FINAL MEMORANDUM

DATE October 14, 2022 **JOB NO.** 2019-0109

TO Dennis Zaia
Hull Redevelopment Authority
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Hull, MA 02045
Transmitted via email: dz@focushr.com
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FROM Mitchell Buck, P.E.
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Coastal Engineering and Conceptual Design for the HRA Properties, Hull, MA

Dear Mr. Zaia:

The Woods Hole Group, Inc. is pleased to present this Technical Memorandum (Memo) summarizing the methodologies and results for the flood risk mapping and conceptual design services completed for the Hull Redevelopment Authority (HRA) based on the agreed upon scope of work dated June 14, 2019. The HRA was created by the Town of Hull (Town) in 1961 under a charter from the Federal and State Government as part of an urban renewal program. The HRA currently owns ten (10) properties (Properties) in the vicinity of Nantasket Beach within Hull (Figure 1). We understand that the HRA intends to redevelop these vacant properties and therefore need to understand the risks of storm flooding, impact of future sea level rise, and how this will influence future development. As part of this study, the Woods Hole Group reviewed previously completed work for this area of Hull including the *Climate Change and Extreme Weather Vulnerability for the Central Artery of Boston for the Massachusetts Department of Transportation* (Bosma et al., 2015), the *Coastal Climate Change Vulnerability Assessment and Adaption Study* (Kleinfelder, 2016), *Letter of Map Revision (LOMR) Application for Town of Hull, Plymouth* (Woods Hole Group, 2016), and *Additional Engineering Services for the Town of Hull WPCF and Pumps Stations* (Woods Hole Group, 2019).

Woods Hole Group first completed a flood risk mapping analysis that generated data deliverables to help understand the flood risks including probabilistic flood risk maps, flood pathways maps, establishment of design flood elevations (DFEs), and a FEMA FIRM evaluation. Note that these data products are only considered valid for the HRA Properties themselves and the results are not confirmed for abutting properties. Three (3) coastal resiliency concepts (Concepts) were then developed to improve the coastal resiliency and mitigate flood risks for the HRA properties that would allow for future development. The Concepts are presented as graphics intended to help guide the HRA and inspire potential collaborators on the types of coastal resiliency measures could be implemented, the level of protection that they provide, and what the general kind of development that they would allow for. No actual infrastructure such as buildings is included since the Concepts constitute a conceptual planning level design that will need to undergo a full engineering design and permitting process before they can be implemented. Design aspects can be modified or are potentially interchangeable between Concepts. This Memo is not intended to remove any responsibility from the HRA, planners, developers in determining the specific design criteria, regulatory requirements, or building codes for a future project.

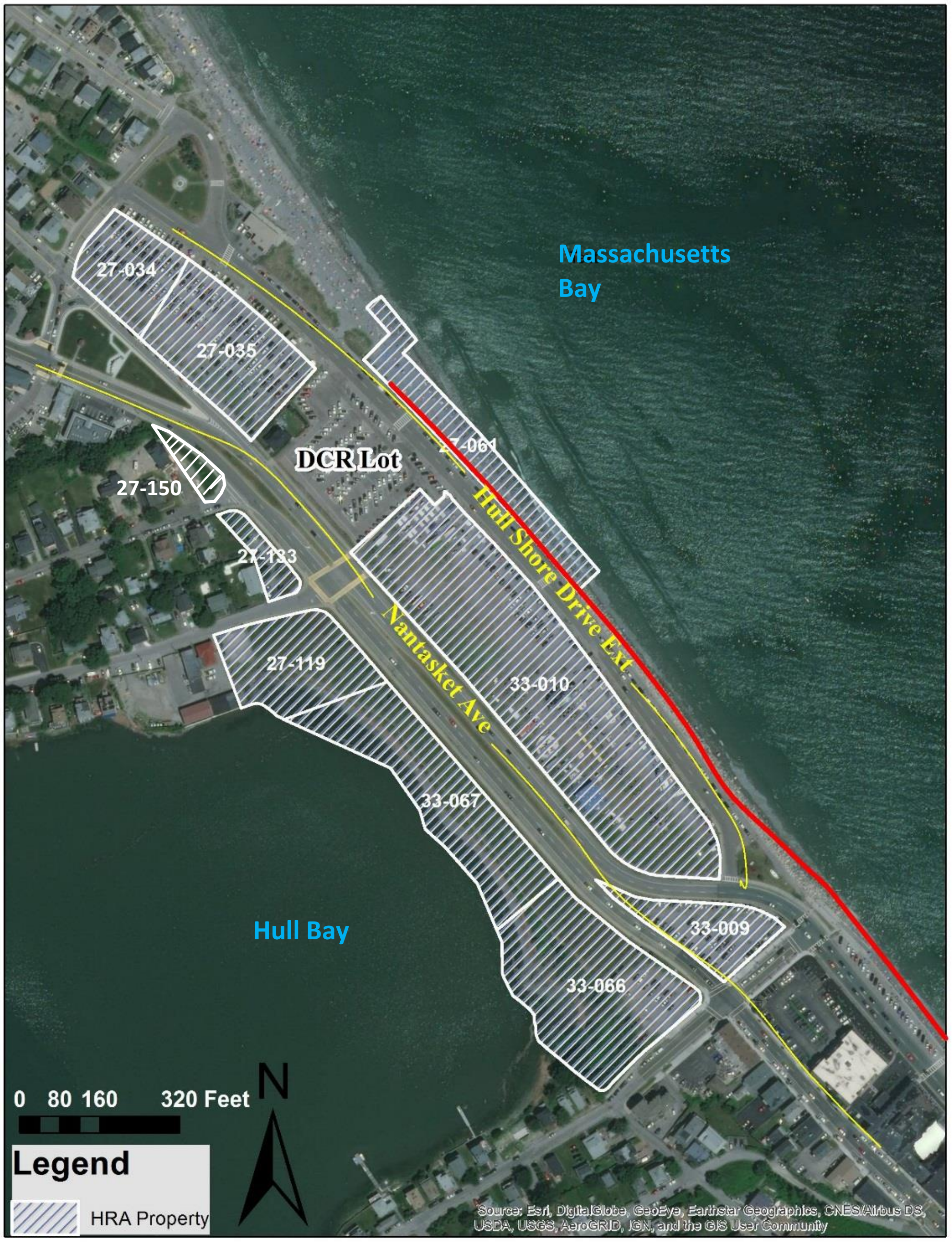

Figure 1. Overview of the ten HRA Properties in Hull, MA.

Background & Site Overview

Available background data for the site was compiled to provide a basis for understanding the site and for use in model development. The HRA Properties (Properties) consist of ten (10) separate parcels including four (4) parcels between Nantasket Avenue and Hull Shore Drive Extension except for the DCR parking lot, one (1) beach parcel on Nantasket Beach, and five (5) parcels on the Hull bayside as indicated by the white cross-hatching in Figure 1. The figure also shows Nantasket Seawall as a red line that extends south from the DCR Lot and has additional protection from a rock revetment fronting it throughout the stretch seaward of the HRA parcels. This seawall has provided coastal resiliency for the landward parcels, but it is approaching the end of its design lifetime and efforts have been ongoing by the Town to design its replacement.

Figure 2 shows the existing topography for the Properties as a series of color contours developed from the most recently available LIDAR data set collected from U.S. Geological Survey (USGS) in 2014 and referenced to the North American Vertical Datum of 1988 (NAVD) in feet (ft). Contours above 15 NAVD-ft or below 10 NAVD-ft are not shown in an effort to limit the number of contours in the figure but are typically not present on the HRA properties anyway. The contours indicate that there is a 5-foot drop in elevation, 15 NAVD-ft to 10 NAVD-ft, from the northern to southern portion of the HRA Properties, which will play a role in the movement of floodwaters.

In order to help the HRA evaluate permitting requirements for future projects, the coastal resources and regulated areas present on the properties were assessed from publicly available sources. Figure 3 maps the coastal wetlands resources from the Massachusetts Department of Environmental Protection (DEP) along with several other regulatory layers. The majority of the Properties area within the Barrier Beach System that encompasses the entire Hull peninsula between Massachusetts Bay (oceanside) and Hull Bay (bayside). The Barrier Beach System includes subcategories for Coastal Beach and Coastal Dune. Coastal Beach is located seaward of the seawall on the oceanside, and Salt Marsh is mapped along the bayside shoreline. Between these two shorelines the Barrier Beach likely consists of altered historic even though it was not mapped by DEP. However, the primary dune starts north of the HRA Properties, and it is possible that this resource may extend into this area. These wetland resources are significant because Barrier Beach, Coastal Beach, Coastal Dune, and Salt Marsh each have their own separate regulatory performance standards that will have to satisfied by a future project if it falls within those resource areas or buffers. A wetlands resource delineation will need to be conducted to confirm the presence of these resources and flag the boundaries before any permits for a future project can be filed.

The historic high-water (HHW) line is indicated as a black and white checkered line, which is typically delineated based on historic maps and/or aerial photographs. The HHW line represents the landward limit for DEP Chapter 91 jurisdiction, and any project that extends seaward of this line will be within their jurisdiction requiring Chapter 91 licensing and possibly Army Corp of Engineers permitting. Since the Hull Properties are located within FEMA's regulatory floodway, they are also located within Land Subject to Coastal Storm Flowage that has additional standards. Additional consideration should be made for the Natural Heritage's Estimated Species & Priority (NHESP) Habitat shown as a green dashed line in the northern oceanside parcels. This resource area regulates impacts to habitat and species of concern and for this area in Hull, the species of concern are Piping Plovers and Common Terns. Within the NHESP, the types of projects that can be implemented are closely regulated, and there can also be time of year restrictions for construction. For Piping Plovers, there are typically time of year restrictions during the nesting season: April 1 to August 31.

Figure 2. Topographic (elevation) map with 1-foot contours for the HRA Properties (checker board outline).

Figure 3. ***Delineated DEP wetland resource layers, NHESP priority habitat, and historic high water for the HRA properties.***

Water Level Data Sources

The Properties are vulnerable to flooding and inundation during significant storm events and this section identifies the available data sources of extreme (storm) water levels needed for the subsequent analyses. The FEMA Flood Insurance Rate Map (FIRM) panel #25023C0038J (effective 7/17/2012 & revised 1/24/2018) for this location indicates that the Properties are within the FEMA Special Flood Hazard Area (SFHA) that will be discussed in detail later. The FEMA mapping is only based on the 100-year return period (or 1%-annual-chance) storm and, therefore, is not necessarily the best source to use for flood risk planning since it does not account for different storm levels, climate change or future sea level rise. The closest available record of water level data is the Boston NOAA Station 8443970 shown in Figure 4. Here the sea level has been rising 2.87 millimeters/year (0.11 inch/year) based on monthly mean sea level data from 1921 to 2020, which is equivalent to a change of 0.94 feet in 100 years. However, the recent rates of sea level rise are exceeding their historic rates and are only further projected to further accelerate in the future. Therefore, other sources of future sea level rise need to be consulted for future planning.

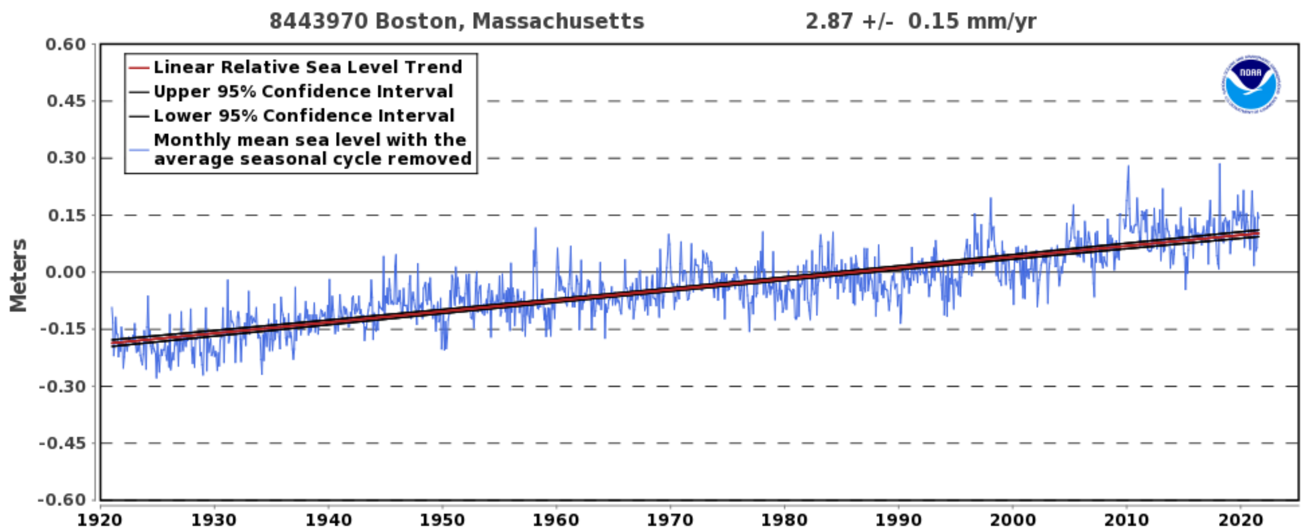

Figure 4. Boston NOAA Station 8443970 historical sea level trends plot.

For this project, water level projections that incorporate future sea level rise trends were extracted from the Boston Harbor Flood Risk Model (BH-FRM), which was created by Woods Hole Group and University of Massachusetts at Boston (UMB) for the Massachusetts Department of Transportation (MassDOT) (Bosma et al., 2015). The BH-FRM was developed using the hydrodynamic ADvanced CIRCulation model (ADCIRC), which is able to accommodate complex geometries and bathymetries. The BH-FRM model domain encompasses the entirety of Boston Harbor including the Town of Hull and is defined using a grid mesh that is generated based on regional bathymetry and topography. The BH-FRM invokes a Monte Carlo storm simulation approach to estimate the probability of flooding throughout the Boston Harbor region based on a large suite of storms (more than 200), unlike FEMA mapping that only looks at a single large storm event. The BH-FRM produces model results for the entire coastline of Hull since it is a grid-based model, unlike FEMA's mapping that only produce results at select locations (transects) along the coast with results interpolated between. The BH-FRM also incorporates present day water levels with future projections of sea level rise (SLR) based on the *Global Sea Level Rise Scenarios for the US National Climate Assessment* (Parris, 2012), which includes regional considerations for the Northeast and fully evaluates both present- and future-day storms.

Tables 1 provides the water surface elevations for normal lunar tides extracted from the BH-FRM model, which are shown as tidal datums that represent that arithmetic mean of that particular datum over a monthly lunar tidal cycle. Note that the mean tidal range (MR) is a height (in feet), not an elevation, which is the difference between MLW and MHW. Table 2 provides the water surface elevations for extreme water levels (storm surge) extracted from the BH-FRM model for annual percent chance (or return period) storm events. Results are provided for both present day and the future years 2030 and 2070. The year 2030 was chosen because it represents a near-future (10-year horizon) condition while 2070 was chosen because it is associated with the approximate service life of any future development or structure (50-year horizon).

Table 1. Projected tidal datum elevations (NAVD-ft) under normal tides for present and future day based on the BH-FRM results.

Tidal Datum	Tidal Datum	Water Surface Elevation (NAVD88, feet)					
		2030		2030		2070	
		Ocean	Bay	Ocean	Bay	Ocean	Bay
Mean Lower Low Water	MLLW	-3.6	-3.8	-2.4	-2.7	-0.7	-1.0
Mean Low Water	MLW	-3.3	-3.6	-2.2	-2.4	-0.5	-0.7
Mean Tide Level	MTL	1.3	1.2	2.4	2.5	4.3	4.3
Mean High Water	MHW	5.9	6.1	7.1	7.4	9.0	9.3
Mean Higher High Water	MHHW	6.3	6.5	7.5	7.8	9.4	9.6
Mean Tidal Range (feet)	MR	9.2	9.7	9.3	9.8	9.5	10.0

Table 2. Projected water surface elevations (NAVD-ft) for return period storms (% / years) in present and future day based on the BH-FRM results.

Annual Percent Chance (%)	Return Period Years	Water Surface Elevation (NAVD88 feet)		
		2030	2030	2070
0.1	1,000	13.0	14.2	15.5
0.2	500	12.7	13.8	14.8
0.5	200	12.1	13.3	14.3
1.0	100	11.9	12.8	13.8
2.0	50	11.5	12.5	13.4
5.0	20	11.0	12.0	12.3

Probabilistic Flood Mapping

Woods Hole Group utilized the storm modeling results from the Boston Harbor Flood Risk Model (BH-FRM) to develop probabilistic flood maps showing the annual-percent-chance risk of flooding for the HRA Properties (white outline) in both present day (Figure 5) and future 2030 and 2070 storm events (Figures 6 & 7), respectively. These Figures show the annual percent chance risk that any given patch of ground will be inundated (i.e., wet) due to storm flooding in any given year based on the colored shading. The figures do not indicate the severity of that flooding, which that could be very shallow (inches) or deep (feet). They are simply intended to demonstrate the annual percent risk of where storm flooding (inundation) could occur in both present and future day. This is different from the FEMA mapping that shows both the extent and severity of flooding inundation for a single storm (1%-annual chance / 100-yr) in present day. Note that these probabilistic flood maps are only valid for the HRA properties themselves since the BH-FRM results were refined within the context of those property boundaries.

The present-day flood risk as shown in Figure 5 indicates that the majority of the Properties between Nantasket Avenue and Hull Shore Drive Extension has a 5% annual chance of flooding with a higher percent chance (10-20%) at the coastline due to runup and overtopping processes at the seawall/revetment. It is also apparent that there is an area at lower risk for annual flooding in the southern portion of the central HRA parcels due to higher ground elevation (15 NAVD-ft). This is indicated by the lack of colored contours in the mapping. On the bayside, there is minimal flooding since Hull Bay is sheltered from open ocean waves and has a restricted fetch that only allows for small locally generated wind-waves to propagate. It is also apparent that Nantasket Avenue acts as an elevated barrier between the ocean and bayside since the annual probability of flooding along the roadway is minimal.

The near-future flood risk in 2030 (10-year horizon) as shown in Figure 6 indicates that while the extent of the flood risk mapping is similar to the present-day (Figure 5), the probability of flooding increases within this area. The annual percent chance flood risk for the central HRA Properties increases from 5% to 10% and there are similar increases of 20% or more along both the ocean and bay coastlines. The portion of the HRA Properties located on higher ground still remains mostly dry.

The distant future flood risk in 2070 (50-year horizon) as shown in Figure 7 indicates that there is a substantial increase in the flood risks where there is a 30% chance of annual flooding for the central portion of the HRA Properties except for the most northern parcel that has a 100% annual chance of flooding. Along the seawall the annual flood risk is upwards of 100%. The flood elevations are now high enough that the flood risk extends from the oceanside and across northern and southern portions of Nantasket Avenue connecting to the bayside. The portion of the HRA Properties and Nantasket Avenue shows minimal probability of flooding. While the extent of flooding (inundation) is severe in 2070 for the HRA Properties, it should be noted that under this scenario that much of the rest of the Hull peninsula would likely be experiencing severe flooding (inundation) as well.

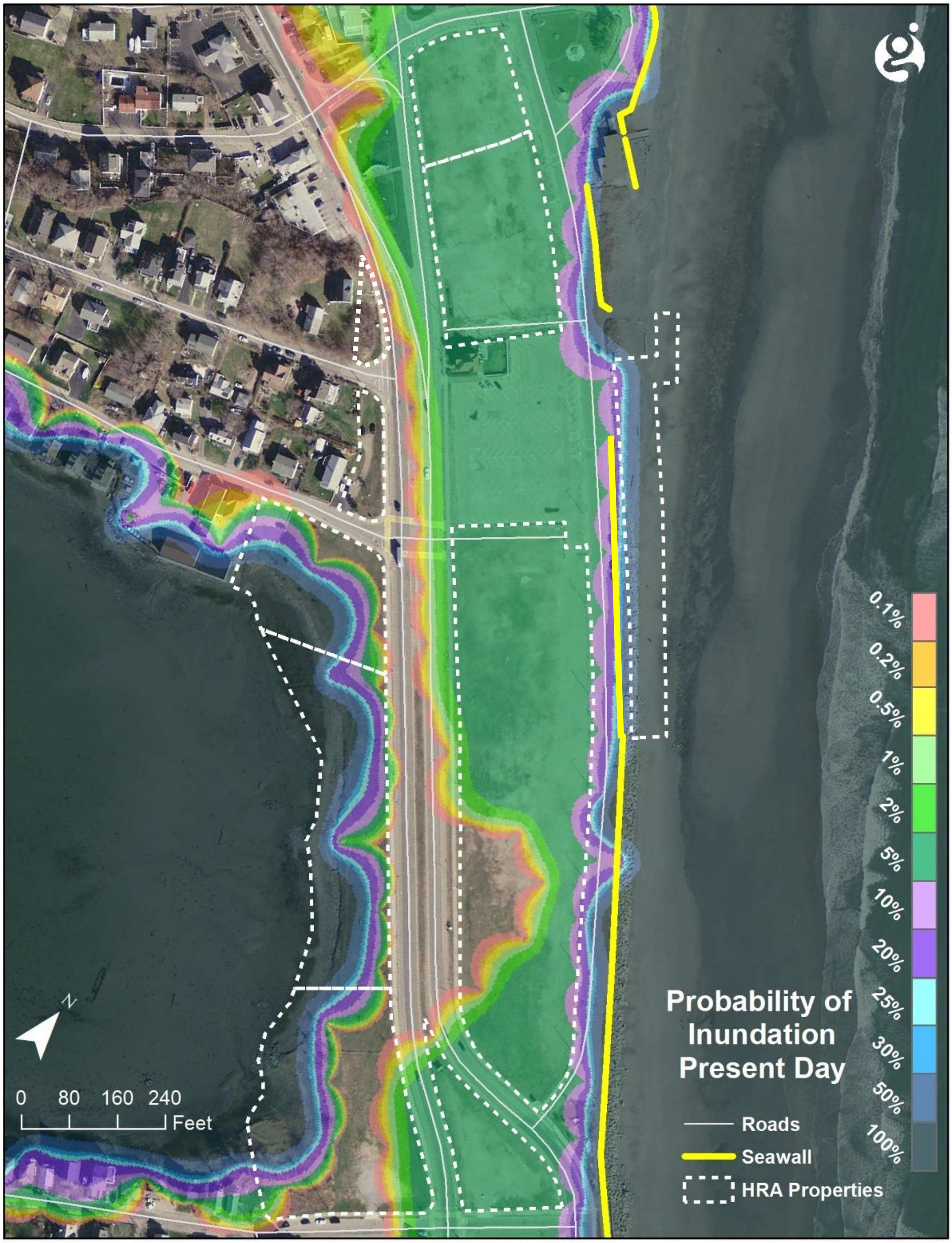

Figure 5. Annual percent chance (probability) of flooding (inundation) for present day conditions using the BH-FRM results for the HRA properties (white outline). Results only valid for HRA properties.

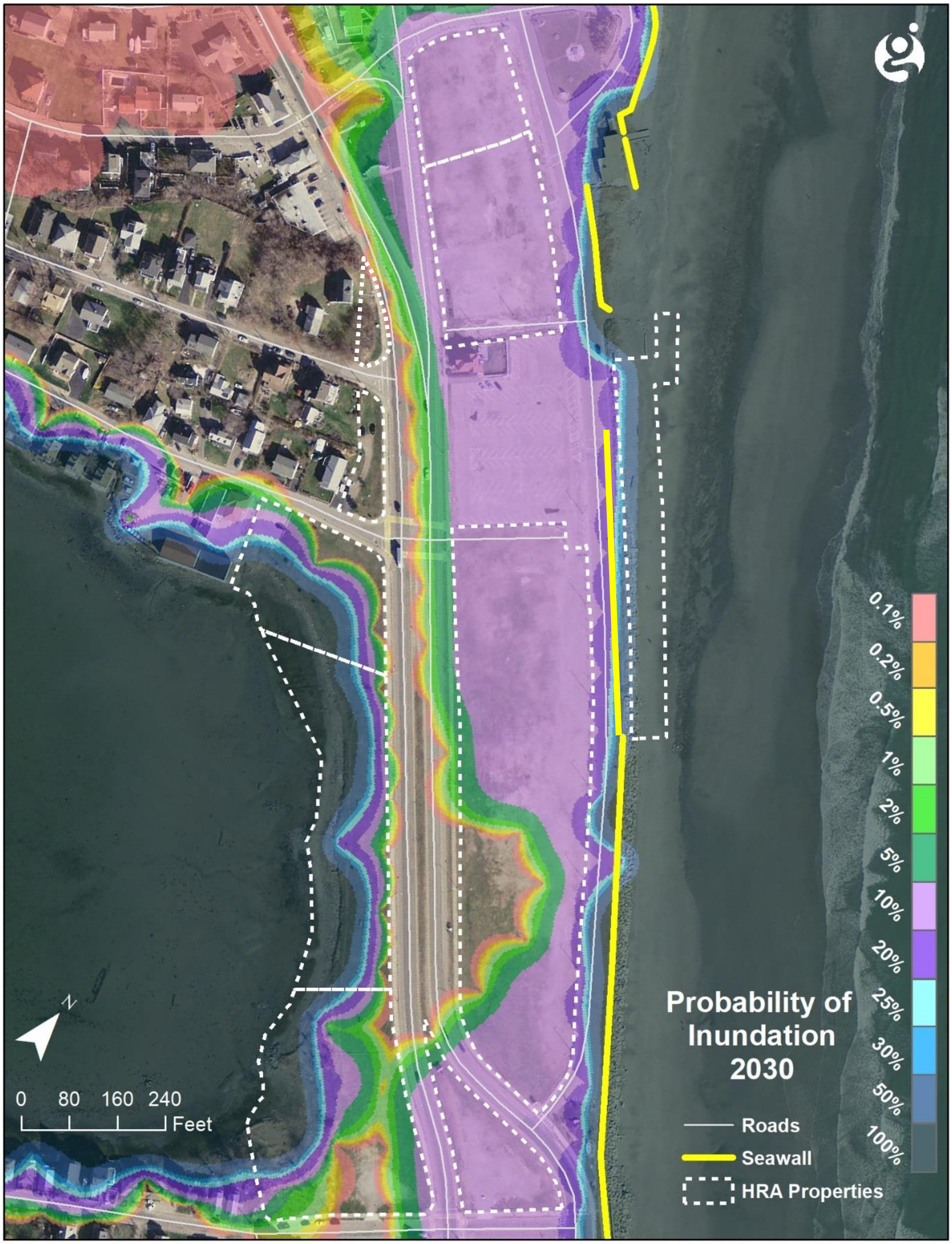

Figure 6. Annual percent chance (probability) of flooding (inundation) in 2030 with SLR using the BH-FRM results for the HRA properties (white outline). Results only valid for HRA properties.

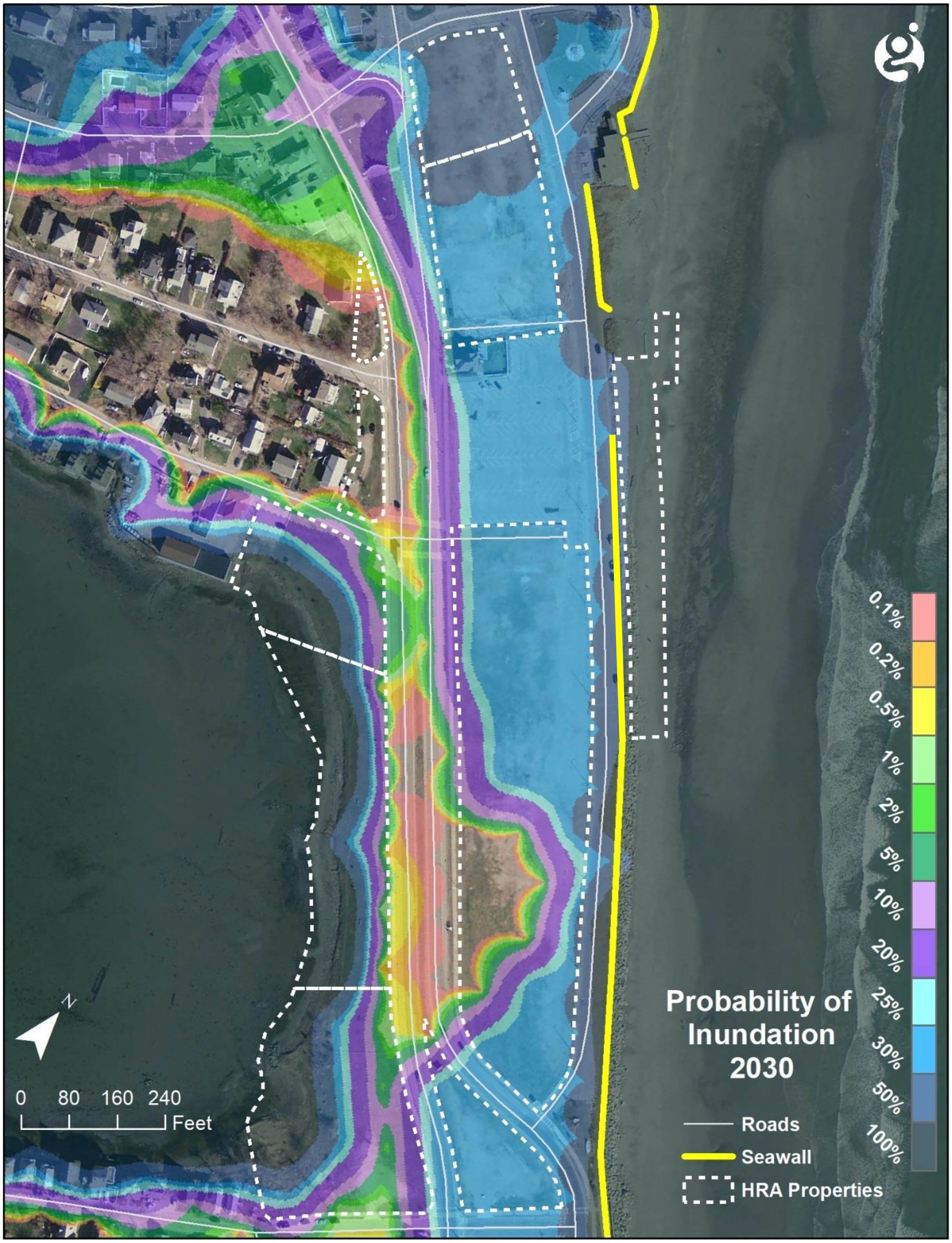

Figure 7. Annual percent chance (probability) of flooding (inundation) in 2070 with SLR using the BH-FRM results for the HRA properties (white outline). Results only valid for HRA properties.

Flood Pathway Analysis

While the probabilistic flood maps (Figures 5, 6, & 7) developed for the HRA Properties demonstrate the annual risk of flooding (inundation) for any patch of ground, the figures do not show the time dependent storm progression of where flood waters enter, where those floodwaters flow to, or where they ultimately end up. The flood pathway analysis described in this section attempts to answer these questions utilizing the same BH-FRM results as the probabilistic flood mapping. The intent here is to identify points of flood water entry (vulnerabilities), characterize the flood dynamics and progression as flood waters move overland, and finally identify areas where flood waters ultimately end up resulting in ponding. This is an important exercise since some areas may only experience short-term intermittent flooding as floodwaters move overland, while other areas may experience static ponding where these flood waters collect and can cause further damage. Ultimately, these results will aid in the development of resilient building adaptation designs and the location of development that accounts for both present- and future-day conditions. For instance, areas where flood waters collect (pond) may not be ideal to construct a new residential building, however, they may be more readily placed in areas where intermittent overland flow occurs so long as the buildings are designed accordingly.

Figures 8, 9, and 10 show the flood pathway mapping for present day, 2030, and 2070, respectively, where:

- The orange arrows indicate entry points of direct flooding from the ocean or bay,
- the black curved arrows indicate wave overtopping (splash over) of the seawall,
- the black squiggly arrows represent overland floodwater progression as sheet flow, and
- the black dashed arrows indicate flows that exit out of the study area.

Additionally, the blue-pink color shading helps illustrate the time-dependent flood progression where dark blue represents the source of flood water entry, light blue indicates the flooding progression overland, and the pink represents where the flood waters end up. However, it should be noted that if flood waters initially inundate an area and remain there that the color shading stays blue (such as in the northern HRA parcel).

Figure 8 shows the time-dependent flood pathways and progression results for present day (current risk) that can be interpreted as follows:

1. The figure indicates that the northern portion of the HRA parcels, where there is no coastal structure and low elevation, is the first entry point for storm flooding as indicated by the blue shading and orange arrow near the David Cook Comfort Station.
2. Simultaneously there is wave runup occurring along the entire length of Hull Shore Drive Extension seawall that results in overtopping flows over the seawall (black curved lines).
3. These overtopping flows become overland sheet flows on the ground following natural gradients across Hull Shore Drive Extension and onto the central HRA parcels.
4. Nantasket Ave is built on higher ground which acts as a barrier to flood waters from reaching the bayside. From here the floodwaters are directed north as sheetflow, represented by the black squiggly lines, following the 5-ft vertical drop in gradient from the southernmost to the northernmost HRA parcel until reaching the northern most parcel where they pond as indicated by the color shading.
5. Additional flooding occurs inland (north) from the northernmost parcel to Nantasket, Samoset, and Manomet Avenues as indicated by the large, dashed arrow.
6. On the bayside coastline, flooding is primarily the result of direct stillwater storm flooding since waves are small since Hull Bay is sheltered from open ocean wave energy and Hull Bay has a restricted geometry with short fetch lengths over which only small local wind-waves can be generated. The entry

points for flooding along the bayside occur at the northern and south corners of the HRA bayside parcels as indicated by the orange arrows, but the flooding is contained to the shoreline meaning flooding form the bayside is minimal during present day conditions.

Figure 9 presents flood pathways and progression results for 2030 conditions, which represents how risks can change in the near-future (approximate 10-year horizon) due to sea level rise. Overall, the extent (color shading) and progression (arrows) of flood waters are similar to present day conditions, but the flooding now extends further south into the central portion of the HRA properties indicating that the ponding has become more extensive. Additional flooding occurs inland (north) from the northernmost parcel to Nantasket, Samoset, and Manomet Avenues as indicated by the large, dashed arrow. The southernmost HRA parcel, the parking triangle between Nantasket Ave and Water St, now begins to flood which continues across Water Street. The bayside flooding is still similar to present day as indicated by the shading.

Figure 10 presents flood pathway and progression results for the distant future 2070 climate conditions (50-year horizon), which is on the order of the design lifetime for any potential development. While the flood progression is similar to the previous cases, the flooding itself is much more significant throughout the rest of the HRA Properties. Flooding occurs with more frequency and from smaller scale storm events as indicated by blue/pink coloring. Additional flooding occurs inland (north) from the northernmost parcel to Nantasket, Samoset, and Manomet Avenues and beyond as indicated by the large, dashed arrow. At the southernmost HRA property, the parking triangle between Nantasket Ave and Water St, flooding is more significant and extends across Water Street and now Nantasket Avenue. Along the bayside HRA Properties, while there is more inundation the flooding does not reach Nantasket Avenue. This futuristic flood mapping demonstrates the potential severity of future storms incorporating sea level rise within the design lifetime for any potential development. However, the model does not consider overland flow arriving at the HRA parcels from adjacent areas north or south of the HRA parcels since this is outside the model domain.

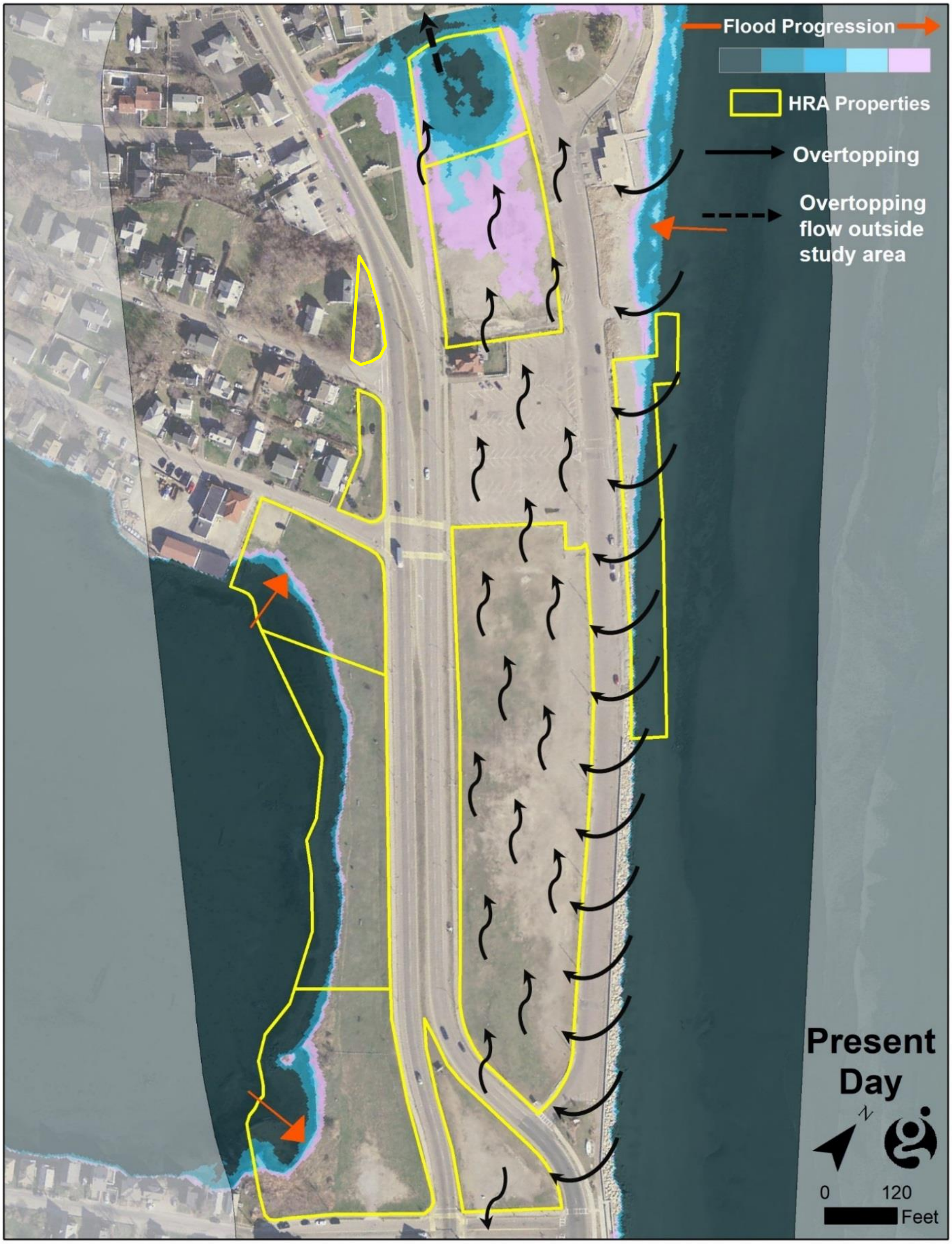

Figure 8. Flood pathway results at the HRA Properties in Hull, MA for present day conditions. Results only valid for HRA Properties.

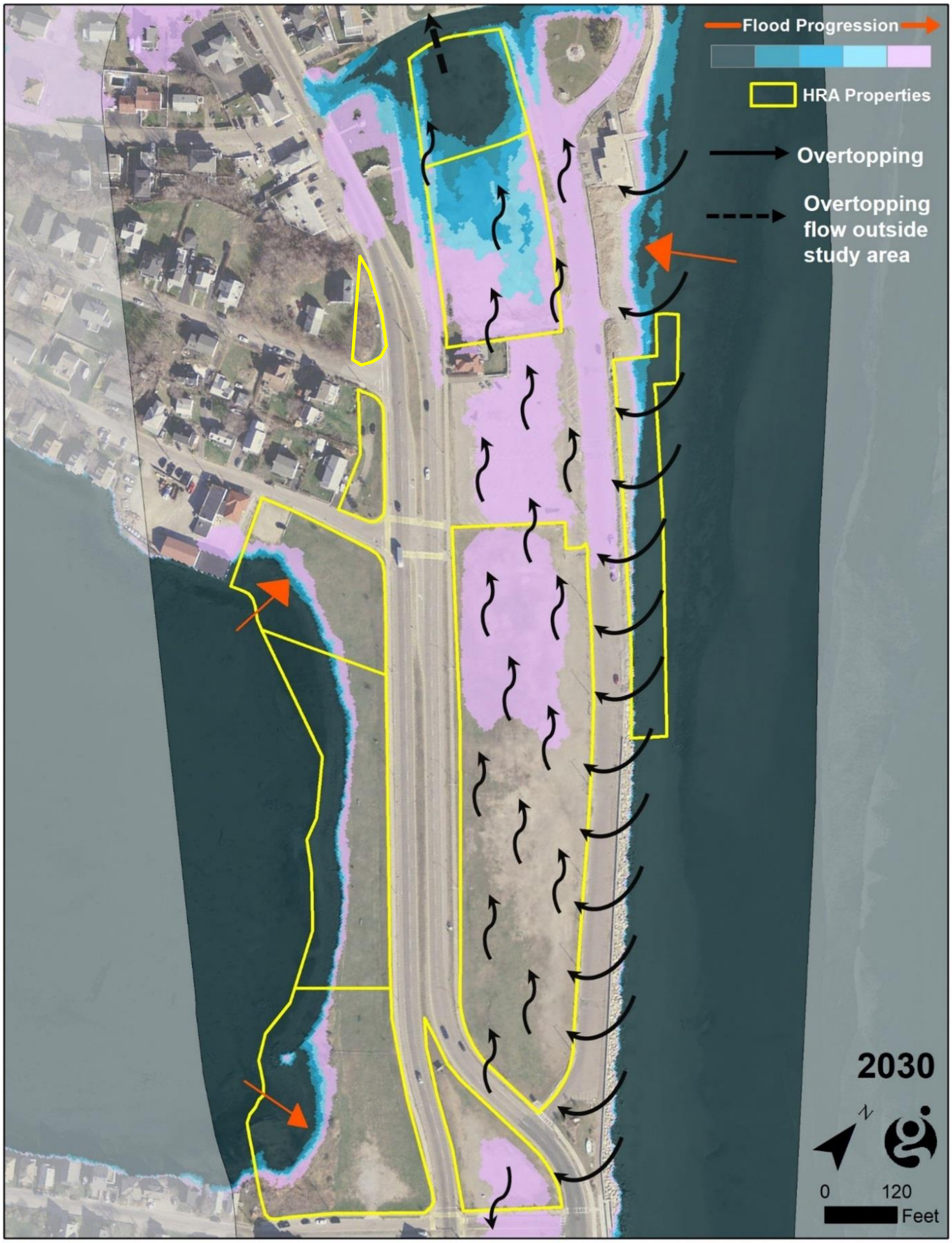

Figure 9. Flood pathway results at the HRA Properties in Hull, MA for 2030 conditions. Results only valid for HRA Properties.

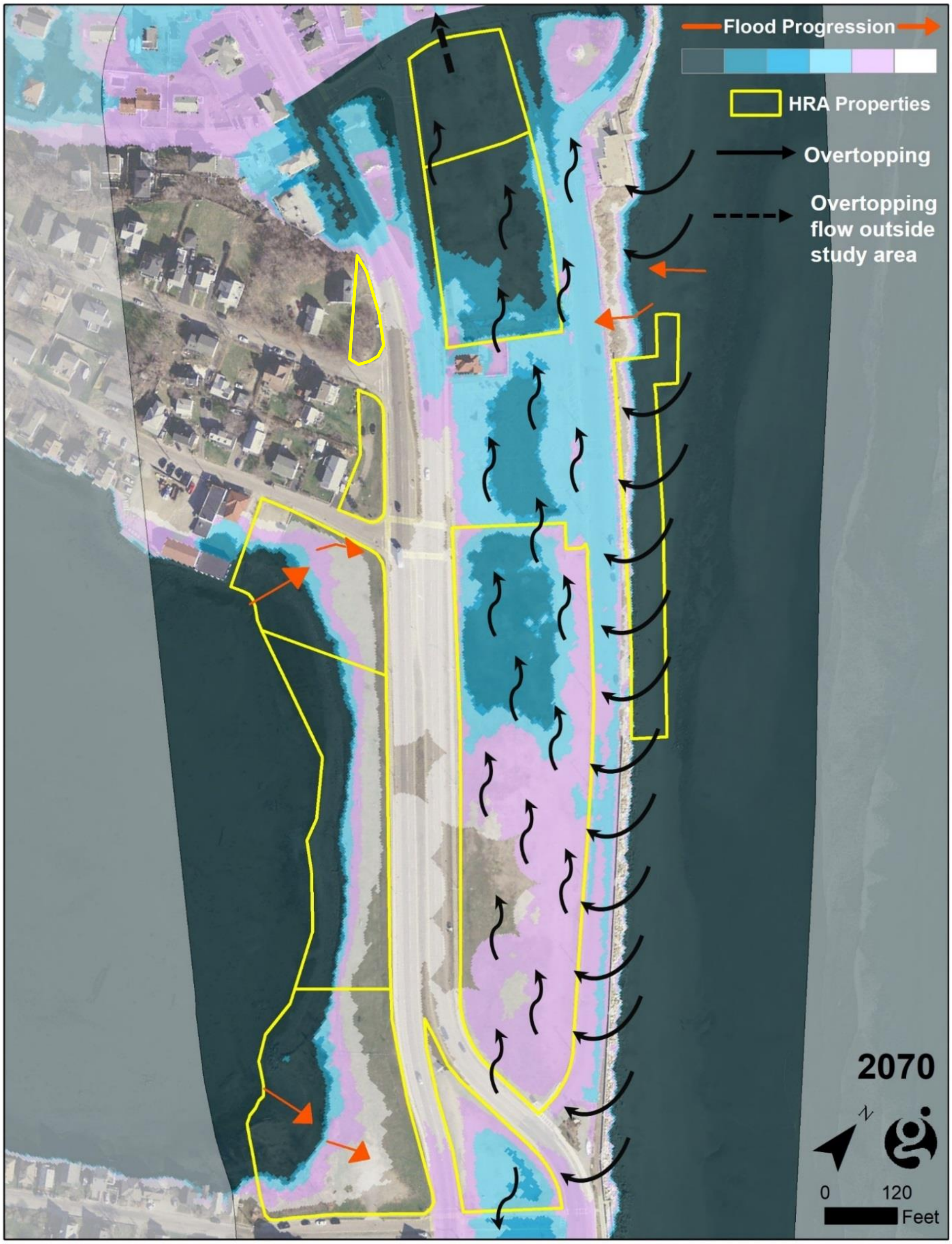

Figure 10. Flood pathway results at the HRA Properties in Hull, MA for 2070 conditions. Results only valid for HRA Properties.

Evaluate FEMA FIRM

The FEMA FIRM Panel #25023C0038J (effective 7/17/2012 & revised 1/24/2018) indicates that the HRA Properties are all mapped within the regulatory FEMA floodway for the 1% annual chance storm (100-year event). The flood mapping shows a VE(18) zone along ocean (eastward) facing coastline of Hull, which is a Velocity Zone of significant wave activity (wave height greater than 3-feet) where the number in parentheses "18" refers to the Base Flood Elevation (BFE) that is the elevation (NAVD-ft) resulting from storm surge and waves during the 1%-annual-chance (100-year) storm event. The VE(18) zone transitions into an AO (3ft) zone approximately 30-ft landward of the seawall/revetment, where the "AO" designation indicates an area of overland sheet flow resulting from wave overtopping (of the seawall) during the 1% annual chance storm while the number "3" in parentheses refers to the depth (feet) of flooding. The AO (3ft) zone extends across the Hull peninsula before terminating in an AE (10) zone at Hull Bay (Figure 11), where the "AE" designation refers to a zone of lesser wave activity (wave heights less than 3-feet) and the BFE of 10 NAVD-ft is simply the stillwater flooding elevation for the 1%-annual-chance storm. The FIRM shows that the oceanside parcel on northern Nantasket Beach is located in a VE(18) zone, the central parcels are located in the AO(3) zone, and the bayside parcels are mapped as an AE(10) zone. The effective FEMA flood mapping for the Properties will result in stricter building codes which can be more costly for development and may limit the types of development that can occur. Additionally, certain construction practices are not allowed in VE or AO Zones, and there are implications for flood insurance premiums.

Woods Hole Group previously prepared a FEMA Letter of Map Revision (LOMR) to revise the mapping based upon updated data for the Town of Hull that was accepted in 2016. The work was based on remodeling and mapping of existing FEMA transects, and the HRA Properties was remapped based on a model result for a coastal transect that bisects the peninsula through the Nantasket Beach Resort to the south. No site-specific modeling was conducted for the HRA parcel itself, and, therefore, the mapping may not be fully representative of the actual conditions on the HRA parcel. Considering the limitations of FEMA FIRMs and the potential benefit of revising the FEMA flood mapping, Woods Hole Group conducted a re-evaluation of the FEMA FIRMs utilizing the BH-FRM model results along with revised wave runup and overtopping analyses for the wall/revetment. A revised flood depth map is shown in Figure 12 utilizing the BH-FRM results for the 1% (100-year) annual chance storm in present day that shows the HRA Parcel having 0.5 ft or less of flooding inundation depth during the 1% annual chance storm. A flooding depth of 0.1 - 0.5 ft would result in the existing AO(3ft) being remapped as an AO(1), which would mark a significant 2-foot reduction the flooding depth. The VE splash zone would remain landward of the seawall, along with an AO Zone with a depth of 2 to 3 feet between the VE and AO (1ft) zones along Hull Shore Drive Extension. On the bayside, the extent or BFE of the AE zone would likely not change since no changes to the flooding analysis would be made in Hull Bay. Nantasket Ave appears to be outside the floodplain and is mapped in an X-zone. Additionally, the AO/AE zone boundary at the northern parcels may shift south resulting in the northern parcels being mapped in an AE(10) zone that may or may not be beneficial since the BFE is at ground level. In order to confirm the flood zone changes, a topographic site survey would need to be conducted and then mapping would need to be conducted using the FEMA methods to verify the results, both of which are outside of this scope of work.

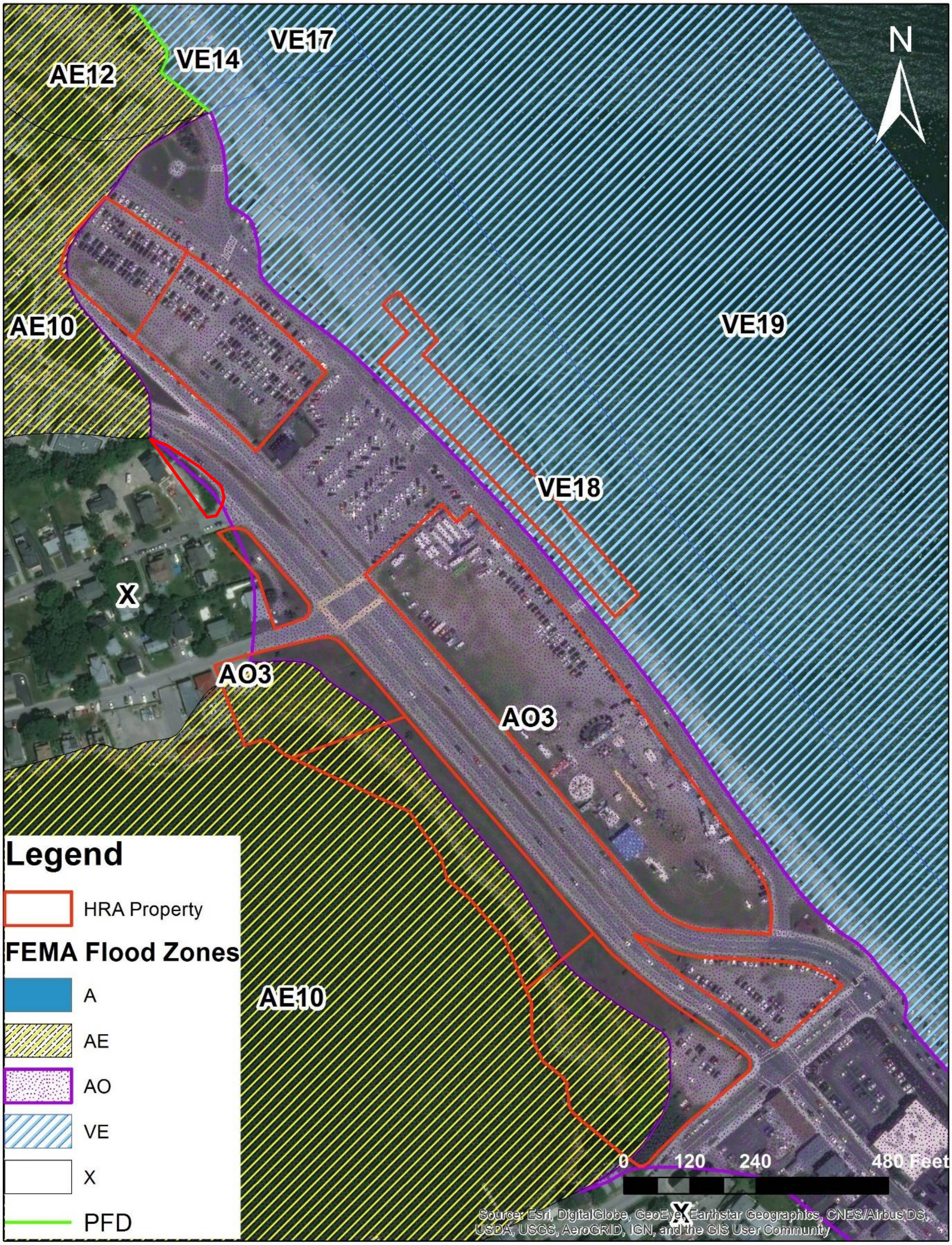

Figure 11. FEMA FIRM (revised 1/24/2018) flood hazard mapping for the HRA Properties in Hull, MA.

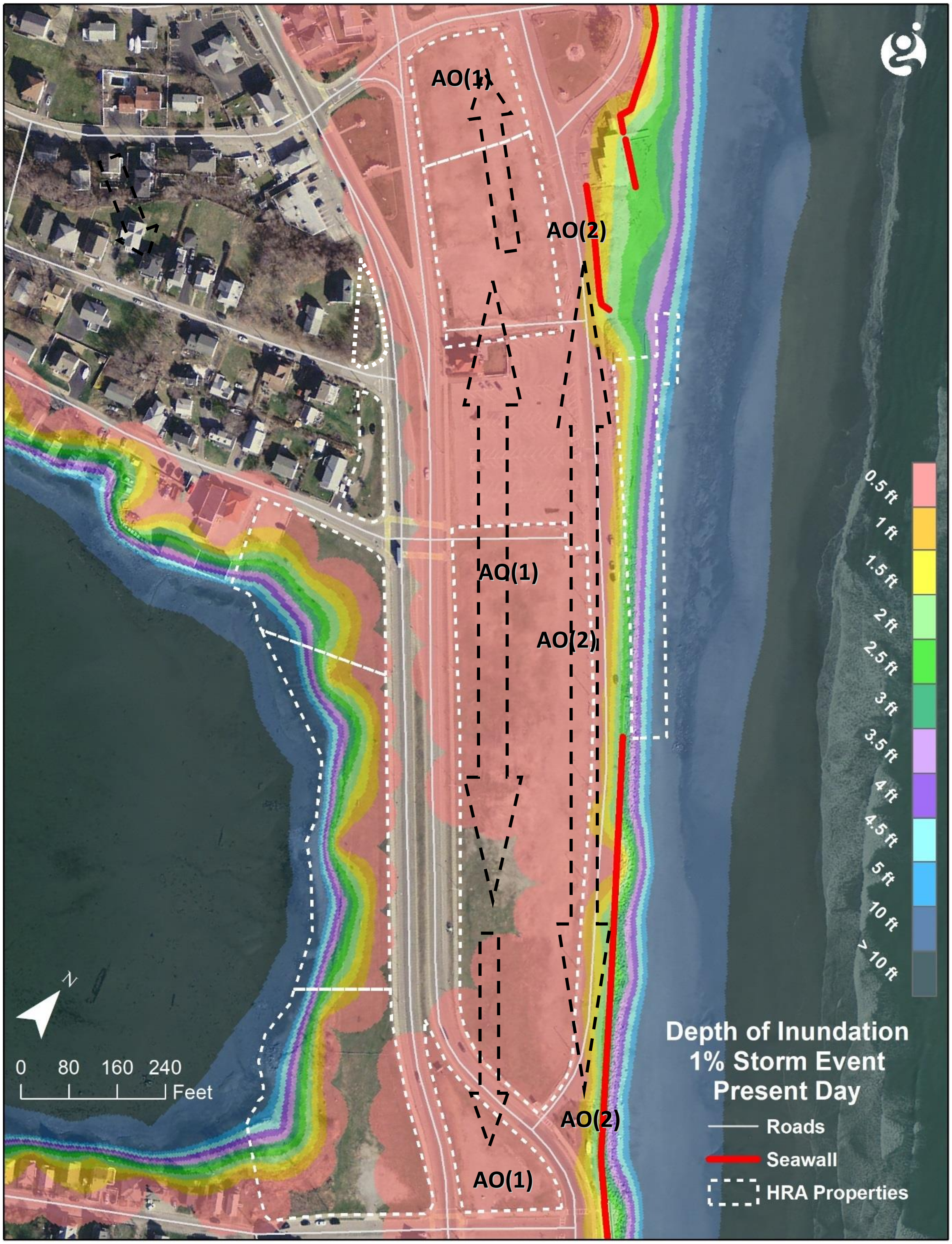

***Figure 12.** Flooding inundation depths (feet) during the 1% annual chance (100 year) storm in present day for the HRA properties based on the BH-FRM results. Note results are only valid for HRA properties.*

Develop DFEs for HRA Properties

Design Flood Elevations (DFEs) were developed to provide both planning and design level criteria for the development of the HRA Properties that incorporates future storms and sea level rise. DFEs established here will also ensure that any development on the Properties will be compliant with regulatory standards and guidelines. The American Society of Civil Engineer's Flood Resistant Design and Construction (ASCE 24-14, 2015) is the standard used by most states and federal agencies but relies on FEMA BFEs with an added prescribed freeboard to establish DFEs. The additional freeboard that is added to the BFE varies on the class and use of a particular structure, and ASCE 24-14 lists four (4) building/structure design classes including:

- Class 1 – Structures that are normally unoccupied and or pose minimal risk to the public or minimal disruption to the community should they be damaged or fail due to flooding such as parking structures or minor storage facilities. The DFE is typically less than the BFE.
- Class 2 – Structures that pose a moderate risk to the public or moderate disruption to the community should they be damaged or fail due to flooding such as most residential, commercial, and industrial buildings. The DFE is set to the BFE plus approximately 1 ft of freeboard.
- Class 3 – Structures that pose a high risk to the public or significant disruption to the community should they be damaged, be unable to perform their intended functions after flooding, or fail due to flooding such as community centers, theaters, schools, and places of worship. The DFE is set to the BFE plus 1-2 ft of freeboard.
- Class 4 – Structures that contain essential facilities and services necessary for emergency response and recovery, or that pose a substantial risk to the community at large in the event of failure, disruption of function, or damage by flooding. This includes first responder facilities, power stations, water/wastewater plants, or facilities that manufacture, use, produce, or store hazardous waste. The DFE is set to the 500-year flood elevation.

Based on previously submitted developer proposals submitted to the HRA, it appears that mixed use development is being proposed that includes residential living space, commercial retail, parking facilities, recreational park space, and a public use building such as a community center. Therefore, it appears that the majority of the structures being proposed will be Design Class 2 for residential and commercial space. A community center, if constructed, would be designated Class 3 or Class 4 if it were to also to be designated as an emergency shelter. Class 1 would include structures such as proposed parking facilities and recreational park structures.

Presently, the majority of the Properties are mapped within an AO(3) Zone except for the beach parcel that is located within a VE(18) Zone. The calculated DFEs for these two flood zones are presented in Table 3. The number '3' associated with the AO Zone is a depth, not an elevation, and, therefore, the depth was added to the ground elevation (Figure 2) to develop a range of DFEs for a particular design class in the table. While the ASCE 24-14 guidelines are useful for estimating DFEs for the Properties, they only provide an estimate based on extrapolation of the FEMA BFE and do not account for the effects of future SLR. Therefore, Woods Hole Group utilized the return period storm water level projections from the BH-FRM presented herein along with the ASCE 24-14 prescribed freeboard to develop DFEs specifically for the Properties. This is a similar approach to the MassPorts climate design guidance, and the DFEs are complaint with Massachusetts State Building Codes. Table 3 presents the recommended DFEs along with the ASCE 24-14 DFEs based on the FEMA BFEs for comparison. The 'target' level DFE refers to the elevation that should be designed for today, while the 'modular' level refers to one in which could be designed for in the future with some forethought. For instance, if the seawall along Hull Shore Drive was reconstructed to the target elevation of 18.6 NAVD-ft, it could be designed such that it could be constructed to the modular elevation of 24.6 NAVD-ft in the future without having to completely rebuild it if steps are taken. This could be accomplished by engineering the foundation to accommodate the additional weight of a future structure while also ensuring that there is sufficient footprint for future expansion.

Table 3. Design Flood Elevations (DFEs) for Hull HRA Properties. Recommended DFEs include sea level rise, waves, & freeboard.

ASCE 24-14 Design Class		ASCE 24-14 Guidelines		Recommended DFE	
Class #	**Description**	**AO (3) Zone (NAVD-ft)**	**VE (18) Zone (NAVD-ft)**	**Target (NAVD-ft)**	**Modular (NAVD-ft)**
1	Parking / storage structures	10.0 – 15.0	18.0	18.6	24.6
2	Residential/commercial space	11.0 – 16.0	19.0		
3	Places of large gatherings	12.0 – 17.0	20.0		
4	Critical facilities / 1st responders	12.5 – 18.8	22.5		

Conceptual Designs for Coastal Resiliency at the HRA Properties

The probabilistic flood maps and flood pathway maps were utilized to aid in the development of three (3) coastal residency concepts (Concepts) that would improve the coastal resilience and flood protection for the HRA properties to allow for future development consistent with best management practices. The Concepts presented herein are intended to be first order design concepts meant to inspire the HRA, engineering firms, developers, etc. about what coastal resiliency improvements for the Properties could be implemented and identify where further development (buildings, parking, etc.) could take place. These Concepts do not limit what could be implemented for the HRA Properties, however, as there may be different concepts (e.g., brought forth by a developer/firm) that would be acceptable as well. The Concepts do not include any buildings, parking lots, etc. as this would be left to the HRA, developers, etc. to design later. Note that individual design component(s) are not necessarily exclusive to the particular concept where they are shown as they could potentially be applied to other concepts as well. These Concepts attempt to incorporate nature-based solutions known as "green infrastructure" in varying degrees (e.g., the dune nourishment, marsh restoration, etc.) in an effort to provide innovative and ecologically enhanced flood protection to the benefit of the HRA, habitat, and public alike. Regulations may also limit the types of projects that can be constructed within the coastal wetland resource areas, and typically green infrastructure components are more permittable and may also be mitigation to offset gray infrastructure components (buildings, pavement, seawalls, etc.). Note that these Concepts are not to scale since they are simple graphical depictions of the Concepts and do provide any specific design parameters, dimensions, materials, or costs that will require a full engineering design and permitting process. The Concepts have also been designed to incorporate the proposed two-way road pattern in a general graphical sense. It is intended that these Concepts would be further developed in subsequent stages and/or utilized to acquire resiliency grant funding. Note that any future proposed project would have to satisfy the performance standards for wetland resources and/or regulatory areas present as shown in Figure 3.

Three (3) Concepts are presented below, each with its own set of goals in an effort to implement coastal resiliency for the HRA properties:

1. **Enhance resiliency of the coastline:** Enhance resiliency at the coast by improving existing coastal structures and resources to keep the HRA properties and adjoining roadways dry.
2. **Build nature-based resiliency landward of the coastline**: Create nature-based resiliency landward of existing coastal structures and coastline to keep the Properties dry using a green infrastructure framework.

3. **Adapt to living with flooding**: Allow the property to flood as it does now but build berms and/or swales to train storm flows and improve drainage. Infrastructure such as buildings and parking lots would have to be designed to handle episodic flooding.

Concept 1 – Enhance existing coastal resiliency at the coastline

Concept 1 shown in Figure 13 (at the end of this section) uses more traditional coastal resiliency practices where existing hard infrastructure is improved in an effort to keep pace with rising sea levels so that the HRA Properties would remain as dry under most conditions to allow for development. This would be accomplished by elevating or reconstructing the existing seawall-revetment fronting Hull Shore Drive Extension to a higher crest elevation set to the DFE (Table 3). An adaptive approach could be taken where a modular structure could be constructed by adding levels over time to keep pace with sea level rise so long as the foundation is designed to accommodate the additional levels; this may provide some cost savings for the Town. Note that any work on the coastal structure will likely require a Chapter 91 license, MEPA certificate, U.S. Army Corp of Engineers permit, and possible others in addition to the required Notice of Intent filed with the Town of Hull Conservation Commission.

The northern portion of Nantasket Beach north of the DCR Parcel does not have any existing coastal structure and is also the most vulnerable portion of the HRA Properties to storm flooding due to its low elevation. While extending the existing coastal structure (wall or revetment) into this area would be the most logical solution, it would likely not be permittable since there is no existing structure making it difficult to permit a hard structure in wetland resources areas consisting of Barrier Beach, Coastal Beach, Coastal Dune, Land Subject to Coastal Storm Flowage, NHESP priority habitat, and possibly other resource areas (see Figure 3). Therefore, soft green infrastructure solutions such as dune restoration would be a possible solution here since it would provide needed elevation for storm protection. Placement of the dune will also determine the required permits and wetland resource performance standards that would need to be satisfied. The dune crest would be constructed to the DFE in an effort to keep the Properties dry and then planted with native vegetation such as Cape American Beach Grass to improve its resiliency and aesthetics. Note that a dune restoration would require more regular maintenance in the form of nourishment and plantings in comparison to the hard solutions. If the constructed dune is kept landward of the historic high-water mark (black-white lines in Figure 3), then it likely will not need either a Chapter 91 license or U.S. Army Corp of Engineers permit. This would provide a 50 – 100 ft wide section of beach to construct dune restoration, which is likely sufficient for a viable dune restoration project. However, since this area is also within NHESP priority habitat there will be strict building standards for any coastal project, for instance, the seaward face of a constructed dune would likely have to have a gentle sloped face, on the order of 1V:10H, to accommodate the piping plovers. As a result, the seaward dune face becomes very long and reduces the crest width since there is only a 50 – 100 ft width of beach to construct it, thereby reducing dune volume and resulting in a less resilient dune. Additionally, if the dune is constructed on mapped coastal beach resource, then NHESP could consider this action as a ‘Take’ and require a conservation management plan that would add significant cost and time to any project. Lastly, there will likely be time of year restrictions for project construction due to the plovers, which are typically during the nesting season between April and September.

The other consideration for constructing dunes is that the native sediment consists of a mix of sand, gravel, and even cobble, and any fill (sediment) brought to the site for dune restoration matches the native material. Therefore, sediment samples would have to be collected and analyzed to ensure the grain size of the fill matches. Along Hull Shore Drive Extension, there are large natural deposits of gravel and cobble on the beach adjacent to the road, and a cobble berm may be more appropriate than a dune to match the native material. A cobble berm is essentially a dune constructed with cobbles that would be more resilient than a sand dune due to the large size of the material and could function as a “dynamic revetment” that can be reshaped by waves. In an effort to provide a buffer for the David Cook Comfort Station (DCCS) from the dune, a retaining wall was proposed to be constructed around the building but permitting the retaining wall may be difficult if this building is determined to be in a coastal wetland resource area. Because this building is vulnerable if the proposed dune is eroded during a storm, other alternatives could be considered such as elevating the building on a raised foundation or even relocating the building.

The goal on the bayside coast is to transform this open area into a waterfront park that would not only provide additional flood protection, but also enhance habitat and recreational use as shown in Figure 13. This would be accomplished by restoring the fringing salt marsh along the shoreline and raising the grade landward using more natural solutions (vegetated berms) since the bayside is not subject to the large open ocean storm waves. A fringing salt marsh currently exists along this stretch of coastline as shown in Figure 3 and would need to be confirmed on the ground with a wetland delineation. As a result, any work completed within the salt marsh would have to satisfy those performance standards that likely limits the scope of work here to simple salt marsh restoration/enhancement (if anything at all). Salt marsh restoration could require both Chapter 91 licensing and an Army Corp permit since they are below the HHW line. Marsh restoration could include providing sediment to the marsh plain to help raise its elevation and stave off the effects of SLR, but the sediment would likely have to be a thin layer so that the existing marsh is not smothered. A larger restoration effort could include expanding the existing marsh seaward through the creation of a raised marsh with fill and protecting the seaward limit with stones to retain the material and mitigate erosion. Then salt marsh plantings could occur to stabilize the fill and help promote plant growth. Landward of the salt marsh a grassy open area where raising the grade and incorporating raised topographic features, such as berms, could increase coastal resiliency for Nantasket Avenue. Prior developer proposals included a waterfront park with a pier to provide community enhancement and recreational access, but it may be difficult to permit a pier of any kind considering the salt marsh resource. A simpler alternative to provide public access along this shoreline could just be a simple access path. An elevated walkway is shown as an option to provide safe passage for pedestrians over Nantasket Avenue and connect the central HRA Properties with the Bayside Properties.

The interior (central) HRA parcels between Nantasket Avenue and Hull Shore Drive Extension is where the residential and commercial development would be proposed (red outline in Figure 13). Figure 13 indicates that even if all shoreline improvements are made by the HRA, flood waters could still flank these parcels from the north and south (as indicated by the blue arrows) if additional improvements are not made by the Town of Hull and DCR to their abutting properties. The Properties are located within Land Subject to Coastal Storm Flowage since the Properties are mapped in a V or Coastal A zone. These interior parcels are also still within the Barrier Beach resource area (Figure 3) meaning that any work completed here would have to satisfy those performance standards. As a result, there will likely be strict design requirements regarding the placement of fill, foundation design, stairs, materials, lowest elevation of the first floor, placement of utility/mechanical systems, and usage that the developer(s) will have to evaluate. Depending upon the proposed development, ASCE 24-14 must be consulted by any developer to determine the Flood Design Class for any proposed structure(s). Any residential and commercial construction will likely be class 2, and a community center would be class 3 or 4 depending on whether it would also be an emergency shelter.

This concept would be the most difficult to permit and costly to construct and would likely require private and public partnerships and possibly land acquisition(s) to be fully realized. It would be more difficult to obtain grant funding due to the heavy use of hard “gray infrastructure” structures.

Concept 2 – Build inland resiliency relying on green infrastructure

Concept 2 shown in Figure 14 presents a second adaptation approach that focuses on using nature-based solutions landward of existing coastal structures (seawalls) to accomplish Concept 1 goal of keeping the interior portions of the Properties dry under most conditions to allow for development. The existing seawall along Hull Shore Drive Extension would remain intact and a vegetative berm or terrace would be constructed landward of the roadway to provide flood protection for the central HRA Properties. The seawall would overtop during extreme storm events as it does now and flow into the roadway where the terrace would act as a barrier to floodwaters. The target crest elevation of this new berm would be set to the DFEs in Table 3, but an adaptive approach could also be taken where a modular terrace could be constructed in levels (or lifts) over time to keep pace with sea level rise so long as the foundation is designed to accommodate the additional levels. The berm or terrace would be planted with native coastal vegetation to increase its resiliency and improve aesthetics. Figure 14 indicates that flood waters could still flank Concept 2 from the north and south (as indicated by the blue arrows) if additional improvements are not made by the Town of Hull and DCR to their abutting properties. A drawback of Concept 2 is that it would take up a portion of the existing DCR and HRA Properties that would reduce the area available for development, and DCR would also have to be consulted on this approach. However, Concept 2 would likely be easier to permit since it could be kept above the HHW and MHW lines and outside of some of the sensitive wetland resource areas that would negate the need for Chapter 91 License or Army Corp Permit.

For the northern HRA Properties, the dune enhancements from Concept 1 are still included but the retaining wall around the building since gray infrastructure components have been minimized here. On the bayside, the approach from Concept 1 would be retained using a combination of marsh restoration and upland improvements to build resiliency while simultaneously enhancing public space and access to the water.

The development of the interior HRA parcels would be subject to the same regulatory performance standards and building codes as in Concept 1. While it is possible that floodwater flanking from adjacent properties may be mitigated by constructing berms at the northern and southern end of the Properties, it may be difficult to entirely remove this area from the FEMA special flood hazard and/or barrier beach resource areas. In terms of permitting, any proposed work on the barrier beach, coastal beach, land subject to coastal storm flowage, or salt marsh would require that their performance standards be satisfied just as with Concept 1.

This concept would be less difficult to permit than Concept 1, but it will still be costly to construct based on our experience with projects of this type. It will require private and public partnerships and possibly land acquisition(s) to be fully realized. It is possible this concept would be eligible to acquire grant funding due to the heavy implementation of nature based “green infrastructure” solutions.

Concept 3 – Living with flood waters

Concept 3 shown in Figure 15 presents an alternate approach that focuses on adapting the Properties and potential future development to be more flood resilient instead of trying to keep the Properties dry. Minimal changes would be made to the Properties themselves meaning that it would still have the same flood risk as it does now, however, the flooding extent and duration could be reduced by creating swales and berms to improve drainage. On the oceanside, the storm flows would be directed back to the ocean via swales, while flood waters on the bayside would be directed back into Hull Bay. Of course, this depends on the flood elevation being low enough during a storm for the flood waters to be able to drain via gravity back to the ocean or bay. Because Concept 3 allows the Properties to flood, action must be taken to ensure that Nantasket Avenue remains open during most/all conditions since it is the only emergency route off of the Hull Peninsula. This could be accomplished by constructing low embankments or berms along Nantasket Avenue and incorporating self-rising (or deployable barriers) at the connecting roads. Since Nantasket Avenue is already built on higher elevation the embankments may not need to be built as high as the seawall or vegetated berm. Elements of Concepts 1 and 2 could still be implemented under this Concept such as dune restoration on the oceanside and a marine park and/or marsh restoration on the bayside. The elevated walkway would certainly be needed in this case to provide public access between the central and bayside HRA Properties.

Concept 3 will put more onus on the HRA, developers, etc. for planning and development. Any development will still have to satisfy the performance standards for a barrier beach and land subject to coastal storm flowage. The lowest elevation of the lowest (first) floor for any structure will likely need to be set to at minimum the DFE, which has a target elevation of 18.6 NAVD-ft. Considering that the elevation of the Properties ranges from 10 NAVD-ft in the northern portion to 15 NAVD-ft in the southern portion of the Properties, the first floor elevation will have to be raised to 3.6 to 8.6 ft above grade using piles, foundations with flood openings, or breakaway walls which means that the ground floor will not be livable space, but could be used for parking. Additionally, any mechanical systems or utilities will have to be elevated. These requirements are further detailed in ASCE 24-14, and likely apply to Concept 3 as they are specified for buildings within the V or Coastal A zones. This Concept would likely be the least expensive to construct and have the easiest permitting path since minimal changes are being proposed to the landscape or existing coastal structures, but it will still involve private and public partnerships to be fully realized. It is possible this concept could also be eligible for grant funding with the use of nature based “green infrastructure” solutions.

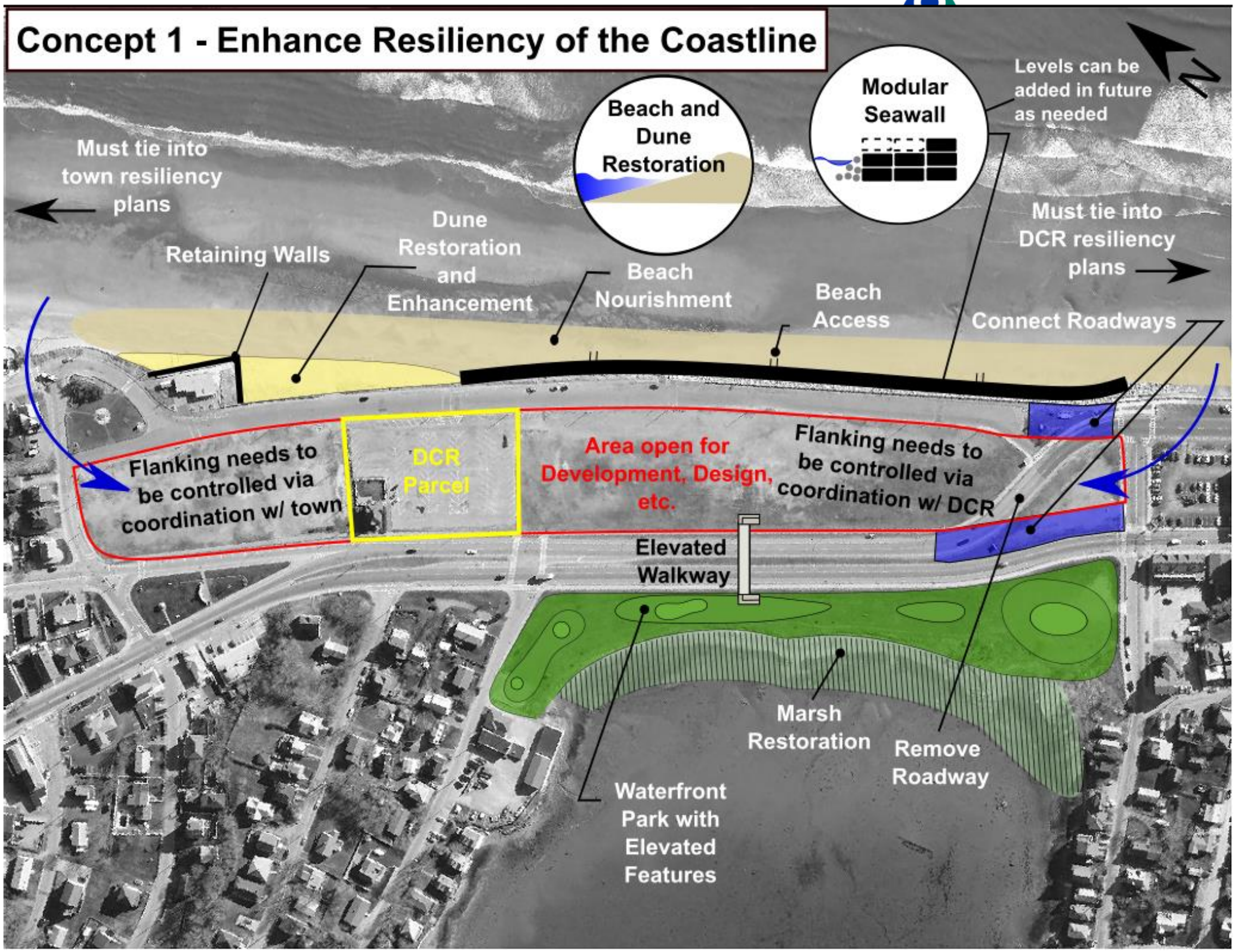

Figure 13. Concept 1 improves coastal resiliency at the shorelines by enhancing existing structures and resources with a mixture of green (dune/marsh restoration) and gray (seawalls) solutions.

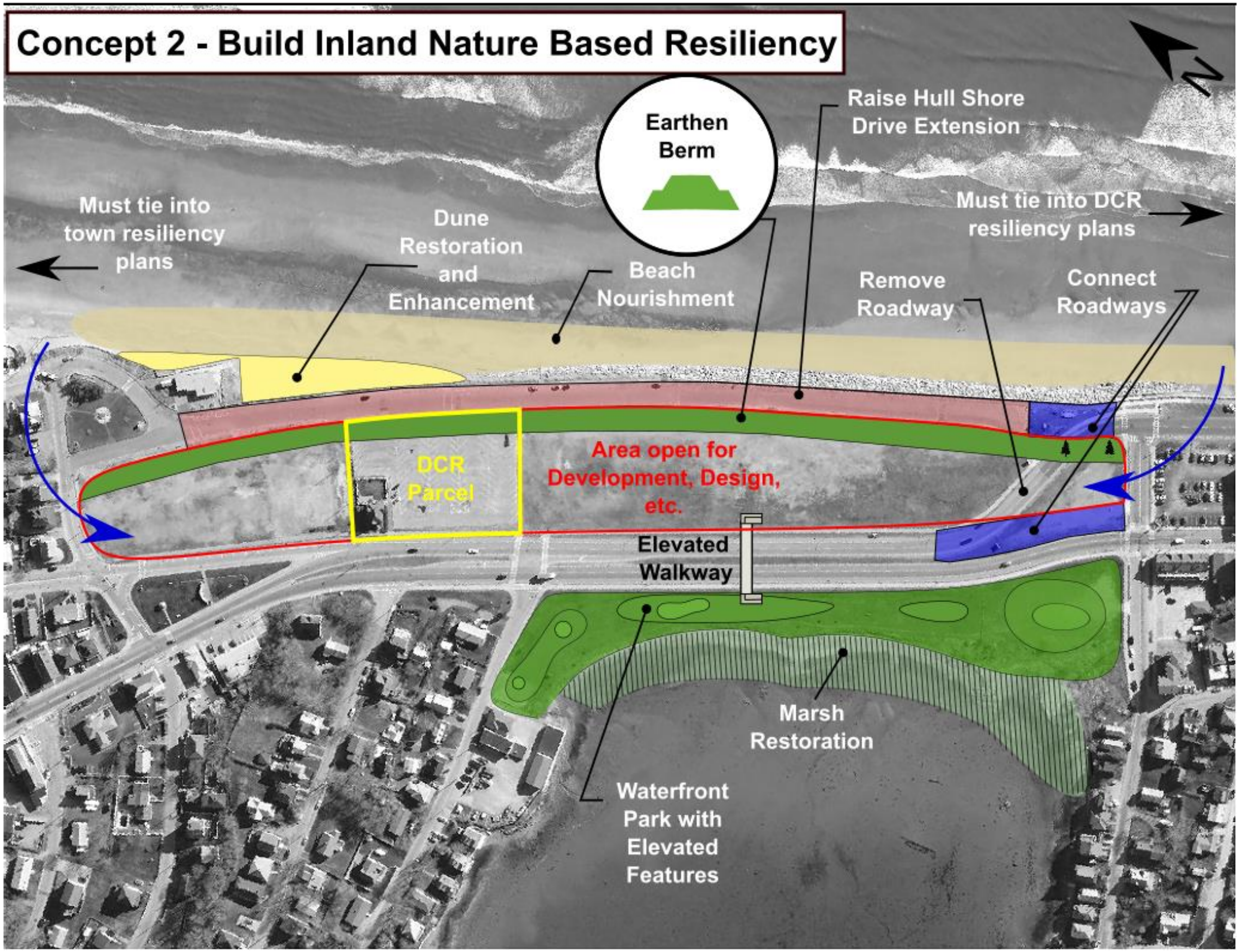

Figure 14. Concept #2 that incorporates nature-based resilience landward of shoreline.

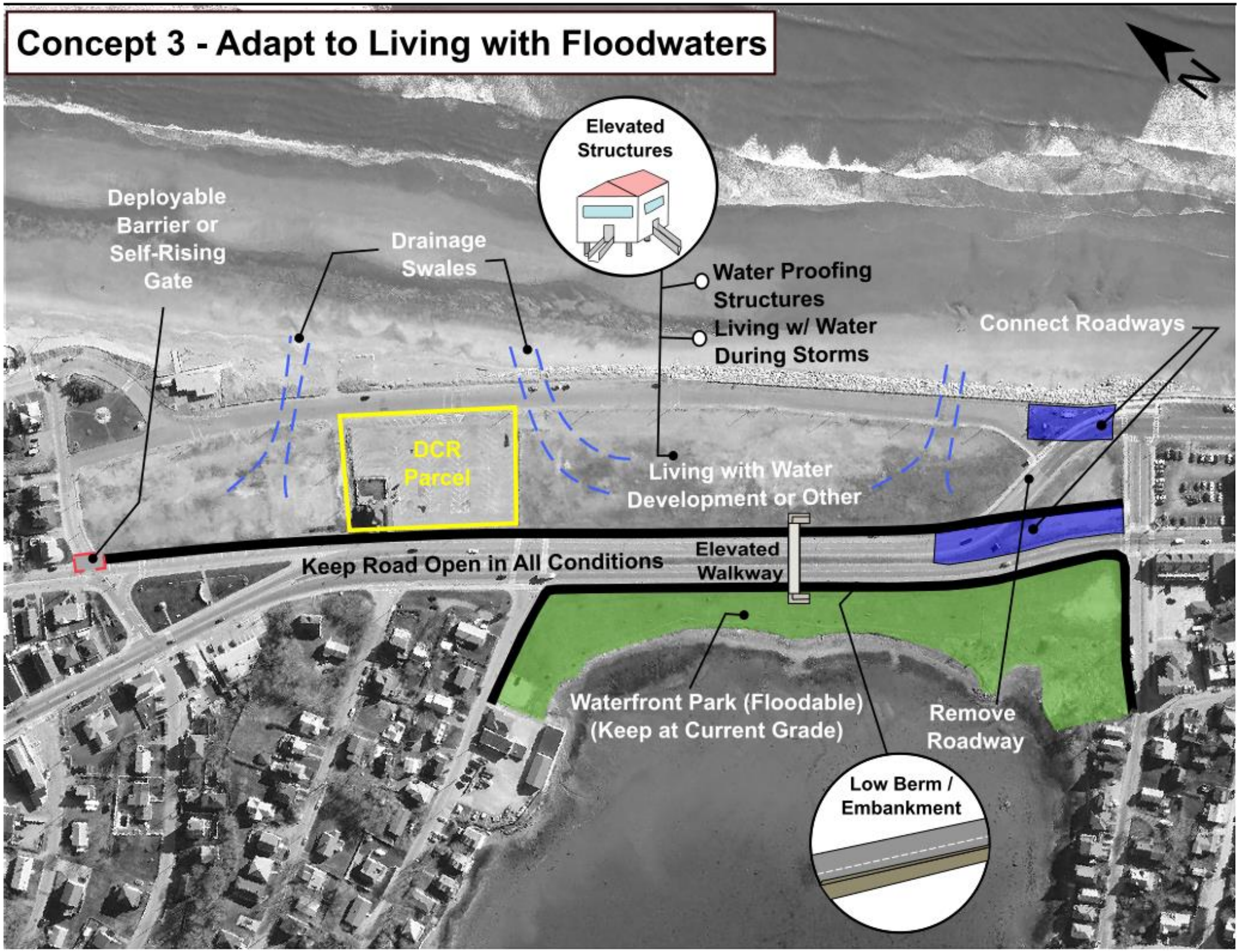

Figure 15. Conceptual Design Concept #3 for living with floodwaters.

Discussion

Based on the work completed within this memo, the Woods Hole Group can make the following summary statements:

- The annual chance of flooding for HRA Properties is on the order of 5% in present day and increases to 10% and 30% in 2030 and 2070, respectively. This demonstrates how the annual flood probability increases significantly from present to future conditions.
- The topographic contours for the Properties indicate that the gradient decreases approximately 5-feet between the southernmost and northernmost parcels, which creates an overland flow pathway for wave overtopping of the seawall and resulting ponding in the vicinity of Phipps Street.
- As such, the most vulnerable area is the northern HRA parcel (especially 2 Samoset Ave) that has both low elevation and no coastal structure providing protection, which may make it a less suitable area to develop unless adequate coastal resiliency measures are taken in this area.
- Conversely, the least vulnerable area is the southern portion of the central parcel (5 Water St) that has higher elevations and coastal protection provided by the existing seawall, which would likely be more favorable to development.
- The design flood elevations (DFEs) for the HRA Properties have a target elevation of 18.6 NAVD-ft (present day) and future modular elevation of 24.6 NAVD-ft (future). It is possible that the DFE for any potential development on the central HRA parcels could be reduced if sufficient coastal resiliency measures are taken seaward.
- The DEP natural resource layers indicate that all the HRA properties are located within the barrier beach system while the along with coastal beach, coastal dune, and NHESP priority habitat on the oceanside coastline and salt marsh on the bayside shoreline. Any proposed development on the Properties will therefore have to meet the performance standards for work within those regulated and resource areas.
- The Properties are located within Land Subject to Coastal Storm Flowage that is delineated by the limits of the FEMA V and/or A Flood Zones, and any proposed development will have to comply with those building codes and other design standards.
- A reevaluation of the FEMA FIRMs indicates that the extents of flood zones likely will not change significantly, however, it is possible that the AO(3) that encompasses the majority of the Properties could be reduced to an AO(2) or AO(1). A LOMR could be pursued to revise this area, which would provide more flexibility for design of projects since the BFE would be slightly lower.

From this information, the following three (3) conceptual designs were developed:

- Concept 1 improves the coastal resiliency at the coast by rebuilding/reinforcing existing structures and creating other natural barriers in other areas with the goal to keep the interior portions of the HRA parcels dry. On the bayside, a combination of salt marsh restoration and a waterfront park incorporating elevated berms to provide flood protection in this low wave energy environment is presented. Concept 1 would likely be the most difficult and costly option to design, permit, and construct considering the large coastal structures and permits involved, but it could still be pursued.
- Concept 2 builds coastal resiliency utilizing green infrastructure concepts landward of Hull Shore Dr with the goal of keeping the interior portions of the HRA parcels dry while using a portion of potentially buildable lots to construct these measures. By constructing landward of the existing coastal structure, the permitting path will likely be simpler than Concept 1 since it is outside of some wetland resources and agency jurisdictions while incorporating green infrastructure alternatives that Agencies prefer. On

the bayside, a combination of salt marsh restoration and a waterfront park could be proposed as was for Concept 1.

- Concept 3 focuses on living with flood waters by improving the ability of the Properties to handle flooding and inundation through creating swales and berms to train flow and improve drainage and reduce flooding extent and duration. The resiliency would be focused on the buildings themselves. A low embankment or barrier could be constructed on either side of Nantasket Avenue to limit road flooding and keep it open during all conditions since it is an emergency route. On the bayside, salt marsh restoration and a waterfront park could still be incorporated. Concept 3 would likely have the easiest permitting path and be less expensive to construct that Concepts 1 or 2 since the responsibility is on the planner/developer to design more resilient structures.
- Regardless of which Concept is chosen, both the coastal dune restoration on the oceanside and the salt marsh and park enhancements on the bayside could be implemented with any concept or even as a standalone project(s). The permitting paths would likely be straight forward, and the constructed projects would provide coastal resiliency ahead of any future development.
- Any planner or developer needs to be aware that any development on the Properties will have satisfy the performance standards for their delineated resource area(s), and that design standards for should be consistent with ASCE 24-14 for work within the V or Coastal A Zones. Based on the analyses conducted herein, it is unlikely that even with higher seawalls and flood map revisions that these permitting constraints and design standards will be much less stringent.
- It is recommended that a full site survey be conducted for the Properties prior to any development that would include a topographic survey, wetlands resource delineation, and sediment sampling and analysis to confirm ground elevations, the presence and boundaries of resources areas, and determine design criteria. This will be needed eventually for design and permitting, however, having this information sooner may help guide developer proposals.
- Confirmation of the coastal and wetland resources will be important for determining what wetland performance standards that the various parcels may be subject to for construction. The barrier beach-coastal beach and barrier beach-coastal dune delineations based on the MassDEP mapping could be very limiting in terms what could be allowed here. A careful review of the local, state, and federal wetlands regulations will need to be conducted before any of these coastal resiliency measures or development is proposed.
- The impacts of any future project to abutting properties and wetland resources will have to be conducted as part of the permitting process that will likely require additional confirmatory coastal engineering analyses and/or flood modeling.
- The HRA should consider pursuing grant funding opportunities, such as those through the FEMA or Massachusetts Coastal Zone Management (CZM) office, to fund parts or all of any chosen Concept.
- Considering that the HRA properties have a significant flood risk potential that will only increase in the future, we recommend the HRA conduct its due diligence when reviewing any development proposals to ensure that development is flood resilient for both present and future conditions, will be permittable in the designated resource area(s), and provides a degree of benefit to the community.

Glossary of Terms

AO Zone – FEMA flood zone designation where there is risk of overtopping/overwashing during the 1% annual chance storm.

ADCIRC – ADvanced CIRCulation model, which the hydrodynamic computer model used to develop the BH-FRM.

AE Zone – FEMA flood zone designation where there is risk of significant flooding and wave attack less than 3 feet during the 1% annual chance storm.

ASCE – American Society of Civil Engineers

Barrier Beach – A narrow, low-lying strips of beach and dunes that are roughly parallel to the coastline and are separated from the mainland by a body of water or wetland.

BFE – The Base Flood Elevation relative to NAVD (feet) associated with the FEMA FIRM flood zones.

BH-FRM – Boston Harbor Flood Risk Model developed by Woods Hole Group and University of Massachusetts at Boston to simulate current and future storms for the greater Boston Harbor.

Coastal Beach – A gently sloping shoreline on saltwater consisting of unconsolidated sediment subject to wave, tidal and coastal storm action. 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.

Coastal Dune – Any natural or artificial hill, mound or ridge of sediment landward of a coastal beach deposited by wind action or storm overwash serving the purpose of storm damage prevention or flood control.

Cobble Berm – A mound, berm or dune constructed with cobbles that tends to be more resilient than a similar version with sand due to the use of larger material (cobbles).

Concepts – Coastal resiliency conceptual design.

CZM – Massachusetts Coastal Zone Management

DCR – Department of Conservation and Recreation

DEP – Massachusetts Department of Environmental Protection

DFE – Design Flood Elevation, which is guidance criteria for development.

Ft – Units of feet

FEMA – Federal Emergency Management Agency

FIRM – The FEMA Flood Insurance Rate Map that depicts the regulatory floodway and zones.

Freeboard – The height of a coastal structure above the storm surge elevation.

Green Infrastructure – Infrastructure or development that is constructed using natural and/or biodegradable materials such as sand, soil, and vegetation to reduce impacts on the natural environment.

HHW – Historic high-water line derived by DEP based on historic maps and charts

HRA – Hull Redevelopment Authority

Inundation – An area of measurable flooding where the magnitude or severity is not directly indicated.

Land Subject to Coastal Storm Flowage – Regulated area in Massachusetts consistent with the FEMA floodway.

LIDAR – LIght Detection And Ranging

LOMR – Letter of Map Revision, which is used to revise flood zones and BFEs with FEMA.

MassDOT – Massachusetts Department of Transportation

Memo – Technical Memorandum

MEPA – Massachusetts Environmental Policy Act Office

Nature Based Solution – Infrastructure or development that uses natural materials to reduce impacts to the natural environment.

NAVD – North American Vertical Datum of 1988 (units of feet)

NHESP – Natural Heritage and Endangered Species Program which regulates threatened and endangered species and their habitat in Massachusetts.

NOAA – National Ocean and Atmospheric Administration

Properties – The ten properties owned by the HRA and which are the subject of this study.

Resilient Coast – A coast built and/or managed to protect against the impacts of current and future storms.

Resilient Structure – A coastal engineering structure built to withstand the impacts of current and future storms.

Revetment – a sloping coastal engineering structure consisting of large stones.

Salt Marsh – an intertidal area colonized by saltwater grasses and vegetation.

Seawall – Typically, a vertically constructed hardened coastal engineering structure.

SLR – Sea Level Rise.

SFHA – FEMA's Special Flood Hazard Area, also known as the regulatory floodway.

Tidal datum - The arithmetic mean of a particular datum (MLW, MHW, MTL, etc.) over a monthly lunar tidal cycle.

Town – Town of Hull

USGS – United States Geological Survey

UMB - University of Massachusetts at Boston

VE Zone - FEMA flood zone designation where there is risk of significant flooding and wave attack greater than 3 feet during the 1% annual chance storm.

X-Zone – Area outside of the FEMA regulatory floodway.

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The Woods Hole Group appreciates the continued opportunity to support the work for this project. Please contact Mitch with any questions, comments, or requirements for additional information.

Sincerely,

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