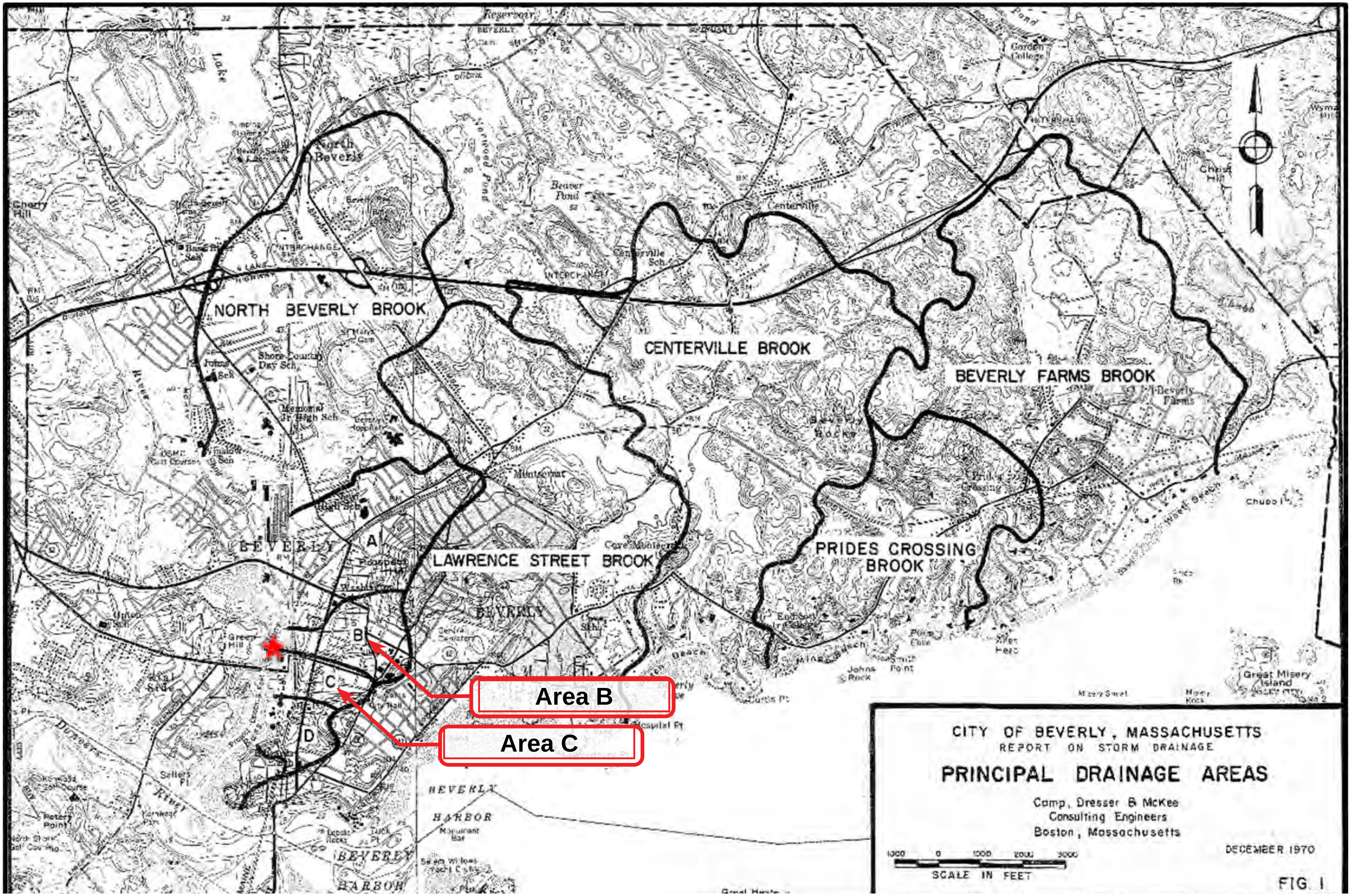


Figure 5
1970 Designated Principal Drainage Areas
Source: CDM, 1970

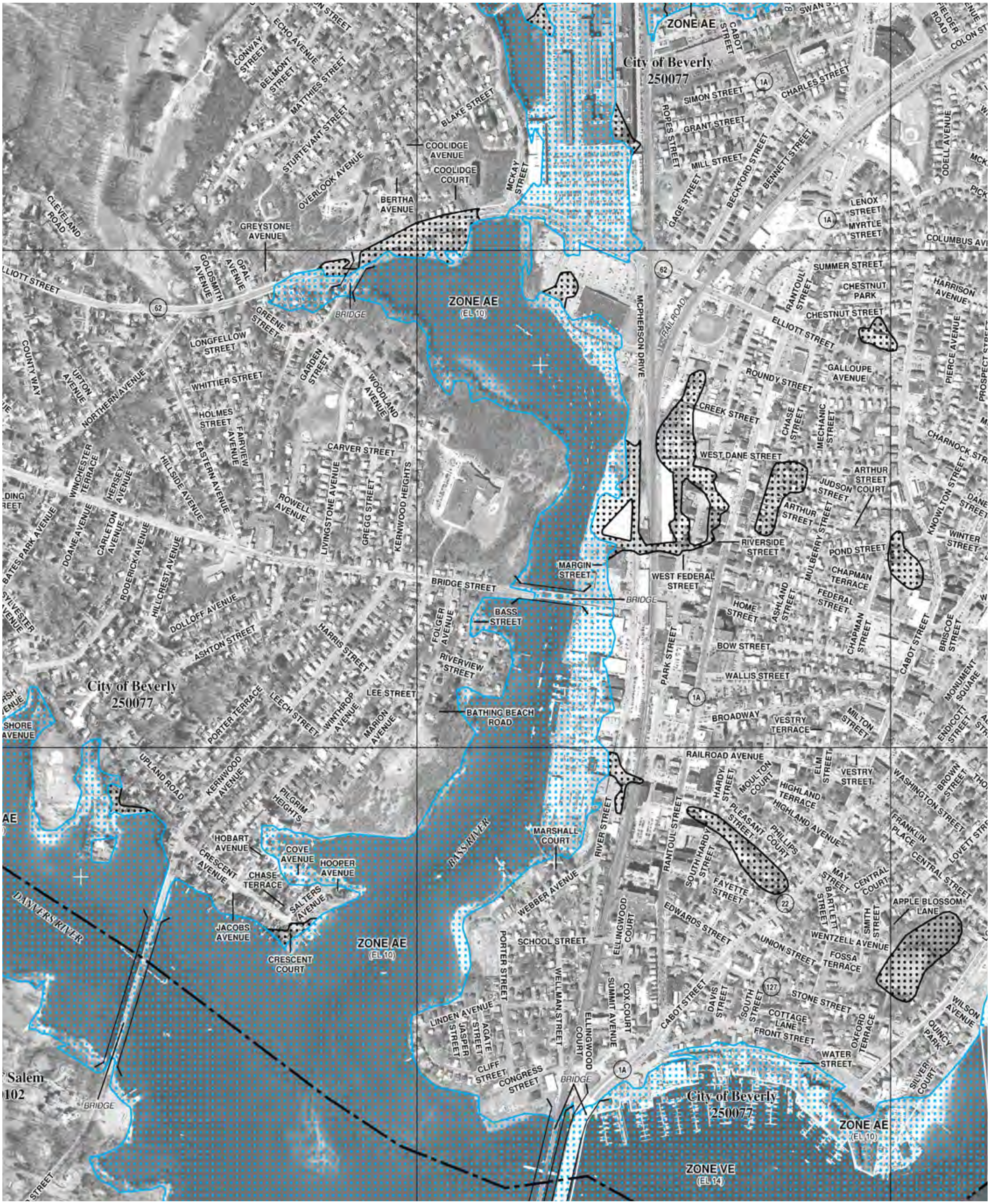


Figure 6
FEMA FIRM, 25009C0417G
Source: FEMA, 2014

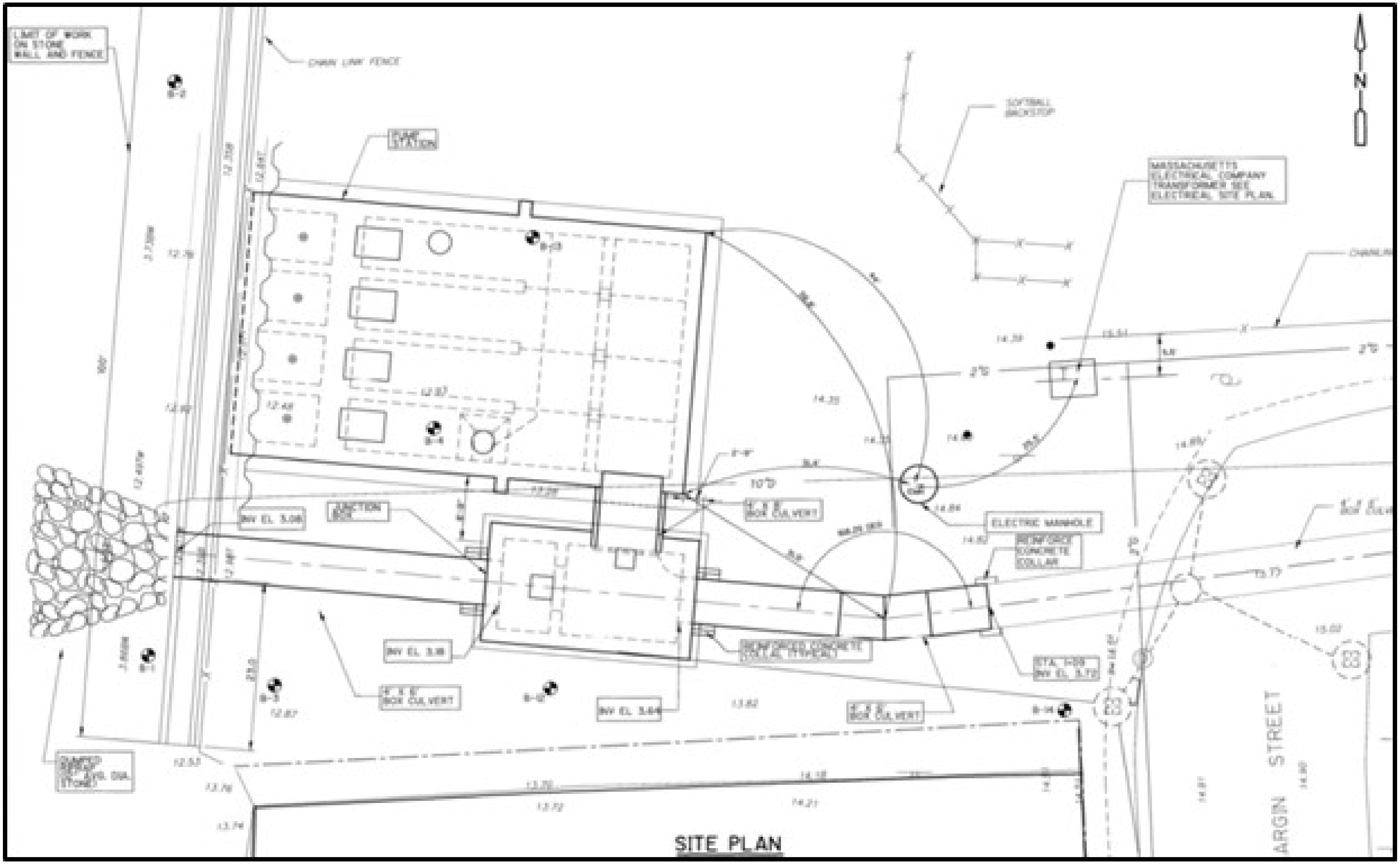


Figure 7
Pump Station Site Plan (Record Plan)
Source: CDM, 1970

Figure 8
Existing Storm Drain Utility Infrastructure
Source: City of Beverly, 2023

Appendix A – 2030, 2050, and 2070 Inundation Maps

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2030 0.1% FLOOD DEPTH

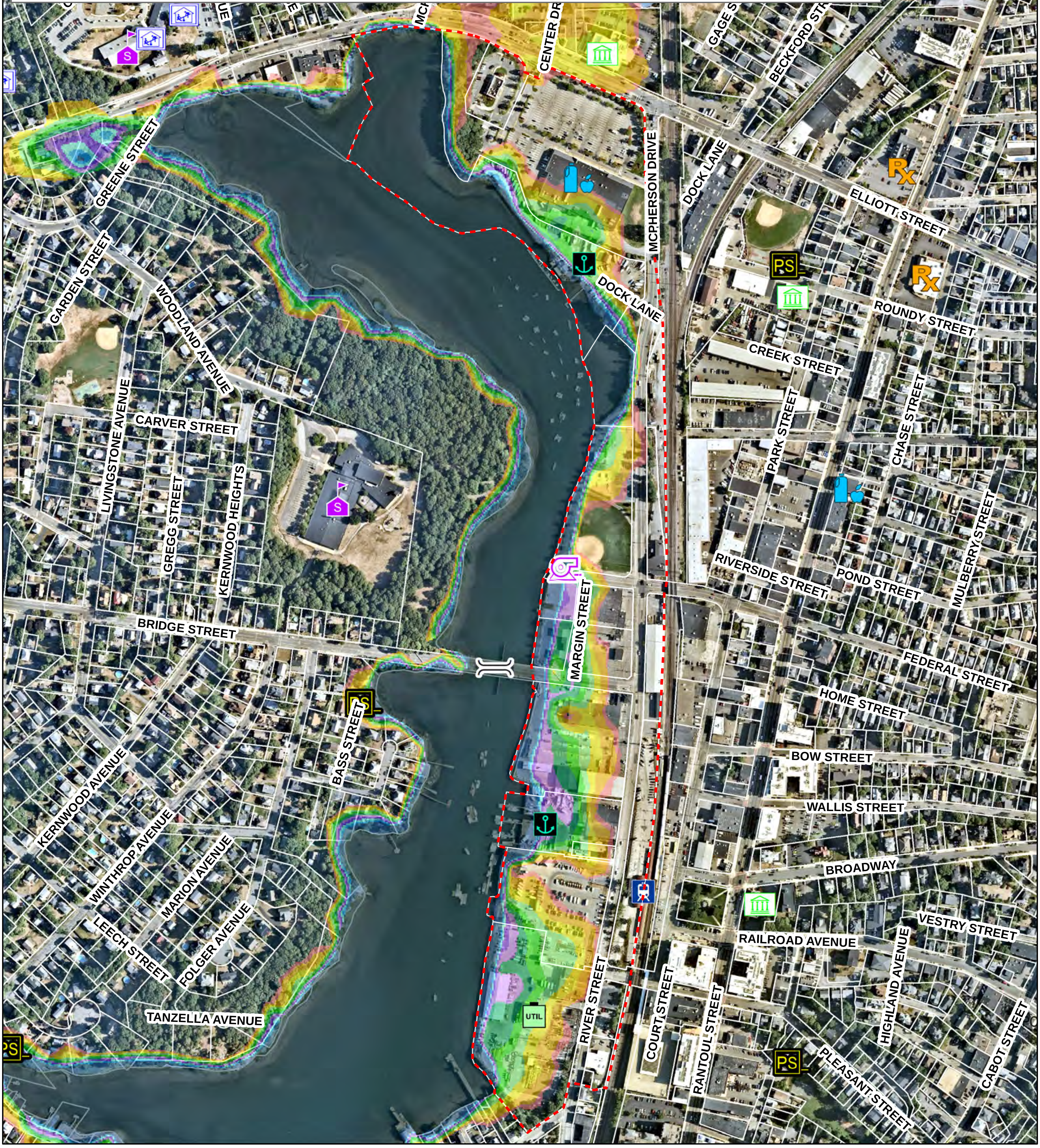
Legend

Beverly Bass River District	Pharmacies
Bridge	School
Child Care Facilities	Sewer Pump Station
Church	Storm Pump Station
PCR Cultural Resource	Supermarket
Government	Train Station
Marina	Utility

Projected 2030 Flood Depths (0.1%)

0.5 ft	3.5 ft
1 ft	4 ft
1.5 ft	4.5 ft
2 ft	5 ft
2.5 ft	10 ft
3 ft	>10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2030 0.5% FLOOD DEPTH



TETRA TECH

WOODS HOLE GROUP

0 500 1,000 1,500 2,000 Feet

N

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2030 Flood Depths (0.5%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2030 1% FLOOD DEPTH

0 500 1,000 1,500 2,000 Feet

N

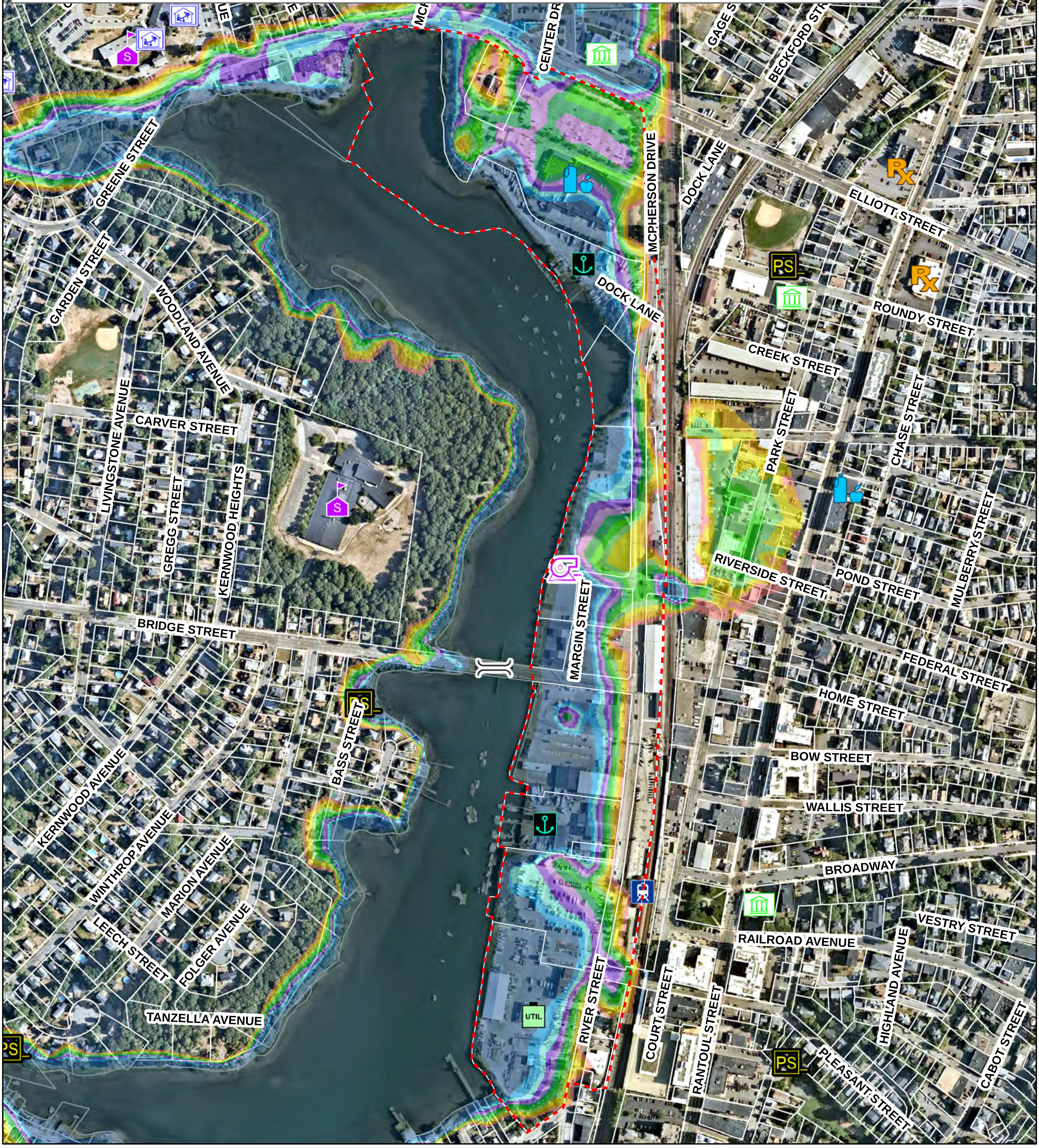
Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2030 Flood Depths (1%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2050 0.1% FLOOD DEPTH



Fort Point Associates, Inc.
Urban Planning Environmental Consulting Project Permitting
A TETRA TECH COMPANY

WOODS HOLE GROUP

0 500 1,000 1,500 2,000 Feet

N

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2050 Flood Depths (0.1%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2050 0.5% FLOOD DEPTH

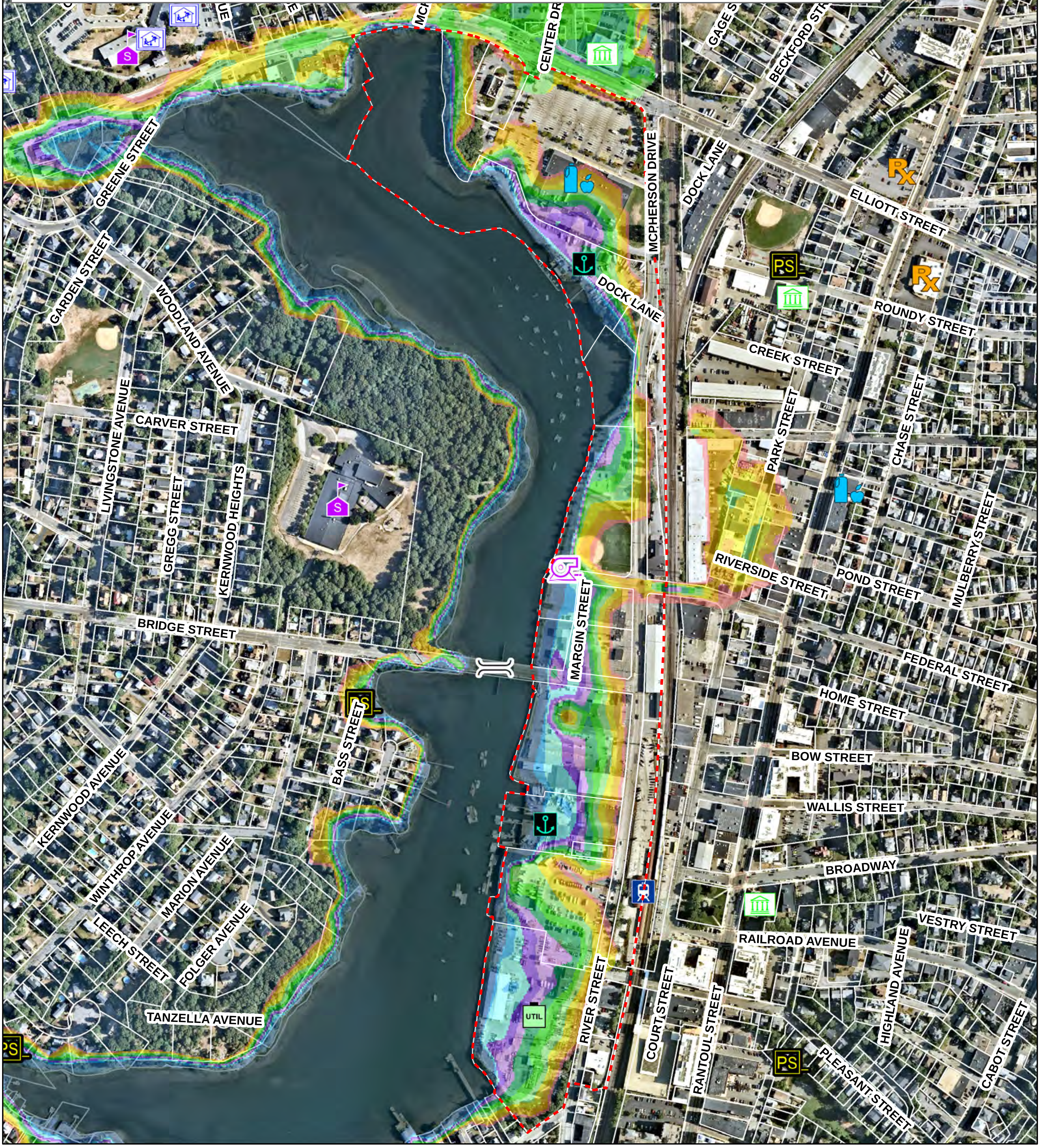
Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2050 Flood Depths (0.5%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2050 1% FLOOD DEPTH



0 500 1,000 1,500 2,000 Feet

N

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2050 Flood Depths (1%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2070 0.1% FLOOD DEPTH

Fort Point Associates, Inc. Urban Planning Environmental Consulting Project Permitting A TETRA TECH COMPANY

WOODS HOLE GROUP FOR EARTH, FROM SPACE A CLS COMPANY

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2070 Flood Depths (0.1%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2070 0.5% FLOOD DEPTH

Fort Point Associates, Inc. Urban Planning Environmental Consulting Project Permitting A TETRA TECH COMPANY

WOODS HOLE GROUP FOR EARTH, FROM SPACE A CLS COMPANY

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2070 Flood Depths (0.5%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

BEVERLY BASS RIVER FLOOD RESILIENCE PLAN
PROJECTED 2070 1% FLOOD DEPTH

TETRA TECH

WOODS HOLE GROUP

0 500 1,000 1,500 2,000 Feet

N

Legend

- Beverly Bass River District
- Bridge
- Child Care Facilities
- Church
- PCR Cultural Resource
- Government
- Marina
- Pharmacies
- School
- Sewer Pump Station
- Storm Pump Station
- Supermarket
- Train Station
- Utility

Projected 2070 Flood Depths (1%)

- 0.5 ft
- 1 ft
- 1.5 ft
- 2 ft
- 2.5 ft
- 3 ft
- 3.5 ft
- 4 ft
- 4.5 ft
- 5 ft
- 10 ft
- >10 ft

Appendix B – NOAA Atlas 14 Point Precipitation Frequency Estimates

NOAA Atlas 14, Volume 10, Version 3
Location name: Beverly, Massachusetts, USA*
Latitude: 42.5507°, Longitude: -70.8867°
Elevation: 8 ft**
* source: ESRI Maps
** source: USGS

POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Sandra Pavlovic, Michael St. Laurent, Carl Trypaluk, Dale Unruh, Orlan Wilhite

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches/hour)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	3.60 (2.80-4.56)	4.38 (3.40-5.54)	5.65 (4.38-7.19)	6.72 (5.16-8.58)	8.17 (6.10-10.9)	9.25 (6.78-12.6)	10.4 (7.44-14.7)	11.8 (7.92-16.8)	13.8 (8.94-20.3)	15.5 (9.80-23.2)
10-min	2.55 (1.98-3.23)	3.10 (2.41-3.93)	4.00 (3.10-5.08)	4.75 (3.65-6.07)	5.78 (4.32-7.71)	6.55 (4.80-8.91)	7.37 (5.27-10.4)	8.34 (5.60-11.9)	9.77 (6.32-14.4)	11.0 (6.95-16.5)
15-min	2.00 (1.56-2.53)	2.43 (1.89-3.08)	3.14 (2.43-3.99)	3.73 (2.87-4.76)	4.54 (3.39-6.05)	5.14 (3.77-6.99)	5.78 (4.13-8.16)	6.54 (4.40-9.34)	7.66 (4.96-11.3)	8.61 (5.45-12.9)
30-min	1.37 (1.06-1.73)	1.66 (1.29-2.11)	2.15 (1.66-2.73)	2.55 (1.96-3.25)	3.10 (2.32-4.13)	3.51 (2.57-4.78)	3.95 (2.82-5.58)	4.47 (3.01-6.39)	5.25 (3.40-7.73)	5.91 (3.74-8.86)
60-min	0.868 (0.674-1.10)	1.06 (0.819-1.34)	1.36 (1.05-1.73)	1.62 (1.24-2.06)	1.96 (1.47-2.62)	2.22 (1.63-3.03)	2.50 (1.79-3.54)	2.84 (1.91-4.05)	3.33 (2.16-4.91)	3.76 (2.38-5.63)
2-hr	0.563 (0.441-0.708)	0.692 (0.541-0.871)	0.902 (0.703-1.14)	1.08 (0.834-1.36)	1.32 (0.992-1.75)	1.49 (1.10-2.03)	1.69 (1.22-2.39)	1.93 (1.30-2.74)	2.30 (1.49-3.37)	2.62 (1.67-3.91)
3-hr	0.435 (0.342-0.546)	0.537 (0.421-0.673)	0.703 (0.550-0.884)	0.840 (0.653-1.06)	1.03 (0.778-1.36)	1.17 (0.868-1.58)	1.32 (0.960-1.87)	1.51 (1.02-2.14)	1.81 (1.18-2.65)	2.08 (1.32-3.08)
6-hr	0.281 (0.222-0.350)	0.346 (0.274-0.431)	0.453 (0.356-0.565)	0.541 (0.424-0.680)	0.663 (0.504-0.873)	0.752 (0.562-1.01)	0.851 (0.621-1.19)	0.974 (0.661-1.37)	1.17 (0.761-1.69)	1.33 (0.851-1.97)
12-hr	0.176 (0.141-0.218)	0.217 (0.172-0.268)	0.282 (0.224-0.351)	0.337 (0.266-0.420)	0.412 (0.315-0.538)	0.468 (0.351-0.624)	0.528 (0.386-0.733)	0.602 (0.411-0.841)	0.717 (0.470-1.03)	0.816 (0.522-1.20)
24-hr	0.106 (0.085-0.130)	0.132 (0.106-0.162)	0.173 (0.138-0.214)	0.208 (0.165-0.258)	0.256 (0.197-0.332)	0.291 (0.220-0.387)	0.329 (0.243-0.456)	0.377 (0.258-0.523)	0.452 (0.297-0.647)	0.517 (0.332-0.752)
2-day	0.060 (0.049-0.074)	0.077 (0.062-0.094)	0.103 (0.083-0.126)	0.125 (0.100-0.154)	0.155 (0.120-0.201)	0.177 (0.135-0.235)	0.201 (0.150-0.279)	0.233 (0.160-0.321)	0.284 (0.187-0.404)	0.329 (0.212-0.476)
3-day	0.044 (0.036-0.054)	0.056 (0.045-0.068)	0.075 (0.060-0.091)	0.090 (0.073-0.111)	0.112 (0.087-0.145)	0.128 (0.098-0.169)	0.145 (0.109-0.201)	0.169 (0.116-0.232)	0.206 (0.136-0.292)	0.239 (0.154-0.345)
4-day	0.036 (0.029-0.044)	0.045 (0.036-0.054)	0.059 (0.048-0.072)	0.072 (0.058-0.088)	0.088 (0.069-0.114)	0.101 (0.077-0.133)	0.114 (0.086-0.158)	0.132 (0.091-0.181)	0.161 (0.107-0.228)	0.187 (0.121-0.269)
7-day	0.025 (0.020-0.030)	0.030 (0.024-0.036)	0.039 (0.031-0.047)	0.046 (0.037-0.056)	0.056 (0.044-0.071)	0.063 (0.049-0.083)	0.071 (0.053-0.097)	0.082 (0.056-0.111)	0.099 (0.065-0.139)	0.114 (0.074-0.163)
10-day	0.020 (0.016-0.024)	0.024 (0.019-0.029)	0.030 (0.024-0.036)	0.035 (0.029-0.043)	0.042 (0.033-0.054)	0.048 (0.037-0.062)	0.053 (0.040-0.073)	0.061 (0.042-0.083)	0.073 (0.048-0.102)	0.083 (0.054-0.118)
20-day	0.014 (0.011-0.016)	0.016 (0.013-0.019)	0.019 (0.016-0.023)	0.022 (0.018-0.027)	0.026 (0.021-0.033)	0.029 (0.022-0.037)	0.032 (0.024-0.043)	0.036 (0.025-0.048)	0.041 (0.027-0.057)	0.046 (0.030-0.065)
30-day	0.011 (0.009-0.013)	0.013 (0.010-0.015)	0.015 (0.012-0.018)	0.017 (0.014-0.021)	0.020 (0.016-0.025)	0.022 (0.017-0.028)	0.024 (0.018-0.032)	0.027 (0.019-0.036)	0.030 (0.020-0.042)	0.033 (0.021-0.046)
45-day	0.009 (0.008-0.011)	0.010 (0.008-0.012)	0.012 (0.010-0.014)	0.013 (0.011-0.016)	0.015 (0.012-0.019)	0.017 (0.013-0.021)	0.019 (0.014-0.024)	0.020 (0.014-0.027)	0.022 (0.015-0.031)	0.024 (0.015-0.033)
60-day	0.008 (0.007-0.009)	0.009 (0.007-0.010)	0.010 (0.008-0.012)	0.011 (0.009-0.014)	0.013 (0.010-0.016)	0.014 (0.011-0.018)	0.015 (0.011-0.020)	0.016 (0.011-0.022)	0.018 (0.012-0.025)	0.019 (0.012-0.027)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

Back to Top

PF graphical

Appendix C – Floodproofing Specification Sheets

Custom Door & Window Flood Barrier

FRA FLOOD PANEL

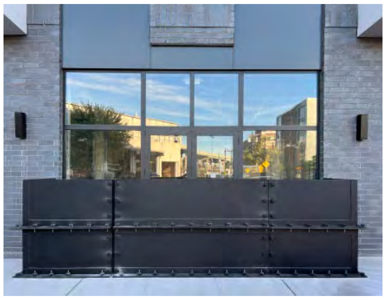
A custom-engineered barrier that protects any sized opening against intrusion & flood water damage.

The Flood Risk America (FRA) Flood Panel uses sustainable flood-seal technology to protect any opening against flood water & is highly resistant to heavy impact forces. Each panel is custom-engineered to meet individual installation requirements & job-specific demands. It is easy to install, deploy, & remove.

Storefront Protection Door & Window Barrier

Applications

Storefronts | Windows/Doors | Vehicle Access Points | Drain Covers



Storefront Application

Single Door Barrier

Extended Run Barrier With Corner

Technical Specifications

MATERIAL	High Density Foam Core, Fiberglass Skin, Structural Coating
SEAL	Gasket Compression
HARDWARE	Stainless Steel Anchors
WEIGHT	4 lbs PSF
DESIGN	Meets FEMA & ASCE Requirements
WARRANTY	Lifetime (Panel Only)

Custom Color Application

Close Up of Easy-Turn Knob

HAND TIGHTENING TOOLLESS DEPLOYMENT

FEATURES

Durable

Strong Composite Materials

Custom Sizes

Dimensions to Fit Your Needs

Lightweight

Less Than 4 Pounds Per Ft^2

Quick Deployment

Panels Are Easy To Transport & Install

Versatile

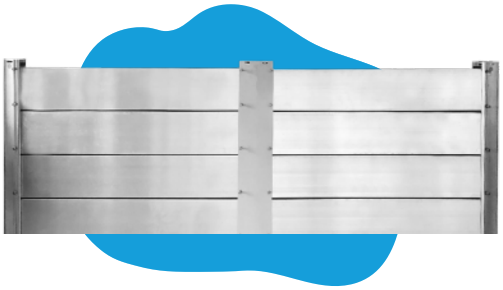
Gasket Conforms To Uneven Surfaces

Florida dbpr Department of Business & Professional Regulation

Florida Product Approved #FL41703

Flood Logs

MULTIPLE OPTIONS



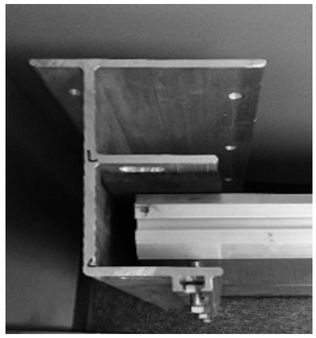
A customizable, stackable aluminum flood barrier that is a time-tested solution for flood or hurricane prone locations

The Flood Log system is designed to be resistant to impact forces & withstand high-velocity water loads. Ideal for uses where higher protection is needed. Meets ASCE & FEMA requirements.

Applications

Storefronts | Select Windows | Doors | Vehicle Access Points

Emergency egress stairs



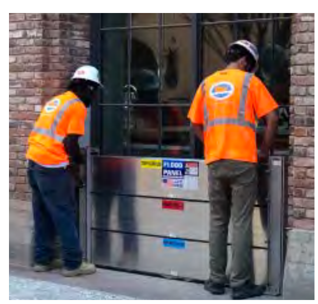
Offset Bracket Gives Wall Clearance

Flood log storage

STACKABLE "C" POSTS

Flood Logs are strengthened by stackable "C" shaped posts & hollow aluminum beams fitted with watertight rubber seals, ensuring maximum stability & flood protection. Each support post can easily be removed, minimizing aesthetic impact to any building.

MOUNTING OPTIONS JAM | OFFSET | FLUSH



FEATURES

User Friendly
Color Coded For Guided Assembly

Durable
Aluminum Support Posts & Beams To Anchor Systems

Versatile
Engineered to Accommodate Slopes of 20°

Custom Sizes
Dimensions to Fit Your Needs

Storage Solutions
Custom Rack Configurations Available

DIMENSIONS	MATERIAL	IMPACT RESISTANT
Customizable	Aluminum Log Panels, Compression Gaskets	Yes

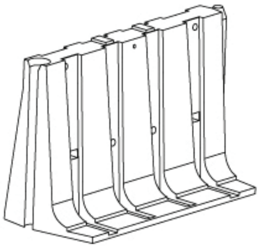
MUSCLE WALL®

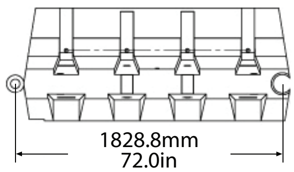
FLOOD • CONTAINMENT • STORMWATER

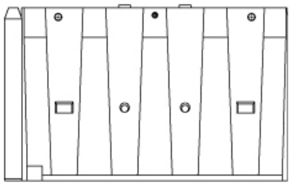
4-FOOT MUSCLE WALL

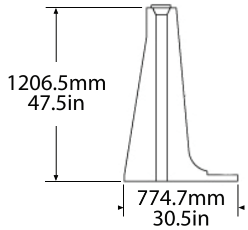
SPECIFICATIONS

- Material
  - Low density polyethylene
  - Elongation to yield: 20%
  - Impact strength: 190 ft-lb
  - Tensile strength at yield: 2600 psi
- Dimensions
  - Minimum polyethylene thickness: 0.25"
  - Footprint on ground: 14.5 ft^2
  - 6 ft. wide x 2.54 ft. deep x 4 ft. high
  - Installed in 6 ft. sections
  - Fit 96 units on one 48 ft. flatbed trailer
- Portable
  - Weight per unit (empty): 110lbs
  - Weight per unit (filled): 1400lbs
  - Units nest together for transportation
  - 12 walls per pallet
- All Season Compatible
  - Temperature range: -40˚ F to 180˚ F
  - 10 year UV rated
- Ground Pressure
  - Empty: 0.0527 psi
  - Filled: 0.6705 psi









FEATURES

- **Quick Setup & Take Down**
  - Male to female connection that slides easily into place with another Muscle Wall
  - 4-Foot spring liner clip secures the liner to the Muscle Wall as well as reduces liner tenting
  - Each joint acts like a hinge allowing up to 22˚ range of motion
  - Reversible corner unit enables the Muscle Wall system to make a 90˚ turn in any direction
- **Intuitive Design**
  - Two walls nestle together to reduce storage & shipping space
  - Threaded top hole cap
  - Releasable bung-plug cap for rapid emptying
  - Safety ratchet straps restrain adjacent panels
  - 7 strategically placed kiss-throughs with multiple purposes based on location - structural integrity, safety strap installation, and hand-holds

phone | 435.213.9253 email | info@musclewall.com web | musclewall.com address | 675 N 600 W Ste. 1 Logan, UT 84321

diluvium

Diluvium™ Flood Barrier

Technical specifications

Highlights

- Ultrastrong
- Ultralight
- Low footprint
- Very easy to use
- Fully mobile
- Reusable
- Patented
- 100% Recyclable

Product details

Diluvium is manufactured from **Technical Textiles** and is an ultralight, ultrastrong flood barrier.

Its patented design creates excellent flood protection combined with maximum ease of use. It is quick to set up and works in almost any environment.

4 Sizes to suit your requirements

Height: **90 cm / 3 ft**

Footprint: 120 cm / 4 ft
Weight: 8 kg/m - 5 lbs/ft

Height: **120 cm / 4 ft**

Footprint: 150 cm / 5 ft
Weight: 10 kg/m - 7 lbs/ft

Height: **150 cm / 5 ft**

Footprint: 180 cm / 6 ft
Weight: 12 kg/m - 8 lbs/ft

Height: **180 cm / 6 ft**

Footprint: 210 cm / 7 ft
Weight: 14 kg/m - 9 lbs/ft

Details

Fabric barrier
Base fabric - Technical Textiles
Tensile Strength - 7400/ 6400 N/ 5cm
Tear Resistance - 1200/ 1000 N
Flex resistance - at least 100,000 bends

Zippers - load bearing
Material (Teeth) - Polyacetal
Lateral strength – 142 kg
Operating force – 0.7 – 1kg
Durability – 500 cycles
Lateral strength after durability – 133 kg

Zippers - water sealing
Material (teeth) - Polyamide
Air/ water tightness – 0.3 bar
Durability – 500 cycles
Operating force <2.5 kg/ 5.5lbs

Support bracket
Material – Glass Fiber

Structural/ Anchor bars
Material – Glass Fiber

Eye Bolts
Material – Stainless Steel

Load bearing wires
Material – Stainless steel
Grade – 316
Break load – 5.72 KN

Disclaimer: all figures are estimated and rounded up/ down to the nearest whole number.

Contact

Tel +47 56 35 64 00
Fax +47 56 35 64 01
post@nwp.as
faktura@nwp.as

Adress

Norwegian Weather Protection AS
Rosslandsvegen 410
5918 Frekhaug

Web

www.diluviumfloodbarrier.com

Appendix G

PUBLIC FORUM #1

Beverly Bass River District Resilience Study

Public Forum #1

City of Beverly

Supported by:

MVP
Municipal Vulnerability Preparedness

Project Team:

TETRA TECH

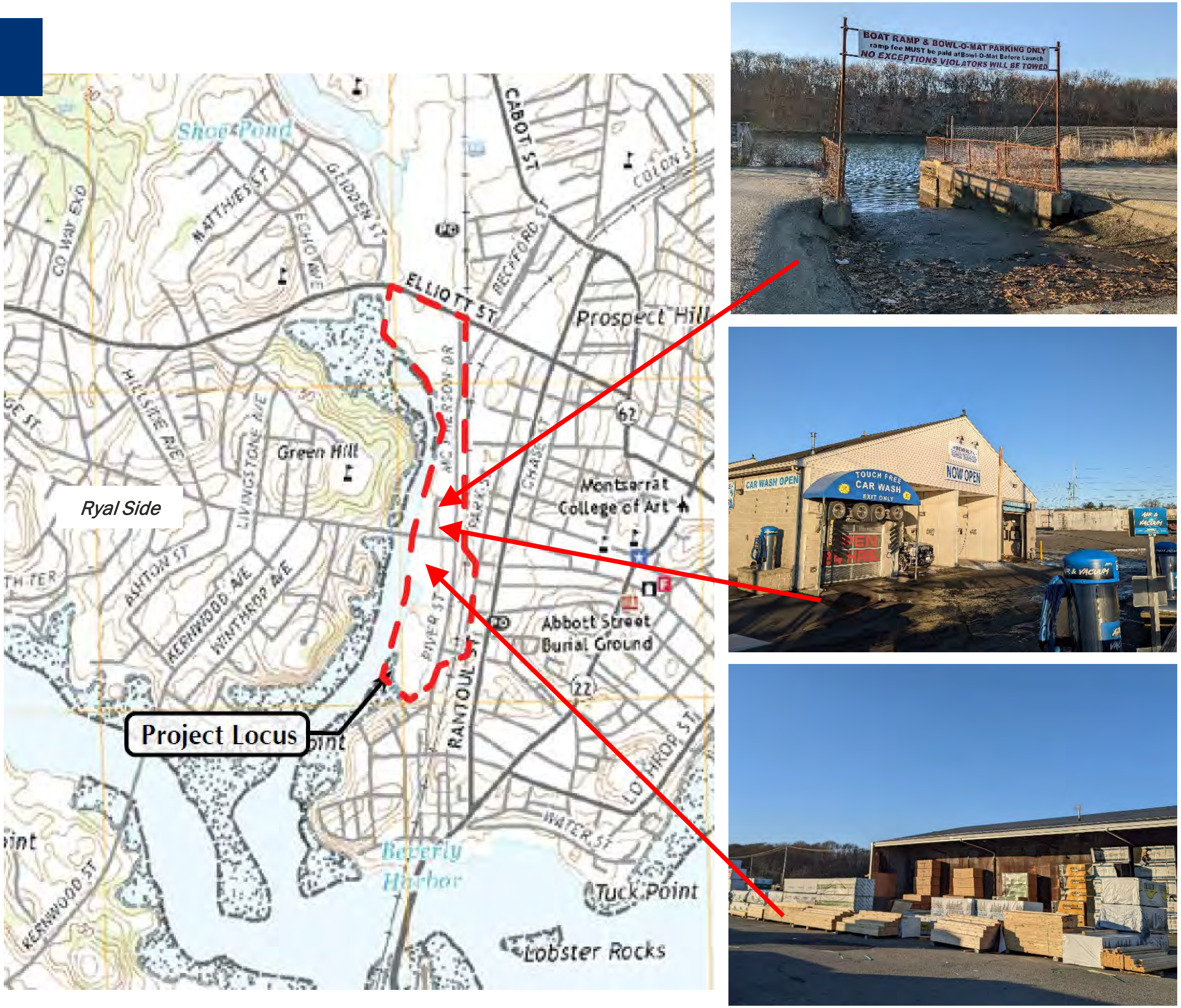
WOODS HOLE GROUP
A CLS COMPANY

Salem Sound COASTWATCH

March 21, 2023

Project Focus Area

- Elliott Street/Route 62 to the north;
- MBTA Newburyport/Rockport Line to the east;
- Webber Avenue and River Street intersection to the south;
- Bass River to the west.



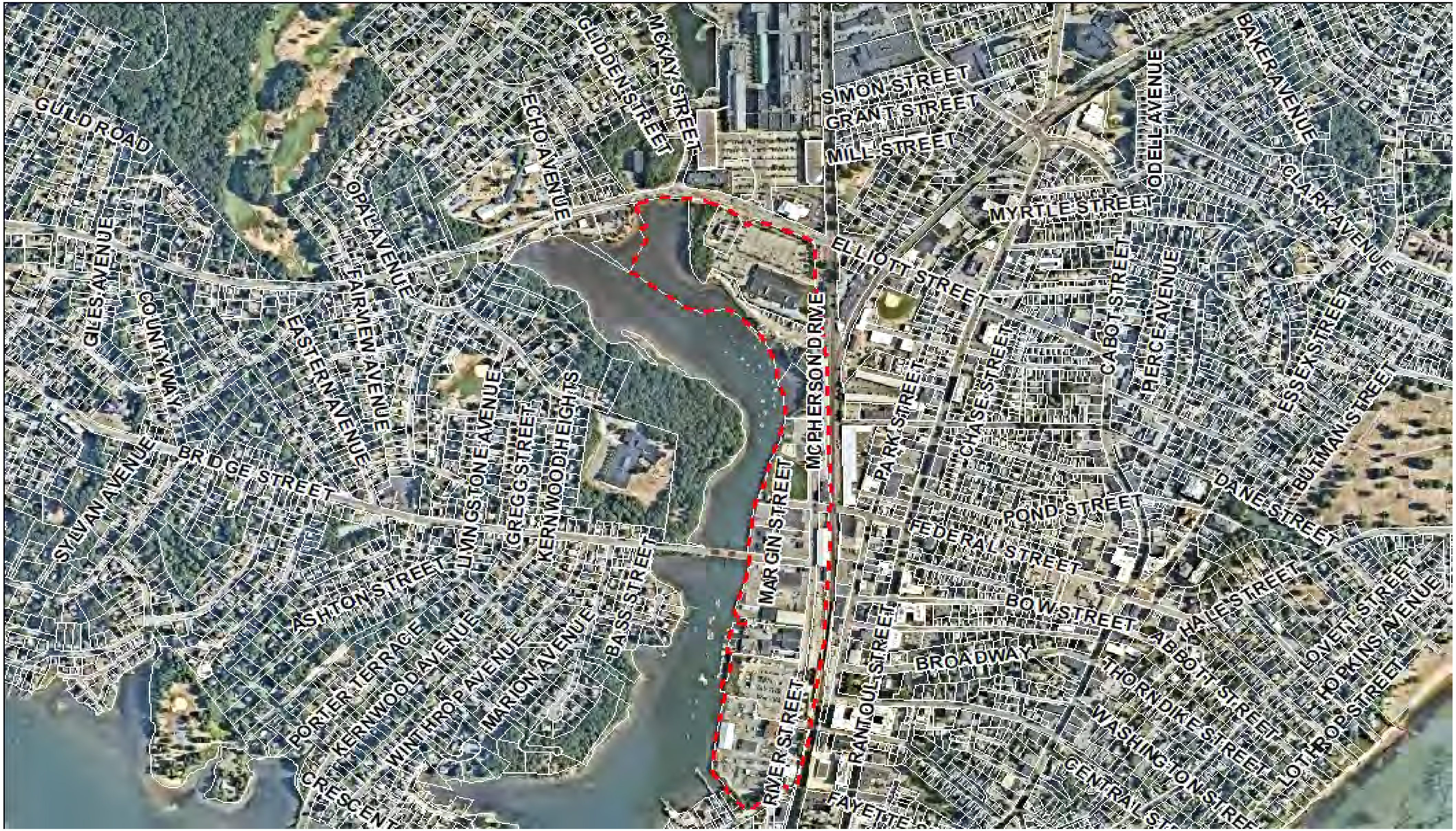
Properties and infrastructure along the Bass River are currently at risk of flooding

Project Funding: $200,000 from MassEEA MVP Grant and $67,000 from City of Beverly as a local match.

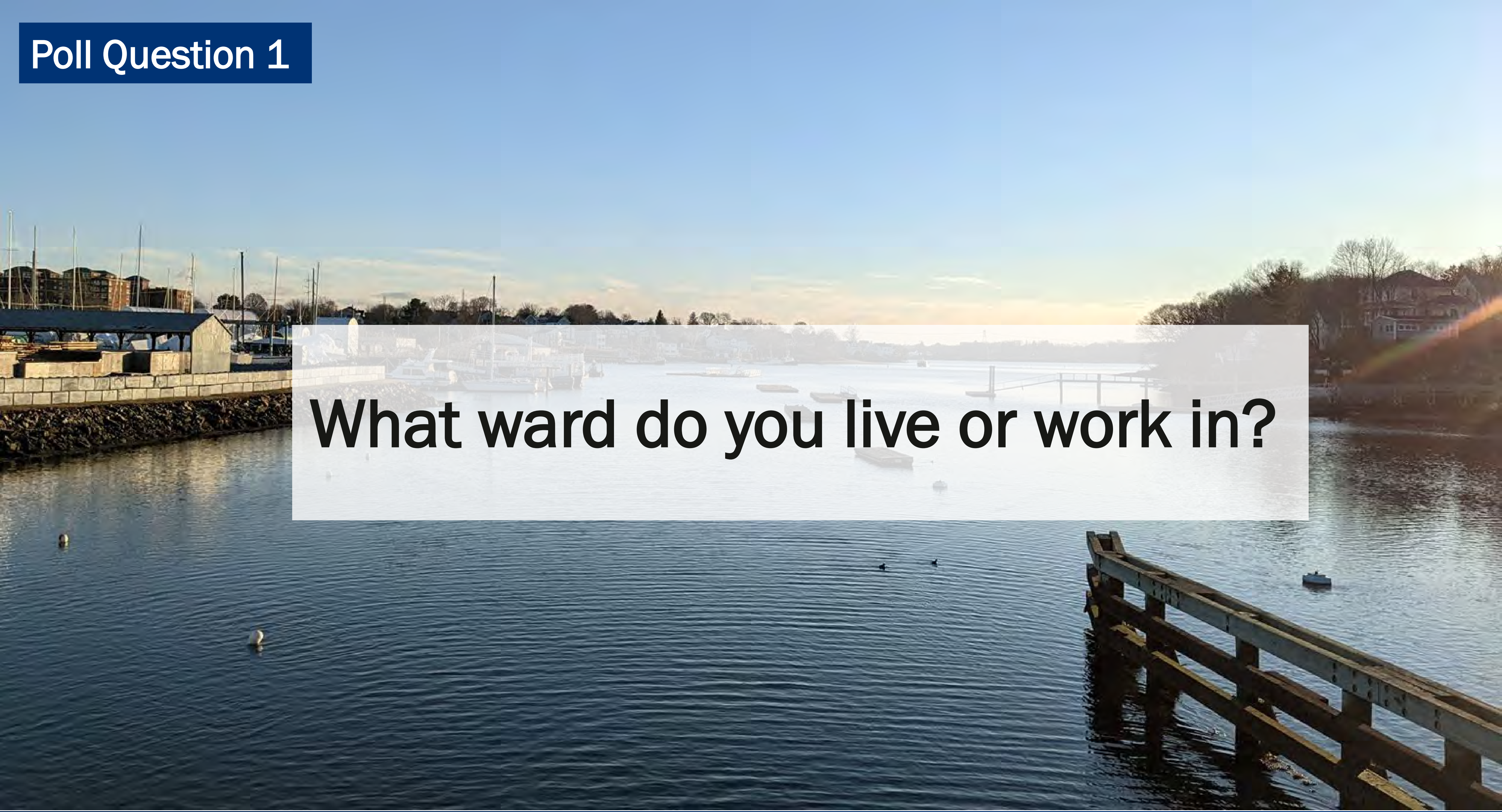
The frequency and intensity of coastal flooding will increase in the future

This study will analyze and select options to increase flood resilience to protect critical infrastructure & assets

Beverly Bass River District



Poll Question 1

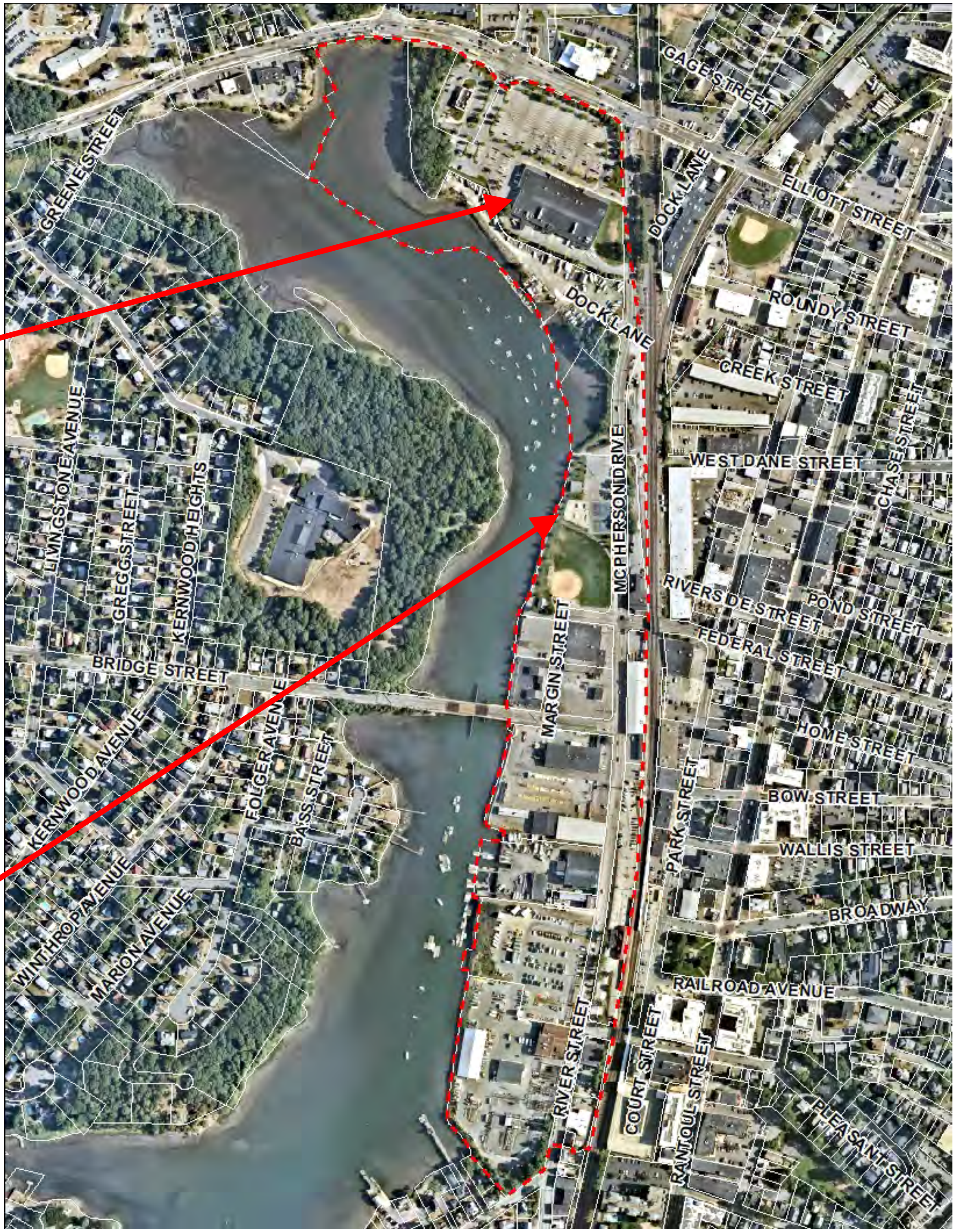


What ward do you live or work in?

Existing Conditions

Existing Supermarket

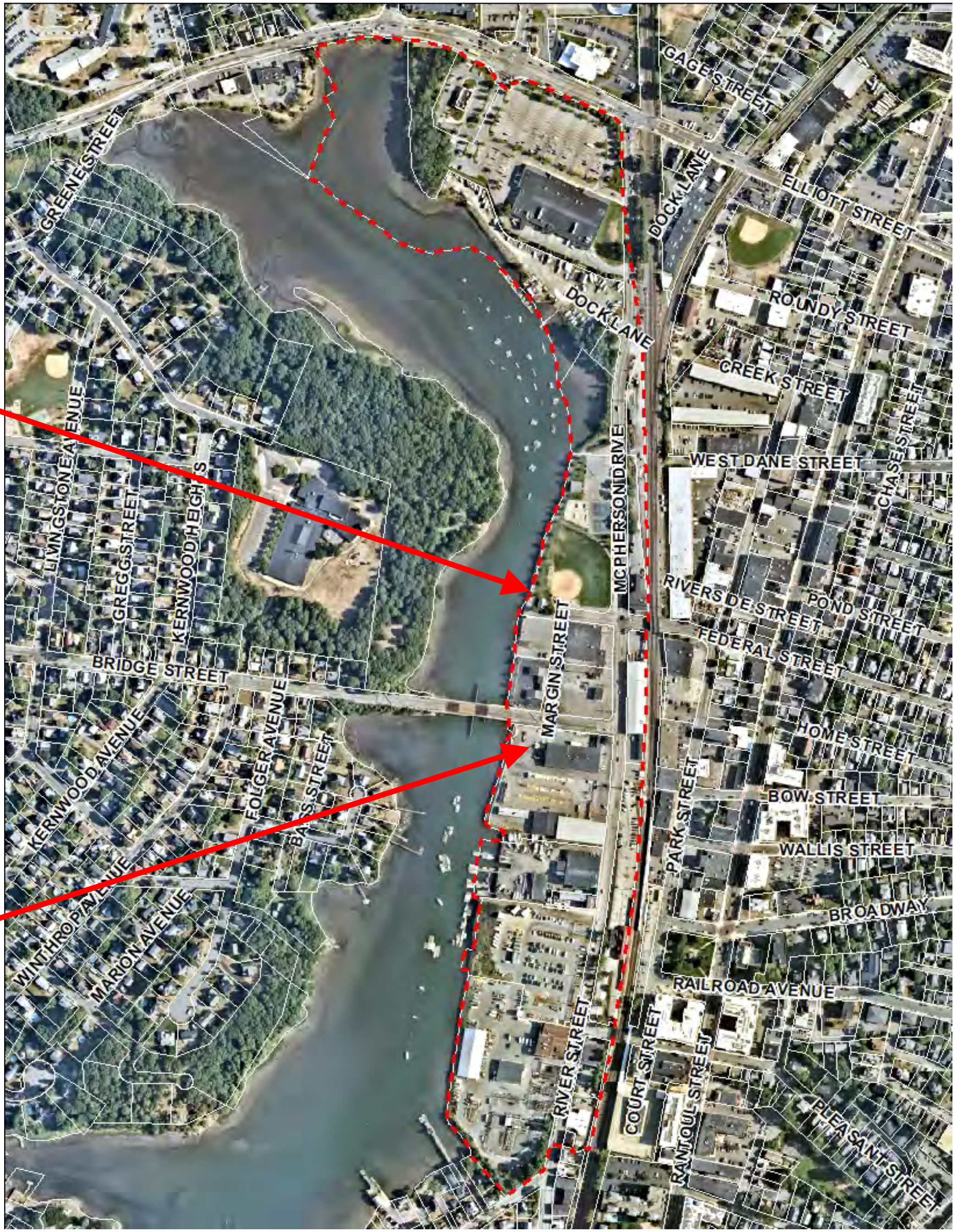
Innocenti Park / McPherson Youth Center



Existing Conditions

Margin Street Stormwater Pump Station

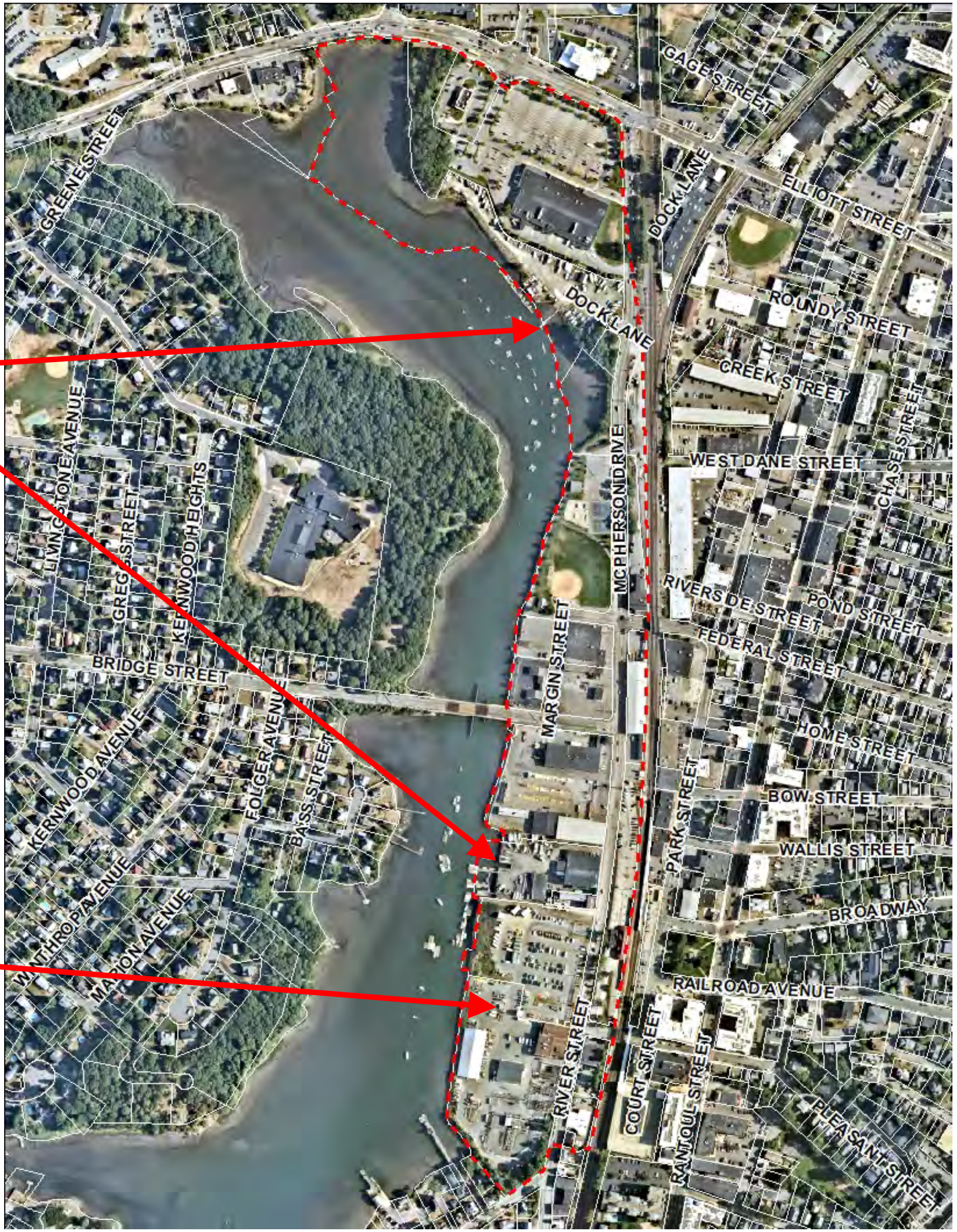
Existing Lumber Yard

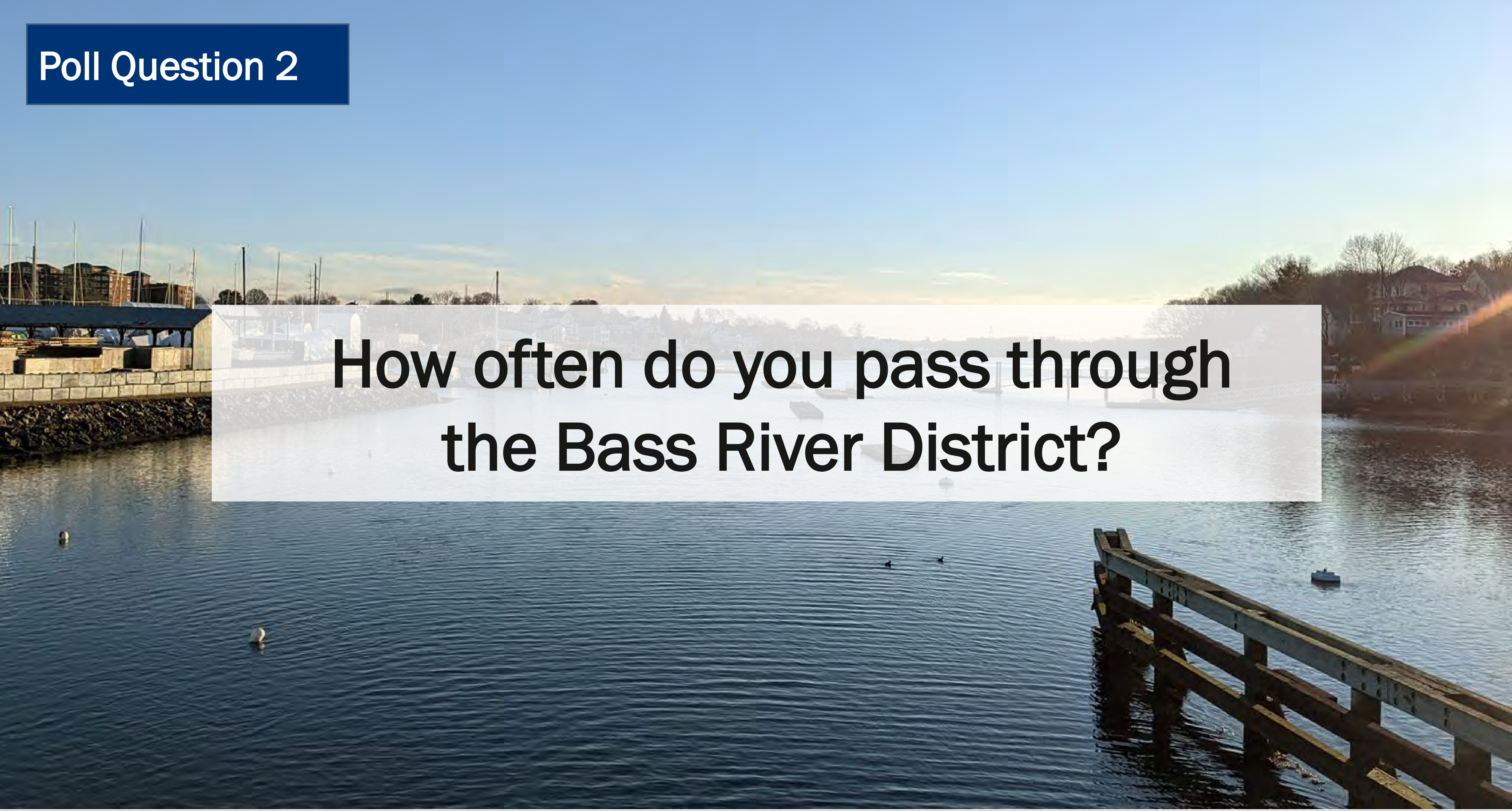


Existing Conditions

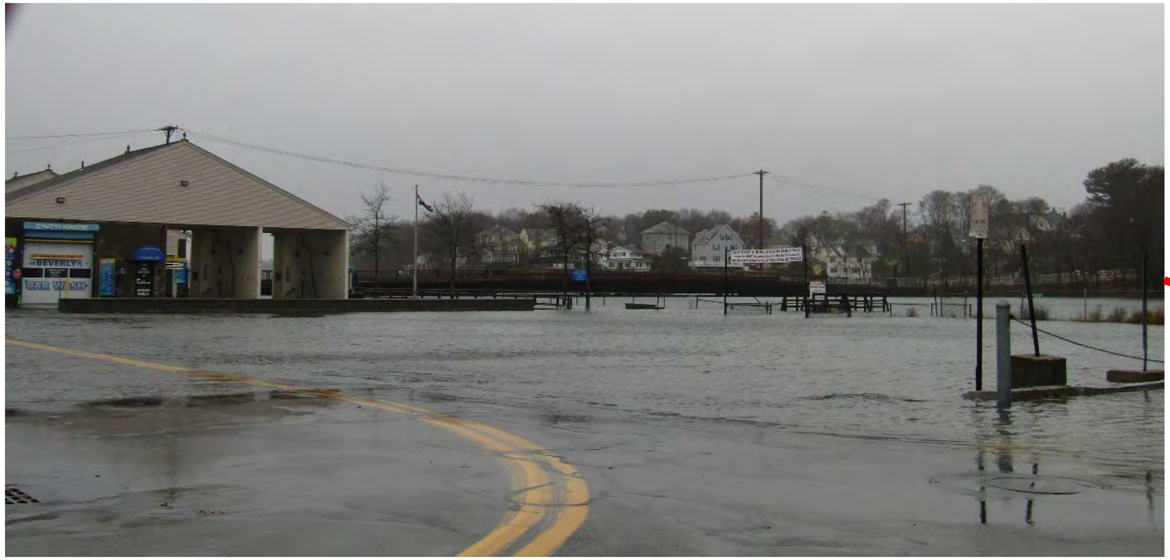
Yacht Clubs & Marinas

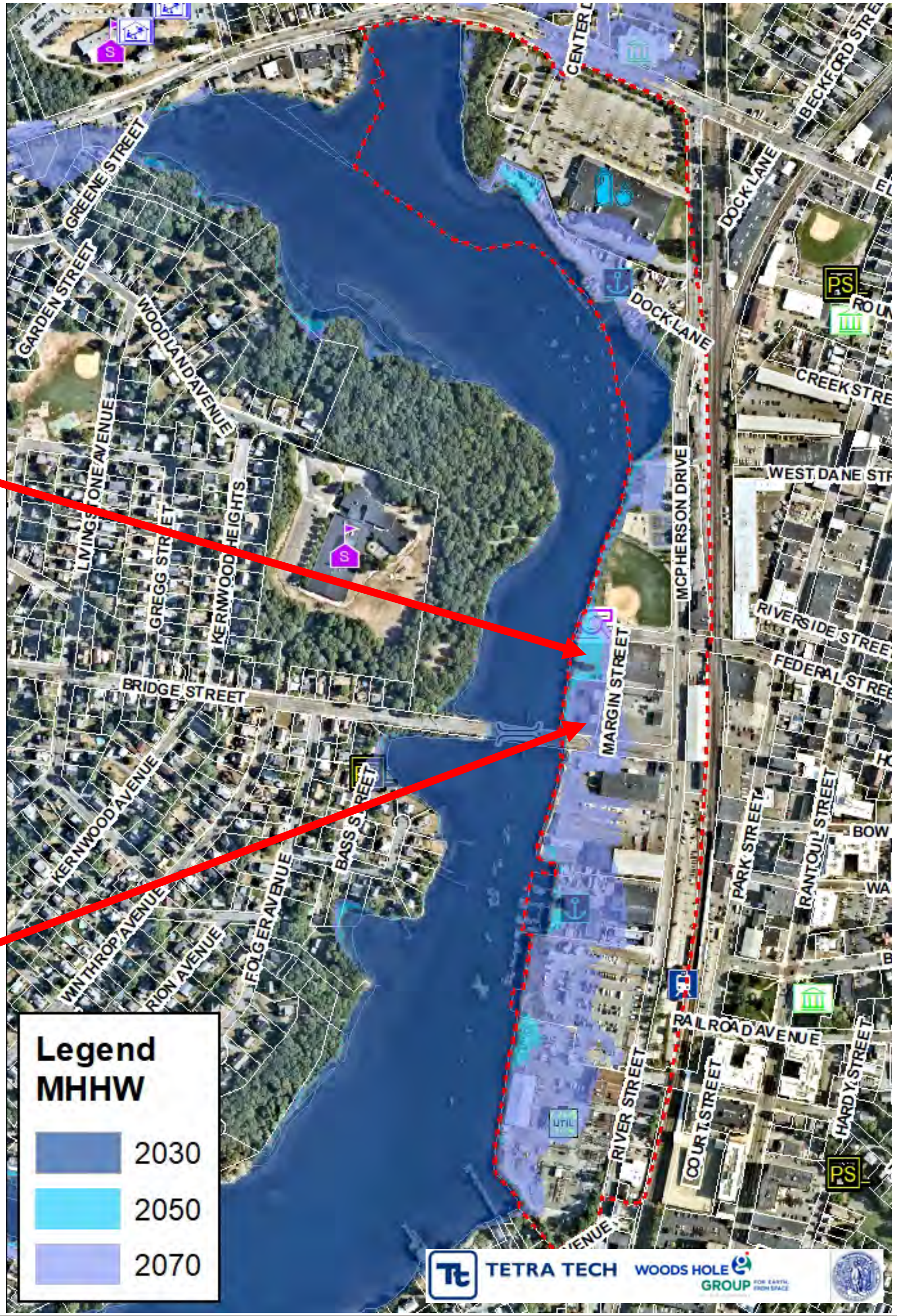
Existing Utility Substation



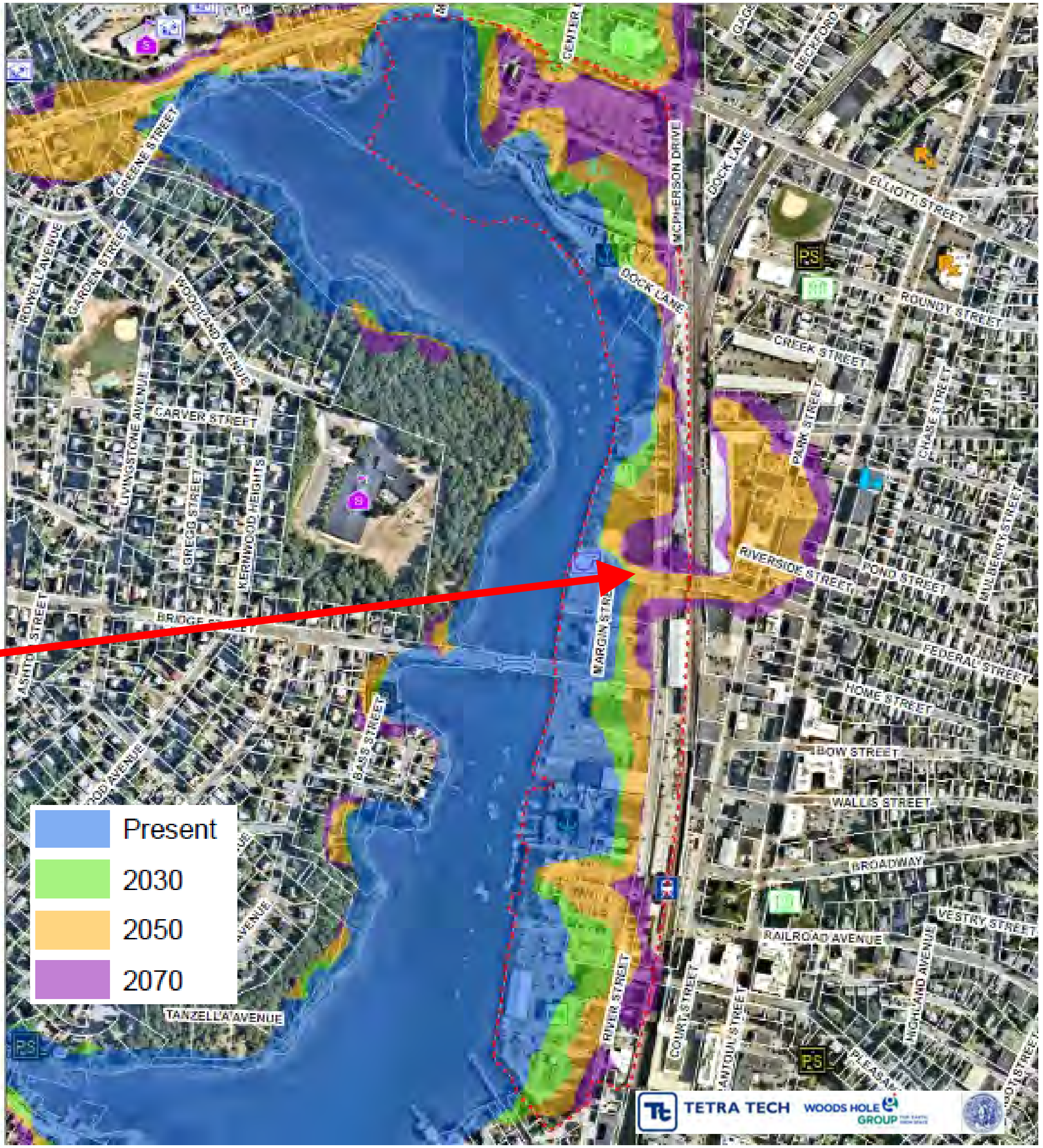

Poll Question 2
How often do you pass through the Bass River District?

Increase in Tidal Flooding Incidents





Growing Flood Risk in the Bass River District

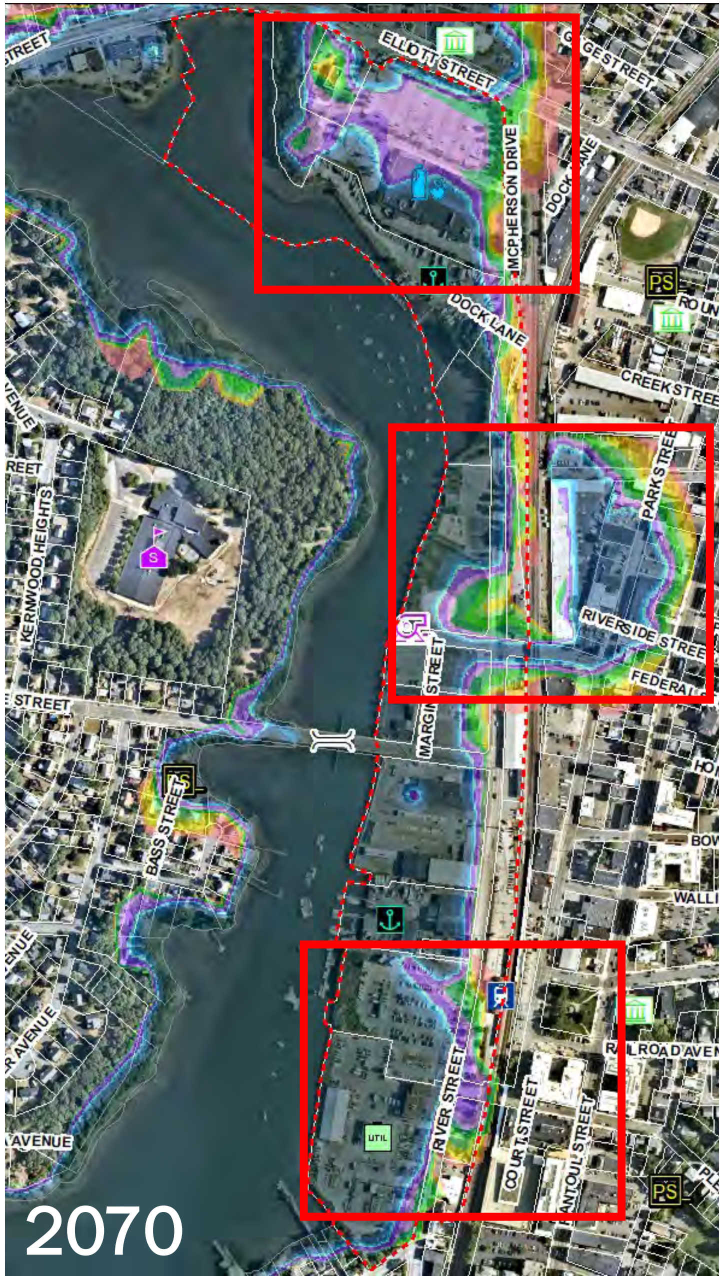


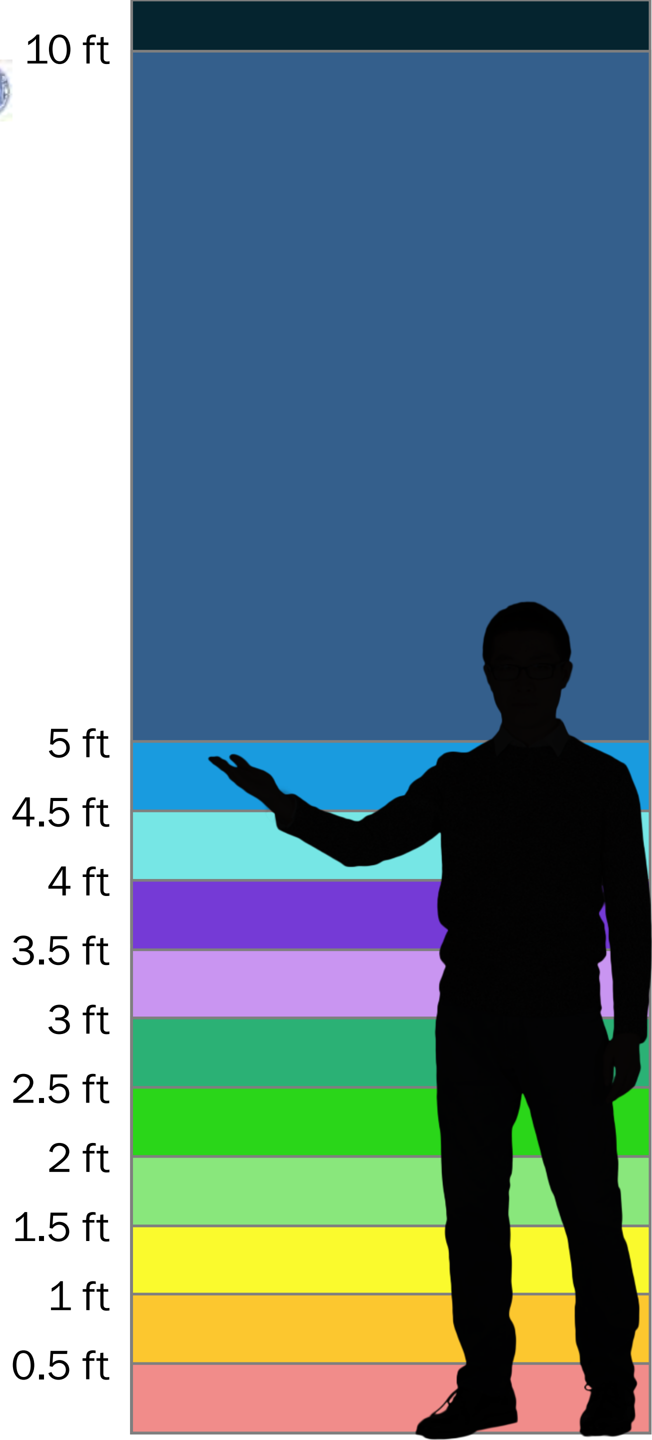
Future Flood Risks from Coastal Storms

Existing Supermarket

Innocenti Park

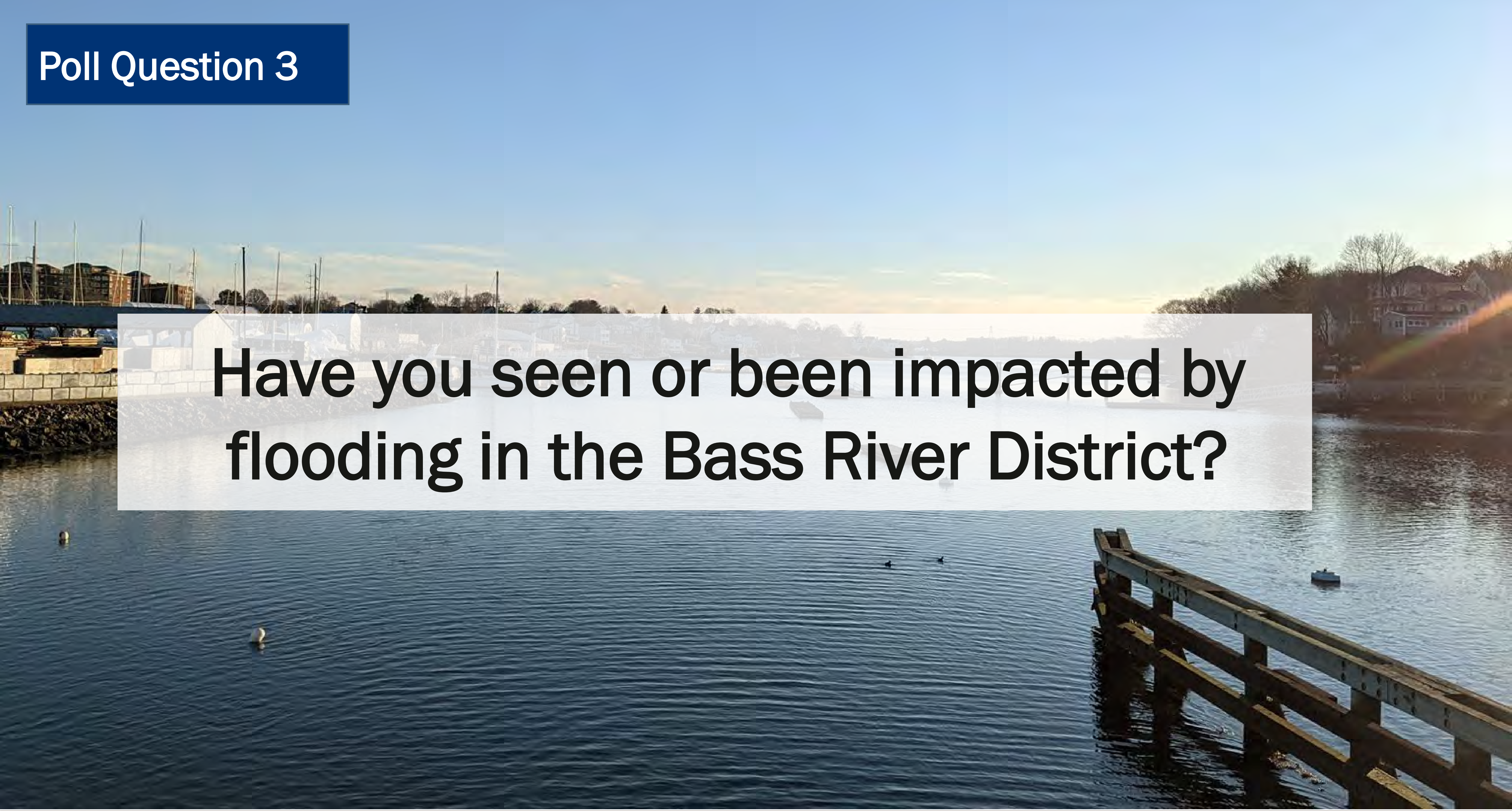
Existing Utility Substation



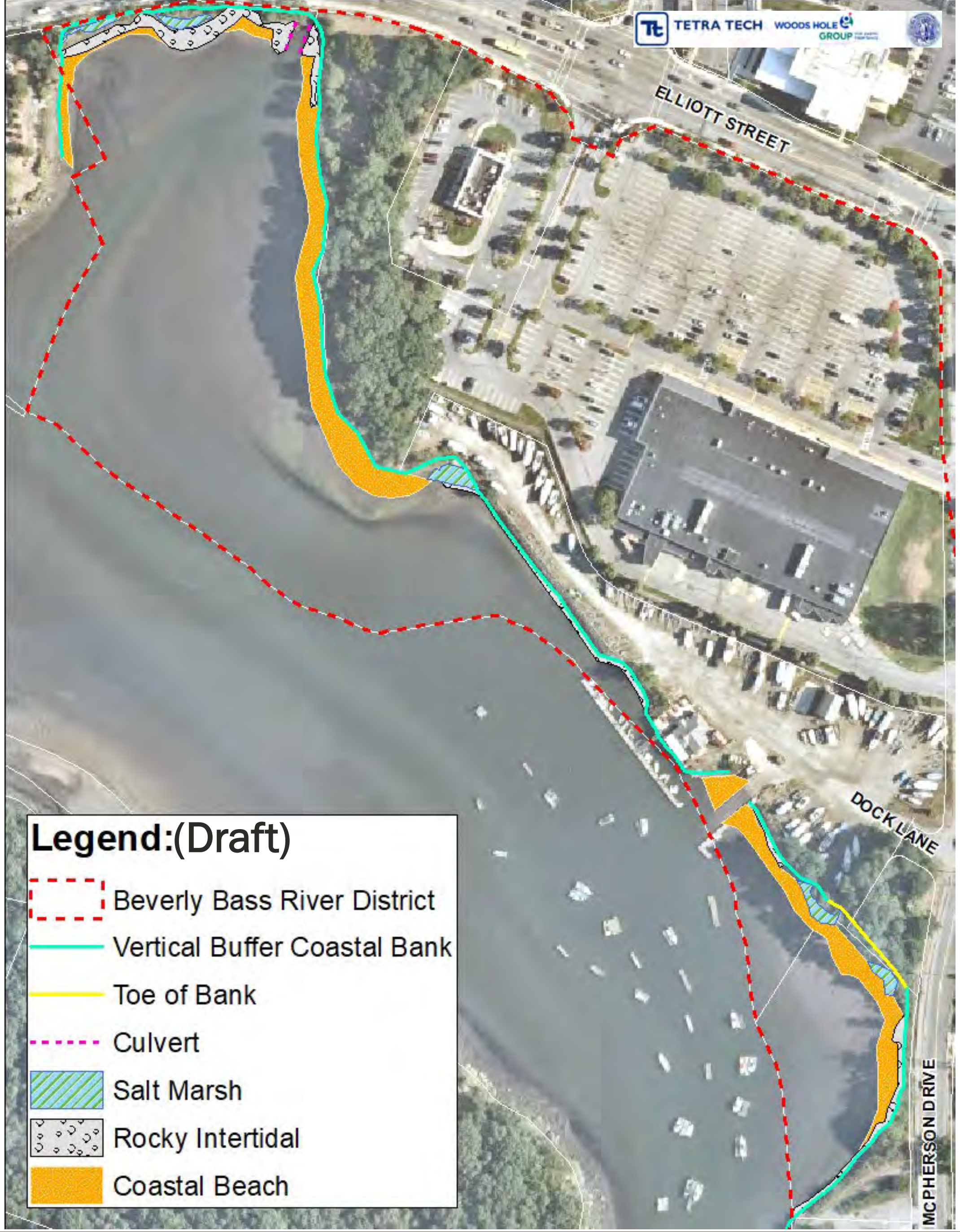


Poll Question 3

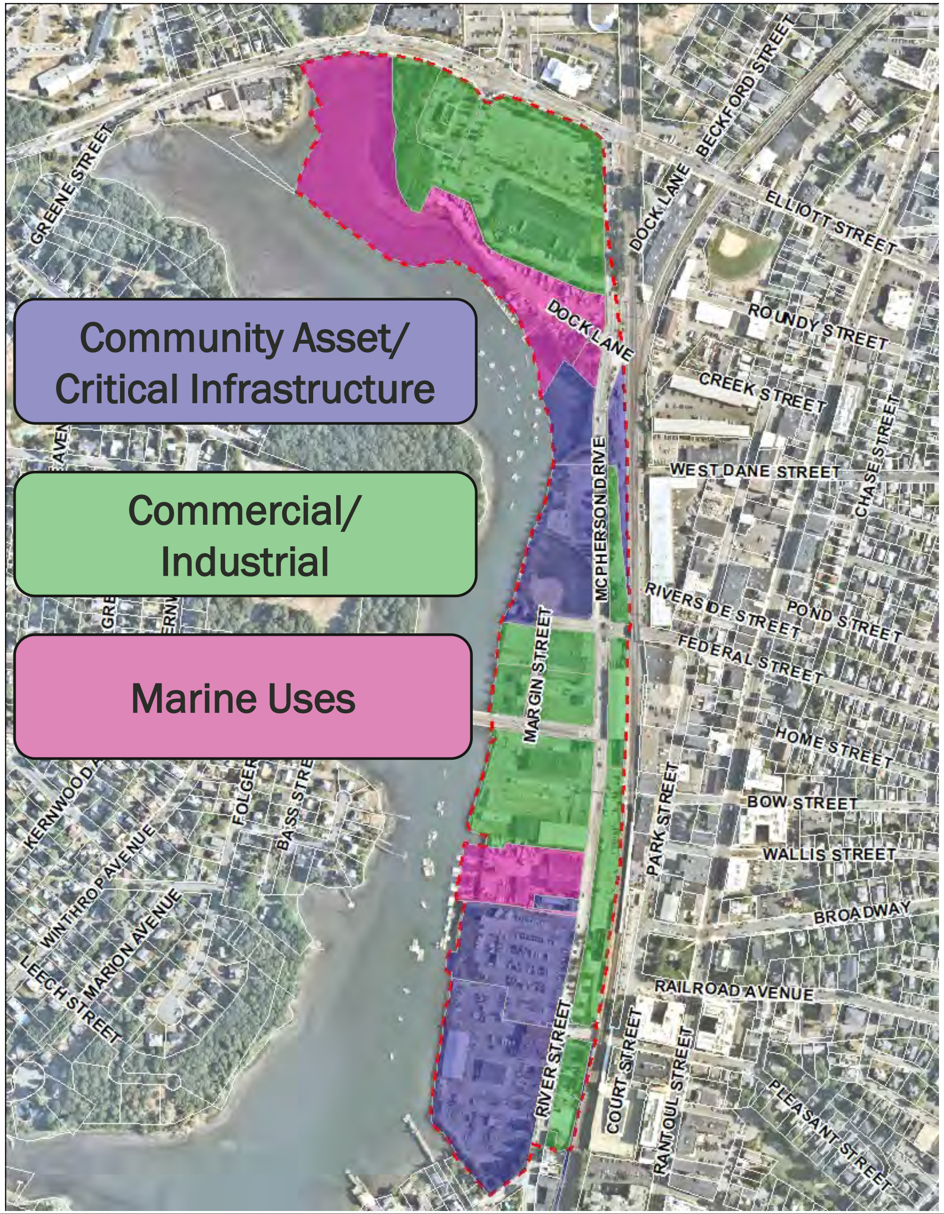
Have you seen or been impacted by flooding in the Bass River District?



Coastal Resource Areas

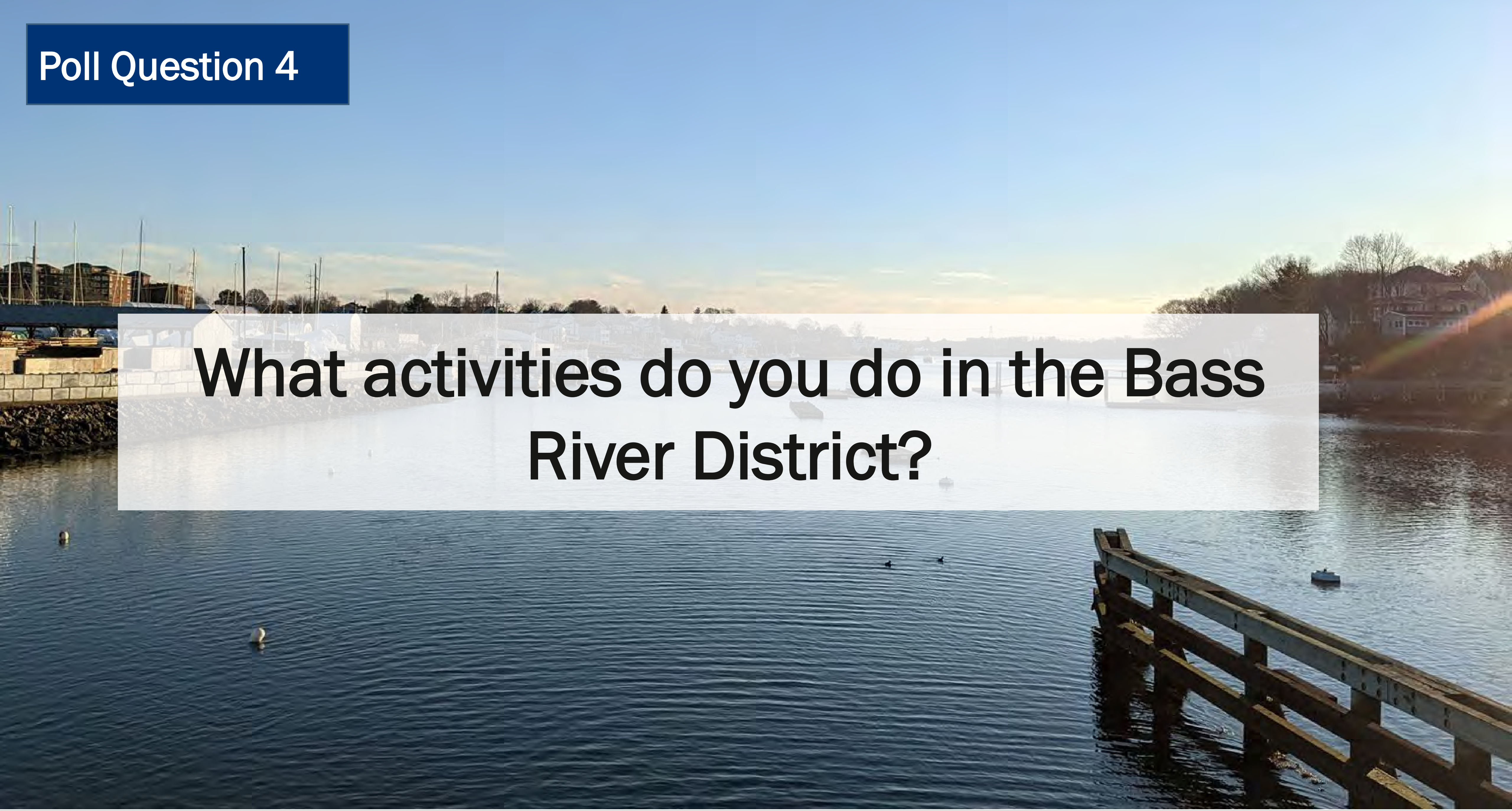


Existing Land Use Categories



Margin Street Stormwater Pumping Station & Infrastructure

Poll Question 4



What activities do you do in the Bass River District?

March 9, 2023: Bass River Clean Up

March 11, 2023: Walk & Talk Event

Ongoing Stakeholder Interviews

Next Steps

Upcoming Community Engagement:

- Bass River Clean Up with the YMCA
- Beverly Bootstraps Event
- Continued Stakeholder Interviews

Future Public Events:

- April 23rd: EarthFest Event
- May 21st: Bass River Paddle
- May/June: Public Forum #2

Conceptual Resilience Strategies

Develop near-term and long-term flood resilience strategies for:

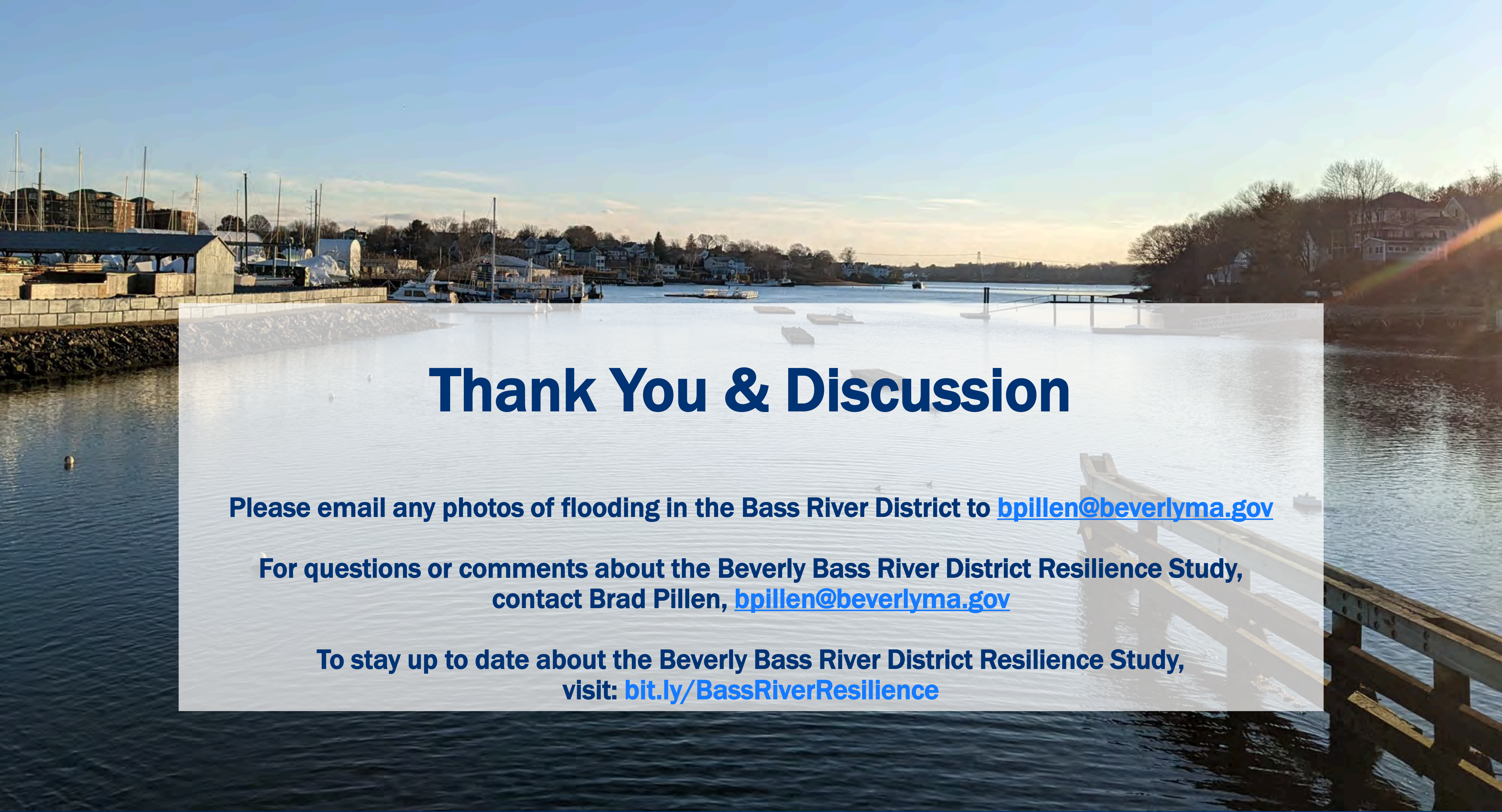
- Coastal Resource Areas
- Critical Infrastructure & Community Assets
- Marine Uses
- Other Commercial/Industrial Sites

Flood Resilience Concepts

- Develop District-Wide Flood Resilience Concept Plans
- Develop a Concept for Nature-Based Solutions along Bass River
- Use Coastal Flood Model to Evaluate Concepts
- Develop Flood Resilience recommendations for future work

Flood Risk America (FRA) Flood Panels   Winter Street Pumps Station June, 9 Public Presentation
Example of coastal Berm – Google Images

Photo: Coast to Coast Paddle



Thank You & Discussion

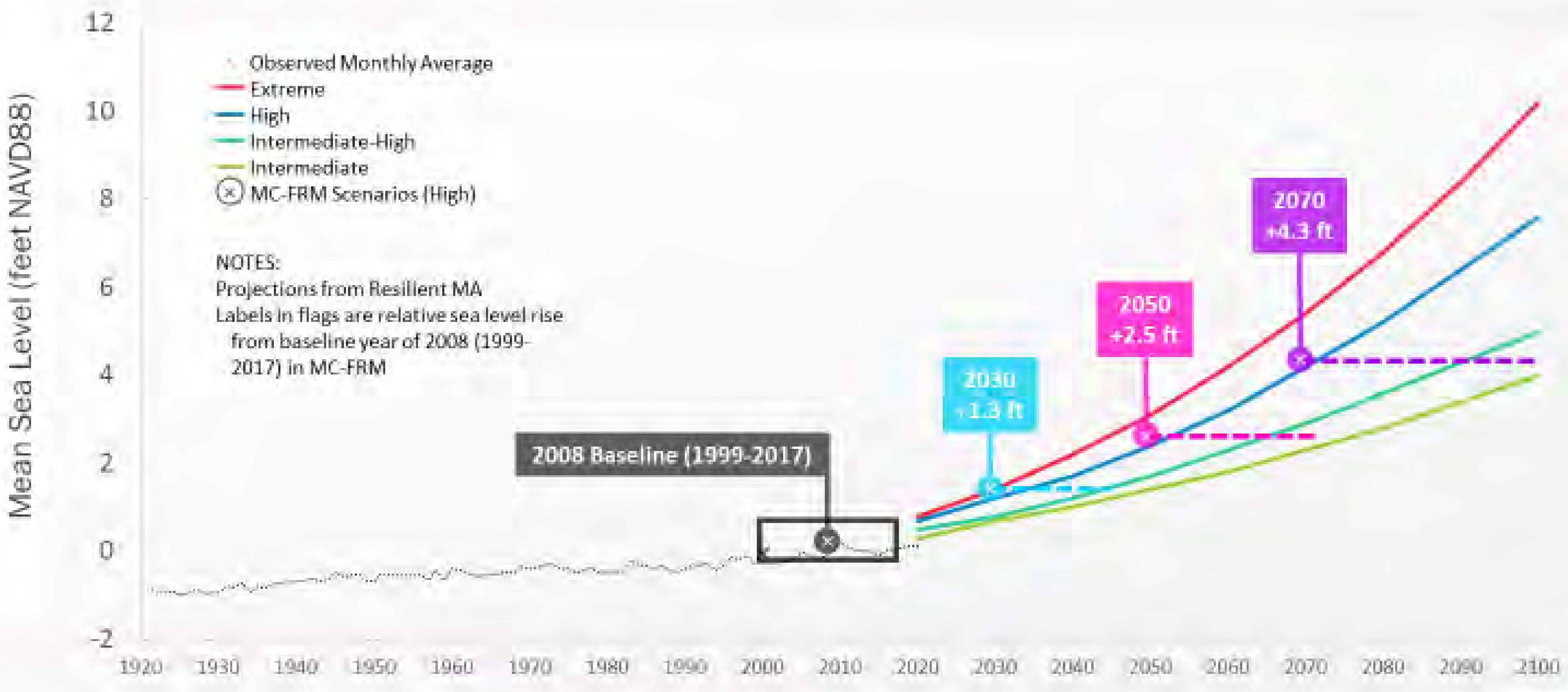
Please email any photos of flooding in the Bass River District to bpillen@beverlyma.gov

For questions or comments about the Beverly Bass River District Resilience Study, contact Brad Pillen, bpillen@beverlyma.gov

To stay up to date about the Beverly Bass River District Resilience Study, visit: bit.ly/BassRiverResilience

Commonwealth of Massachusetts Sea Level Rise Projections

MC-FRM NORTH



WOODS HOLE GROUP

Appendix H

PUBLIC FORUM #2

Beverly Bass River District Resilience Study

City of Beverly

Public Forum #2

Project Team:

TETRA TECH

WOODS HOLE GROUP

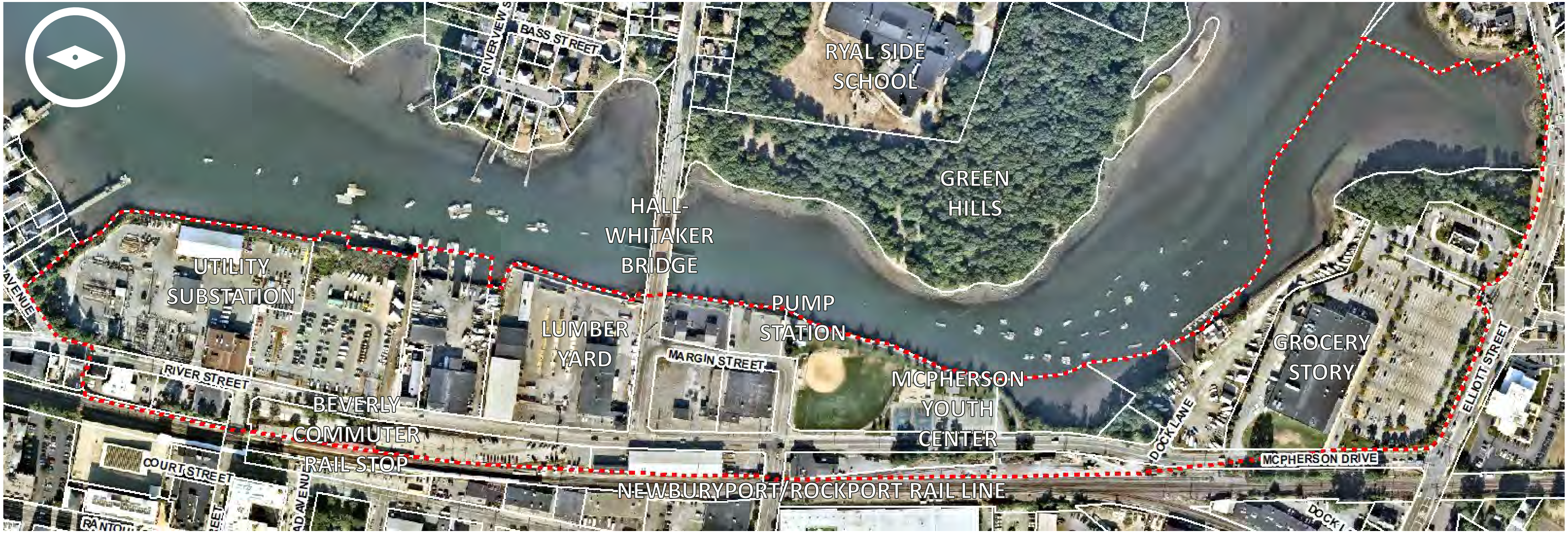
Salem Sound COASTWATCH

Supported by:

MVP Municipal Vulnerability Preparedness

June 13, 2023

Project Focus Area



Coastal Resource Areas North of Bridge

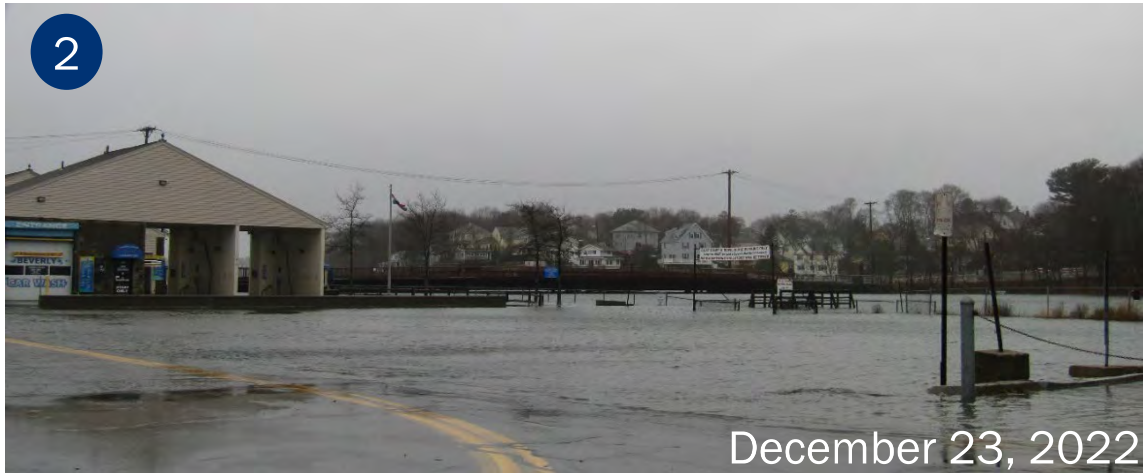
Properties and infrastructure along the Bass River are currently at risk of flooding

Project Funding: $200,000 from MassEEA MVP Grant and $67,000 from City of Beverly as a local match.

The frequency and intensity of coastal flooding will increase in the future

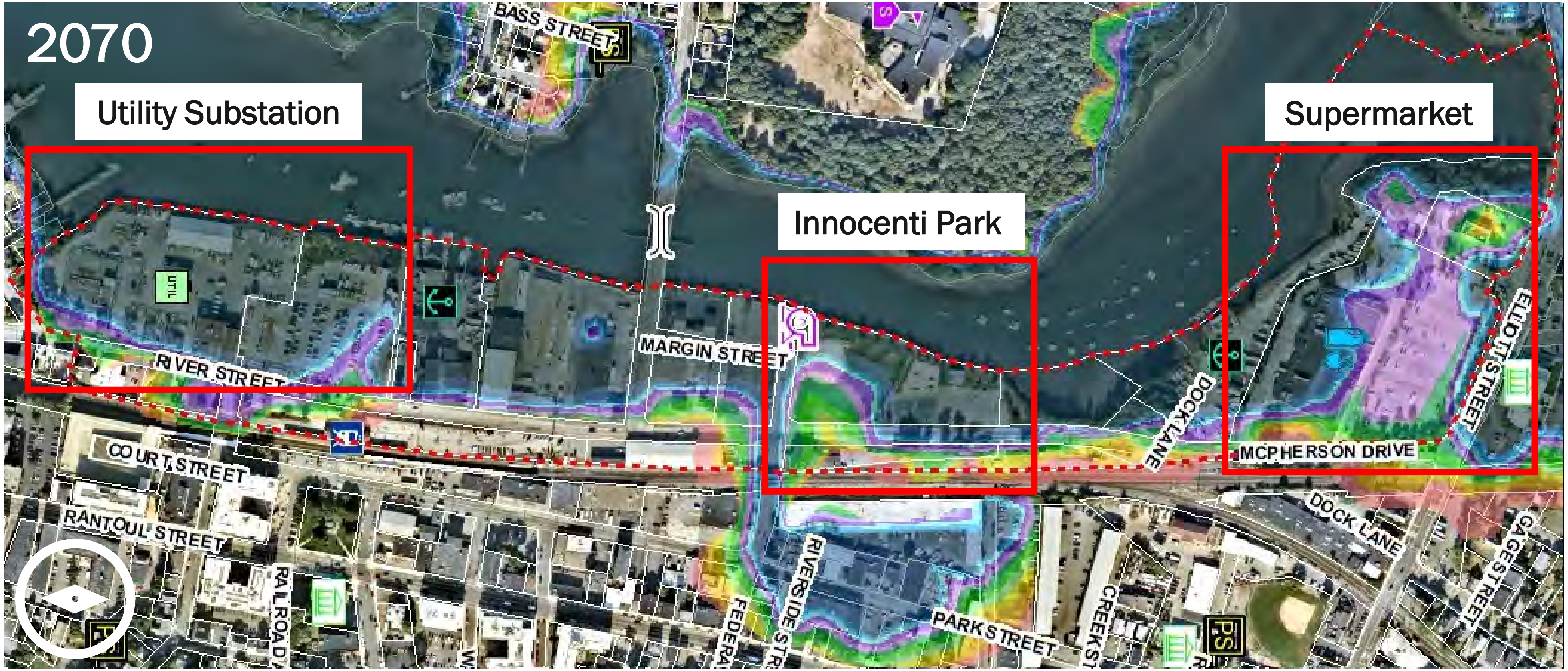
This study will analyze and select options to increase flood resilience to protect critical infrastructure & assets

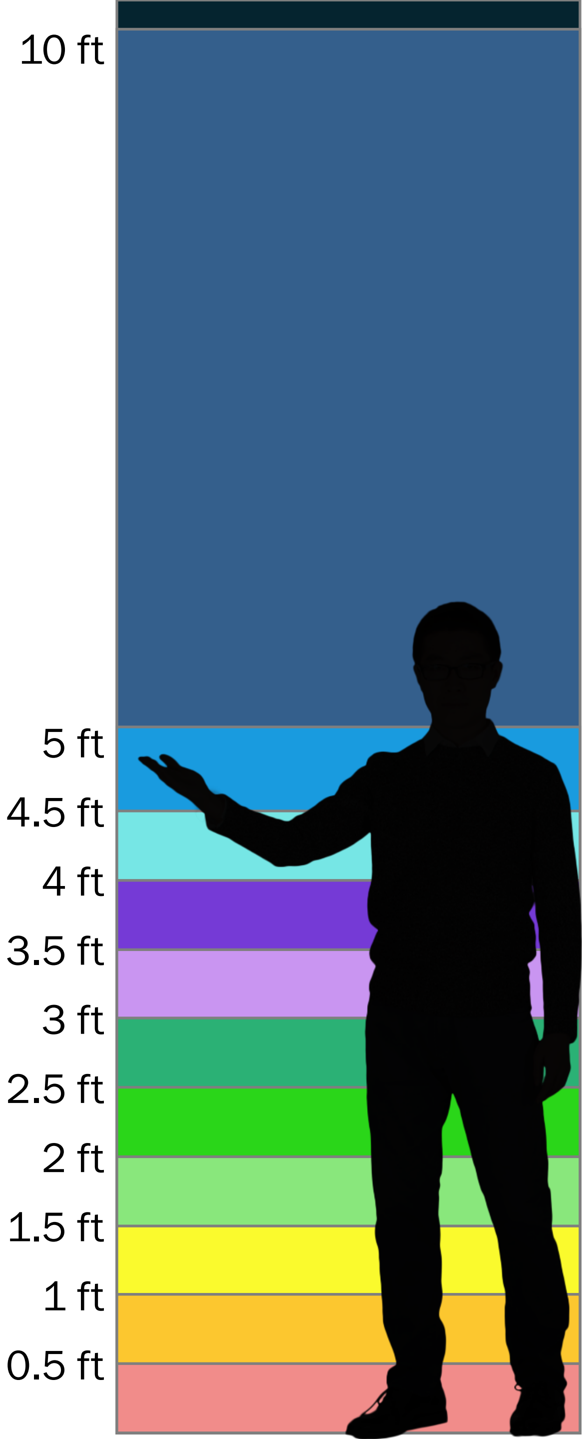
Increase in Tidal Flooding Incidents



Growing Flood Risk in the Bass River District

Future Flood Risks from Coastal Storms





TETRA TECH WOODS HOLE GROUP

Site Level Flood Resilience Strategies

RESTORING COASTAL RESOURCE AREAS

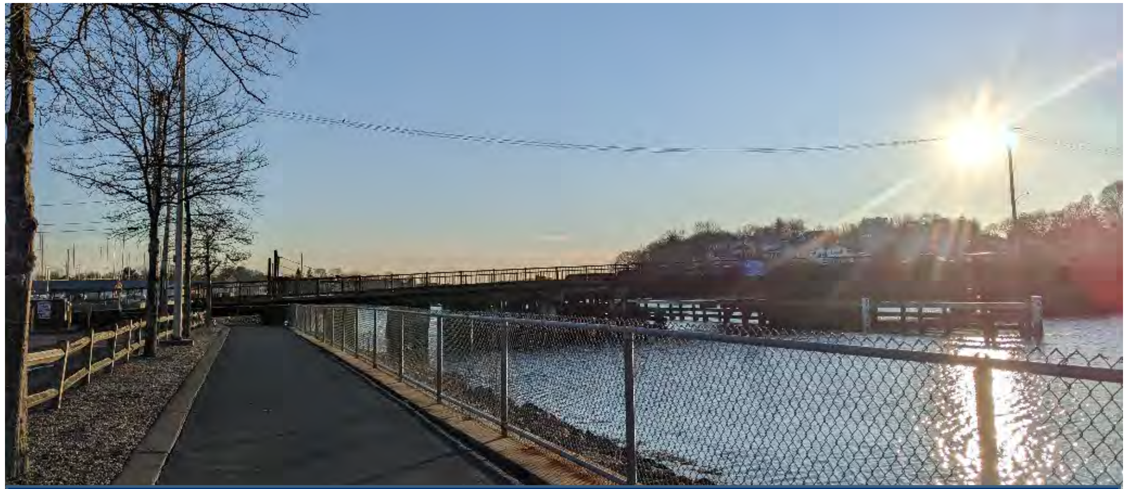
PROTECTING CRITICAL INFRASTRUCTURE

IDENTIFYING PARAMETERS FOR RESILIENT REDEVELOPMENT AT RIVER ST/MCPHERSON DR

AIDING ADAPTATION AT MARINE INDUSTRIAL USES

Options for Site Level Flood Resilience

TEMPORARY FLOOD BARRIERS

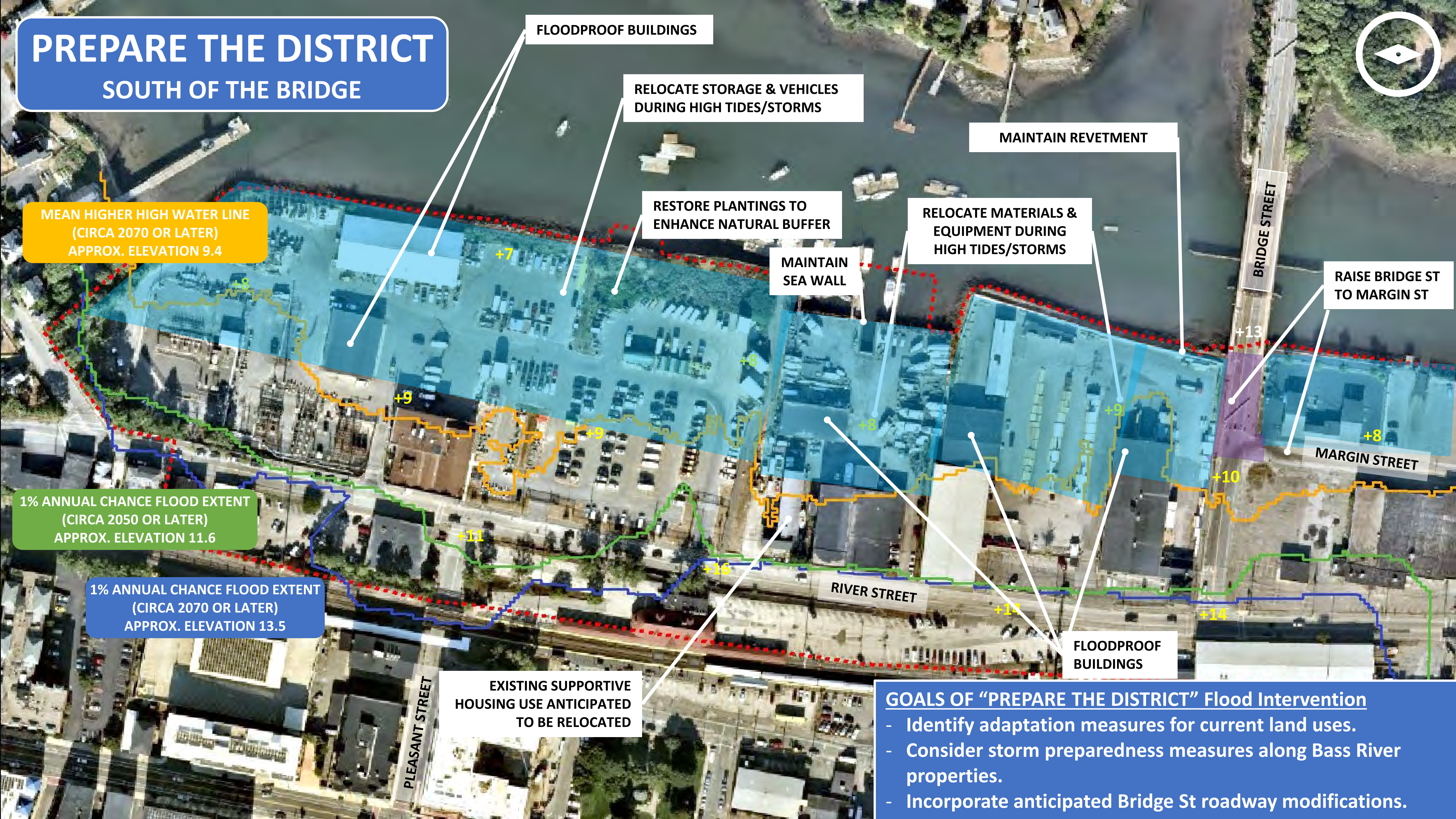


SITE PREPAREDNESS FOR HIGH TIDES/STORMS

ENHANCING VEGETATED BUFFER ALONG SHORE

FLOODPROOFING VULNERABLE STRUCTURES

PREPARE THE DISTRICT
SOUTH OF THE BRIDGE

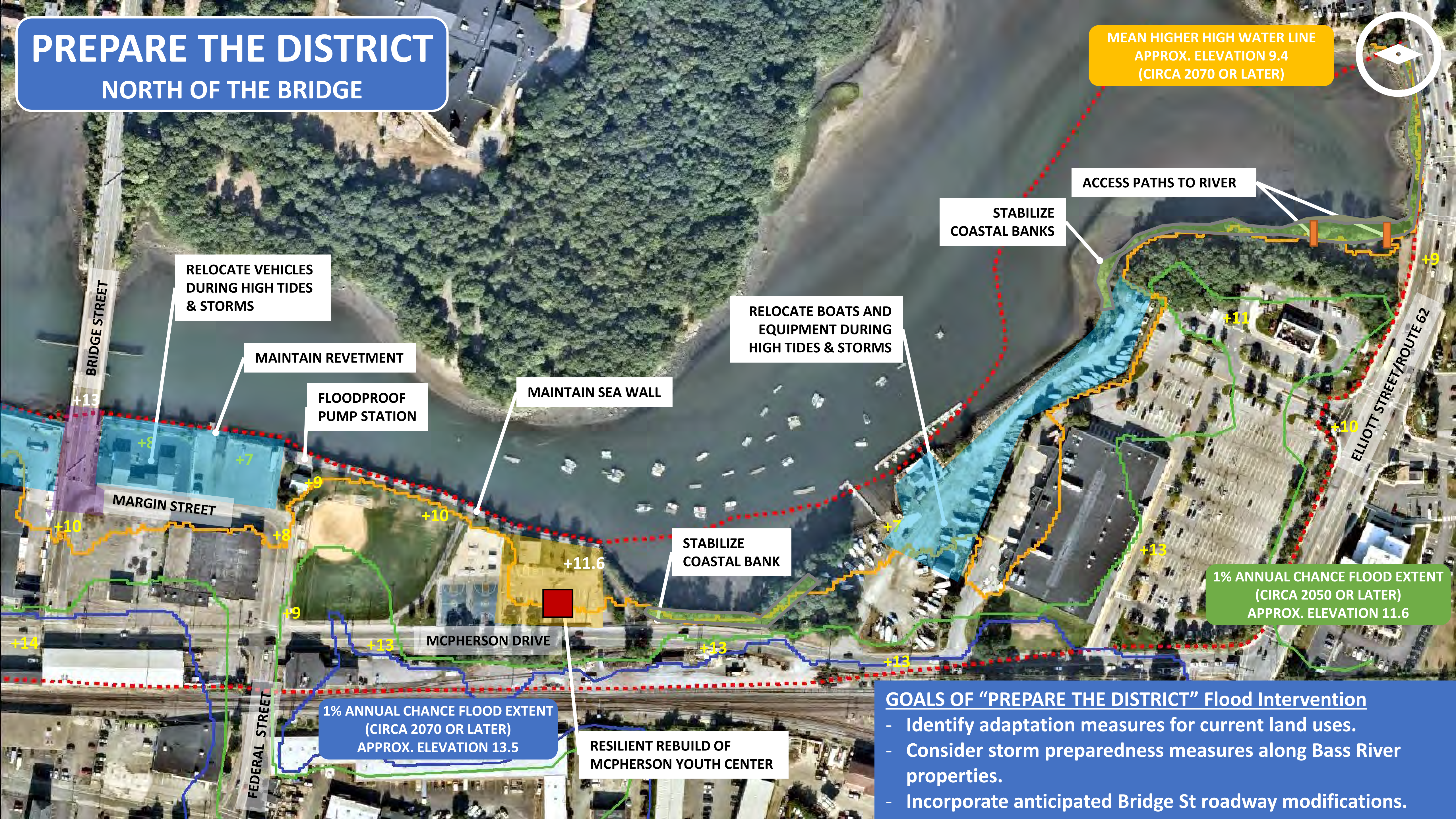


GOALS OF "PREPARE THE DISTRICT" Flood Intervention

- Identify adaptation measures for current land uses.
- Consider storm preparedness measures along Bass River properties.
- Incorporate anticipated Bridge St roadway modifications.

PREPARE THE DISTRICT

NORTH OF THE BRIDGE



GOALS OF "PREPARE THE DISTRICT" Flood Intervention

- Identify adaptation measures for current land uses.
- Consider storm preparedness measures along Bass River properties.
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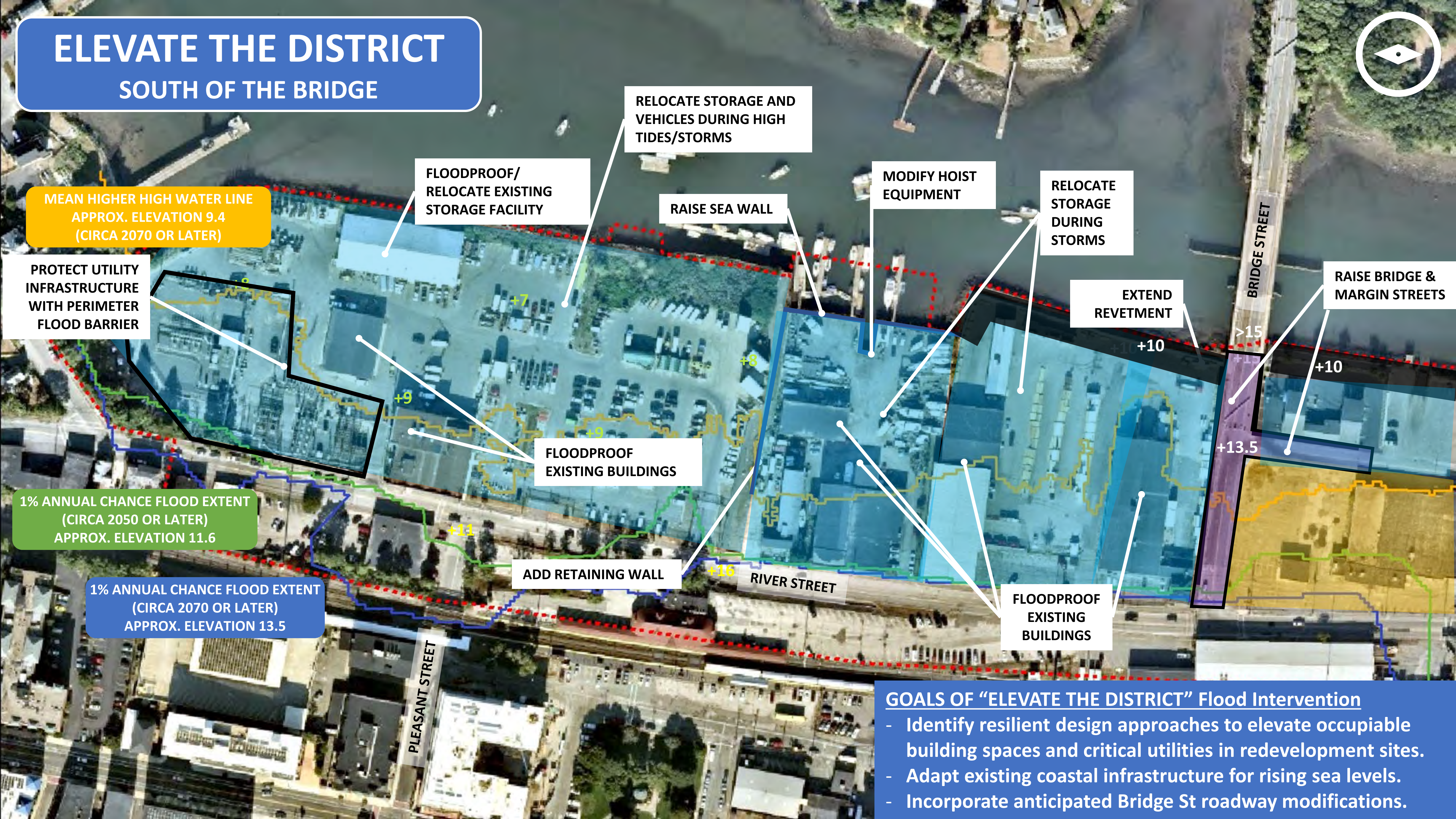
ELEVATE THE DISTRICT

SOUTH OF THE BRIDGE

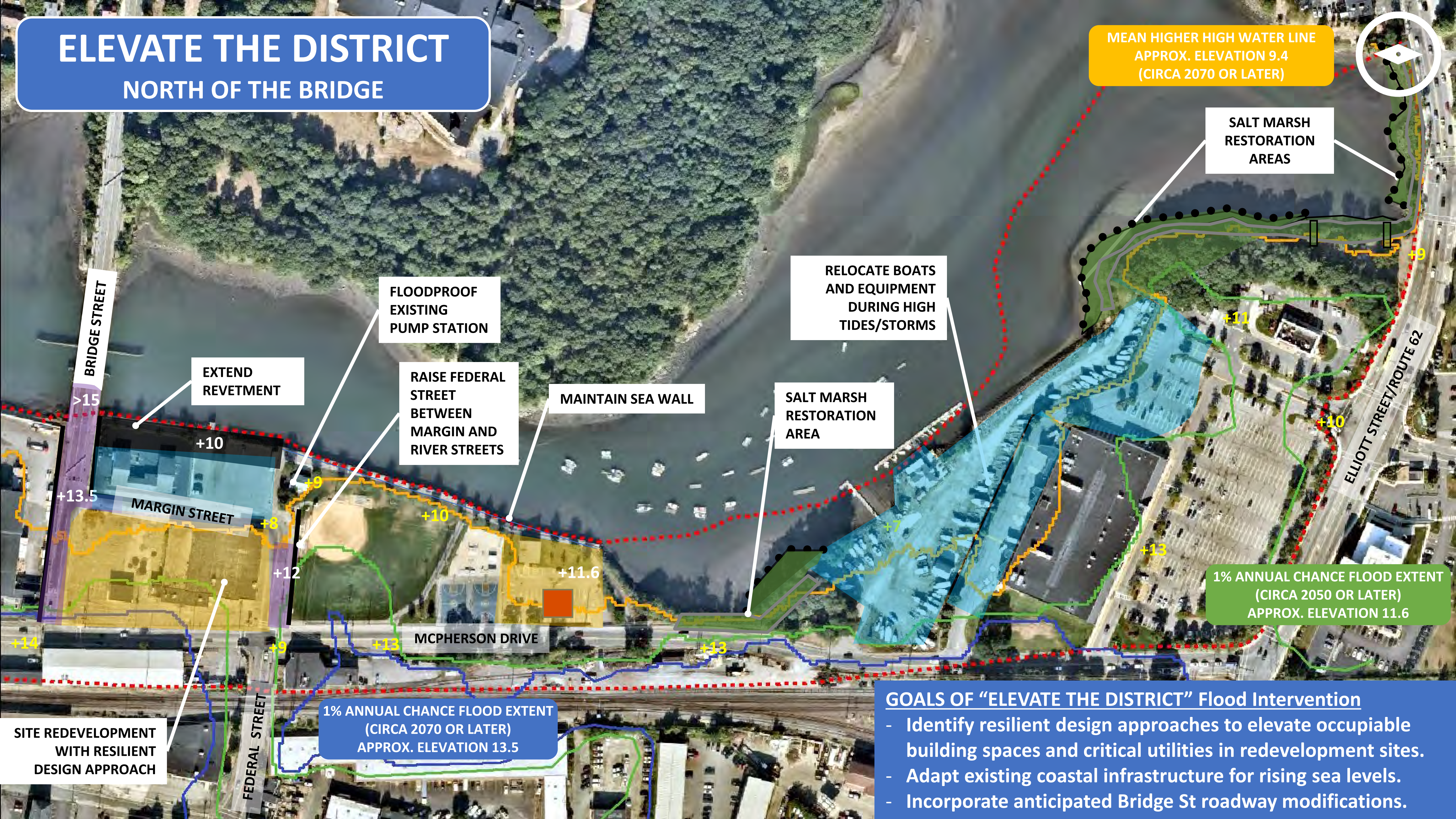


GOALS OF "ELEVATE THE DISTRICT" Flood Intervention

- Identify resilient design approaches to elevate occupiable building spaces and critical utilities in redevelopment sites.
- Adapt existing coastal infrastructure for rising sea levels.
- Incorporate anticipated Bridge St roadway modifications.

ELEVATE THE DISTRICT

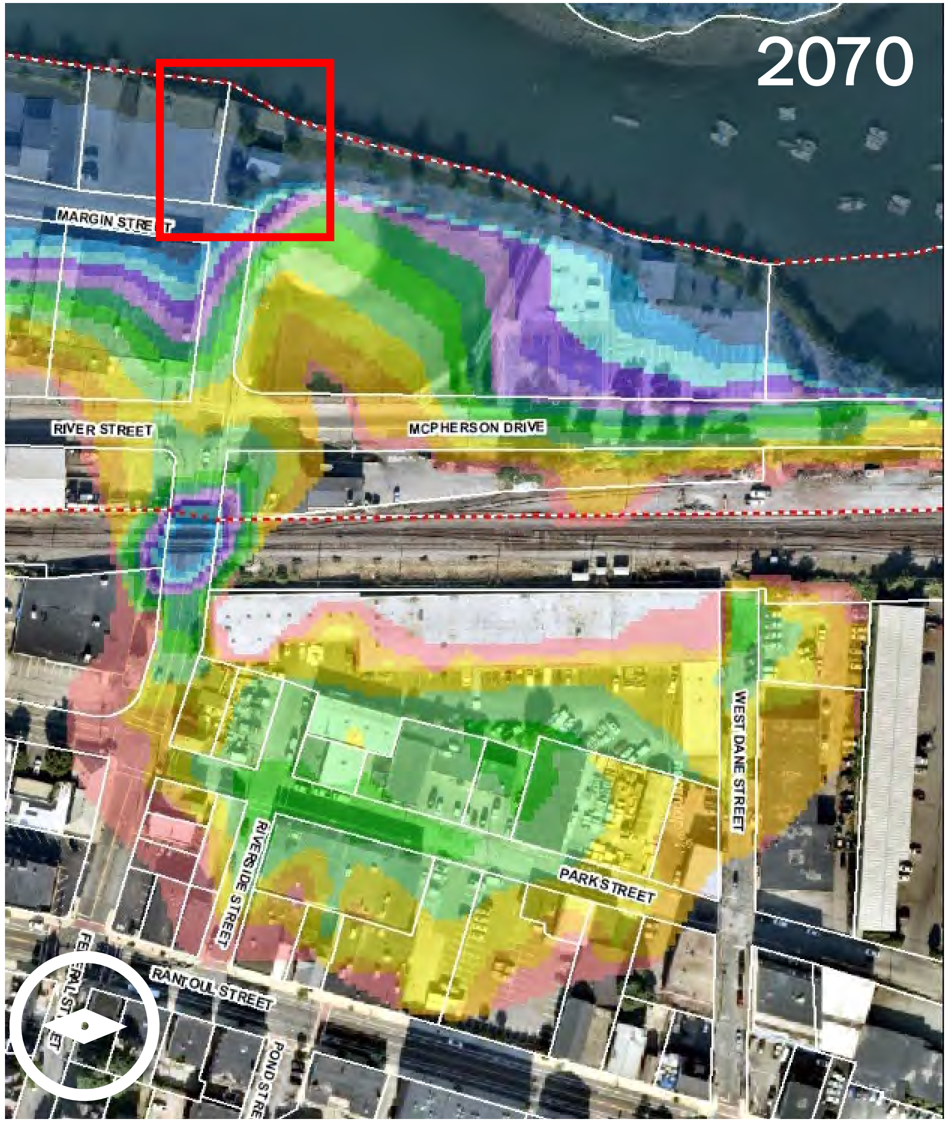
NORTH OF THE BRIDGE



GOALS OF "ELEVATE THE DISTRICT" Flood Intervention

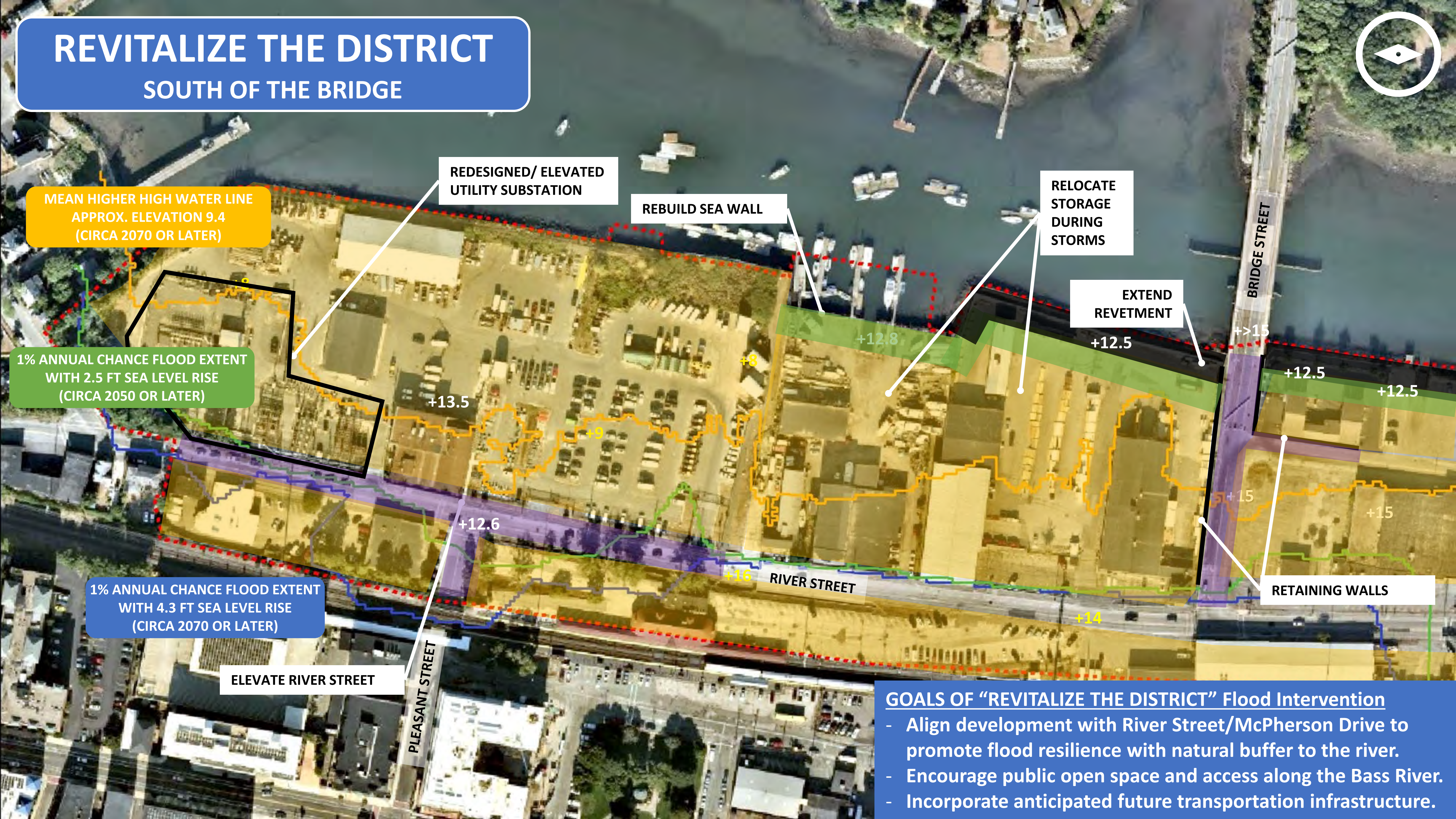
- Identify resilient design approaches to elevate occupiable building spaces and critical utilities in redevelopment sites.
- Adapt existing coastal infrastructure for rising sea levels.
- Incorporate anticipated Bridge St roadway modifications.

Margin Street Stormwater Pumping Station



REVITALIZE THE DISTRICT

SOUTH OF THE BRIDGE



GOALS OF "REVITALIZE THE DISTRICT" Flood Intervention

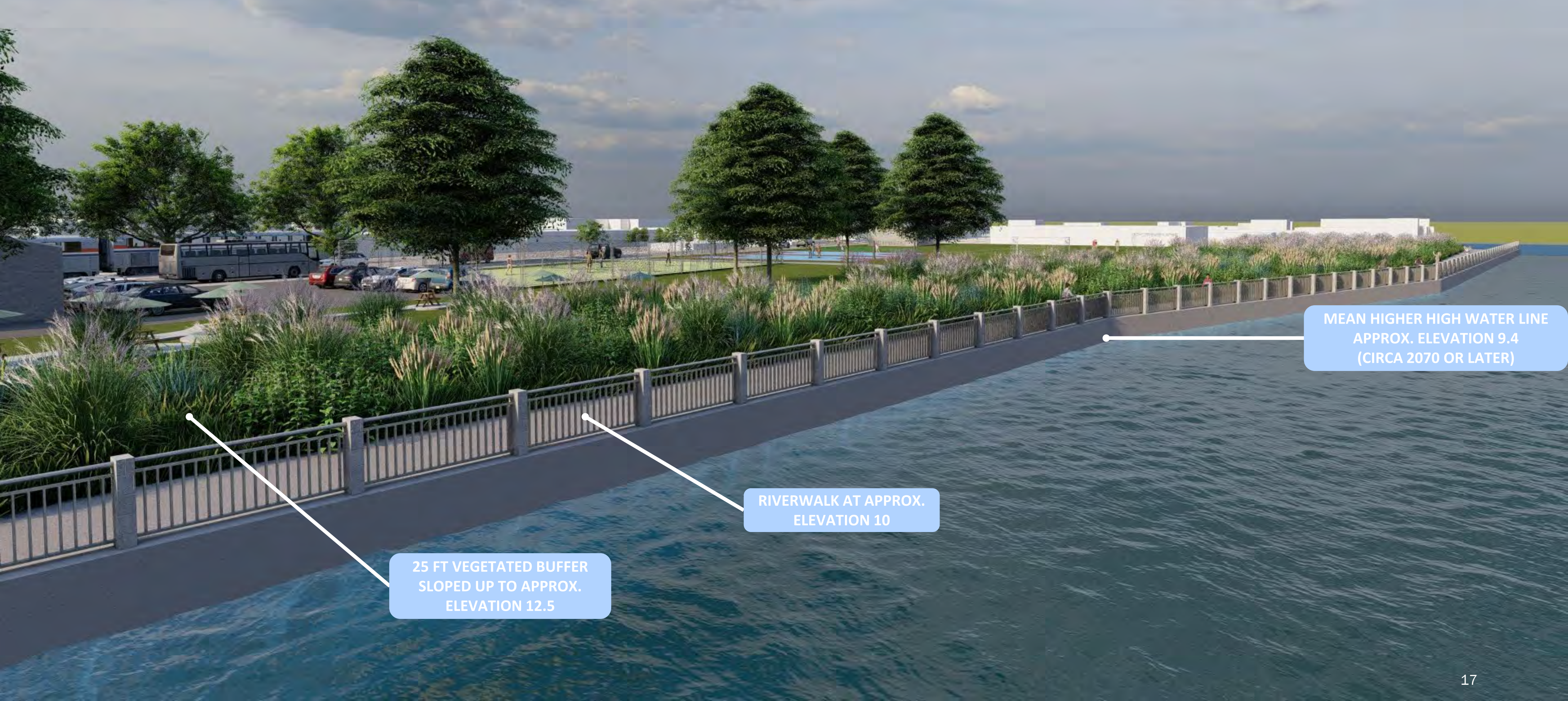
- Align development with River Street/McPherson Drive to promote flood resilience with natural buffer to the river.
- Encourage public open space and access along the Bass River.
- Incorporate anticipated future transportation infrastructure.

REVITALIZE THE DISTRICT
NORTH OF THE BRIDGE

GOALS OF "REVITALIZE THE DISTRICT" Flood Intervention

- Align development with River Street/McPherson Drive to promote flood resilience with natural buffer to the river.
- Encourage public open space and access along the Bass River.
- Incorporate anticipated future transportation infrastructure.

Rendered View from North Looking at Innocenti Park in REVITALIZE Approach



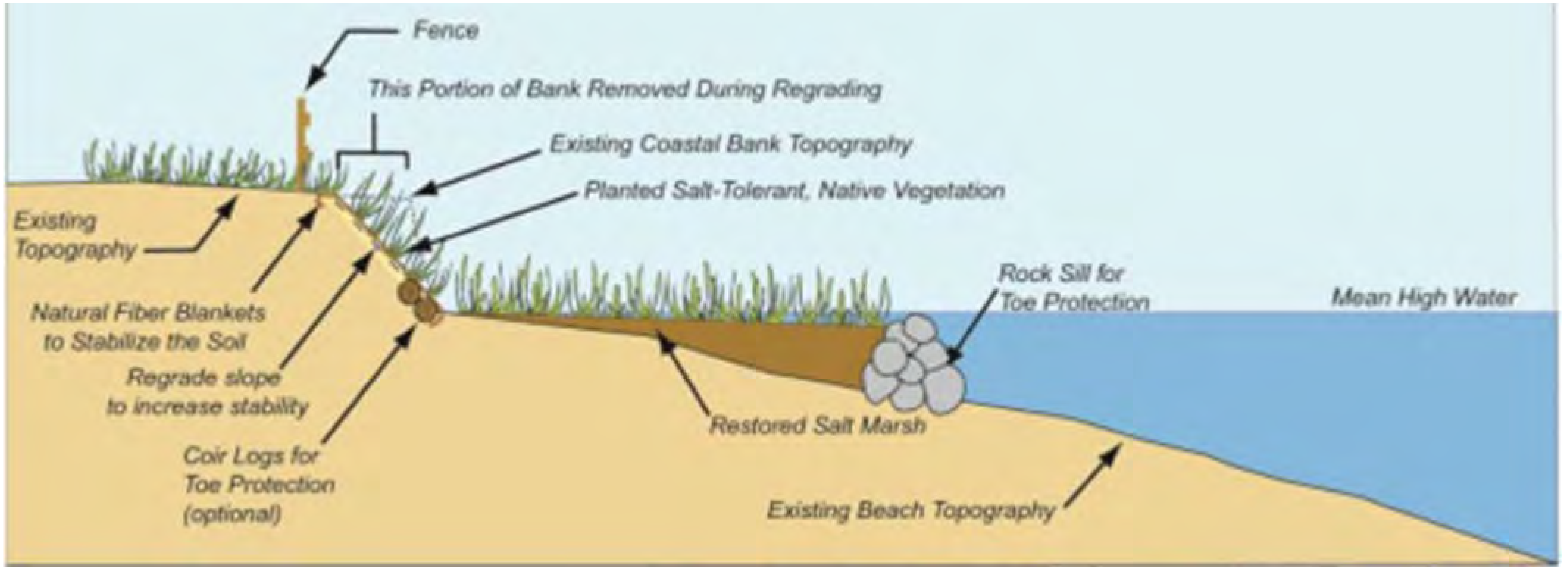
Rendered View from South of Innocenti Park in REVITALIZE Approach

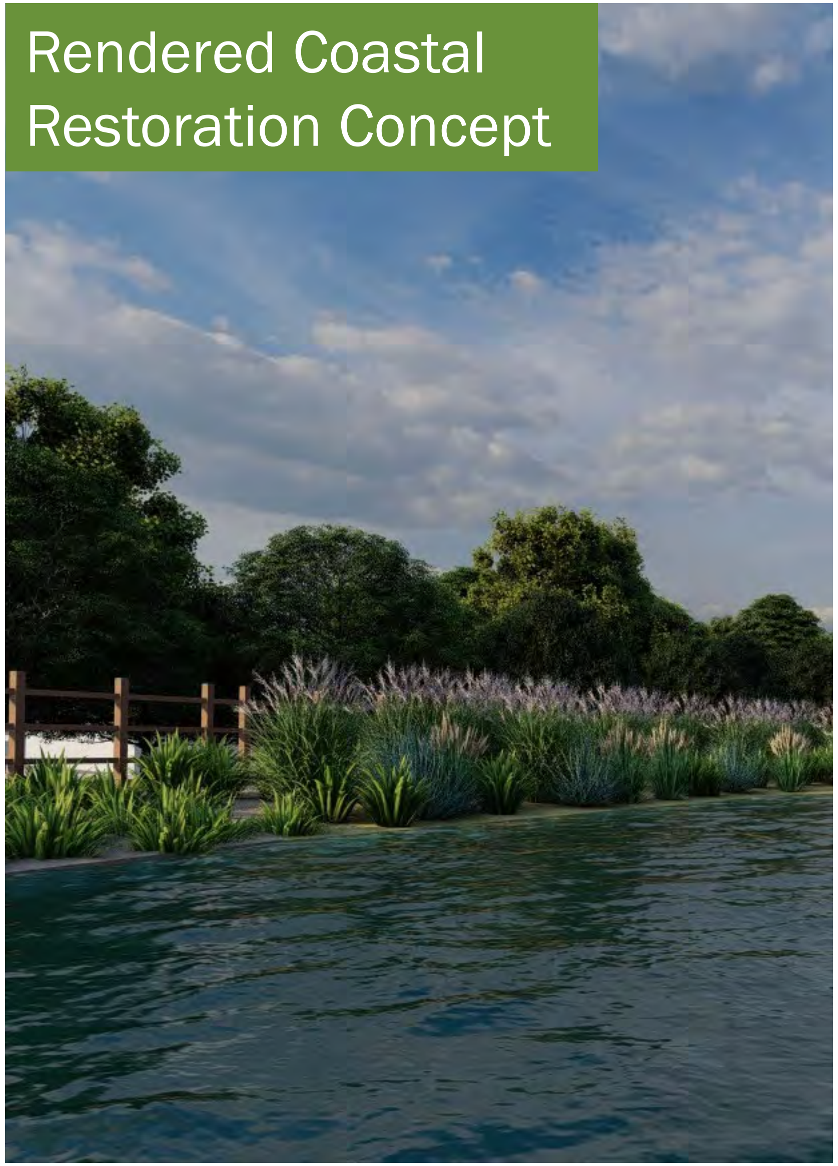
BUFFER THE DISTRICT
NATURE-BASED SOLUTIONS

GOALS OF "BUFFER THE DISTRICT" Flood Intervention

- Enhance existing coastal resource areas along the Bass River.
- Address existing erosion issues on the coastal riverbanks.
- Expand coastal resource areas through creation of living shorelines/salt marsh restoration areas to provide buffer.

Coastal Resource Areas





Rendered View from Elliott St/Rte. 62 of BUFFER Approach

April 29, 2023: Bass River Clean Up

May 21, 2023: Bass River Paddle

Bass River District Resilience Plan Recap

December 2022 – Project Kick Off

January 2023 – Initiate Data Collection and Engineering Asset Evaluation

February 2023 – Initiate Conceptual Resilience Planning and Public Outreach Efforts

March 2023 – Initiate Stakeholder Interviews

April 2023 – Complete Conceptual Resilience Planning and Initiate Flood Interventions Study

June 2023 – Submit Final Report

Community Outreach

- March 9th: Bass River Clean-up #1
- March 11th: Bass River Walk and Talk
- March 21st: Public Forum #1
- April 29th: Bass River Clean-up #2
- May 21st: Bass River Paddle
- June 13th: Public Forum #2

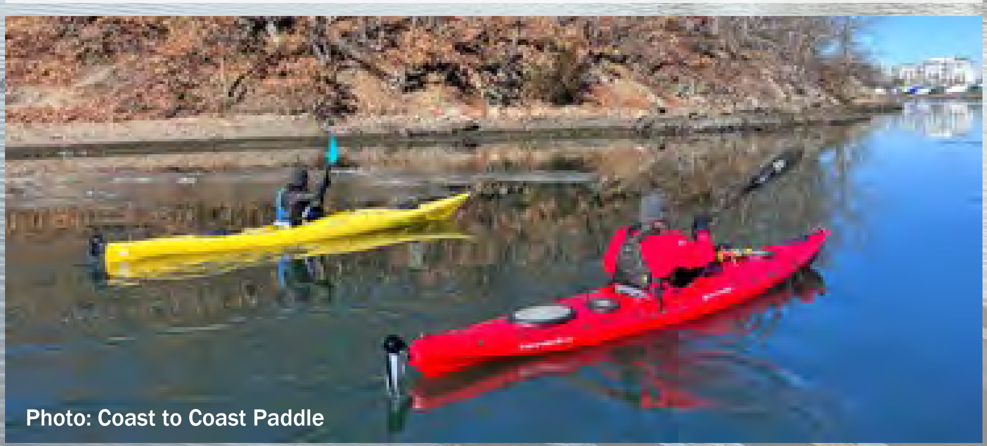


Photo: Coast to Coast Paddle

Thank You & Discussion

Please look for the final report in July 2023!

To stay up to date about the Beverly Bass River District Resilience Study, visit: https://beverlyma.gov/1005/Bass-River-Resilience-Study

For questions or comments about the Beverly Bass River District Resilience Study, contact Erina Keefe, ekeefe@beverlyma.gov