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Boston Water and
Sewer Commission

Coastal Stormwater Discharge Analysis

Project Report
BWSC No. 20-206-004
Hazen No. 90028-003
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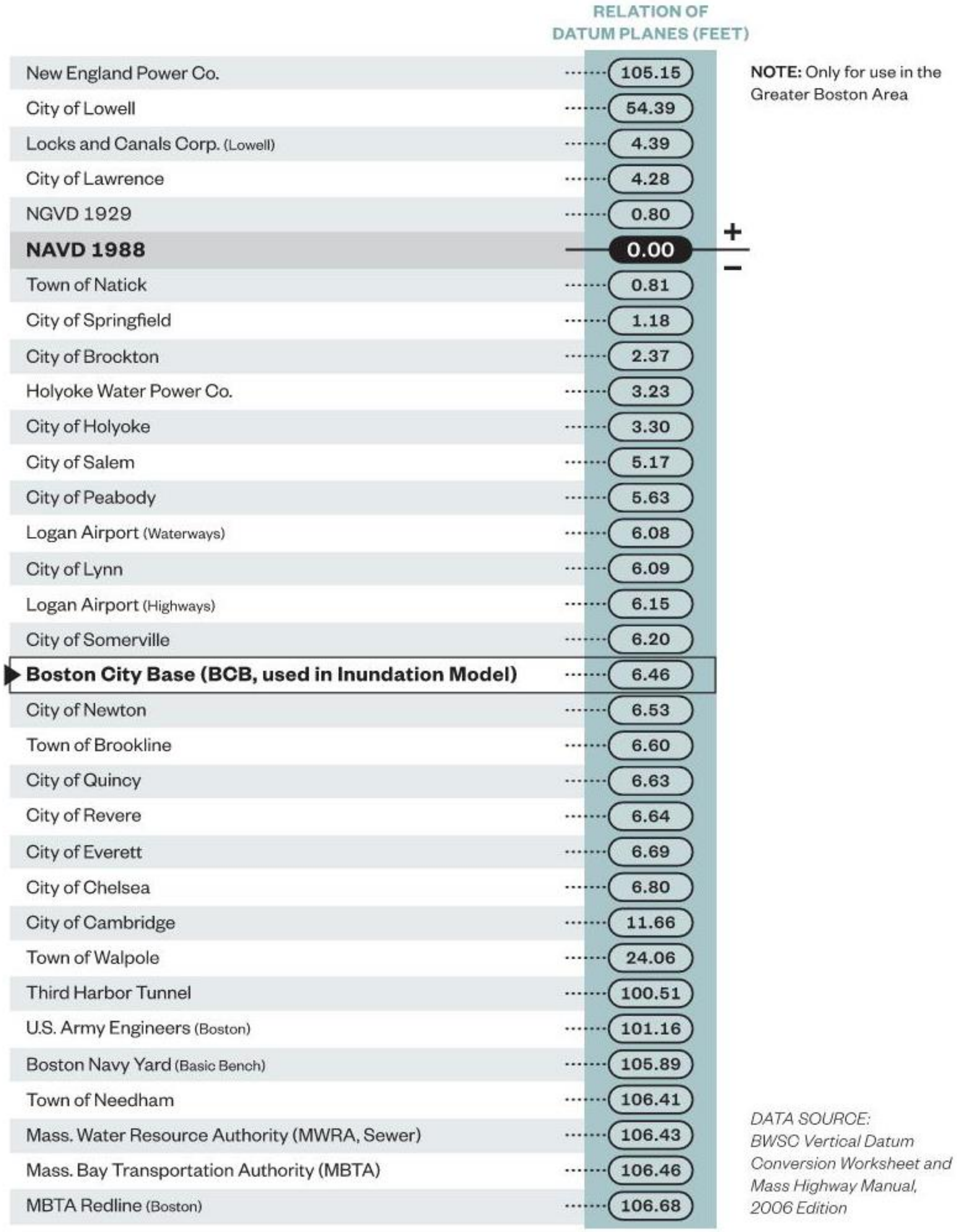
Datum Conversions



	RELATION OF DATUM PLANES (FEET)
New England Power Co.	105.15
City of Lowell	54.39
Locks and Canals Corp. (Lowell)	4.39
City of Lawrence	4.28
NGVD 1929	0.80
NAVD 1988	**0.00**
Town of Natick	0.81
City of Springfield	1.18
City of Brockton	2.37
Holyoke Water Power Co.	3.23
City of Holyoke	3.30
City of Salem	5.17
City of Peabody	5.63
Logan Airport (Waterways)	6.08
City of Lynn	6.09
Logan Airport (Highways)	6.15
City of Somerville	6.20
▶ **Boston City Base (BCB, used in Inundation Model)**	6.46
City of Newton	6.53
Town of Brookline	6.60
City of Quincy	6.63
City of Revere	6.64
City of Everett	6.69
City of Chelsea	6.80
City of Cambridge	11.66
Town of Walpole	24.06
Third Harbor Tunnel	100.51
U.S. Army Engineers (Boston)	101.16
Boston Navy Yard (Basic Bench)	105.89
Town of Needham	106.41
Mass. Water Resource Authority (MWRA, Sewer)	106.43
Mass. Bay Transportation Authority (MBTA)	106.46
MBTA Redline (Boston)	106.68

NOTE: Only for use in the Greater Boston Area

DATA SOURCE: BWSC Vertical Datum Conversion Worksheet and Mass Highway Manual, 2006 Edition

List of Acronyms

Abbreviation	Definition
1D / 2D	One-Dimensional / Two-Dimensional
AACE	Association for the Advancement of Cost Estimating
ANSI	American National Standards Institute
BCB	Boston City Base
BH-FRM	Boston Harbor Flood Risk Model
BPDA	Boston Planning and Development Agency
BRAG	Boston Research and Advisory Group
BRIC	Building Resilient Infrastructure and Communities
BWSC	Boston Water and Sewer Commission
C-CCVA	Cambridge Climate Change Vulnerability Assessment
CDC	Centers for Disease Control
CFS	Cubic Feet per Second
CRB	Climate Ready Boston
CSO	Combined Sewer Overflow
CUDEM	Continuously Updated Digital Elevation Model
DBB	Dorchester Bay Basin
DEM	Digital Elevation Model
DFE	Design Flood Elevation
EJ	Environmental Justice
FEMA	Federal Emergency Management Agency
FPC	Fort Point Channel
ft	Feet
GCM	Global Climate Model
GDP	Gross Domestic Product
GIS	Geographic Information System
HGL	Hydraulic Grade Line

Abbreviation	Definition
HI	Hydraulic Institute
hr	Hour
HVAC	Heating, Ventilation, and Air-Conditioning
in	Inches
IPCC	Intergovernmental Panel on Climate Change
LiDAR	Light Detection and Ranging
LODES	Longitudinal Origin Destination Employment Statistics
LOS	Level of Service
MassDCR	Massachusetts Department of Conservation and Recreation
MassDOT	Massachusetts Department of Transportation
Massport	Massachusetts Port Authority
MBTA	Massachusetts Bay Transit Authority
MC-FRM	Massachusetts Coastal Flood Risk Model
MG	Million Gallons
MLW	Mean Low Water
MWRA	Massachusetts Water Resources Authority
NAVD 88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
NPSH	Net Positive Suction Head
NRCS	Natural Resources Conservation Service
O&M	Operations and Maintenance
PCSWMM	Personal Computer Storm Water Management Model
PowerBI	Power Business Intelligence
RCP	Representative Concentration Pathway
SCS	Soil Conservation Service
SDO	Storm Drain Overflow
SLR	Sea Level Rise

Abbreviation	Definition
SRES	Special Report on Emission Scenarios
SSB	Storm Surge Barrier
SVI	Social Vulnerability Index
TP-40	Technical Paper Number 40
USDA	United States Department of Agriculture
VFD	Variable Frequency Drive
WSE	Water Surface Elevation

Executive Summary

In the City of Boston (the City), storm sewer systems typically collect rainfall runoff and discharge by gravity into a receiving waterbody (e.g., Boston Harbor, Fort Point Channel, Neponset River, etc.). If the sea level ("tailwater") is sufficiently high, discharge by gravity is limited or no longer possible, which can lead to surcharging and interior flooding during intense rain events. As such, storm sewers require tailwater conditions below a particular threshold to function as designed, and Sea Level Rise (SLR) is slowly increasing these tailwater elevations. During extreme storm events ("named" storms such as hurricanes or nor'easters), the combined effect of SLR and storm surge could restrict or prevent stormwater discharge in many locations, leading to widespread flooding throughout the City, even if the shoreline is protected from the direct impact of storm surge by measures such as shoreline elevation or barriers. Considering this, the Boston Water and Sewer Commission (Commission) undertook the *Coastal Stormwater Discharge Analysis* to achieve the following goals:

1. Identify Commission owned outfalls that are vulnerable to higher sea levels, and which may not function (i.e., discharge stormwater) as intended due to future SLR and storm surge (herein referred to as coastal flood vulnerable outfalls).
2. Develop conceptual designs at an initial set of locations to adapt the Commission-owned outfalls with the greatest coastal flood vulnerability.
3. Create a planning framework that could be used to continue to adapt the remainder of the Commission's coastal flood vulnerable outfalls. [1]

The *Coastal Stormwater Discharge Analysis* builds on the Citywide flood modeling that the Commission completed during the *Inundation Model* project. The *Inundation Model* project led to the creation of a two-dimensional (2D) model, using PCSWMM software, capable of predicting the extent and duration of flood inundation within the City for a variety of extreme wet weather events. Model predictions (generated during the *Coastal Stormwater Discharge Analysis* and *Inundation Model* projects) were used to identify outfalls with the greatest coastal flood vulnerability, and to quantify the flood reduction benefits associated with the concepts developed as part of this project.

The *Coastal Stormwater Discharge Analysis* project was undertaken in the context of the City's ongoing Climate Ready Boston (CRB) program. The CRB program was established to evaluate climate related vulnerabilities throughout the City, including those related to SLR and storm surge, and is developing concepts for shoreline protection for each neighborhood. As shown in **Table ES-1**, shoreline protection (implemented via the CRB program) provides coastal flood protection of land surfaces from SLR and storm surge, while the concepts developed as part of the *Coastal Stormwater Discharge Analysis* facilitate stormwater discharge from existing outfalls during these types of conditions. As documented in this report, the Commission's proposed concepts were designed for consistency (i.e., considering timing and location) with planned CRB shoreline adaptations where possible. As the CRB program continues to evolve over time, the Commission's assumptions in this project will also need to be revisited.

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[1] It is important to note that this project only considered outfalls owned by the Commission. Outfalls owned by other agencies may be coastal flood vulnerable, and require protection as part of a comprehensive adaptation strategy.

Table ES-1: Benefits of CRB Shoreline Protection and Coastal Stormwater Adaptations

Adaptation Program	**Shoreline Protection *(for SLR and Storm Surge)***		**Stormwater Discharge**
	Sunny Day Flooding (SLR Only)	*Overland Coastal Flooding (Storm Surge)*	*Rainfall + SLR + Storm Surge*
Climate Ready Boston	✓	✓	
Coastal Stormwater Discharge Analysis		✓	✓

For the purpose of this project, “coastal flood vulnerability” was defined as an elevation of 13.8 feet NAVD88 (20.3 feet BCB) or less; this elevation is the approximate peak flood elevation during a 100-year tropical storm event in Boston in 2070, based on projections from the Massachusetts Coast Flood Risk Model. **Figure ES-1** depicts coastal flood vulnerable outfalls as well as vulnerable land areas in the City, based on this stated threshold. Note that watersheds and outfalls that drain to the Charles River were not classified as coastal flood vulnerable since the Charles River Dam (and pump station) currently protects these outfalls from high sea levels (and future MassDCR programs/projects are anticipated to continue to harden the dam under future climate conditions).

In order to identify the first set of coastal flood vulnerable outfalls in the Commission’s storm drain and combined sewer systems for development of conceptual designs, a comprehensive framework for identification, screening, and prioritizing outfalls was developed. **Table ES-2** contains the criteria that were used to screen and rank outfalls.

Once the outfalls were screened using this tool, field investigations were performed throughout a variety of neighborhoods at the 31 highest ranked locations to further evaluate the outfalls/locations with respect to coastal flood risk vulnerabilities and opportunities (or constraints) for implementation of coastal stormwater discharge concepts. The final subset of sites that advanced to the conceptual design phase was developed based on coordination with Commission staff and consideration of where the Climate Ready Boston initiative data indicated near-term shoreline protection being proposed. A total of 37 outfalls (multiple outfalls were grouped into one solution/location where possible) were advanced to conceptual design, as shown in **Figure ES-2**.

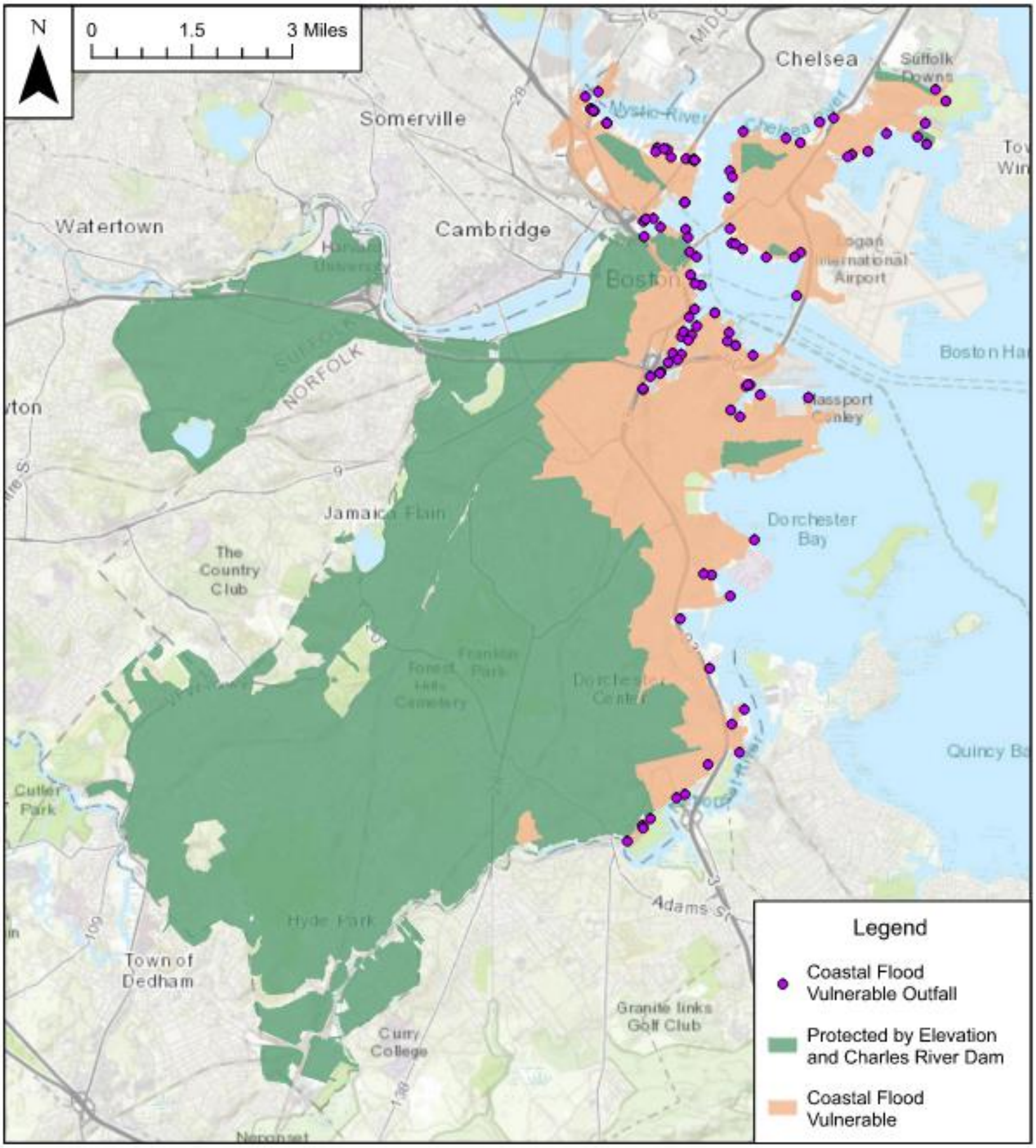


Figure ES-1: Coastal Flood Vulnerability in Boston

Table ES-2: Outfall Ranking Criteria

Category	Criteria	Definition	Data Source
Physical Considerations: Infrastructure Importance and Vulnerability	Discharge Volume	Discharge volume from modeled outfalls for 10-year, 24-hour, design storms and nor'easter and tropical events	BWSC Inundation Model Simulations
	Invert Elevation	Scoring to be done based on ranked list of outfall invert elevations	BWSC (GIS, tile maps)
	Outfall Size	Diameter/dimensions of immediate upstream pipe from GIS	BWSC (GIS, tile maps)
Tributary Area Characteristics (upstream considerations)	Flooded Area	Flooded area from Inundation Model simulations within tributary areas	BWSC Inundation Model Simulations
	Transportation Routes	Length of roadways classified as evacuation routes, transit, and commuter rails within tributary area	MassGIS and BPDA
	Critical Facilities	Number of Critical Facilities in Tributary Area	BWSC "Contact List of Centers"
	Population	Number of Residents within Tributary Area	Boston Open Data (2010 Census)
	Economic Importance	Number of employees within tributary area	risQ (LODES* database and ACSS*)
	Land Use	Land ownership of parcels adjacent to/containing outfalls within tributary area	Boston Open Data (2016 Parcels) BWSC "Open Space"
	Environmental Justice/Social Vulnerability	Social vulnerability of residents within tributary	risQ (LODES* database and ACSS*)

1. *LODES – Longitudinal Origin-Destination Employment Statistics
2. *ACSS – American Community Survey and Statistics

Outfalls identified through this process were prioritized for further desktop analysis to verify physical vulnerability to SLR and storm surge, and site visits were conducted to characterize site constraints and opportunities for conceptual design of a stormwater discharge solution. The criteria described in **Table ES-2** were used directly to "score" and rank each Commission-owned outfall in this desktop analysis step. In recognition of the fact that different stakeholders may value (i.e., weight) some criteria more than others, a PowerBI (Power "Business Intelligence") dashboard was developed to provide the Commission the ability to adjust the weight of criteria ("on the fly," resulting in automated updates to the priority list when a criterion changes).

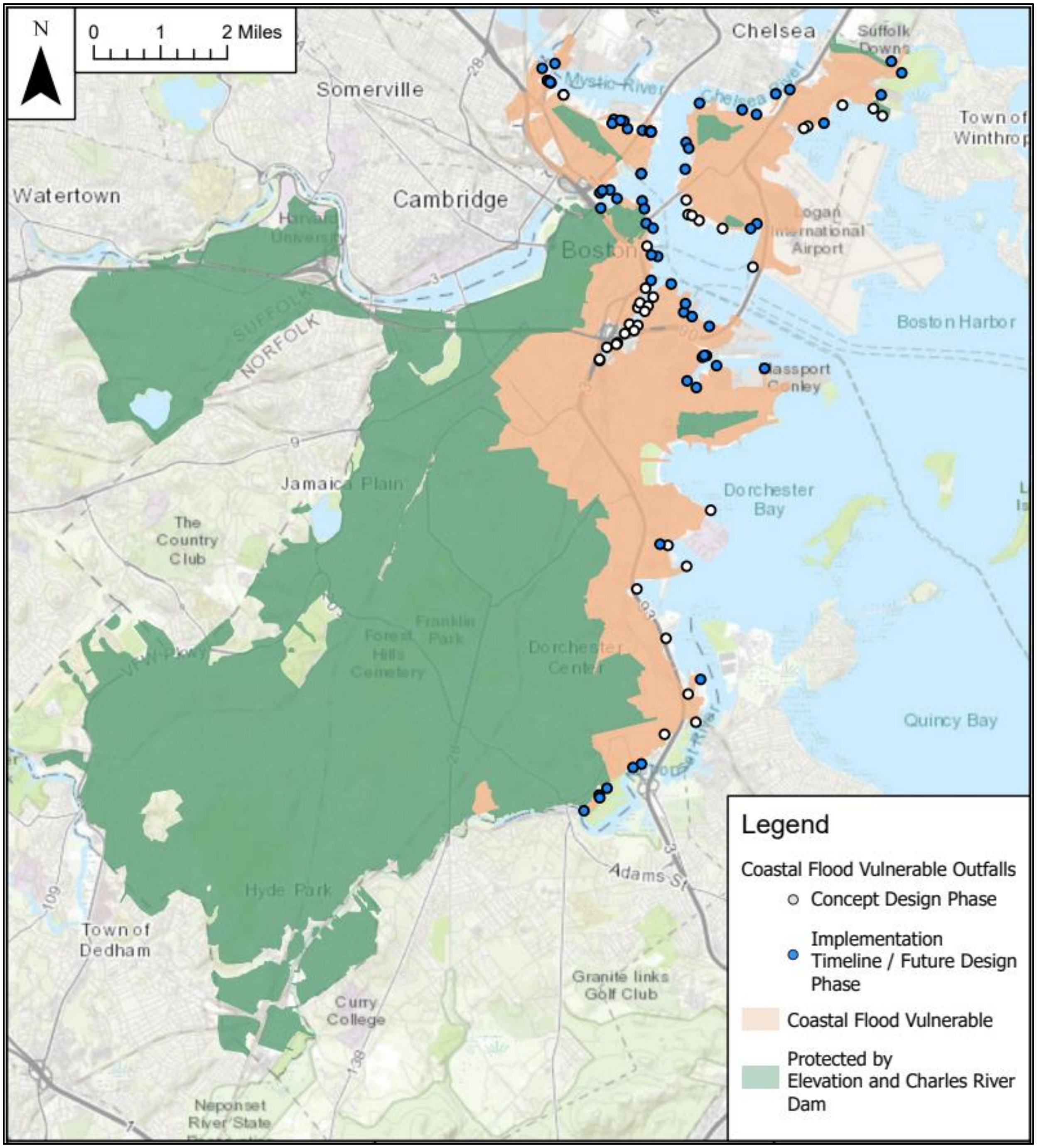


Figure ES-2: Commission-Owned Vulnerable Outfalls by Concept Design Phase

While the Commission’s intent is ultimately to address all vulnerable outfalls (and their associated drainage areas), more detailed conceptual solutions were developed for these initial outfalls as a starting point; beyond these initial locations (covering 37 outfalls), a plan was developed (the “Implementation Timeline”) for replicating these types of detailed solutions to the remainder of the Commission’s outfalls.

As schedule and budget planning is advanced in the coming years, the Commission (or another entity) may carry out a similar level of conceptual design at these other outfalls as well.

Two different wet weather events were used in this project to develop conceptual designs and evaluate flood reduction benefits as described below:

- 100-year tropical storm – used to evaluate the flood reduction benefits of the proposed solutions (this storm is consistent with the approach that CRB is taking with regard to a 1% chance storm for analysis purposes). A rainfall hyetograph (and other parameters including storm speed and direction) for this storm event was developed during the *Inundation Model Project*). The 100-year tropical storm results in 9.58 inches of rainfall in 48 hours.
- 2070 projected 10-year 24-hour design storm – used to size proposed infrastructure solutions (since the Commission's collection system is understood to generally have capacity to convey flows from a 10-year storm). This storm event was developed by updating the Commission's previous design storm using up-to-date rainfall distributions and precipitation projections. The 2070 projected 10-year design storm results in 6.18 inches of rainfall in 24 hours.

This project utilized SLR and storm surge predictions that the Commission obtained during the *Inundation Model Project* from the Massachusetts Coast Flood Risk Model (MC-FRM). The SLR values applied in MC-FRM are consistent with the standards for the Commonwealth of Massachusetts developed by Coastal Zone Management. The MC-FRM utilizes a "High" SLR scenario. This scenario is based on the relative SLR projections under RCP 8.5 (a "worst case scenario" of increasing atmospheric carbon concentrations) and represents elevations that have a 99.5% probability of not being exceeded within the respective timeframes. In 2030, that amounts to an increase of 1.3 ft in Boston from a baseline condition (2008 centered tidal epoch), and in 2070 that amounts to an increase of 4.3 ft.

The concept solutions developed in this project were analyzed using coastal conditions that include 2070 projected SLR and storm surge resulting from a 100-year tropical storm. The peak water surface elevation (WSE) predicted by the MC-FRM during these conditions is approximately 13.8 ft NAVD88 (varies by location).

For each conceptual design location, a combination of conveyance, storage, and pumping alternatives were evaluated to develop a solution that improves the discharge of stormwater (and reduces upstream flooding), with the most feasible alternative(s) selected based on site characteristics and system configuration. Where possible, nature-based features were incorporated into these conceptual designs. The conceptual designs were developed at 11 locations to protect a total of 37 Commission owned outfalls from SLR and storm surge. **Together with shoreline protection measures (identified by CRB) and installation of tide gates, these conceptual solutions could protect 71% of the coastal flood vulnerable land area in Boston.**

Each concept design was summarized in a succinct package (**Appendix G**) that includes an overview of the proposed concept, basis of design summary/assumptions, flood reduction benefits (2D model results), economic benefits (damage analysis), project cost estimate, conceptual design drawings/schematics, as well as considerations for implementation and adaptability.

Construction cost opinions were developed for each concept. These cost opinions include estimates that are considered to be AACE (Association for the Advancement of Cost Estimating) International Class 4, which has a typical accuracy range of -30% to -15% on the low side and +20% to +50% on the high side.

Table ES-3 presents total project costs (including an approximation of design and construction engineering) for each location. The costs in **Table ES-3** for Fort Point Channel and Dorchester Bay Basin exclude the storm surge barriers. Design and Construction Administration costs are calculated based on 20% of the total cost (less design contingency). **Table ES-4** presents sub-totals for the storm surge barriers alone, including two different types of barriers for the Fort Point Channel location. **Appendices L and M** include detailed cost estimate backup data.

The estimates are comprised of unit costs calculated from a combination of detailed takeoff, forced takeoff, factoring, and allowances. Design contingency carried is at 50% based on the status of the design, the nature of the project, the estimate classification, and estimator judgment for most locations and features. The two projects which are the furthest along in the design process, the Fort Point Channel and Dorchester Bay Basin storm surge barriers, carried a 35% contingency, as the more-developed designs inherently have less uncertainty. The reason for the difference in estimating level is that the storm surge barrier designs needed to be advanced to a slightly higher level of detail to accurately capture the potential construction costs (including temporary costs, such as cofferdam construction).

The estimates include direct and indirect construction costs, as well as markups that represent contractor and subcontractor overhead and profit, escalation to midpoint of construction for labor and materials, bonds/insurance, and contract allowances. The assumed timeframe for construction work is late-2030’s, evident in the assumed escalation (based on 15 years from date of pricing to expected midpoint of construction).

Items that are excluded in the cost estimate include:

- Land/property easements/purchase/transfers
- Microtunneling or other costs related to railroad or major highway crossings (applies to Dorchester Bay Basin storm sewers)
- Improvements related to Climate Ready Boston projects (shoreline protection)
- Site restoration above and beyond current site conditions

Table ES-3: Concept Cost Estimate Subtotals (Exclusive of Storm Surge Barriers)

	Airport	**Charlestown Schrafft Center**	**Columbus Park**	**Con**stitution Beach	**Davenport Creek**	**Dorchester Bay Basin[2]**	**East Boston Greenway**	**East Boston Waterfront**	**Fort Point Channel[1]**	**Old Harbor Park**	**Joseph F**innegan Park
Direct Construction Costs	$7,236,248	$11,596,079	$4,731,915	$7,615,841	$17,902,197	$48,774,375	$2,936,938	$6,256,022	$8,968,000	$7,012,000	$9,246,000
Indirect Construction Costs	$1,447,250	$2,319,216	$946,383	$1,523,168	$3,580,439	$9,754,875	$587,388	$1,251,204	$1,794,000	$1,402,000	$1,849,000
Mark-Up (incl. escalation)	$9,645,964	$15,544,944	$6,366,233	$10,209,454	$24,110,121	$65,740,034	$3,926,783	$8,373,533	$11,858,649	$9,319,302	$12,443,046
Construction Sub-total	**$18,329,462**	**$29,460,239**	**$12,044,521**	**$19,348,463**	**$45,592,757**	**$124,269,284**	**$7,451,109**	**$15,880,759**	**$22,620,649**	**$17,733,302**	**$23,538,046**
Design Continency	$8,833,538	$14,197,762	$5,804,479	$9,324,537	$21,972,243	$59,888,716	$3,590,892	$7,653,220	$10,901,147	$8,545,899	$11,343,712
Sub-total	**$27,163,000**	**$43,658,001**	**$17,849,000**	**$28,673,000**	**$67,565,000**	**$184,158,000**	**$11,042,001**	**$23,533,979**	**$33,521,796**	**$26,279,201**	**$34,881,758**
Design & Construction Administration	$3,666,000	$5,893,000	$2,409,000	$3,870,000	$9,119,000	$24,845,000	$1,491,000	$3,177,000	$4,524,000	$3,547,000	$4,708,000
Total Project Cost	**$30,829,000**	**$49,551,001**	**$20,258,000**	**$32,543,000**	**$76,684,000**	**$209,003,000**	**$12,533,001**	**$26,710,979**	**$38,045,796**	**$29,826,201**	**$39,589,758**

Notes:

1. Fort Point Channel location excludes the storm surge barrier estimate; includes only the pump station
2. Dorchester Bay Basin location excludes the storm surge barrier estimate; includes only the conveyance and diversion structures

Table ES-4: Storm Surge Barrier Cost Estimate Subtotals

	Fort Point Channel[1]			**Dorchester Bay Basin**
	Submerged Axis Flap Gate *(4 gates)*	**Submerged Axis Flap Gate - South Location** *(3 gates)*	**Vertical Lift Gate**	**Vertical Lift Gate**
Remaining Design Development & BWSC Construction Administration	$60,553,000	$49,851,000	$36,350,000	$14,169,000
Direct & Indirect Construction Costs Total (Marked-up)*	$329,465,000	$271,236,000	$197,328,000	$76,917,000
Escalation (15 Years)	$240,119,000	$197,682,000	$143,867,000	$56,078,000
Design Contingency	$136,506,000	$112,381,000	$81,788,000	$31,881,000
Total	**$766,643,000**	**$631,150,000**	**$459,333,000**	**$179,045,000**

<u>Notes:</u>

1. Fort Point Channel location excludes the pump station estimate; includes only the storm surge barrier portion of the cost.

In addition, Hazen and its subconsultant, risQ, Inc. (recently acquired by Intercontinental Exchange, Inc.), developed estimates of economic impact (i.e., damage) on the physical environment (i.e., buildings, etc) due to flooding both with and without the solutions in place. This damage analysis included calculations of three metrics:

- Replacement value (of buildings) – total value of the impacted buildings in each area, based on rebuild cost; this is a conservative number as it assumes the entire structure needs to be rebuilt regardless of flood depth/duration; a structure is included in the cost if flooding is predicted to encroach it
- Physical damage (to buildings) – presented as both minimum, maximum values (and a simple average of the two numbers)
    - Minimum values are based on the affected buildings as indicated by the minimum predicted depth of flooding in the area and the lower value of replacement cost estimates (a range was evaluated)
    - Maximum values are based on the affected buildings as indicated by the maximum predicted depth of flooding in the area and the higher value of replacement cost estimates (a range was evaluated)
- Lost Usage - Gross Domestic Product (GDP) impairment, presented as both minimum, maximum (and a simple average of the two numbers); includes:

  - Business interruption for commercial and industrial properties
  - Lost rental income and property taxes for residential properties

Model-predicted flooding data (in the form of GIS shapefiles) from the 2D Inundation Model simulations, for the 100-year tropical storm event, were input into risQ’s economic database/framework. Two scenarios were evaluated: 1) Shoreline protection only (CRB proposed projects), and 2) Shoreline protection + conceptual solution (flood mitigation) + installation of tide gates on all coastal flood vulnerable outfalls. Economic impacts before and after the solutions are implemented were calculated, for each “area of interest”, which correspond to the outfall tributary areas at each conceptual design location.

This Section provides a concise summary of the economic damage analysis performed, but for additional detail please refer to **Section 7** of this report and **Appendix K** for complete documentation. Values reported in **Table ES-5** are shown in 2022 dollars and are reported in thousands for simplicity.

Table ES-5: Economic Damage Analysis Results (Thousands of Dollars)

Area	Scenario	Replacement Value of Impacted Buildings	Min Physical Damage	Max Physical Damage	Average Physical Damage	Min Lost Usage	Max Lost Usage	Average Lost Usage
Fort Point Channel	Shoreline Protection Only	20,470,236	2,938,938	5,105,728	4,022,333	1,842,013	3,894,824	2,868,419
Fort Point Channel	Conceptual Solution	4,616,728	676,619	1,145,390	911,005	86,588	225,193	155,891
Joseph Finnegan Park	Shoreline Protection Only	152,077	24,789	41,516	33,153	46,119	77,888	62,004
Joseph Finnegan Park	Conceptual Solution	30,029	4,290	7,025	5,658	12,606	21,034	16,820
Old Harbor Park	Shoreline Protection Only	310,681	45,805	76,698	61,252	27,815	76,874	52,345
Old Harbor Park	Conceptual Solution	0	0	0	0	0	0	0
East Boston Waterfront	Shoreline Protection Only	482,821	69,255	115,439	92,347	7,805	22,399	15,102
East Boston Waterfront	Conceptual Solution	6,789	987	1,665	1,326	8	29	19
Constitution Beach	Shoreline Protection Only	519,621	52,906	89,495	71,201	22,837	42,692	32,765
Constitution Beach	Conceptual Solution	166,283	2,382	3,991	3,187	6,055	10,115	8,085
East Boston Greenway	Shoreline Protection Only	12,754	2,008	3,392	2,700	20	54	37

Area	Scenario	Replacement Value of Impacted Buildings	Min Physical Damage	Max Physical Damage	Average Physical Damage	Min Lost Usage	Max Lost Usage	Average Lost Usage
East Boston Greenway	Conceptual Solution	0	0	0	0	0	0	0
Dorchester Bay Basin	Shoreline Protection Only	1,408,902	186,031	315,066	250,549	326,320	866,024	596,172
Dorchester Bay Basin	Conceptual Solution	467,912	50,691	84,433	67,562	78,449	225,660	152,055
Davenport Creek	Shoreline Protection Only	161,816	22,380	37,466	29,923	10,053	17,382	13,718
Davenport Creek	Conceptual Solution	0	0	0	0	0	0	0
Columbus Park	Shoreline Protection Only	4,432,483	714,699	1,239,409	977,054	1,232,970	2,281,389	1,757,180
Columbus Park	Conceptual Solution	1,258,120	186,800	324,124	255,462	370,274	867,807	619,041
Charlestown Schrafft Center	Shoreline Protection Only	115,431	14,032	24,831	19,432	8,625	36,397	22,511
Charlestown Schrafft Center	Conceptual Solution	6,281	757	1,262	1,010	0	$2	$1
Boston Logan Airport	Shoreline Protection Only	883,069	125,137	214,588	169,863	74,862	199,502	137,182
Boston Logan Airport	Conceptual Solution	54,545	5,787	10,028	7,908	2,490	8,319	5,405

Notes:

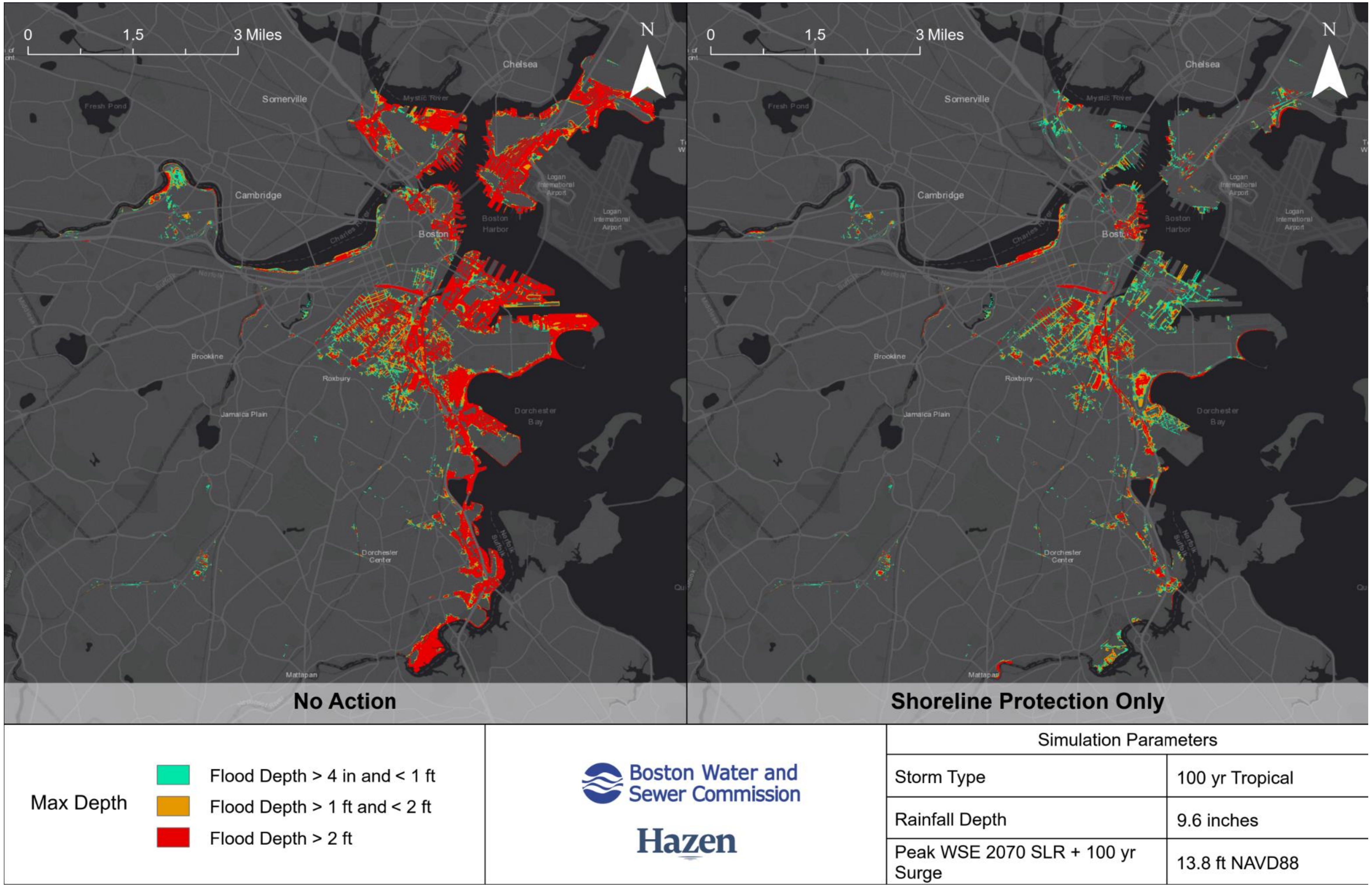
1. Costs are presented in 2022 dollars (no net present value assumed)

Although no net present value was assumed for the damage estimates presented in **Table ES-5**, a comparison of estimated project costs with damage estimates illustrates that the coastal stormwater adaptations developed as part of this project have the potential to avoid significant losses (in exceedance of estimated project costs) during future extreme storm events.

At the conclusion of the project, 2D coastal flood model simulations were performed at all conceptual design locations simultaneously to evaluate the cumulative effectiveness of the proposed conceptual solutions. **Figure ES-3** depicts a comparison of "no action" model predictions during a 100-year tropical storm event in 2070 versus a scenario including complete shoreline protection (i.e., CRB projects completed). As this figure illustrates, shoreline protection alone reduces peak flood depths and extents throughout the City, but does not fully alleviate substantial interior flooding in many neighborhoods and drainage areas, including the area tributary to the Fort Point Channel.

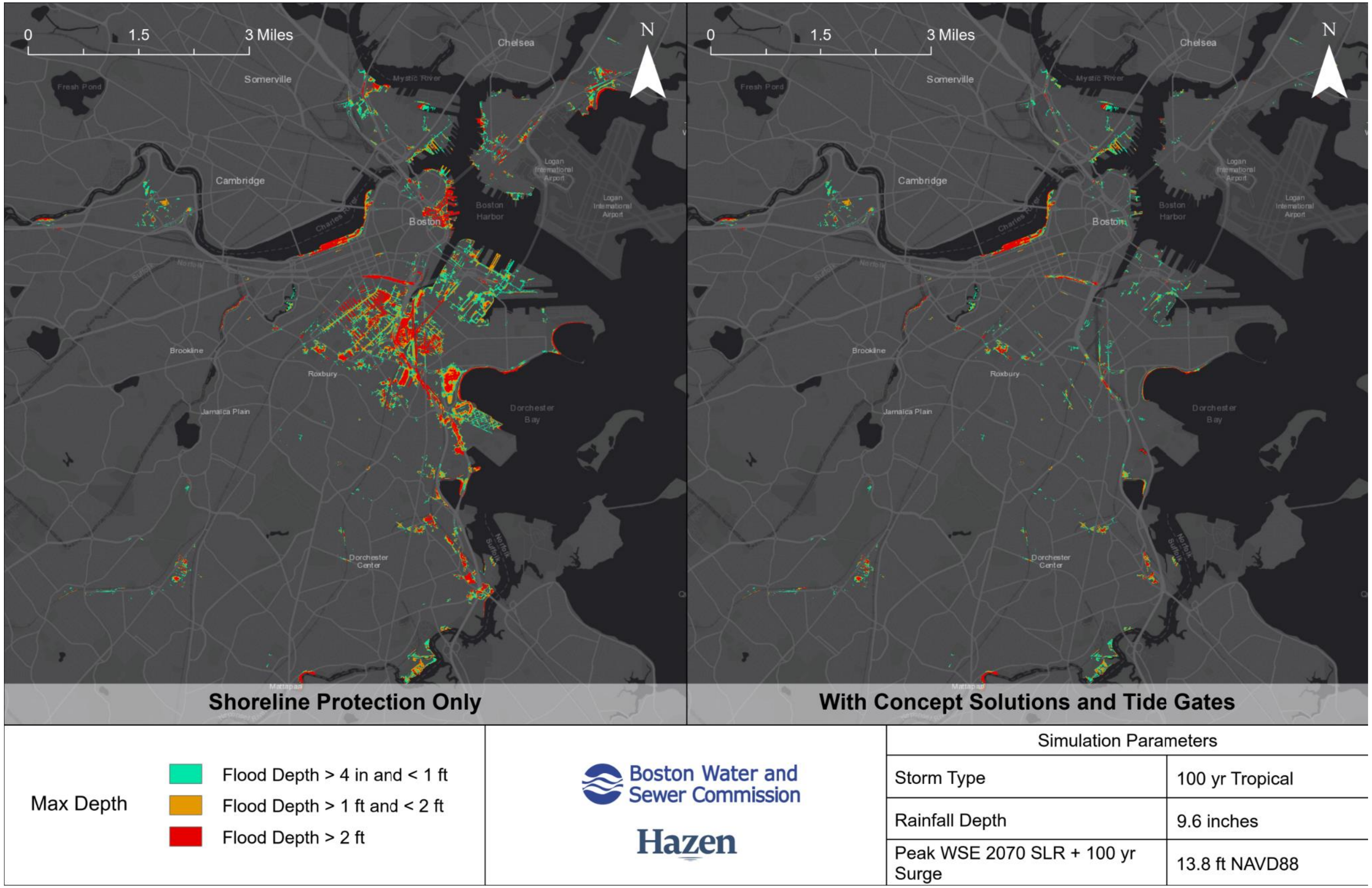
Figure ES-4 depicts a comparison of the shoreline protection scenario versus a scenario that includes shoreline protection in addition to the proposed coastal stormwater concepts documented in this report, as well as tide gates on all coastal flood vulnerable BWSC owned outfalls. As shown in this figure, the coastal stormwater discharge concepts and tide gates substantially reduce flooding compared to shoreline protection only. This comparison illustrates the effectiveness of the concepts documented in this report, and the need to closely coordinate shoreline protection with coastal stormwater discharge adaptations and installation of tide gates on coastal flood vulnerable outfalls. Additional flooding that could result from unprotected non-Commission outfalls was not accounted for in these simulations or in this project.

It is important to note that this project did not include an analysis of outfalls owned privately or by other agencies. These outfalls should be accounted for and adapted in the future. Unprotected outfalls (without tide gates) have the potential to serve as conduits that "bypass" shoreline protection measures (and adapted Commission outfalls). As such, identification and protection of these other outfalls are crucial elements of a complete Citywide adaptation program.



Simulation Parameters	
Storm Type	100 yr Tropical
Rainfall Depth	9.6 inches
Peak WSE 2070 SLR + 100 yr Surge	13.8 ft NAVD88

Figure ES-3: No Action versus Shoreline Protection Only Flood Scenarios



Simulation Parameters	
Storm Type	100 yr Tropical
Rainfall Depth	9.6 inches
Peak WSE 2070 SLR + 100 yr Surge	13.8 ft NAVD88

Figure ES-4: Shoreline Protection Only versus With Concept Solutions Flooding Scenarios

The concepts developed during this project provide benefits beyond the shoreline; the coastal stormwater adaptations in this report could substantially reduce flooding across the City (when paired with shoreline protection) and offer benefits to multiple agencies and sectors. Given the large potential benefits and impact of the concepts, there are many potential auxiliary funding opportunities for these concepts, including potential for federal funding assistance.

Considering the broad scope and the substantial cost of constructing and maintaining these concepts, it may be prudent to consider the creation of new agency, consisting of multiple agencies/stakeholders (including the Commission) responsible for funding, maintaining, and operating solutions with regional benefits. Possible stakeholder entities for a new “Massachusetts Coastal Defense Agency” are illustrated in **Figure ES-5.**

Figure ES-5: Massachusetts Coastal Defense Agency

The City is working with the U.S. Army Corps of Engineers (ACOE) on the CRB program. The Commission has submitted drafts of the conceptual designs that were developed as part of this project to the City for comment. After the ACOE completes their review of adaptation strategies proposed for Boston, it may impact the proposals/concepts documented in this report. It is recommended that after ACOE submits their findings, that the Commission revisit these recommendations and update them as necessary.

This project is an important milestone in the Commission's climate adaptation efforts. The concepts developed as part of this project were designed to be replicable and scalable, allowing the Commission to adapt outfalls in coordination with the City as CRB is implemented. In addition, the following conclusions can be drawn:

- Shoreline protection (via CRB) is important to prevent "sunny day" flooding due to SLR. Despite this, substantial Citywide flooding is still expected to occur during future rain events due to the effects of higher sea levels on coastal flood vulnerable outfalls.
- Regionalized solutions (such as the FPC Storm Surge Barrier or Dorchester Bay Basin) have the potential to adapt a large number of Commission outfalls (and portion of the coastal flood vulnerable drainage area in Boston) without the need for distributed pump stations. The Commission (and City) should continue efforts to implement regionalized solutions with significant Citywide benefits.
- Installation of tide gates on coastal flood vulnerable outfalls is an important near-term measure that can be taken to reduce the impacts of higher sea levels. Despite this, many coastal flood vulnerable outfalls require additional adaptation to ensure stormwater discharge is still possible during extreme rain events (with higher sea levels).
- It is important that coastal flood outfalls owned by other entities/agencies are identified and protected as necessary. Unprotected coastal flood vulnerable outfalls have the potential to "bypass" adaptations implemented by the City and the Commission.
- 2D flood modeling results indicate that implementation of the concepts documented in this report has the potential to substantially reduce flooding during future extreme storm events and avoid significant monetary/economic losses. Given the large cost and regionalized benefits of these projects, the creation of a new agency, consisting of multiple agencies/stakeholders (including the Commission) responsible for funding, maintaining, and operating these solutions should be considered.

As a next step, the Commission should continue coordination with the City as the CRB program is implemented. Commission-owned coastal flood vulnerable outfalls that align with areas being adapted by CRB should be prioritized for final design and construction efforts. The conceptual designs developed as part of this project are intended to be replicable, as outlined in **Section 8 - Implementation Timeline** and **Appendix E**, and can serve as a starting point for adaptation design efforts at these locations.

1. Background and Project Objectives

1.1 Background

In the City of Boston (the City), storm sewer systems typically collect rainfall runoff for discharge by gravity into a receiving waterbody (e.g., Boston Harbor, Fort Point Channel, Neponset River, etc.). If the sea (“tailwater”) level is sufficiently high, discharge by gravity is limited or no longer possible, which could lead to surcharging and interior flooding during some rain events. As such, storm sewers require tailwater conditions below a particular threshold to function as designed, and Sea Level Rise (SLR) is slowly increasing these tailwater elevations. During extreme storm events (“named” storms such as hurricanes or nor’easters), the combined effect of SLR and storm surge could restrict or prevent stormwater discharge in many locations, leading to widespread flooding throughout the City, even if the shoreline is protected from the direct impact of storm surge by measures such as shoreline elevation or barriers. Adaptations (e.g., storage, pumping, conveyance, etc.) that maintain the required tailwater elevation at tidally influenced outfalls are being evaluated as part of this project, referred to as the Boston Water and Sewer Commission’s (the Commission) Coastal Stormwater Discharge Analysis.

In the meantime, the City has already implemented (and is continuing to update/advance) the *Climate Ready Boston* (CRB) program to evaluate climate related vulnerabilities throughout the City, including those related to SLR and storm surge, and is developing concepts for shoreline protection for each neighborhood. The Commission has undertaken efforts to coordinate with the City, to help make sure that vulnerable areas are protected both by shoreline adaptations and by coastal stormwater discharge solutions.

The objective of the Coastal Stormwater Discharge Analysis is to identify highly vulnerable coastal outfalls (Commission-owned) and develop concepts to facilitate stormwater discharge under future high tide conditions. As part of this project, conceptual designs were developed at 11 locations to protect a total of 37 Commission owned outfalls from SLR and storm surge. Together with shoreline protection measures (identified by Climate Ready Boston), these additional concept solutions could protect 71% of the coastal flood vulnerable area in Boston. **It is important to note that outfalls owned by other entities (e.g., private, DCR, etc.) were not included in this project, and additional adaptations would need to be considered by their owners to protect them against SLR and storm surge.**

The Coastal Stormwater Discharge Analysis also included development of an Implementation Timeline that establishes a “roadmap” for protecting other less vulnerable outfalls throughout the City (by replicating successful design concepts) as SLR and storm surge continue to threaten coastal infrastructure.

It is important to recognize that the Commission’s stormwater system depends on the functionality of several hundred outfalls that are located throughout the City. Some of these outfalls are relatively small, and not directly subject to tidal influences. Although recommendations for adaptation of these smaller and less vulnerable outfalls were included in the Implementation Timeline, the primary focus of this initial project was development of adaptations for the Commission’s most vulnerable outfalls.

1.2 Key Data Sources and Definitions

The Coastal Stormwater Discharge Analysis utilized a variety of data types from different sources throughout the project as documented here:

- **Sea Level Rise and Storm Surge** data were obtained from the Massachusetts Coastal Flood Risk Model (MC-FRM) developed by Woods Hole Group. According to Woods Hole Group, the firm that developed and operated the MC-FRM, "*sea level rise projections utilized in MC-FRM are based on the Representative Concentration Pathways (RCP) greenhouse gas concentration trajectories developed as part of the Intergovernmental Panel on Climate Change (IPCC). These pathways describe a wide range of possible scenarios that may occur due to future anthropogenic greenhouse gas emissions. The RCP pathway utilized in this assessment (RCP 8.5) assumes that no changes are made to human based emissions. The sea level rise produced under this scenario (RCP 8.5) was developed specifically for the Commonwealth of Massachusetts, is being used in the MC-FRM, and is consistent with the projections being used in the Massachusetts State Hazard Mitigation Climate Adaptation Plan. These projections are being used by coastal communities developing resiliency plans and for mitigation planning through the Massachusetts Office of Coastal Zone Management, and the Massachusetts Emergency Management Agency programs. Projections were developed for the Commonwealth of Massachusetts and take into account regional considerations for the Northeast.*"

  The Commission obtained data from the MC-FRM in 2019 during the *Inundation Model Project* for scenarios in 2030 and 2070. In 2030, SLR projections amount to an increase of 1.3 ft in Boston from a baseline condition (2008 centered tidal epoch), and in 2070 projected SLR amounts to an increase of 4.3 ft. According to Woods Hole Group, "*this scenario is based on the Relative Sea Level Rise (RSLR) projections under RCP 8.5 and represents elevations that have a 99.5% probability of not being exceeded within the respective timeframes*".

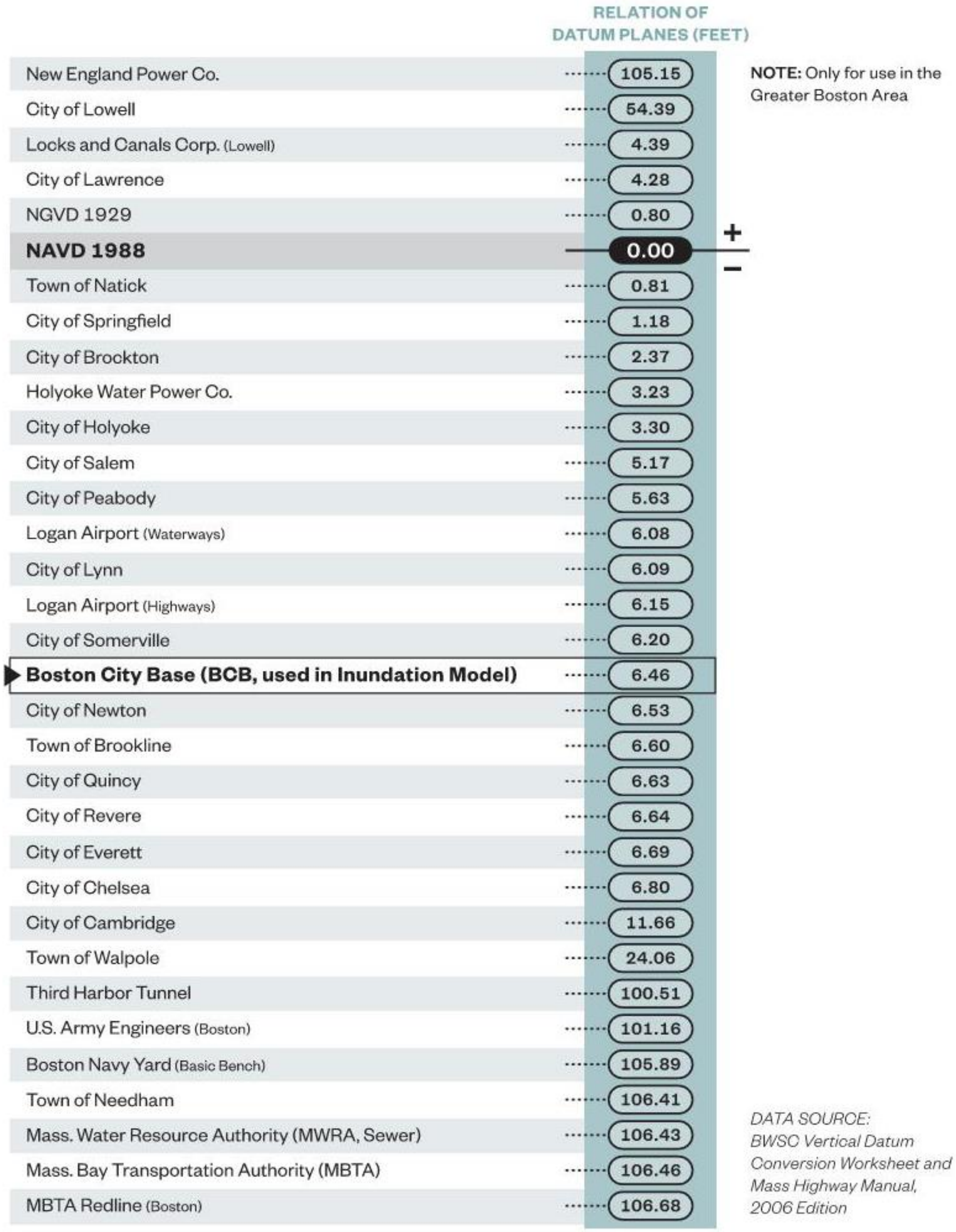
- **Extreme Rainfall and Design Storm Events** for analysis and design were specially developed for the purposes of this project. **Section 2** of this report documents the methodologies that were employed to develop rain event data for modeling purposes. In summary, the Commission utilized the 100-year tropical storm event that it previously developed during the *Inundation Model Project* for the purpose of analyzing the benefits of proposed solutions, and updated its 10-year, 24-hour design storm using 2070 climate projections for the purpose of sizing and designing the conceptual solutions herein.

- **The Commission's 2D Inundation Model** was an important data source for this project. In addition to certain wet weather events, the *Inundation Model Project* included an extensive modeling effort and resulted in a unified sewer and drain model. Section 5 of *the Inundation Model Report* (2021) contains a summary of model development and configuration. The two-dimensional (2D) model networks that were developed as part of this project utilized the *2013-2014 USGS CMGP: Post Sandy* LiDAR (Light Detection and Ranging) dataset as described in Section 2.2 of the *Inundation Model Report*.

- **Climate Ready Boston** was an important consideration throughout the project. In addition to several meetings with the CRB project team, the CRB website and neighborhood level planning reports were consulted throughout the project to identify the location and timing of planned shoreline adaptations.

1.3 Datum Conversions

Figure 1-1 illustrates a summary of datum conversions for the Boston area that can be used when reading and interacting with the content in this report. The primary datum used in this project is NAVD88 (North American Vertical Datum of 1988). *Note: 0.00 NAVD88 = 6.46 BCB.*



	RELATION OF DATUM PLANES (FEET)
New England Power Co.	105.15
City of Lowell	54.39
Locks and Canals Corp. (Lowell)	4.39
City of Lawrence	4.28
NGVD 1929	0.80
NAVD 1988	**0.00**
Town of Natick	0.81
City of Springfield	1.18
City of Brockton	2.37
Holyoke Water Power Co.	3.23
City of Holyoke	3.30
City of Salem	5.17
City of Peabody	5.63
Logan Airport (Waterways)	6.08
City of Lynn	6.09
Logan Airport (Highways)	6.15
City of Somerville	6.20
Boston City Base (BCB, used in Inundation Model)	6.46
City of Newton	6.53
Town of Brookline	6.60
City of Quincy	6.63
City of Revere	6.64
City of Everett	6.69
City of Chelsea	6.80
City of Cambridge	11.66
Town of Walpole	24.06
Third Harbor Tunnel	100.51
U.S. Army Engineers (Boston)	101.16
Boston Navy Yard (Basic Bench)	105.89
Town of Needham	106.41
Mass. Water Resource Authority (MWRA, Sewer)	106.43
Mass. Bay Transportation Authority (MBTA)	106.46
MBTA Redline (Boston)	106.68

NOTE: Only for use in the Greater Boston Area

DATA SOURCE: BWSC Vertical Datum Conversion Worksheet and Mass Highway Manual, 2006 Edition

Figure 1-1: Datum Conversions

1.4 Other Existing Information

This section contains a description of existing information that was used throughout the project. As such, climate adaptation efforts and projects being developed by outside agencies and stakeholders are documented. In addition, this section provides an overview of additional data/tools that were used to evaluate projects in subsequent stages of the project.

1.4.1 Existing Commission Information

1.4.1.1 Geographic Information System (GIS)

The Commission maintains a GIS database that includes spatial and physical characteristics of its infrastructure. This database includes pipes, manholes, pump stations, outfalls, and other similar types of infrastructure. Parameters such as invert elevations, coordinates, sizes, etc. informed an evaluation of the vulnerability of the Commission's coastal infrastructure to SLR and storm surge. GIS data in this project was obtained from the Commission throughout 2020-2022.

1.4.1.2 Inundation Model

The Inundation Model is a 2D hydrologic/hydraulic model, built using Personal Computer Storm Water Management Model (PCSWMM) software, designed to predict the extent and duration of flood inundation within the City of Boston. The Commission previously developed this tool in 2020 to identify impacted critical infrastructure and populations throughout the City during varied wet weather events. For this project, this tool was further developed and refined to predict the flood impacts that result from "blocked" coastal infrastructure. 2D modeling was also conducted to evaluate conceptual designs and to support the *Damage Analysis* task.

1.4.2 Climate Ready Boston

In 2016, the Boston Research Advisory Group (BRAG) published a report on various climate projections to predict how climate change could impact Boston. The report included projections for future precipitation, sea level rise, heat extremes, and other factors. This report serves as a basis for the City's *Climate Ready Boston* initiative, which is currently evaluating strategies and projects to protect vulnerable neighborhoods against these threats.

In 2022 the BRAG issued an updated report with new SLR projections. The report acknowledges that long term SLR projections are associated with significant uncertainty, and that updated projections include less SLR by 2100 (compared to earlier projections in the 2015 BRAG Report). According to the report, the likely range of SLR by 2070 under an RCP 8.5 scenario is 1.4 – 2.8 ft.

1.4.2.1 Climate Ready Boston Website

In addition to containing neighborhood specific reports, the Climate Ready Boston website can be used to obtain information on the status of the initiative. The website features two interactive maps, which were consulted during various phases of this project from 2020-2022, that depict existing vulnerabilities and adaptation concepts:

Climate Ready Boston Map Explorer: This tool depicts predicted flooding impacts from SLR, storm surge, and rainfall. It also provides spatial data for population demographics to better characterize the demographics that fall within these vulnerable areas.

Coastal Resilience Project Tracker: This tool maps coastal resilience plans for each neighborhood. Each project included in this tool is accompanied by background analysis and a document for the pertinent neighborhood, including an overview of flooding risk, resilience solution, and a possible short-, medium-, and long-term timeline for project implementation.

1.4.2.2 Climate Ready Boston – Timeline for Implementation

A meeting between the City of Boston, the Commission, and Hazen was held on December 4, 2020, to obtain more information about a possible schedule for implementation of Climate Ready Boston projects. After this meeting, the City provided a table containing a timeline for project implementation (contained in **Appendix A**). It should be noted that this timeline is preliminary and subject to change.

1.4.2.3 Climate Ready Boston Neighborhood Level Reports

This section contains a brief overview of the neighborhood level evaluations currently in development as part of Climate Ready Boston (as of December 2022). The Climate Ready Boston website continues to serve as the most up-to-date source for information about these projects.

CRB prepared reports for each neighborhood within Boston where coastal flood risks were identified. The reports were led by the City of Boston Environmental Department and Boston Planning & Development Agency (BPDA). The documents contain near-term and long-term strategies for protecting Boston from sea level rise and coastal flooding, including flood barriers/berms, raised coastline, building and site-level adaptations, and ecological adaptation. **Figure 1-2** shows a map of the project locations described within the reports and their expected implementation times. Conceptual designs considered neighborhood-specific design flood elevations (DFEs). The DFEs were determined by CRB and are defined as "*The recommended elevation required to protect an area from a specific level of coastal flooding including water levels and waves*." In CRB projects, the crest of seawalls, raised berms, and other similar flood prevention installations are designed to meet these DFEs. Region-specific DFEs are summarized in **Table 1-1**. Elevations are given in NAVD88. All neighborhoods have a range of DFEs that are specific to areas within the neighborhood. CRB DFEs were not by Hazen; verification of the CRB-determined DFEs is recommended in later stages of design. Technical Memorandum (TM) #1 contains a more complete description of the CRB neighborhood level reports that were consulted in 2020 and 2021 early in the project.

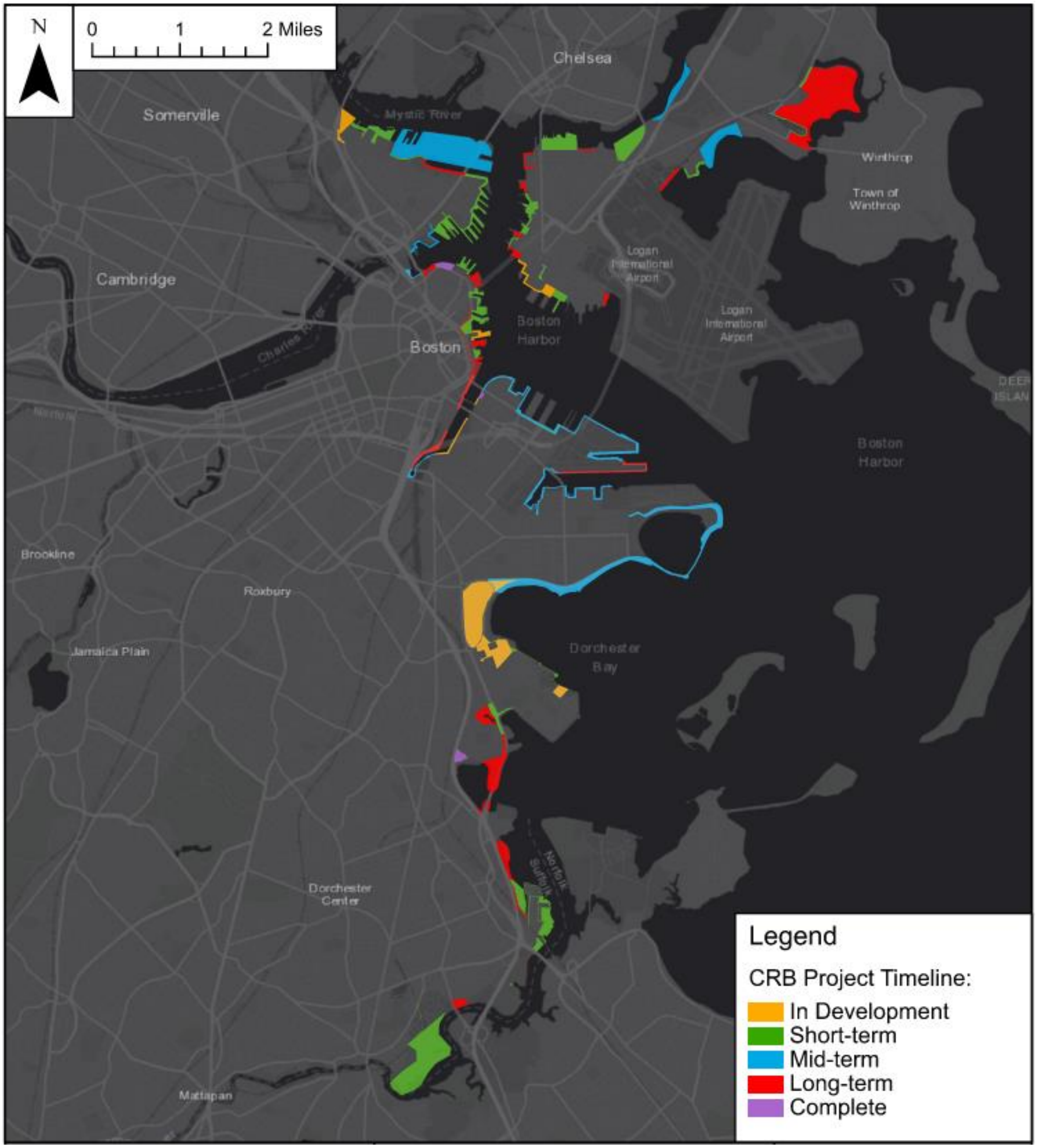


Figure 1-2: CRB Project Locations and Timeline (as of Q3 2022)

Table 1-1: CRB Neighborhood-Specific Design Flood Elevations (as of Q3 2022)

Neighborhood	Design Flood Elevation (NAVD88)
East Boston	14.04 – 16.0
Charlestown	14.04 – 15.5
South Boston	14.0 – 17.0
Downtown and North End	14.5 – 16.5
Dorchester	14.4 – 16.2

1.4.2.4 Climate Ready Boston Summary

It is anticipated that the preliminary recommendations, outlined in Technical Memorandum 1, will evolve over time as various Climate Ready Boston initiatives are better defined and assigned a more definitive timeline for implementation. Coordination with the City and the BPDA was on-going throughout the project to help make sure that highly probable (and well defined) projects were accounted for.

1.4.3 Other Agency Initiatives

The Commission conducted meetings with several other agencies throughout the project to determine if other planned adaptations could impact the baseline conditions assumed for the Coastal Stormwater Discharge Analysis. The Commission requested, but was not able to schedule, a meeting with the Massachusetts Department of Conservation and Recreation (MassDCR) to discuss possible adaptations to the Charles River Dam. It was assumed for the purposes of this project that outfalls discharging to the river behind the dam are protected from higher sea levels by the dam (and/or by any planned improvements to the dam).

1.4.3.1 Massachusetts Department of Transportation (MassDOT)

MassDOT completed the *MassDOT-FHWA Pilot Project* to evaluate existing risks and vulnerabilities (using the Boston Harbor Flood Risk Model (BH-FRM)). In addition, MassDOT is currently in Phase I (Vulnerability Assessment) of the *MassDOT Statewide Climate Change Adaption Plan*, which will identify vulnerable infrastructure. A meeting was held between MassDOT and BWSC in January 2021, and no planned projects were identified that could impact the Commission’s infrastructure relative to this study.

1.4.3.2 Massachusetts Water Resources Authority (MWRA)

The MWRA publicly released a document on its climate change strategy in 2018. A meeting was held between the MWRA and BWSC in January 2021, and no planned projects were identified that could impact the Commission’s infrastructure relative to this study.

1.4.3.3 Massachusetts Department of Conservation and Recreation

Climate Ready Boston and the *Inundation Model Project* have identified flanking and overtopping of the Charles River Dam (operated by MassDCR) as a long-term risk for the City of Boston. As such, any plans to harden this infrastructure and reduce this vulnerability should be accounted for in the baseline conditions for the *Coastal Stormwater Discharge Analysis Project*. MassDCR conducted a public presentation in February 2019 about the *New Charles River Basin Project*, which will implement improvements to the area surrounding the dam and to the dam itself. It is not clear if measures to address the vulnerabilities identified in Climate Ready Boston will be implemented as part of this project. Coordination with MassDCR should continue to occur to develop a clear understanding of its long-term plans for the Charles River Dam, and to then determine if any of the Commission's outfalls (upstream of it) need to be addressed.

1.4.3.4 Massachusetts Bay Transit Authority (MBTA)

In December 2020, a presentation was conducted by the MBTA's Fiscal and Management Control Board on its Climate Resiliency Program. The presentation outlined steps the MBTA is taking to assess vulnerabilities and address specific flooding risks. Other publicly available information from the MBTA shows that the MBTA will undertake a project to reconstruct the Charlestown Sea Wall. A meeting was held between MBTA and BWSC in February 2021, and no planned projects were identified that could impact the Commission's infrastructure relative to this study.

1.4.3.5 Massachusetts Port Authority (Massport)

Massport launched a comprehensive resiliency initiative in 2013. Included in this initiative are resilient design guidelines and best practices. A meeting was held between Massport and BWSC in January 2021, and no planned projects were identified that could impact the Commission's infrastructure relative to this study.

2. Wet Weather and Coastal Conditions for Design and Analysis

This section provides an overview of the rainfall and coastal boundary conditions that were used for analysis and design in subsequent stages of the project. The conditions described herein became part of the baseline conditions used to assess the effectiveness of proposed conceptual designs. As such, it is important to understand how these assumptions are consistent with, and differ from, the assumptions other agencies are using for climate adaptation planning efforts.

It is important to note that two storm events were used in this project for different purposes:

- 100-year tropical storm – used to evaluate the flood reduction benefits of the proposed solutions (this storm is consistent with the approach that CRB is taking with regard to a 1% chance storm for analysis purposes)
- 2070 projected 10-year 24-hour design storm – used to size proposed infrastructure solutions (since the Commission's collection system is understood to generally have capacity to convey flows from this size storm to an outfall)

2.1 100-Year Tropical Storm Rain Event

This storm event was used to support an evaluation of the benefits of proposed conceptual solutions in this project, remaining largely consistent with the 1% chance annual probability storm that the City uses in its Climate Ready Boston initiative. The storm hyetograph was developed during the Commission's Inundation Model Project in 2020. The storm has a duration of 48 hours and total rainfall depth of 9.58 in. It was developed using a combination of historical data from Boston's Logan Airport (for shape, speed and direction) and National Oceanic and Atmospheric Administration (NOAA) Atlas 14 statistical data (for depth/duration). **Figure 2-1** is an incremental hyetograph for the 100-year tropical storm event. This storm was applied in the model using a spatially-varying distribution, to allow it to "travel" across the City.

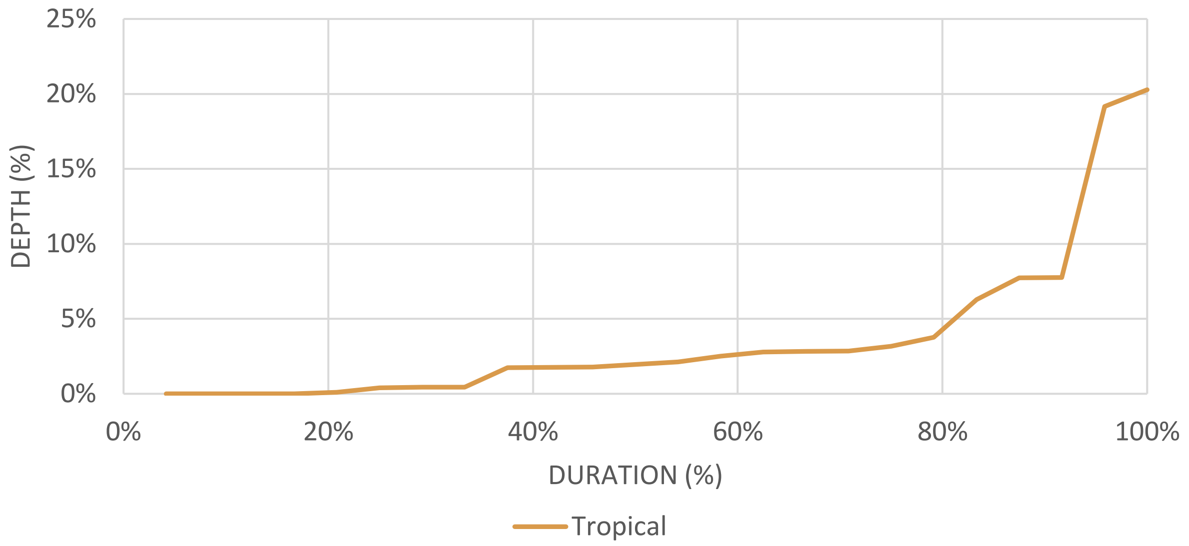


Figure 2-1: Tropical Storm Event Hyetograph

2.2 10-Year Design Storm Rain Event

To support an evaluation of existing infrastructure and proposed conceptual designs, it was necessary to use a standardized “design” storm to determine if infrastructure meets the Commission’s specified level of service (LOS). Historically, the Commission has used a 10-year (10% annual probability of occurrence) 24-hour storm as its target level of service. However, since it is expected that climate change will result in increased precipitation depth and intensity in Boston, it was necessary to re-evaluate the Commission’s existing design storm so that it can be used to evaluate performance in the 2030 and 2070 planning horizons.

Hazen and its sub-consultant, Vieux & Associates, performed an analysis of the Commission’s existing design storm, and completed modifications to “project” the design storm for possible conditions in the decades of 2030 and 2070. **Appendix B** includes this analysis in its entirety. The primary findings and recommendations of the analysis are summarized in this Section.

2.2.1 Methodology

The current 10-year, 24-hour design storm conditions that the Commission applies to facility planning and sewer design were reviewed and recalculated to reflect updated recommendations for design storm development. At present, the Commission utilizes Soil Conservation Service (SCS) Type III distribution (hyetograph) as the basis for its design storm. Studies of the Type III or other legacy rainfall distributions (e.g., SCS method) have concluded that their use can be discontinued in areas covered by NOAA Atlas 14 data. Furthermore, these studies have reported that the use of the Type III or other legacy rainfall distributions in conjunction with the NOAA Atlas 14 data (e.g., utilizing the Type III rainfall distribution with the NOAA Atlas 14 rainfall depth) could introduce errors by application of inaccurate rainfall intensities during a storm event. As such, the design storm was updated using the current National

Resources Conservation Service (NRCS) hyetograph for the 10-year, 24-hour design storm. The analysis was completed following current guidance (United States Department of Agriculture (USDA) NRCS National Engineering Handbook). Compared to the legacy SCS method, the updated NRCS hyetograph is more representative for a given location and more accurately reflects the rainfall depth, duration, and hyetograph shape.

2.2.2 Updated NRCS Distribution

The USDA NRCS method was utilized to compute cumulative rainfall ratios (which are used to determine the shape of the hyetograph), encompassing a 24-hour period with a temporal interval of 15 minutes, using rainfall depths from NOAA Atlas 14 at the Boston Logan International Airport (19-0770) location. The rainfall depths for the 10-year return period and design storm durations ranging from 5 minutes to 24 hours are presented in **Table 2-1**.

Table 2-1: Rainfall Depths (10-year storm) from NOAA Atlas 14 for Boston Logan Airport (19-0770)

Duration	5-min	10-min	15-min	30-min	60-min	2-hr	3-hr	6-hr	12-hr	24-hr
Rainfall Depth (in)	0.567	0.803	0.945	1.26	1.58	2.11	2.48	3.2	4.01	4.91

From these cumulative rainfall ratios, the dimensionless cumulative rainfall distribution for the Boston Logan Airport location was calculated. The distribution is shown in **Figure 2-2** along with the existing distribution used by the Commission.

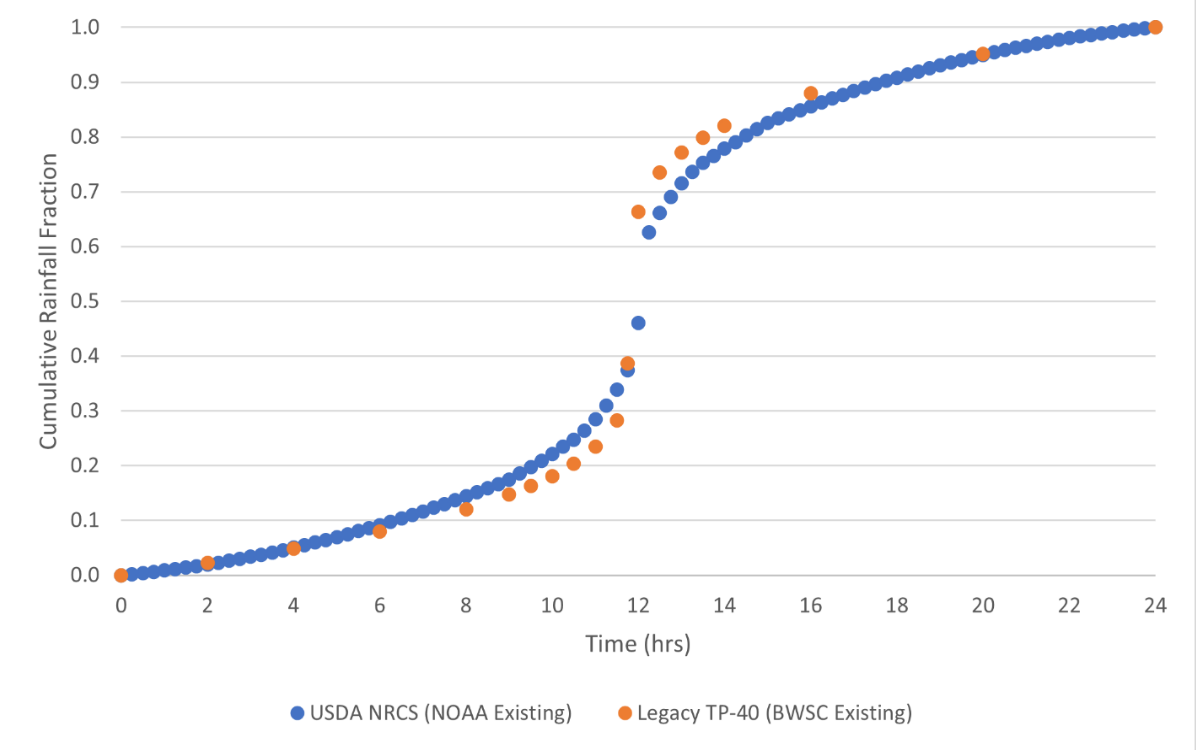


Figure 2-2: Updated Cumulative Dimensionless 24-hour Hyetograph for Boston (NRCS Method)

The rainfall distribution for the Commission's existing design storm was developed following the legacy Technical Paper Number 40 (TP-40) method for a Type III rainfall distribution and exhibits a pattern of rainfall that is characteristically more intense towards the middle of the storm and less intense at the beginning and the end. The updated NRCS distribution is similar but results in more intense rainfall occurring later in the storm.

2.2.3 Future Climate Projections

To utilize the updated distribution shown in **Figure 2-2** in the development of the design storms for the 2030 and 2070 planning horizons, an analysis was done to compare future precipitation projections for Boston.

The Boston Research Advisory Group published a report entitled *Climate Change and Sea Level Rise Projections for Boston* as part of the CRB project in 2016. The objective of this 2016 BRAG report was to outline potential climate change-driven alterations to weather and storm patterns in the greater Boston area, including changes to typical precipitation patterns. The BRAG report found that future short-term extreme precipitation events would increase in intensity in the greater Boston area. The BRAG report summarized estimates of future precipitation from independent reports by the Commission and the Cambridge Climate Change Vulnerability Assessment (C-CCVA). To provide future precipitation estimates, the Commission utilized SimCLIM software with emissions scenarios from the Special Report on Emission Scenarios (SRES) to represent plausible future conditions. The SRES scenarios are comparable to the RCP emissions scenarios and have been previously used by the IPCC for its third and fourth assessments.

The two SRES scenarios used by the Commission, B2 and A1Fi, represent possible future emissions levels, with B2 representing moderate cuts in greenhouse gases (comparable to RCP 6) and A1Fi representing large increases in greenhouse gases, or the “no action” scenario (comparable to RCP 8.5). In contrast to BWSC, C-CCVA statistically downscaled CMIP3 and CMIP5 output using the Asynchronous Regional Regression Model to provide estimates of future precipitation in the greater Boston area. Regardless of the difference in methodologies, the projections put forward by the Commission and C-CCVA assume similar future climate conditions and yield similar future precipitation depths.

Table 2-2 contains a summary of the precipitation depths forecast for the 10-year 24-hour design storm by the Commission, C-CCVA, the current Atlas 14 recommended depth, and the depth that the Commission currently uses for its design storm.

Table 2-2: Comparison of Current and Future Precipitation Depths for the 10-year, 24-hour, Design Storm

CURRENT BWSC	Current NOAA ATLAS 14	Commission (from BRAG Report)				
			BASELINE (1948-2012)	2035	2060	2100
5.15	4.91	B2	5.24	5.55	5.76	6.08
		A1Fi		5.60	6.03	6.65
		C-CCVA				
			BASELINE (1971-2000)	2030s	2070	
		Average Values	4.9	5.60	6.4	

As shown in **Table 2-2**, the Commission’s future rainfall projections are similar to the projections put forward in the C-CCVA, and consistent with widely accepted trends that are expected to govern future precipitation. Although future projections of precipitation and temperature are generally estimated using GCMs and RCP emissions scenarios, BWSC used comparable methods (SimClim) and emissions scenarios (SRES) which yielded comparable results to similar analysis completed by C-CCVA with global climate models (GCMs) or RCP emissions scenarios. As such, it can be concluded that the Commission’s future precipitation projections are consistent with current research, and therefore suitable for use in this project.

Since the *Coastal Stormwater Discharge Analysis Project* evaluated projects in the 2030 and 2070 planning horizons, a linear regression was used to estimate precipitation depths for the year 2070 based on the B2 and A1Fi scenarios published by the Commission. It is recommended that the 2035 depth projections published by the Commission be used to represent the 2030 planning horizon. **Table 2-3** contains the depth projections for 2035 (2030 planning horizon), 2060, 2070 (2070 planning horizon).

Table 2-3: Rainfall Depth (in) BWSC existing, NOAA Existing, and Future 10-year, 24-hour Design Storms

Rainfall Depth (in)					
Scenario	Commission Existing	NOAA Atlas 14 Current	2035	2060	2070
B2	5.150	4.91	5.55	5.76	5.830
A1Fi	5.150	4.91	5.6	6.03	6.177

The rainfall depths shown in **Table 2-3** were applied to the distribution that was developed using the NRCS method (shown in **Figure 2-2**) to develop future 10-year 24-hour design storms, as shown in **Figure 2-3**. For clarity, this chart only shows the central region of the hyetograph to more clearly illustrate the differences between projections. In addition, this chart only shows peak hourly intensity; actual hyetographs use a higher resolution 15-minute timestep.

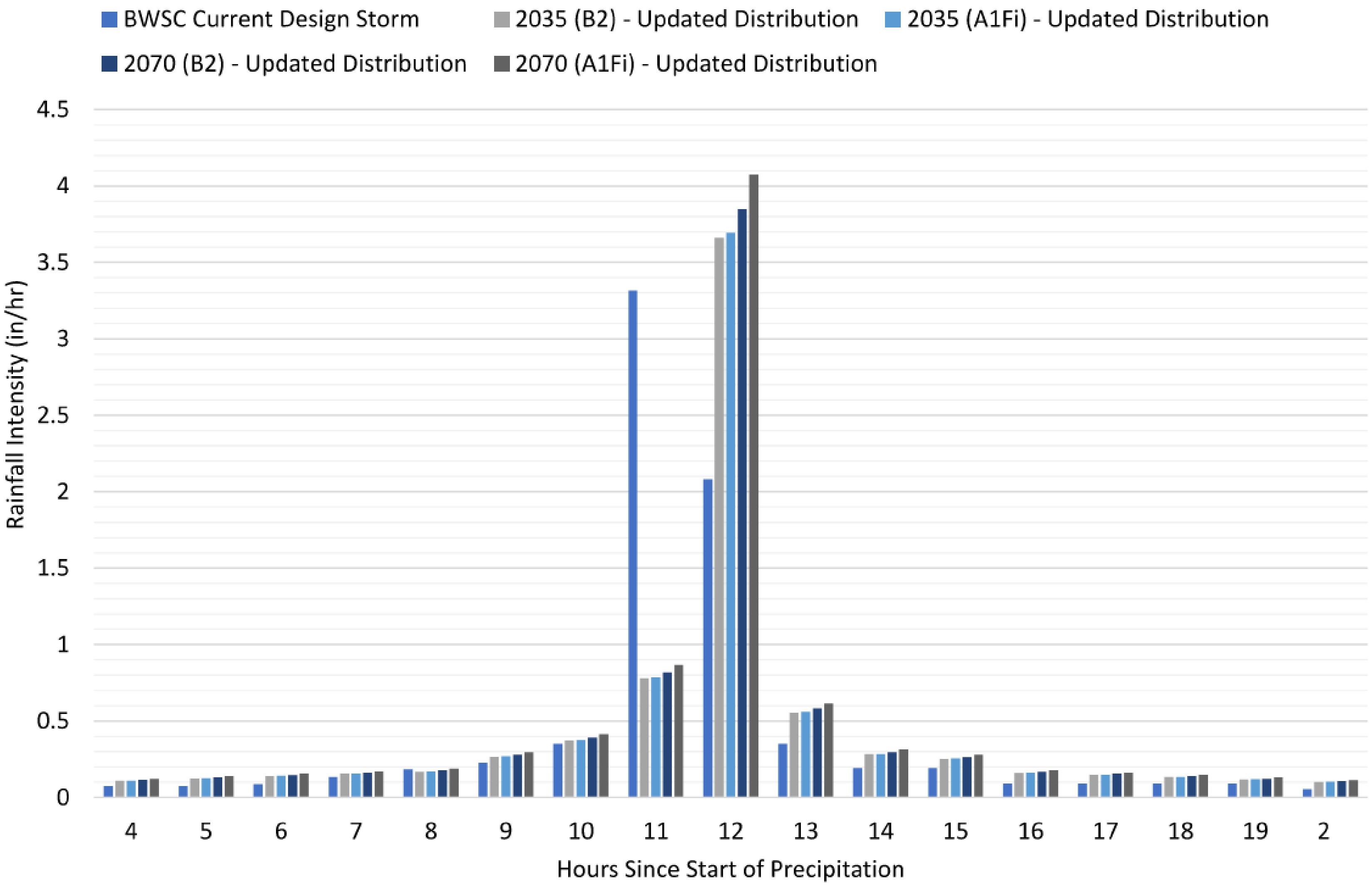


Figure 2-3: 10-year, 24-hour Design Storms (Current BWSC & Future Projections using NRCS Distribution & BWSC Projected Depths)

The precipitation intensity for the 10-year, 24-hour design storm is highest under the 2070 A1Fi scenario. This is consistent with current knowledge of climate change-driven precipitation models. Current research indicates that changes to precipitation patterns will increase towards the end of the 21st century, particularly under higher emissions scenarios such as A1Fi. However, even under the more “moderate” emission scenario of B2, precipitation intensities for the 10-year, 24-hour design storm are still expected to increase when compared to the current and updated rainfall intensities. By comparison, the 10-year, 24-hour design storm rainfall intensity of 3.24 in/hr from NOAA Atlas 14 is less than that of the 10-year, 24-hour design storm currently used by BWSC, which is due to differences, described in the following paragraph, between the legacy TP-40 and USDA NRCS methods used to estimate the storm recurrence, depth, and intensity. For this reason, peak intensity follows a similar trend to total depth, as shown in **Table 2-4**.

Table 2-4: Peak Rainfall Intensity (in/hr) for Existing and Future 10-year, 24-hour Design Storms

Scenario	Commission Existing	NOAA Atlas 14 Current	2035	2060	2070
B2	3.317	3.240	3.66	3.801	3.847
A1Fi	3.317	3.240	3.69	3.979	4.076

2.2.4 Design Storm Recommendations

As shown in **Table 2-3** and **Table 2-4**, the Commission’s existing design storm (using the legacy distribution and depth) results in a greater peak intensity and more total rainfall compared to the updated NRCS distribution using the current NOAA Atlas 14 depth. Therefore, the Commission’s existing design storm depth and distribution were adopted for the present-day design storm. For the 2030 and 2070 planning horizons, this project utilized the updated NRCS distribution and A1Fi projected depths for future design storms.

Due to the substantial uncertainty associated with projections of future precipitation generated by GCMs in the SRES, CMIP3, and CMIP5 experiments, particularly at sub-daily temporal scales, it is not recommended to develop individual rainfall distributions for the 2035, 2060, and 2070 precipitation projections. **Table 2-5** contains a summary of design storm recommendations.

Table 2-5: Recommended 10-year, 24-hour Design Storms

Planning Horizon	Recommended Distribution	Recommended Rainfall Depth Source	Design Storm Depth (in)	Design Storm Peak Intensity (in/hr)
Present Day	BWSC Existing	BWSC Existing	5.15	3.32
2030	USDA NRCS	BWSC A1Fi 2035 Projection	5.60	3.69
2070	USDA NRCS	2070 Interpolation from BWSC 2060 and 2100 A1Fi Projections	6.18	4.08

The recommended design storms maintain an appropriate level of conservatism for evaluating LOS during future conditions (given the uncertainty associated with future climate forecasts) by utilizing the depths resulting from a “no-action” scenario, where greenhouse gas emissions continue their current trajectory. In addition, the 2030 and 2070 planning horizons are consistent with those being used by Climate Ready Boston (the City and BPDA) for future planning efforts. This approach allows the Commission to independently establish LOS targets while maintaining consistency with other planning efforts being undertaken throughout the City.

2.3 Coastal Boundary Conditions

To evaluate the performance under present day and future conditions, it was also necessary to establish coastal boundary conditions. Coastal boundary conditions are determined by SLR and storm surge projections. At present, Climate Ready Boston is conducting planning work based on the SLR projections established in the 2016 BRAG report. **Table 2-6** summarizes the “likely range” SLR projections from the BRAG report for different emissions scenarios, and the values being used by Climate Ready Boston for planning purposes.

Table 2-6: Likely SLR Range (inches, 2022, BRAG)

Emissions Scenario	2030	2050	2070	2100
Low	5.1 - 9.8	7.9 - 16.9	10.6 - 23.2	13.8 - 30.7
Medium	5.5 - 9.4	9.1 - 17.3	13.4 - 26.8	18.9 - 39.4
High	5.5 - 10.6	10.6 - 20.5	17.3 - 33.5	28.3 - 57.5
Climate Ready Boston	9.0	21.0	36.0	N/A

As shown in **Table 2-6**, Climate Ready Boston is currently using more conservative projections for future SLR. The projections being used by Climate Ready Boston near or exceed the “maximum” values published in the BRAG[2] report.

In the *Wastewater Facilities Plan* (2015), the Commission also published projections for SLR. **Table 2-7** contains the projections published by the Commission. As shown in **Table 2-7**, the Commission’s projections for the “medium” emissions scenario are similar to the assumed values being used by Climate Ready Boston.

Table 2-7: Projected SLR (inches, 2015, BWSC)

Scenario	2035	2060	2100
Medium	10.44	20.52	45.72
Precautionary	18.36	33.12	85.80

During the *Inundation Model Project*, the Commission obtained SLR and storm surge projections from the Massachusetts Coast Flood Risk Model. This hydrodynamic model, developed and operated by Woods Hole Group, is an updated version of the Boston Harbor Flood Risk Model (BH-FRM), which has been cited in numerous studies like Climate Ready Boston.

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[2] Unless otherwise noted, all references to the BRAG report refer to the report published in 2016. An updated report was published in 2022. Figure 2-4 depicts the updated SLR projects included in the 2022 report.

According to Woods Hole Group, the SLR projections utilized in the MC-FRM are based on RCP 8.5, which assumes that no changes are made to human emissions. According to Woods Hole Group, "*The RCP pathway utilized in this assessment (RCP 8.5) assumes that no changes are made to human based emissions. The sea level rise produced under this scenario (RCP8.5) was developed specifically for the Commonwealth of Massachusetts, is being used in the MC-FRM, and is consistent with the projections being used in the Massachusetts State Hazard Mitigation Climate Adaptation Plan. These projections are being used by coastal communities developing resiliency plans and for mitigation planning through the Massachusetts Office of Coastal Zone Management, and the Massachusetts Emergency Management Agency programs. Projections were developed for the Commonwealth of Massachusetts and take into account regional considerations for the Northeast.*"

The data that the Commission obtained from the *Inundation Model Project* were tidal time-series which include daily tidal fluctuations for 2030 and 2070. As such, the boundary condition data used during the *Inundation Model Project* implicitly account for SLR in the time series data, rather than utilizing it as a fixed value. Given this, SLR values for 2030 and 2070 can be estimated by comparing the high-water level in the time series to a baseline condition (2008 centered tidal epoch). This results in an increase of 15.48 inches in 2030 and 51.48 inches in 2070. **Figure 2-4** is a comparison of relative SLR projections from the Commission's Facilities Plan, the values being used by Climate Ready Boston, those published in the BRAG report, and values from the MC-FRM. Note that each of these projections is based on a slightly different baseline condition; this chart only depicts SLR *relative* to that baseline and not SLR in absolute terms.

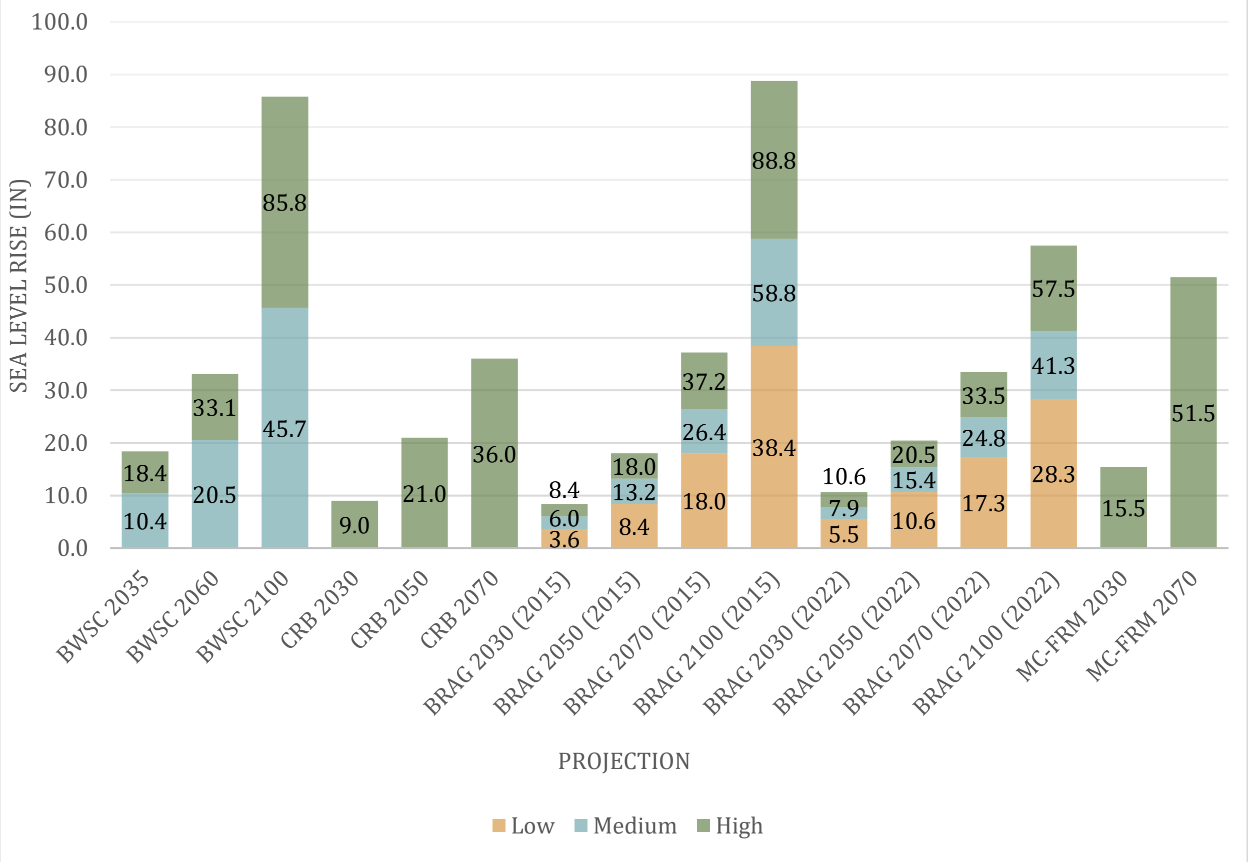


Figure 2-4: Sea Level Rise Projections for Boston

Note: Low, medium, and high values in **Figure 2-4** *are qualitative phrases used only for the purpose of this report to describe relative magnitude of SLR scenarios.*

Low data from BRAG represents the 83rd percentile likely range of possible outcomes, medium data the 50th percentile, and high data the 17th percentile. The medium and high values from BWSC represent "central" and "conservative" projections, respectively. In the Climate Ready Boston planning documents, the forecasted SLR values are notably smaller than those used in the more recent MC-FRM (which were used in this project). The values used in the MC-FRM are conservative and based on similar assumptions used to develop the recommended design storms (A1Fi is approximately equivalent to RCP 8.5).

3. Outfall Ranking and Prioritization

While the Commission's intent is ultimately to address all vulnerable outfalls (and their associated drainage areas), more detailed conceptual solutions were developed for an initial group of outfalls as a starting point; beyond these initial locations, a plan was developed (**Section 8** – Implementation Timeline) for replicating these types of detailed solutions to the remainder of the Commission's outfalls. As schedule and budget planning is advanced in the coming years, the Commission (or another entity) may carry out a similar level of conceptual design at these other outfalls as well.

Locations for conceptual design were selected in a 3-step process:

1. Desktop screening of all Commission outfalls using a decision support tool
2. Site visits (for the highest ranked sites in Step 1) to observe and note vulnerabilities, opportunities, constraints
3. Consideration of near-term Climate Ready Boston proposed shoreline protection projects

This Section describes the process used to complete the steps above. To "screen" outfalls for vulnerability and overall system importance (e.g., criticality in facilitating interior drainage), a methodology to rank and prioritize outfalls for site visits and further evaluation was developed; this methodology is described in detail below.

3.1 Data Sources

To support development of tools for outfall screening, an extensive data collection effort was undertaken. Data were collected to characterize each outfall in terms of its vulnerability to SLR/storm surge, relative importance, and tributary area characteristics. It is important to recognize that the data used in these analyses will evolve over time, and that it may be necessary to update elements of the analyses described herein based on the availability of new data. In addition, the database tool developed in this effort can continue to be used over time as priorities change/evolve and/or as the Commission begins to review vulnerabilities and develop mitigation strategies at other outfalls beyond the scope of this project. Thus, this prioritization tool is scalable and can be used to develop information at other replicable outfalls throughout the system.

While the scope of this project includes only Commission owned infrastructure, the Commission's GIS database contains data on non-Commission owned infrastructure, including outfalls. **Table 3-1** contains the datasets used during the preliminary analysis.

Table 3-1: Data Used for the Preliminary Analysis

Dataset	Data Type	Data Source
BWSC_Data_12212020_Hazen	Geodatabase	BWSC
SEWER_SYSTEM	Feature Dataset	BWSC
MIC_LAND	Feature Dataset	BWSC
Outfalls	Shapefile	BWSC

Dataset	Data Type	Data Source
Sewer Line	Shapefile	BWSC
BWSC Sewer and Drain System Tile Maps	PDF	BWSC
Stormwater Areas	Shapefile	BWSC
Open Space	Shapefile	BWSC
Critical Facilities	Excel, "Contact List of Centers"	BWSC
Flooded Areas	Shapefile	Inundation Model–- PCSWMM
Outfall Discharge Volumes	Excel	Hazen Inundation Model–- PCSWMM
2010 Census	Shapefile	Boston Open Data
Parcels	Shapefile	Boston Open Data
Social, Economic, Demographic Information	GEO JSON	risQ (various)
Commuter Rail	Shapefile	MassGIS
Transit System	Shapefile	MassGIS
Evacuation Routes	PDF	BPDA
Climate Ready Boston Neighborhood Reports	PDF	City of Boston

The "Stormwater Areas" shapefile contains polygons representing drainage areas that are tributary to specific Commission owned outfalls within the City of Boston. Each drainage area polygon contains attributes which identify the area, location, and discharge location (outfall) of the drainage area. This shapefile was used to match outfalls with tributary areas and supported all analyses involving tributary area characteristics. As such, this layer is the basis for several of the criteria used to rank outfalls. If inaccuracies are discovered in the "Stormwater Areas" drainage area delineation, the Tributary Area characteristics (described in **Section 3.2**) that were developed for any impacted outfalls should be updated.

3.2 Outfall Screening Methodology

The objective of the preliminary analysis task was to develop a comprehensive framework for identification, screening, and prioritization of outfalls that:

3. Are physically vulnerable to SLR and storm surge
4. Are integral to overall operation and performance of the Commission's stormwater drainage and discharge system
5. Maintain drainage in areas with socially vulnerable populations, have high economic importance, or contain other essential facilities such as transportation routes, hospitals, etc.
6. Are adjacent to, or potentially impacted by, a planned Climate Ready Boston project

Table 3-2 contains all criteria that were used to screen and rank outfalls.

Table 3-2: Outfall Ranking Criteria

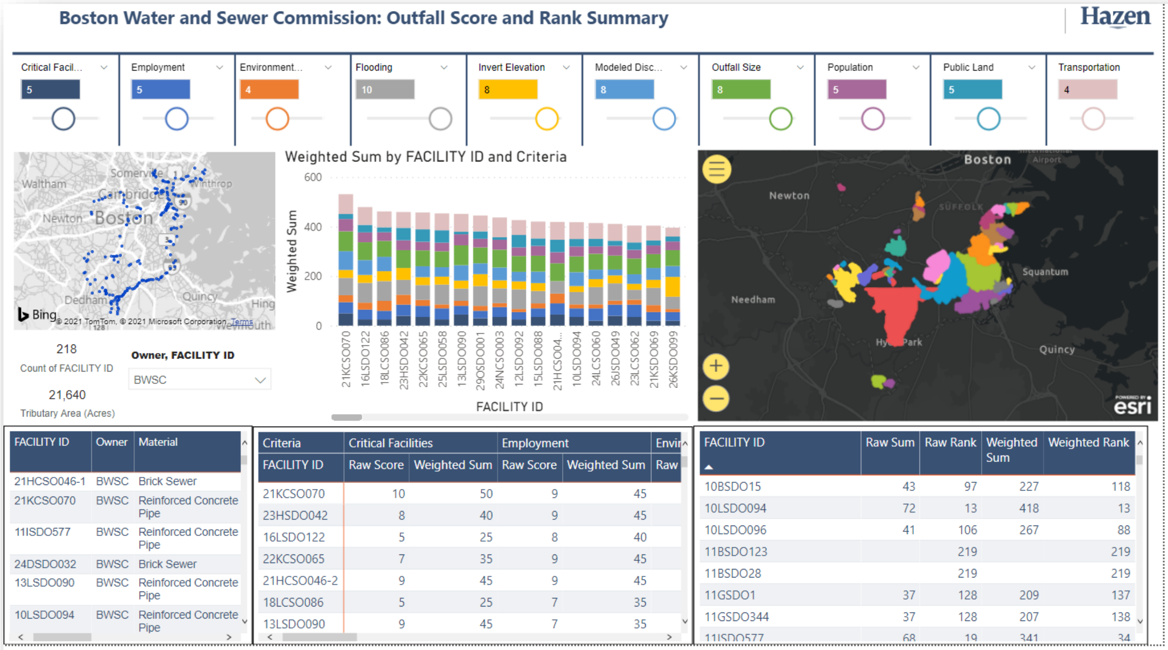
Category	Criteria	Definition	Data Source
Physical Considerations: Infrastructure Importance and Vulnerability	Discharge Volume	Discharge volume from modeled outfalls for 10-year, 24-hour, design storms and nor'easter and tropical events	BWSC Inundation Model Simulations
	Invert Elevation	Scoring to be done based on ranked list of outfall invert elevations	BWSC (GIS, tile maps)
	Outfall Size	Diameter/dimensions of immediate upstream pipe from GIS	BWSC (GIS, tile maps)
Tributary Area Characteristics (upstream considerations)	Flooded Area	Flooded area from Inundation Model simulations within tributary areas	BWSC Inundation Model Simulations
	Transportation Routes	Length of roadways classified as evacuation routes, transit, and commuter rails within tributary area	MassGIS and BPDA
	Critical Facilities	Number of Critical Facilities in Tributary Area	BWSC "Contact List of Centers"
	Population	Number of Residents within Tributary Area	Boston Open Data (2010 Census)
	Economic Importance	Number of employees within tributary area	risQ (LODES* database and ACSS*)
	Land Use	Land ownership of parcels adjacent to/containing outfalls within tributary area	Boston Open Data (2016 Parcels) BWSC "Open Space"
	Environmental Justice/Social Vulnerability	Vulnerability of residents within tributary	risQ (LODES* database and ACSS*)

*LODES – Longitudinal Origin-Destination Employment Statistics
*ACSS – American Community Survey and Statistics

Outfalls identified through this process were prioritized for further desktop analysis to verify physical vulnerability to SLR and storm surge, and for site visits to characterize site constraints and opportunities for conceptual design of a stormwater discharge solution. The criteria described in **Table 3-2** were used directly to "score" and rank each Commission-owned outfall in this desktop analysis step. In recognition of the fact that different stakeholders may value some criteria more than others, a PowerBI (Power "Business Intelligence") dashboard was developed to provide the Commission the ability to adjust the weight of criteria ("on the fly," resulting in automated updates to the priority list when a criterion changes). Both stormwater and combined sewer outfalls were included (outfall type was not considered directly) in this analysis.

3.2.1 PowerBI Dashboard

PowerBI is analytical software developed by Microsoft that allows for the creation of interactive dashboards and reports that distill complex datasets. The dashboard created for this effort allows for each criterion in **Table 3-2** to be assigned a weight from 1 (least important) to 10 (most important). By adjusting the weight of different criteria, it is possible to develop a unique ranked list of outfalls for varying purposes. For example, if the Commission wanted to identify the outfalls primarily serving socially vulnerable areas in Boston, the dashboard weights could be adjusted to weight the "Environmental Justice/Social Vulnerability" criterion higher than all others. **Figure 3-1** is a screenshot depicting the PowerBI dashboard.



Boston Water and Sewer Commission: Outfall Score and Rank Summary

Critical Facil...	Employment	Environment...	Flooding	Invert Elevation	Modeled Disc...	Outfall Size	Population	Public Land	Transportation
5	5	4	10	8	8	8	5	5	4

218
Count of FACILITY ID

21,640
Tributary Area (Acres)

Owner, FACILITY ID
BWSC

FACILITY ID	Owner	Material
21HCSO046-1	BWSC	Brick Sewer
21KCSO070	BWSC	Reinforced Concrete Pipe
11ISDO577	BWSC	Reinforced Concrete Pipe
24DSDO032	BWSC	Brick Sewer
13LSDO090	BWSC	Reinforced Concrete Pipe
10LSDO094	BWSC	Reinforced Concrete Pipe

Criteria	Critical Facilities		Employment		Envir
FACILITY ID	Raw Score	Weighted Sum	Raw Score	Weighted Sum	Raw
21KCSO070	10	50	9	45	
23HSDO042	8	40	9	45	
16LSDO122	5	25	8	40	
22KCSO065	7	35	9	45	
21HCSO046-2	9	45	9	45	
18LCSO086	5	25	7	35	
13LSDO090	9	45	7	35	

FACILITY ID ▲	Raw Sum	Raw Rank	Weighted Sum	Weighted Rank
10BSDO15	43	97	227	118
10LSDO094	72	13	418	13
10LSDO096	41	106	267	88
11BSDO123		219		219
11BSDO28		219		219
11GSDO1	37	128	209	137
11GSDO344	37	128	207	138
11ISDO577	68	19	341	34

Figure 3-1: Power BI Dashboard

In consideration of this project's primary objective (development of solutions for stormwater discharge locations that could be impacted by SLR and storm surge), the criteria in the "Physical Considerations" category received the highest relative weights in the screening process. **Table 3-3** contains the "default" criteria weights that were used in the outfall screening.

Table 3-3: Outfall Screening “Default” Criteria Weights

Criteria	PowerBI Weight
Discharge Volume	8
Invert Elevation	8
Outfall Size	8
Flooded Area	10
Transportation Routes	4
Critical Facilities	5
Population	5
Employment	5
Land Use	5
Environmental Justice/Social Vulnerability	4

Each outfall was scored according to the following formula:

$$Total\ Score = \sum[(Criterion\ 1\ Raw\ Score \times Weight\ 1) + (Criterion\ 2\ Raw\ Score\ \times Weight\ 2) + \cdots]$$

The score of each outfall is compared to the score of all other outfalls to derive its rank (higher scores yield higher ranks). **Section 3.3** documents the raw scoring process associated with each of the criteria identified in **Table 3-3.**

While the PowerBI dashboard was used to screen outfalls and identify high-priority locations for site visits, the “rank” of each outfall is not intended to be a definitive metric that measures an outfall’s importance and vulnerability; rather it is a guiding indicator for outfall screening and taking the next step in the process. Additional desktop analyses were conducted to verify the vulnerability of each high-ranking outfall. Using the Commission’s GIS data, all pipes with an invert elevation below the projected spring high tide level in 2070 (approximately 11.2 ft, NAVD88) were identified. Outfalls with tributary areas containing a high concentration of these low-lying pipes were considered to be vulnerable, while outfalls with a low concentration of these pipes were not. Again, it is important that users of the PowerBI dashboard recognize than the “rank” of an outfall should be treated as a relative indicator of its importance, rather than its absolute importance compared to all other outfalls.

3.3 Raw Scoring Methodology

This section provides information regarding the scoring process associated with criteria identified in **Table 3-2**. The project relevance, data sources, and scoring process associated with each of the criteria are documented below. In general, each outfall was ranked relative to all other outfalls for each criterion.

For example, an outfall with the largest discharge volume would receive a score of “10” while an outfall with the smallest discharge volume would receive a “1”. The score (a static value) each outfall was assigned for each of the criteria is independent of the weight, which is applied dynamically in the PowerBI dashboard to derive the overall rank.

3.3.1 Discharge Volume

3.3.1.1 Project Relevance

By characterizing the volume of water discharged at each outfall during various storm events, it is possible to characterize the relative importance of each outfall to interior drainage. Outfalls that discharge more water are likely to be more critical to interior drainage than outfalls discharging smaller volumes. **It is important to note that this criterion is only applied to outfalls included in the Commission’s existing sewer and drain model (incorporated in the Inundation Model). Outfalls not included in the model receive a score of “0” for this criterion. By design, the Commission’s model includes the most critical infrastructure and outfalls used in planning efforts throughout the years.**

3.3.1.2 Data Sources and GIS Analysis

The Inundation Model (via 1D simulations) was used to quantify discharge volume per outfall. The outfall locations used in the model were assigned to their corresponding outfalls included in the GIS shapefile provided by the Commission in the “Sewer System” dataset.

The following mix of storm events were simulated using the Inundation Model to predict the volume discharged at each outfall:

- 2030 projected 10-year, 24-hour design storm
- 2070 projected 10-year, 24-hour design storm
- 100-year Nor’easter
- 100-year Tropical
- 500-year Tropical

The total volume discharged from all storm events was averaged for each outfall to develop the overall score for each outfall.

3.3.1.3 Scoring Methodology

Each outfall was assigned a relative score from 1-10 based on the average volume of water discharged across all simulations. The outfalls which discharged the most volume were assigned higher scores while outfalls discharging the least water were assigned lower scores (within the discharge volume criterion).

3.3.2 Invert Elevation

3.3.2.1 Project Relevance

Invert elevation is an important metric that can help screen the vulnerability of each outfall with respect to SLR and storm surge. Outfalls with a low invert elevation (relative to sea level) may not be able to discharge if the downstream water level (i.e., tide) is sufficiently high. It should be noted that outfalls with a low invert elevation may not be vulnerable to high sea levels if the upstream pipe network is steeply sloped or can generate enough head to force discharges during high tide conditions.

3.3.2.2 Data Sources and GIS Analysis

The existing BWSC GIS outfalls shapefile did not include the invert elevations of the outfalls themselves; as such, outfalls were assigned an invert elevation from the pipe segment shapefile (using nearest upstream GIS pipe segment from the outfall), or from the BWSC tile maps.

3.3.2.3 Assumptions

The 2005 BWSC tile maps and GIS data were used to match 60 outfalls with their invert elevations. The remaining outfalls in need of invert elevations were found using the upstream pipe segment shapefile. Using the upstream pipe, the downstream invert elevation was assigned to outfalls if available. If the downstream invert elevation was not provided, the upstream invert elevation was used. If the upstream invert was not provided, the next upstream invert elevation was assigned to the outfall.

3.3.2.4 Scoring Methodology

A score of 1 was assigned to outfalls with the highest invert elevations (least vulnerable) and a score of 10 was assigned to outfalls with the lowest invert elevations (most vulnerable). The highest invert elevations using the BCB datum is 232 ft and the lowest is -20 ft.

3.3.3 Outfall Size

3.3.3.1 Project Relevance

Outfall size (cross-sectional area) is an indicator of an outfall’s relative importance. Larger outfalls tend to serve larger drainage areas and have greater overall system importance.

3.3.3.2 Data Sources and GIS Analysis

The existing BWSC outfalls shapefile does not include dimensions for each outfall; as such, the 2005 BWSC tile maps and the GIS pipes shapefile (nearest upstream segment) were used to estimate the size of each outfall.

3.3.3.3 Assumptions

The GIS sewer lines shapefile contained two fields for pipe size (length and width). For the purpose of this analysis, the dimensions of the next upstream pipe segment were used to characterize the size of each outfall.

3.3.3.4 Scoring Methodology

A score of 1 (lowest system importance) was given to the smallest outfall and a score of 10 was given to the largest outfall (greatest system importance).

3.3.4 Flooded Area

3.3.4.1 Project Relevance

If an outfall cannot discharge, the upstream pipe network can become surcharged and impede interior drainage. This condition can lead to basement and surface flooding, as well as sewer backups. This effect is most pronounced in low-lying areas and other flood vulnerable areas. As such, by characterizing how much of each outfalls' tributary area is vulnerable to flooding, it is possible to estimate the criticality of each outfalls' functionality. **It is important to note that only modeled outfalls, and those with a tributary area in the "Stormwater Areas" shapefile were assigned a score for this criterion** (by design, the Commission's model includes the most critical infrastructure and outfalls used in planning efforts throughout the years).

3.3.4.2 Data Sources and GIS Analysis

Flooded area data were obtained from the Inundation Model simulations. All Inundation Model simulations (i.e., scenarios) were included in this analysis by default (it is possible to derive a flooded area score for a specific storm event using the PowerBI dashboard). Model scenarios developed for the Inundation Model study included storms with return frequencies from 2 to 500 years (extreme storms), durations from 6 to 72 hours, and span four types of storms: Airmass (i.e., thunderstorm), Nor'easters, Frontal Storms, and Tropical Storms. Each storm was also paired with representative boundary (tidal) conditions that also included predicted sea level rise conditions for 2030 and 2070 (i.e., the impacts of climate change) as well as dynamic surge impacts. More information on these simulations can be found in *the Inundation Model Report* (Hazen, 2020).

3.3.4.3 Scoring Methodology

The flooded area score for each outfall is calculated as the sum product of predicted flood depths and percent of flooded 2D model cells within an outfalls tributary area. As such, the flooded area score characterizes the extent of a tributary area vulnerable to flooding combined with the magnitude of predicted flooding in the area. Scores were assigned on a relative scale from 1 (lowest flood impacts) to 10 (most extreme flood impacts).

3.3.5 Transportation Routes

3.3.5.1 Project Relevance

The transportation criterion is intended to measure how many of Boston's key transportation systems fall within an outfall's tributary area. This criterion includes MBTA facilities (light rail, commuter rail, and stations) as well as evacuation routes. These transportation systems could be impacted and/or flooded if interior drainage was prevented by a downstream outfall being unable to discharge.

3.3.5.2 Data Sources and GIS Analysis

Shapefiles that included MBTA facilities (including commuter rail lines and stations as well as Blue, Green, Orange, Red, and Silver line stations and tracks) were obtained from MassGIS. In addition, a PDF developed by Boston Planning and Development Agency (formerly the Boston Redevelopment Authority) containing evacuation routes in Boston was used to identify evacuation routes in the City.

3.3.5.3 Scoring Methodology

The number of MBTA stations, linear footage of MBTA track, and linear footage of evacuation routes were summed within each outfall's tributary area. Scores were assigned on a relative scale from 1 (least number/length of transportation facilities) to 10 (greatest number/length of transportation facilities).

3.3.6 Critical Facilities

3.3.6.1 Project Relevance

Critical facilities represent locations (defined by the Commission) that provide necessary social, public safety, and public health services throughout the City of Boston. These facilities could be impacted and/or flooded if interior drainage was prevented by a downstream outfall being unable to discharge.

3.3.6.2 Data Sources and GIS Analysis

The Commission's "contact list of centers" excel workbook was used to obtain the names and locations of critical facilities. There are 14 unique critical infrastructure types as shown in **Table 3-4**.

3.3.6.3 Scoring Methodology

The amount and type of critical facilities within various drainage areas was determined. Different types of critical facilities were ranked in terms of importance to health and safety. Facilities such as hospitals, police, and fire stations, etc. were assigned a higher rank as shown in **Table 3-4**.

Table 3-4 Critical Facilities Ranking

Type of Critical Facility	Total Facilities within Boston	Rank (1-10; Low-High)
Police Department	23	10
Fire Department	35	9
Hospital	29	8
Emergency Center	70	7
Emergency Op Center	6	7
Emergency Medical Services	20	7
BWSC	2	5
Health-Center	156	5
Public Works Facilities	13	5
Sensitive User	90	5
Food Pantry	83	4
School	91	3
University Administrative	18	3
University Dorm	155	3
Total	**792**	

The total score for each outfall was calculated as the sum product of the number of each type of critical facility in an outfall's drainage area and the rank of each type of facility. Scores are relative and scale from 1 (least number of highly ranked critical facilities) to 10 (greatest number of highly ranked critical facilities).

3.3.7 Population

3.3.7.1 Project Relevance

The number of residents within the tributary area of an outfall characterizes how many people could be impacted by flooding if the interior drainage system were unable to discharge stormwater. Vulnerable outfalls that serve areas with larger populations could be prioritized for solutions.

3.3.7.2 Data Sources and GIS Analysis

Census block data were obtained from the 2010 census from Boston Open Data (also used during the Inundation Model Project).

3.3.7.3 Scoring Methodology

Scores were assigned on a relative scale from 1 (least population within an outfall's tributary area) to 10 (most population within an outfall's tributary area).

3.3.8 Economic Importance

3.3.8.1 Project Relevance

The Commission's outfalls provide drainage to widely varied areas throughout the City with different land uses. Some areas that contain many businesses or employers may have greater overall economic importance with respect to the local and regional economy through employment, tax revenue, and GDP contribution/growth.

3.3.8.2 Data Sources and GIS Analysis

Hazen's sub-consultant, risQ, calculated the number of workers employed within the area tributary to each outfall using data obtained from the American Community Survey and Longitudinal Origin Destination Employment Statistics (LODES) database.

3.3.8.3 Scoring Methodology

For the purpose of this analysis, the number of workers employed within a tributary area was used as a proxy to measure its overall economic importance. Scores were assigned on a relative scale from 1 (least number of employees) to 10 (greatest number of employees).

3.3.9 Land Use

3.3.9.1 Project Relevance

The feasibility of constructing a project (adaptation solution) to promote stormwater discharge at each outfall partially depends on land use at (and around) the outfall. Construction feasibility increases at outfalls in close proximity to publicly owned land and open space, and decreases at outfalls surrounded by fully developed, privately owned land.

3.3.9.2 Data Sources and GIS Analysis

Data in the Commission's GIS database and from Boston Open Data were used to determine parcel ownership and identify areas with open space.

3.3.9.3 Scoring Methodology

Each outfall received a score of 2, 4, 6, 8, or 10, depending on its proximity to open space and publicly owned land. For example, a score of "2" was given to the outfalls that have public parcels or open space within a buffer of 500 to 6000 ft (i.e., far from open space), while a score of 10 was given to outfalls that have open space or public parcels within a 50-foot buffer (i.e., much closer to open space).

3.3.10 Environmental Justice/Social Vulnerability

3.3.10.1 Project Relevance

Environmental Justice (EJ) communities are often those most impacted by environmental hazards and risks. While EJ communities have typically been defined by proximity to human-caused environmental hazards (such as pollution) and other socioeconomic stressors, it is important to recognize that EJ communities also have less ability to recover from natural disasters and events like coastal and stormwater flooding. As such, in the context of this project, it was considered prudent to identify socially vulnerable areas that have less capacity to recover from flooding events.

3.3.10.2 Data Sources and GIS Analysis

The EJ/Social Vulnerability Score associated with each outfall is based on data provided by risQ. risQ provided Hazen with a “social impact” score for each outfall’s tributary area. The social impact score considers the following factors:

- Health obstacles
- Housing unaffordability
- Poverty
- Affluence/household incomes
- Educational attainment
- At-Risk employment
- Minority population

Communities with a higher social impact score are generally less able to recover from a major flooding event; as such, these communities are at greater risk of major consequences from flooding and would benefit the most from adaptations to minimize flooding. Complete documentation of the social impact score and visualizations of regional variations in the different metrics can be found in **Appendix C**.

3.3.10.3 Scoring Methodology

Scores were assigned from 1 (lowest social vulnerability) to 10 (highest social vulnerability) based on the social impact score assigned to each outfall (a higher social impact score = greater social vulnerability). It should also be noted that sensitivity testing was performed to evaluate the impact of the EJ/Social Vulnerability criterion on the overall ranking/prioritizing of outfalls. This analysis did not reveal high sensitivity to the EJ/Social Vulnerability criterion, indicating that socially vulnerable areas are generally associated with higher infrastructure vulnerability.

3.4 GIS Key Assumptions

This section documents several key assumptions that were applied when using the Commission's GIS data to develop the criteria described above. These assumptions could influence the rank and score associated with each outfall displayed in the PowerBI dashboard.

3.4.1 Outfall Ownership

At the time of this analysis, there were a total of 587 outfalls contained in the Commission's outfalls shapefile, 273 of which are owned by the Commission (according to GIS data). The remaining outfalls are owned by other entities such as the MWRA, MassDCR, MassDOT, etc. In some locations, Commission-owned pipes connect to outfalls owned by other entities. Even though these outfalls are owned by others, they are included in this analysis, and counted as Commission-owned, given their connectivity to the Commission's system. With this revision, the PowerBI screening tool includes 337 Commission-owned outfalls. **Appendix D, Table D-1** contains the outfalls with differing owners from their upstream pipes.

3.4.2 GIS Outfalls vs. Modeled Outfalls

It was necessary to "match" outfalls in the Commission's sewer and drain model with outfalls in the GIS database. In some cases, the outfall ID in the model did not match an outfall ID in the GIS data. In these cases, outfalls were matched based on spatial similarity and upstream pipe connectivity. **Appendix D, Table D-2** contains a list of 164 modeled outfalls and their corresponding outfall IDs in the Commission's GIS database.

4. Model Analyses and Basis of Design

4.1 Model Simulations

The Commission's hydrologic/hydraulic models (both 1D and 2D models) were utilized to accomplish two key goals:

- Size proposed infrastructure solutions (e.g., pump station, storage, etc.)
- Demonstrate benefits (i.e., flooding reduction) of solutions

The Commission maintains three separate models: sewer model, drain model and Inundation Model, all of which utilize PCSWMM software. The Inundation Model is a 2D model that combines the sewer and drain models into one framework, applies a detailed topography dataset, and predicts flooding depths, duration, and movement of water on the ground surface. Greater detail about development of the Inundation Model and combination of the Commission's sewer and drain models can be found in the *Inundation Model Report* (Hazen, 2021).

It is important to recognize that the modeling performed throughout this project was not intended to capture or characterize interior flooding that is unrelated to coastal conditions. The Commission intends to update the sewer and drain models, as well as the Inundation Model, in the future. It is expected that the updated models will include a greater portion of the combined sewer and drain pipe networks that exist in reality. These expanded model networks may lead to predictions for additional flooding in areas of the City that are not currently modeled.

4.1.1 10-year, 24-hour Design Storm

The 10-year 24-hour design storm, projected for 2070 as described in **Section 2**, was used to size proposed infrastructure. This was accomplished using the Commission's 1D models (sewer and drain), which predict peak flows and volumes through each outfall for a given storm event. This represented the quantity of flow needing to be handled by a pump station (i.e., and established its peak capacity), for example. The boundary condition used in these analyses was the 100-year storm surge with 2070 sea level rise (MC-FRM).

In comparison to the 100-year tropical storm event (described in **Section 2.1 and 4.1.2**) the 10-year, 24-hour design storm achieves a higher peak intensity, and results in a larger peak rate of discharge at most outfalls, despite resulting in less overall volume of runoff and discharge. As such, in most cases, a pump station or pipeline sized to handle the peak flow rate resulting from a 10-year, 24-hour storm event would also be capable of managing the peak flow rate resulting from the 100-year tropical event.

To establish the existing peak Hydraulic Grade Line (HGL) and potential for flooding at each outfall (e.g., characterize existing system performance without SLR) the 1D model was run to simulate the 2070 projected 10-year, 24-hour design storm with an existing tidal time series preloaded (by others) in the Commission's model. A representative tidal time series from 2016 was selected for this purpose. This time series results in a peak tide level of approximately 3.7 ft (NAVD88). Compared to the existing Mean

High Water elevation (approximately 4.3 ft NAVD88), this condition is more hydraulically favorable for gravity discharge at all outfalls. As such, for conservatism, the 2016 tidal time series was utilized to establish baseline system performance (and a target HGL/tailwater elevation for proposed solutions to flooding).

After simulating the 2070 projected 10-year, 24-hour design storm at each outfall (with 2016 high tide), simulations were conducted with the 2070 projected 10-year, 24-hour design storm with 100-year storm surge and 2070 sea level rise (MC-FRM) to determine the increased HGL and flooding that could result from higher sea levels.

To establish the baseline size/magnitude of possible solutions, an iterative modeling process was followed to evaluate different combinations of pumping and storage at each outfall required to reduce the HGL under 2070 SLR/storm surge conditions, back down to the HGL under 2016 conditions (by maintaining a maximum tailwater elevation of ~3.7 ft NAVD88 at each outfall). An example of one of these “Pumping vs. Storage” curves is shown in **Figure 4-1**.

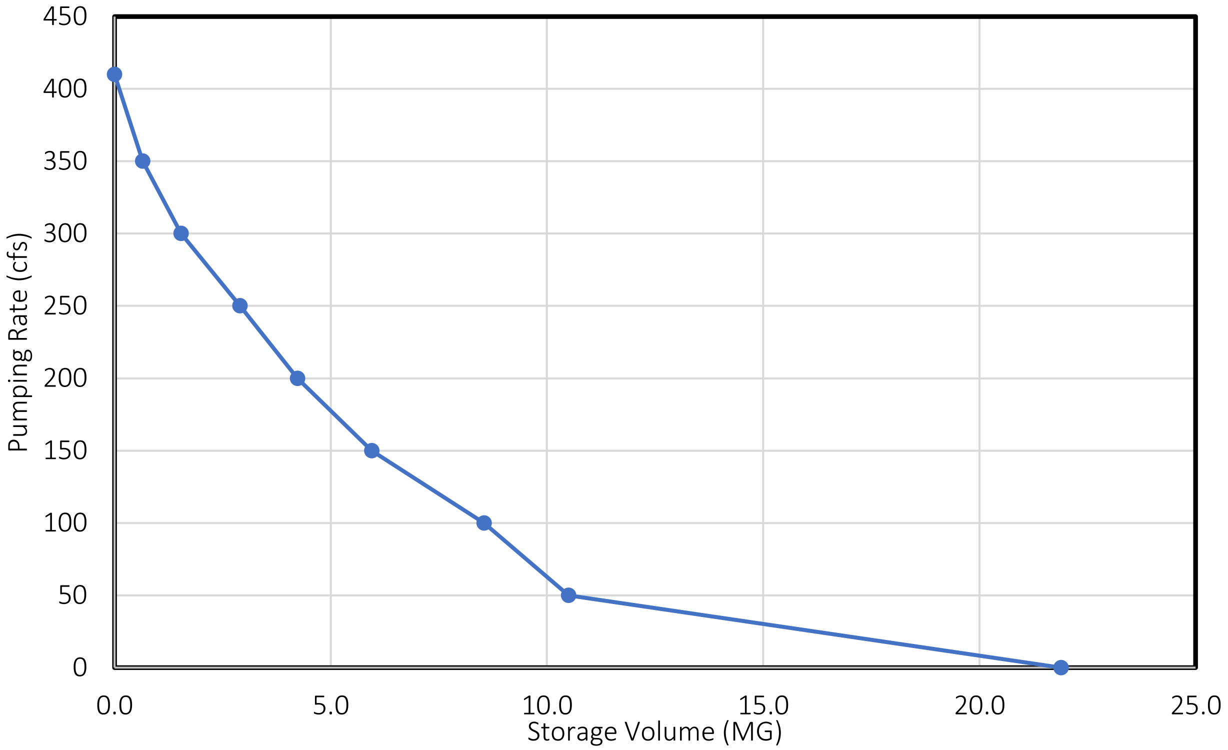


Figure 4-1: Example Pumping vs. Storage Curve

Model-predicted HGL profiles were developed at each outfall to confirm that the possible solutions effectively mitigated the impact of higher sea levels.

4.1.2 100-Year Tropical Storm (1D Simulations)

The 100-year tropical storm (9.58 inches in depth and 48 hours in duration), as developed during the Inundation Model project, was used to demonstrate benefits of each solution (i.e., improved conveyance via flood reduction). This storm was coupled with a boundary condition representing 100-year storm surge and 2070 sea level rise (as established in the MC-FRM). Utilization of the 100-year tropical storm event to evaluate the benefits of proposed solutions provides consistency with CRB and Federal Emergency Management Agency (FEMA) funding requirements.

This storm event was not used directly to size any solutions in most cases, but is representative of the type of extreme storm event the concepts developed during this project would be operated during. In locations with potential “storage only” (no pumping) solutions, the 100-year tropical storm was simulated alongside the 2070 projected 10-year, 24-hour design storm to determine if the proposed storage solution was large enough to manage the additional runoff generated by the 100-year storm event. If it was found that the proposed solution was not large enough to completely manage runoff from the 100-year event, the storage volume was expanded or a pump station was added. **Section 5** contains mapping of the 2D 100-year storm event model simulations that were conducted at each outfall to evaluate the flood reduction benefits of each solution.

4.2 100-year Tropical Storm 2D Simulations

As described in **Section 5** of this report, 2D model simulations were completed to evaluate the potential flood control benefits of coastal stormwater concepts (outfall adaptations). The city was divided into eight zones during modeling, which were combined to serve as citywide results that could be later used for damage analysis, described in **Section 7**. The eight zones are shown in **Figure 4-2,** and the scenarios that were simulated are outlined below.

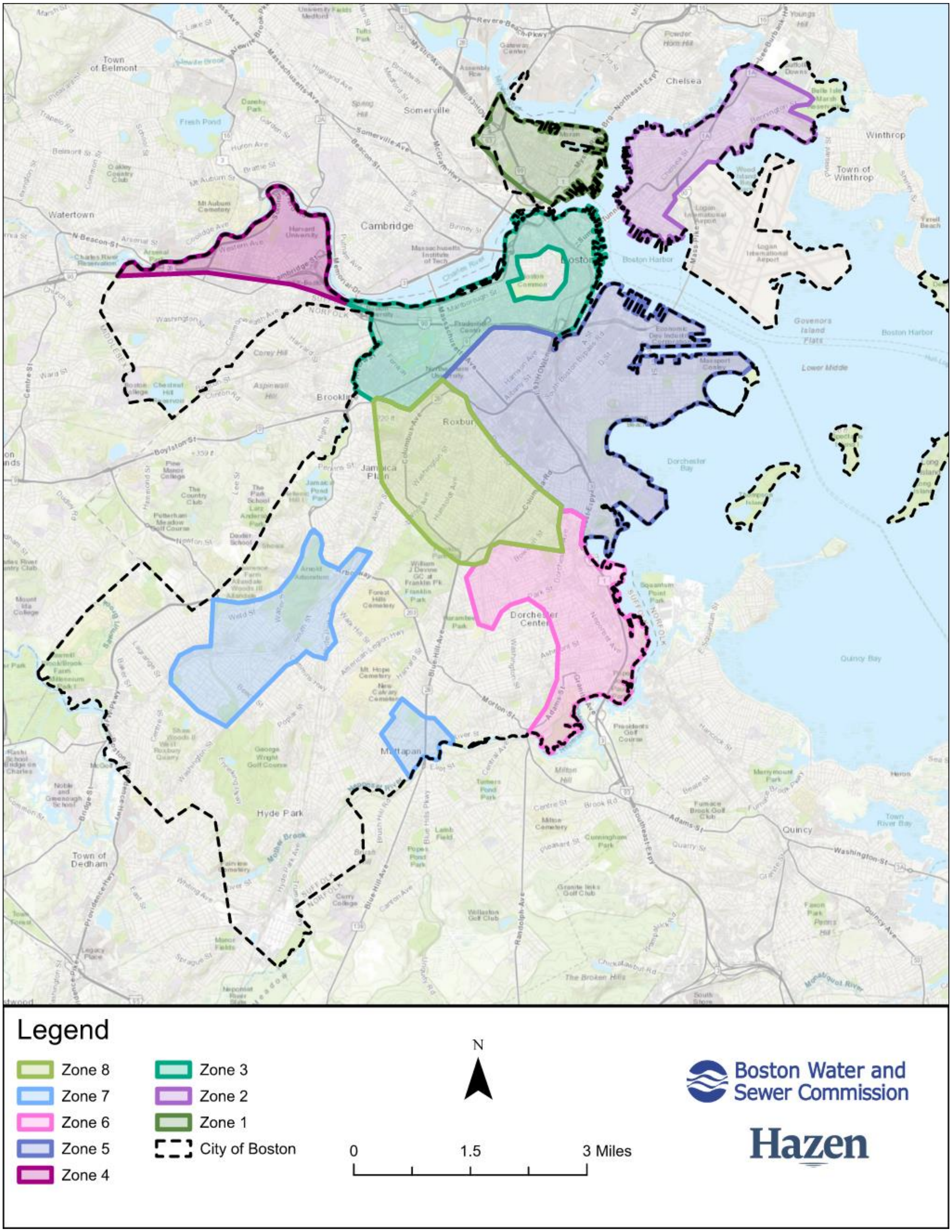


Figure 4-2: Eight City Zones for Flood Modeling and Analysis

4.2.1 No Action

This scenario represents an “existing conditions” scenario under which no adaptations (shoreline protection or coastal stormwater improvements) are implemented. Existing tide gates at the Commission’s stormwater outfalls are included (based on the GIS database called BWSC_Data_12212020_Hazen, dated 12/21/2020).

This scenario represents an “existing conditions” scenario under which no adaptations (shoreline protection or coastal stormwater improvements) are implemented. Existing tide gates at the Commission’s stormwater outfalls are included (based on the GIS database, *BWSC_Data_12212020_Hazen*, dated 12/21/2020).

4.2.2 Shoreline Protection Only

This scenario represents the “baseline” for the development of conceptual solutions that improve stormwater discharge and consequently reduce flooding upstream. It includes complete shoreline protection (currently being studied, planned, and implemented by CRB). From a modeling/analysis standpoint, this scenario assumes that coastal storm surge/tides are not able to directly cause flooding on the land surface. In model simulations, a “wall” is imposed that effectively “blocks” the storm surge/SLR. Existing tide gates at the Commission’s stormwater outfalls are included.

4.2.3 Shoreline Protection and Conceptual Design

This scenario includes two additional items beyond shoreline protection:

- Tide gates are added at all Commission outfalls that currently do not have them (according to the GIS database referenced above)
- Conceptual solutions for flood control are added (e.g., pump station, storage, conveyance, etc.); these solutions are described in more detail in **Section 5**

5. Conceptual Design Overview

5.1 Outfall/Location Selection

While the Commission's intent is ultimately to address all vulnerable outfalls (and their associated drainage areas), more detailed conceptual solutions were developed for an initial group of outfalls as a starting point; beyond these initial locations, a plan was developed (**Section 8** – Implementation Timeline) for replicating these types of detailed solutions to the remainder of the Commission's outfalls. As schedule and budget planning is advanced in the coming years, the Commission (or another entity) may carry out a similar level of conceptual design at these other outfalls as well. **Figure 5-1** depicts the Commission's vulnerable outfalls considered in this phase (conceptual design) as well as future phases.

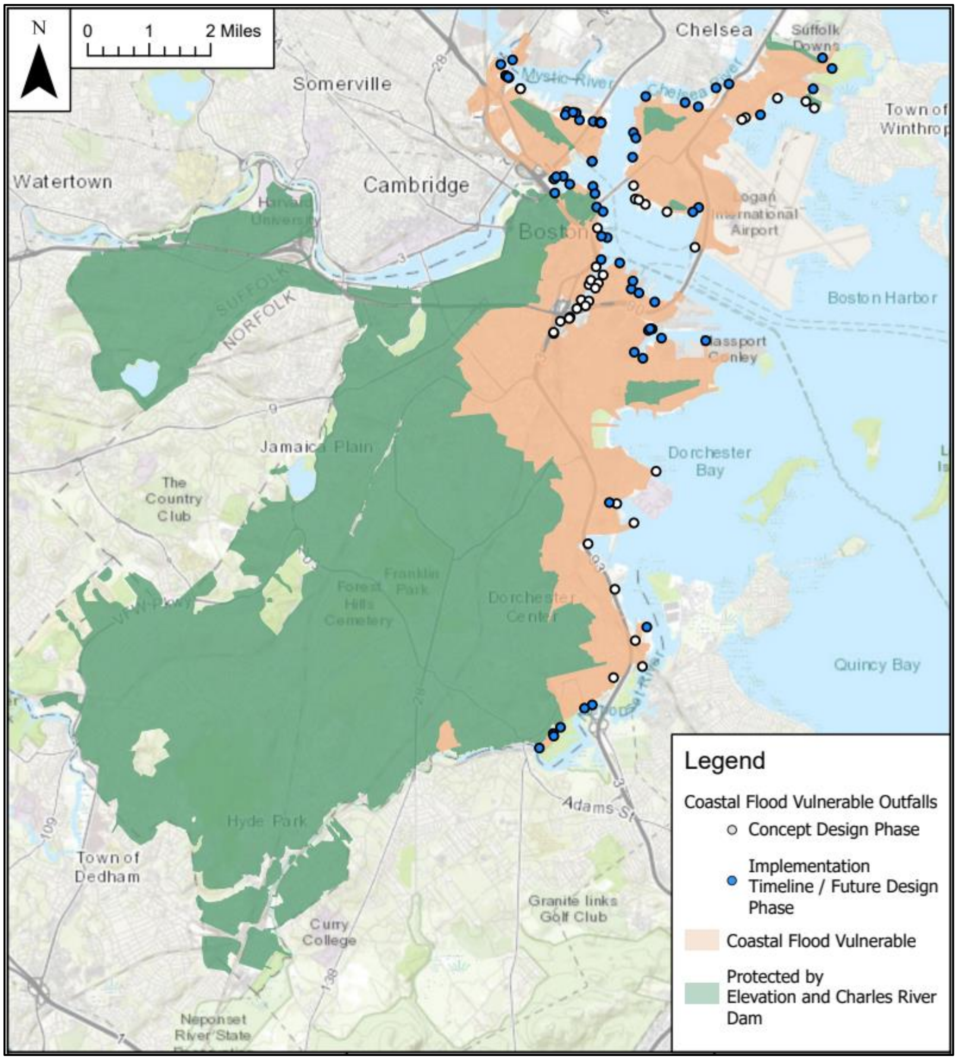


Figure 5-1: Coastal Flood Vulnerable Outfalls

As described in **Section 3**, a decision support tool for prioritizing outfalls was developed and used to rank the highest scoring locations (outfalls) that the Commission owns and operates. The decision support tool was used to screen the multitude of Commission outfalls and prioritize/rank them. Then, field investigations were performed throughout a variety of neighborhoods at the 31 highest ranked locations to further evaluate the outfalls/locations with respect to vulnerabilities, opportunities, and constraints. For example, the amount of space available at the outfall to build a pump station may limit the opportunity for a solution. Or, if there is no publicly-owned land in the vicinity of the outfall, this was noted as a constraint. Photographs were taken at each location and summary sheets were developed for each one (See **Appendix F**).

The final subset of sites that advanced to the conceptual design phase was developed based on coordination with Commission staff and consideration of where the Climate Ready Boston initiative data indicated near-term shoreline protection being proposed. A total of 37 outfalls were advanced to conceptual design. A list of concept outfalls is contained in **Table 5-1**.

Table 5-1: Conceptual Design Outfalls

Concept Name	Outfall ID	Neighborhood	Solution Type	Report Section
Airport	24NCSO003	East Boston	Storage and Pumping	5.4
Constitution Beach	29OSDO001	East Boston	Conveyance and Pumping	5.5
Constitution Beach	29PSDO44	East Boston	Conveyance and Pumping	5.5
Constitution Beach	28PSDO1	East Boston	Conveyance and Pumping	5.5
Waterfront	25MSDO006	East Boston	Conveyance and Pumping	5.6
Waterfront	26LSDO084	East Boston	Conveyance and Pumping	5.6
Waterfront	25MSDO007	East Boston	Conveyance and Pumping	5.6
Waterfront	26LSDO109	East Boston	Conveyance and Pumping	5.6
Waterfront	26LSDO108	East Boston	Conveyance and Pumping	5.6
Greenway	28NSDO156	East Boston	Conveyance	5.7
Greenway	28NSDO207	East Boston	Storage and Pumping	5.7
Schrafft Center	29JCSO017	Charlestown	Storage and Pumping	5.8
Schrafft Center	29JSDO212	Charlestown	Storage and Pumping	5.8
Columbus Park	25LSDO058	Downtown Boston	Storage and Pumping	5.9
Fort Point Channel	23LCSO062	Downtown Boston	Storm Surge Barrier and Pumping	5.10
Fort Point Channel	23LCSO064	Downtown Boston	Storm Surge Barrier and Pumping	5.10
Fort Point Channel	22KCSO065	Downtown Boston	Storm Surge Barrier and Pumping	5.10
Fort Point Channel	22KCSO068	Downtown Boston	Storm Surge Barrier and Pumping	5.10
Fort Point Channel	21KCSO070	South Boston	Storm Surge Barrier and Pumping	5.10
Fort Point Channel	23LSDO196	Seaport	Storm Surge Barrier and Pumping	5.10
Fort Point Channel	23LSDO164	Downtown Boston	Storm Surge Barrier and Pumping	5.10
Fort Point Channel	23LSDO075	Seaport	Storm Surge Barrier and Pumping	5.10
Fort Point Channel	23LSDO074	Seaport	Storm Surge Barrier and Pumping	5.10
Fort Point Channel	22LSDO580	Seaport	Storm Surge Barrier and Pumping	5.10
Fort Point Channel	21KSDO069	South Boston	Storm Surge Barrier and Pumping	5.10
Fort Point Channel	22LCSO073	Seaport	Storm Surge Barrier and Pumping	5.10
Fort Point Channel	22KCSO072	Downtown Boston	Storm Surge Barrier and Pumping	5.10
Fort Point Channel	22KSDO307	South Boston	Storm Surge Barrier and Pumping	5.10
Fort Point Channel	22KSDO318	Downtown Boston	Storm Surge Barrier and Pumping	5.10
Davenport Creek	10LSDO094	Dorchester	Storage and Pumping	5.11
Dorchester Bay Basin	16LSDO122	Dorchester	Conveyance and Storage	5.12
Dorchester Bay Basin	15LSDO088	Dorchester	Conveyance and Storage	5.12
Dorchester Bay Basin	15LSDO089	Dorchester	Conveyance and Storage	5.12
Dorchester Bay Basin	13LSDO090	Dorchester	Conveyance and Storage	5.12
Finnegan Park	12LSDO092	Dorchester	Storage and Pumping	5.13
Finnegan Park	11MSDO093	Dorchester	Storage and Pumping	5.13
Old Harbor Park	17MSDO33	Dorchester	Storage and Pumping	5.14

5.2 Conceptual Design Overview

5.2.1 Overview of Design Package

At each location, a conceptual design package was assembled (**Appendix G**) that includes an overview of the proposed concept, basis of design summary/assumptions, flood reduction benefits (2D model results), economic benefits (damage analysis), project cost estimate, conceptual design drawings/schematics, as well as considerations for implementation and adaptability, as summarized below. The design packages contain a succinct summary of the concepts put forth at each location, while this report provides additional supporting methodology and background information that led to the development of each concept.

Each concept package includes:

- **Overview** – rendering of the conceptual solution, maps depicting location, and a description of the solution and its primary elements.
- **Assumptions –** key assumptions that were applied during development of the concept.
- **Basis of Design –** summary of design objectives and the conditions for which each solution was designed (some concepts include supplemental overview/basis of design sheets if unique elements, like new pipelines, are included in the solution).
- **Flood Modeling and Damage Analysis –** these sheets summarize flood modeling and damage analyses that was performed to quantify the flood reduction benefits of each concept. This analysis was performed by simulating a 100-year tropical storm event with projected sea level rise and storm surge in 2070. These sheets also include a capital cost estimate for the concept, and FEMA BRIC funding metrics that could be used in the future.
- **Planting Palette –** (if applicable) these sheets include a planting palette with biologically appropriate plant species that could be planted at solutions that include nature-based elements.
- **Adaptability and Implementation –** summary of how the concept could be adapted to more intense rain events or additional sea level rise in the future, and a description of key considerations that should be evaluated before progressing the concept in a future project.
- **Replicability and Implementation Timeline –** preliminary mapping depicting locations where a similar concept could be replicated. Additional information about these locations can be found in **Section 8** and **Appendix E**.
- **Appendix G –** conceptual design drawings of major concept elements including pump stations, tanks, new pipelines, etc.

The following sections describe the overall process that was followed to design conceptual solutions at all sites, as well as relevant details about the design process at each site.

5.2.2 Incorporation of Adjacent Outfalls

Although the outfall screening and ranking process described in **Section 3** was used to identify individual outfalls for inclusion in the conceptual design process, analyses were conducted to incorporated "adjacent" outfalls into solutions wherever possible. This philosophy allowed for development of several "regional" solutions that adapt multiple outfalls with a single solution. If any of the concepts herein are advanced for further study or design, incorporation of outfalls owned privately or by other agencies should be considered.

5.2.3 Alternatives Evaluation

For each conceptual design site, conveyance, storage, and pumping alternatives were evaluated to develop a solution to improve discharge of stormwater (and reduce upstream flooding) with the most feasible alternative(s) selected based on site characteristics and system configuration as follows:

<u>Conveyance</u>

This alternative was evaluated in two ways, depending on system characteristics:

- Diversion of stormwater flow from less vulnerable, higher elevation areas (i.e., above the peak storm surge elevation), upstream of the outfall, directly downstream to a new/existing outfall. This is often referred to as an "express" pipe, as it bypasses the downstream piping and moves flow around it. Since the tributary area of this express piping is above the storm surge elevation, conveyance can continue during the storm event and the resulting backwater impacts will not impact the higher elevation areas. A proposed diversion structure would be constructed to "disconnect" the higher elevation area from the more vulnerable lower elevation area downstream.
- Diversion of stormwater flow from an existing outfall (by intercepting it within a new diversion chamber upstream of the headwall) to an adjacent area where a regional solution is contemplated (e.g., Dorchester Bay Basin). The proposed diversion structure could be static (simple weir or slide gate) or dynamic (controlled in real-time depending on storm conditions).
- All conveyance alternatives were designed with slopes of at least 0.05%. The diameters of conveyance pipes were determined by taking the total cross-sectional area of all upstream pipes and rounding up to the nearest readily commercially available pipe size. To advance these types of concept designs, additional hydraulic analysis will be needed.

<u>Storage</u>

This alternative was evaluated through use of the natural landscape as well as constructed storage. Natural storage options were preferred over manmade tanks, though natural solutions were not found to be feasible in some locations depending on site constraints (topography, etc.). The storage options evaluated were as follows:

- Surface storage, if topography allows, by diverting stormwater into the area for storage during the storm event and pumping out post-event.

- Surface storage in an existing bay or inlet using a storm surge barrier to enclose the bay and use it to store stormwater during the event. The barrier would be closed at low tide, preserving maximum storage volume potential upstream of it, and opened post-event. The need for a pump station to draw down the water level pre-event or keep up with incoming storm flows from the drainage system was evaluated.
- Underground storage (tank), with a diversion structure to direct storm flows just upstream of the outfall into it, and often combined with a pump station to handle peak flow entering the tank during a storm.

Pump Station

This alternative was combined with a storage solution (either underground or surface storage) for each pumping concept within this report, with the storage compartment behaving as a “peak-shaving tank”. As further described in the analysis of each individual concept, concepts including both pumping and storage can be considered a continuum of solutions, as there are a range of acceptable combinations of storage and pumping that produce identical reductions in flooding. Storage solutions range from large tanks to simple wet wells, depending on site space considerations and other factors.

Pump types were evaluated, and electric submersible pumps suitable for high flow and low head performance were ultimately selected. Electric submersible pumps minimize the above ground footprint of the pump stations and mitigate negative visual and auditory impacts from diesel engine driven pumps. Vendors were contacted to confirm equipment availability for the given performance requirements. Other similar (currently operating) facilities were researched as well, to understand the context and use of this technology. One site was visited (Dyke Lane flood station in Stamford, CT) to better understand and confirm space considerations and equipment setup for flows of this magnitude.

A consistent process was followed, as described in **5.2.4**, to calculate the space needed for each pump station and size the equipment and facility (i.e., how many pumps, how large each bay should be, duty versus standby, dewatering post-event). The ancillary electrical, HVAC (heating, ventilation, and air-conditioning), and control systems for each pump station would be housed in an above ground electrical building that would be elevated above expected flood stages and incorporated with flood protecting measures for its exterior doors and windows and its interior components.

Onsite backup power generation was not found to be preferable for these concepts; all pumping concepts were designed with the intent that portable power generators can be connected to the electrical system of the pump station as needed. This approach increases the range of acceptable site sizes and prevents recurring sources of noise and pollution associated with frequent generator use required for regular operations and maintenance of onsite backup power generators. For such reasons, excluding onsite generators may be a popular choice with local stakeholders. Typically, larger pump stations are designed with permanently-installed onsite backup power; further consideration during later stages of design should be given to ensure that site conditions warrant this non-standard approach.

It is generally recognized that pump stations impose an additional O&M burden on utilities (such as the Commission) and are not viewed favorably by some stakeholders and residents. As such, where possible, the solutions developed during this project sought to minimize the number and size of pump stations by preferencing solutions relying on conveyance/upstream system optimization and storage. During future studies or design projects, the cost effectiveness of this approach should be considered. Construction of new conveyance systems and storage facilities may be more disruptive and costly than construction and maintenance of a new pump station in some circumstances. It should further be recognized that the feasibility of solutions *without* pump stations is limited by the topography of the City and future sea levels. Low-lying and flat areas that are beneath future flood elevations cannot drain by gravity (under future conditions), and therefore require pumped solutions to prevent flooding. It is important that stakeholders recognize this fundamental constraint when evaluating the use of pump stations as part of a Citywide adaptation strategy.

5.2.4 Overview of Design Process and Calculations

Throughout all designs for this project, all conveyance solutions (except for new discharge pipe sizing for pump station concepts) were designed using the same methodology. In lieu of performing in-depth hydraulic analyses for each new pipeline, the diameter of all new pipelines was chosen such that the total cross-sectional area of proposed pipes (rounded up to the nearest readily-available premade pipe size) was equal to the sum of cross-sectional areas of all pipes being intercepted upstream. Additional hydraulic, constructability, and subsurface conflict analyses will need to be performed to advance the conveyance designs described within this report.

The following process was used to select and size storage tank (based primarily on hydraulic modeling) and pump station components (based primarily on Hydraulic Institute standards). The standard design process was based on guidance from the American National Standards Institute (ANSI) and Hydraulic Institute (HI) Standard 9.8-2018, Rotodynamic Pumps for Pump Intake Design. Detailed calculations for each site can be found in **Appendix H**.

1. The primary design objective at each location was to maintain the existing HGL in the system (starting at the outfall(s) included in the concept) despite additional SLR and storm surge due to a projected 100-year tropical storm in 2070. The maximum HGL, or tailwater elevation (at each outfall) was chosen to be 3.7 ft NAVD88 (typical high tide selected from various time series included in the Commission's existing PCSWMM model as described in **Section 4**). Modeling of the 2070 projected 10-year, 24-hour design storm was conducted to determine the required rates of pumping and volume of storage necessary to maintain this benchmark maximum WSE. A curve of required pumping (rate) was developed based on this modeling.

2. A tank footprint was selected considering the space constraints of the site and other special conditions (e.g., existing trees, property lines, topography,). Generally, the horizontal footprint was maximized as much as reasonable, as deeper construction is generally more expensive and complicated for a given excavation volume. During the final design process, consideration should be given to the approach flow patterns of the inlet to the storage tank based on the orientation of the storage tank to existing pipes and how such flow regimes may or may not impact pump station performance. Additional analysis of the inlet(s) of the storage tank is required before final design.

3. A tank depth was selected to correspond with a point along the storage-pumping curve. The top WSE was chosen to be 3.7 ft NAVD88, as described in Step 1. The low wet well level was determined later in the iterative design process, as described in section 7a. Generally, operating

the tank in a "storage-only" configuration was preferred; if such a configuration was not possible or practical given the required depth or size of the tank, the preferred design was a volume that intersects roughly with the knee of the storage-pumping curve.

4. The volume of the tank was calculated given the footprint and depth.

5. The required pump rate for the chosen storage volume was calculated by interpolating the pumping vs. storage curve.

6. The number of active pumps was selected to utilize as few pumps as reasonable. All pumps specified for this project are axial-flow propeller, electric, submersible, column pumps. Some manufacturer outreach was performed for the project, particularly for the Fort Point Channel concept, to confirm that the general ranges of pump rates and pressures required were possible for several manufacturers to produce. Generally, this meant limiting pump rate to below 120 CFS (per pump). For most concepts, pump rates were chosen at around 80 CFS or lower, as larger pump rates generally require deeper tanks to accommodate the additional required submergence of the pump. The number of standby pumps was selected to reflect the relative criticality of the particular concept. As a general rule, all proposed pump station concepts (except for the Fort Point Channel concept) included one standby pump. Additionally, two dewatering pumps were specified for each pump station concept to handle dewatering the tanks entirely, as the main pumps will not be able to remove all water from the storage tank given their chosen configuration.

7. Minimum pump submergence was calculated using Hydraulic Institute Standard 9.8-2018. All concepts have been designed with a depth sufficient for HI standards, but additional tank depth may be required for some concepts, depending on the specific net positive suction head (NPSH) requirements of the pumps available on the market.

    a. It was checked whether the selected tank depth could provide the necessary minimum submergence and usable height (active storage). Generally, a usable height of at least 6 ft was preferred, to allow for alarms and pump controls to function without overlap. Here, the usable height is defined as the height of the tank minus the height of the minimum submergence required for proper pump function. If the tank depth did not meet the requirements for minimum submergence and usable height, the design process began again at step 2 with a deeper tank and repeated until an appropriate combination of tank depth and pumps were found, except for some concepts where space constraints dictated a smaller usable height. Such concepts will need to be considered further to evaluate potentially needing to use an alternative controls schema versus making the tank deeper. Tank heights may need to be adjusted to comply with specific manufacturers' requirements for pump controls and instrumentation in later design phases.

    b. *Note: This method produces a flexible, robust pump station design. The design process here is primarily applicable for constant-speed pumps, which are specified for each concept and are preferred for these stormwater applications given their ability to quickly meet demand during intense peak flows in critical wet weather events. The need for a minimum range of elevations, the "active storage" or "usable height", can be greatly* *reduced with the use of Variable Frequency Drives (VFDs), which are designed to vary the speed of the pumps to maintain the water level in the pump station, but the simplicity and reliability of constant-speed pumps was selected for these projects. In the future, with some electrical retrofitting, any concept could be updated to include VFDs if so desired.*

8. The Hydraulic Institute Standard 9.8 was followed to calculate pump intake design dimensions for the pump bays. All pumping concepts were designed to have partitioned pump bays instead of a single intake structure, as recommended by HI 9.8-2018. Changes to the pump station geometry may be required, subject to additional investigation (possibly including physical modeling) as prescribed by HI.

    a. It was checked whether the pump bays could be accommodated inside the tank footprint or on site. If no, the design process began again until this constraint could be met.

    b. *Note: Structural calculations and material selection were not performed for the pump stations at this stage of design. Modifications may be necessary to the pump bay dimensions (particularly the width of the dividing and exterior walls, foundation design, and existence and placement of internal support structures) to satisfy structural requirements, depending on information from site-specifical geotechnical investigations.*

9. A conservative pump rate for the dewatering pumps was calculated: each of the two dewatering pumps was designed to dewater the tank from full to empty in 6 hours. This dewatering rate was chosen to ensure that dewatering pumps would be conservatively sized. Two dewatering pumps were selected for redundancy. Additional hydraulic modeling at each location may indicate that lower pump rates are acceptable for some concepts. Some concepts may not need separate dewatering pumps at all if they are found to be able to drain by gravity during later stages of design. Due to the uncertainty involved with the required dewatering rate, the dewatering pump sump was not designed for any of the pumping concepts. The exact size and shape of the dewatering pump bay sump will have to be calculated at a further stage of the design process. All concepts are expected to have small dewatering pumps less than 10 CFS.

    a. *Note: typically, dewatering pumps are not designed at conceptual levels of design. Dewatering is a site-specific endeavor, as there are sometimes opportunities for passive or active dewatering with several different methods, including underdrains, active flow control valves, and weirs. A conservative method of dewatering (pumping, without the use of the main pumps to dewater to the minimum submergence) was chosen with a rapid pump rate. Further analysis may determine that the size of the dewatering pump bays should be changed, depending on desired pump rate and other factors.*

10. Wherever feasible, pump stations were designed to be as close as possible to the discharge location, to minimize the discharge pipe length. The elevations at which all pump stations discharge are above the CRB-determined DFEs at their respective locations. This avoids the need to consider differential head caused by varying water levels at the outlet and protects the pump station (and drainage system) in the event of failure of a backflow prevention valve. At such sites, smaller discharge pipe diameters can be used without excessive head losses, generally assumed to

be equal to the size of the vertical tubes that the pumps are located within. For sites that utilized force mains for discharge:

   a. A diameter of discharge pipe was selected.

   b. The Hazen Williams Equation was used to calculate the slope of the energy line "s" (head loss per length of pipe). Discharge pipes were assumed to be made of ductile iron with a friction factor, C, of 120.

   c. Head loss was calculated for the assumed length of pipe.

      i. If head loss was found to be too large, a new diameter of pipe was selected and the process began again at step 9a.

      ii. *Note: As previously specified in step 10, force mains were avoided whenever possible in concept designs, as the axial flow pumps specified for these projects are generally not best-suited in applications with high head losses. For concepts where a force main is found to be required, pump manufacturers should be consulted to determine what head losses are acceptable for their particular pumps. In some cases, a mixed-flow impeller may be required instead of an axial-flow impeller.*

11. For sites that utilized force mains for discharge, Steps 10 a-c were repeated to size the discharge pipes for the dewatering pumps.

5.3 Common Design Assumptions for all Sites

This section contains a description of assumptions and information that applies to all conceptual design locations.

5.3.1 Sea Level Rise and Datum

The concepts were designed for consistency with Climate Ready Boston proposed adaptations and analyzed based on sea level rise projections in the Massachusetts Coastal Flood Risk Model. The SLR values applied in MC-FRM are consistent with the standards for the Commonwealth of Massachusetts developed by Coastal Zone Management. The MC-FRM utilizes a “High” SLR scenario. This scenario is based on the relative SLR projections under RCP 8.5 (a “worst case scenario” of increasing atmospheric carbon concentrations) and represents elevations that have a 99.5% probability of not being exceeded within the respective timeframes. In 2030, that amounts to an increase of 1.3 ft in Boston from a baseline condition (2008 centered tidal epoch), and in 2070 that amounts to an increase of 4.3 ft. The difference between present day and projected 2070 sea levels is shown in **Figure 5-2.**

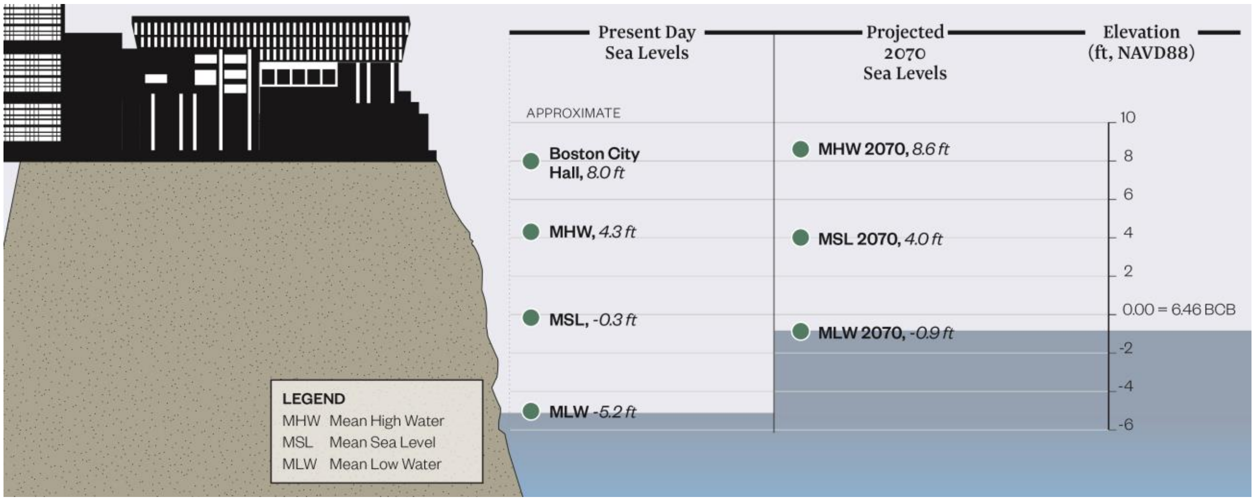


Figure 5-2: Present and Projected 2070 Sea Levels

The concepts developed in this project were analyzed using coastal conditions that include 2070 projected SLR and storm surge resulting from a 100-year tropical storm. The peak water surface elevation (WSE) predicted by the MC-FRM during these conditions is approximately 13.8 ft NAVD88 (varies by location). In mid 2022, the Greater Boston Research Advisory Group issued an updated report with new SLR projections. The report acknowledges that long term SLR projections are associated with significant uncertainty, and that updated projections include less SLR by 2100 (compared to earlier projections in the 2015 BRAG report.) According to the report, the likely range of SLR by 2070 under an RCP 8.5 scenario is 1.4 – 2.8 ft. Based on this new information, projections from the MC-FRM that were utilized in this project are conservative and appropriate for long term planning purposes.

Unless otherwise noted, all elevations are based on the NAVD88 vertical datum. Elevations given in NAVD88 can be converted to Boston City Base elevation by adding 6.46 ft.

5.3.2 Climate Ready Boston Shoreline Protection

The concepts were developed to maintain consistency with possible Climate Ready Boston adaptations based on the latest available information at the time they were developed. As the CRB program continues to evolve, it is anticipated that proposed concepts will need to be adapted.

The concepts were developed to be consistent with stated neighborhood design flood elevations (DFEs). The DFEs are regional minimum elevations for flood control projects, such as seawalls. Within this report, proposed pumps were designed to discharge to a minimum elevation matching the stated design flood elevation in the location of the pump station. The concept-specific design flood elevations are summarized in **Table 5-2**.

Table 5-2: Concept Design Flood Elevations (based on CRB documentation as of 2022)

Concept	**Design Flood Elevation** (NAVD88)
Airport	16.0
Constitution Beach	16.0
East Boston Waterfront	16.0
East Boston Greenway	16.0
Charlestown Schrafft Center	15.5
Columbus Park	15.0
Fort Point Channel	15.5
Davenport Creek	14.4
Dorchester Bay Basin	16.1
Joseph Finnegan Park	14.4
Old Harbor Park	16.2

At the time of this project, many CRB concepts were in early planning stages and not fully defined. **In consideration of this, it was assumed the shoreline protection around the City of Boston is 100% effective for all modeling evaluations (except for no-action/baseline scenarios, which did not include shoreline protection).** This assumption eliminates overland coastal flooding from model predictions, allowing for isolation of flooding that results only from rainfall and stormwater that cannot be discharged due to high sea levels. It is important to recognize that additional flooding, beyond what is depicted herein, would be expected if 100% effective shoreline protection is not implemented at each concept location.

5.3.3 Nature-Based Considerations

Planting palettes were developed for concepts, where possible. Broadly, two types of planting palettes were developed: one for the “dry” areas surrounding the stormwater storage zones, and one for the “wet” areas within the stormwater storage areas that are designed to temporarily flood during intense rain events (e.g., Davenport Creek Stormwater Park). The plant species selected for the “wet” palette are tolerant of occasional temporary flooding.

The “dry” planting palettes can be applied to the greenspace surrounding the proposed concept electrical buildings and discharge pipes, helping to mitigate the visual impact of any new “grey” infrastructure, and providing environmental benefits associated with native species. The “wet” planting palettes can help prevent soil erosion in the stormwater storage zones and provide a public amenity in the form of green space planted with native species. See concept sheets in **Appendix G** for more details.

5.3.4 Adaptability

During the design process of the concept solutions, emphasis was placed on ensuring that the designs would function under conditions more severe than used for design. **Figure 5-3** below depicts historical daily rainfall totals and tide levels. As shown in this figure, the conditions that were used to design and analyze the concepts herein are conservative and represent more extreme conditions than have occurred historically, as compared to 10-year, 24-hr, rainfall with 2070 SLR. Certain measures could be implemented to adapt the concepts to more severe conditions (i.e., additional SLR, more intense rainfall, etc.) in the future. A description of specific measures that could be implemented at each concept is included in the sub-section describing it.

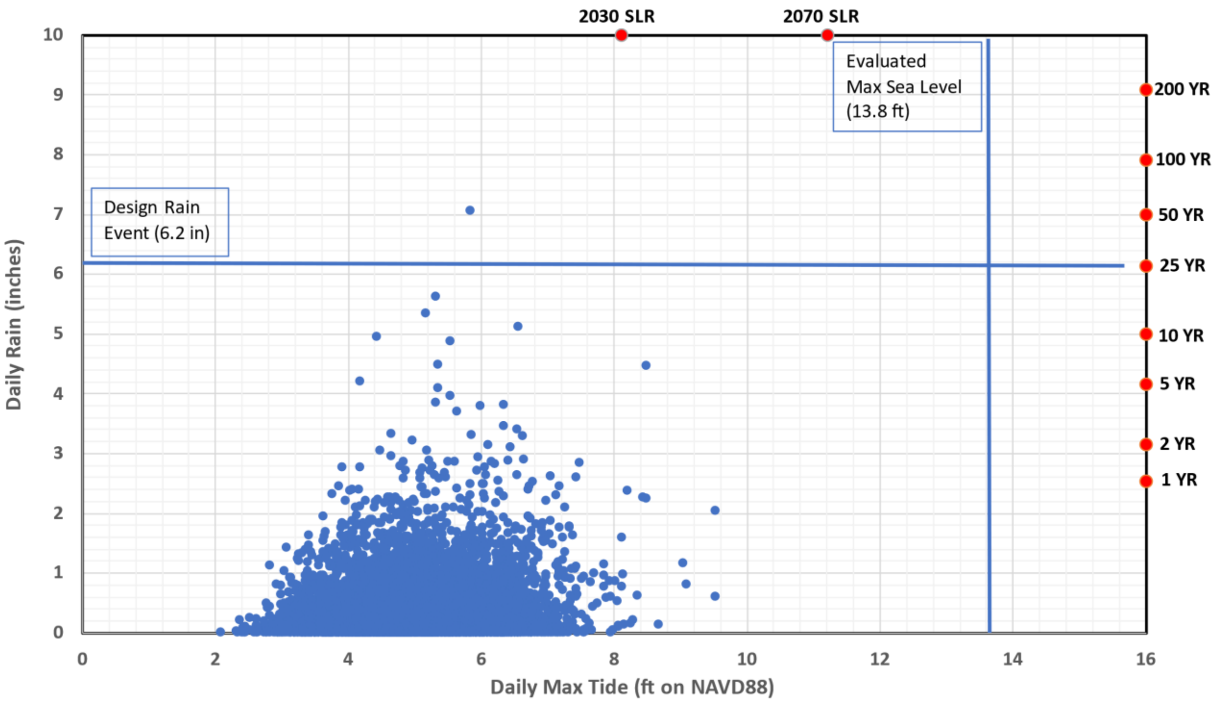


Figure 5-3: Design and Analysis Conditions vs. Historical Tide and Rainfall

Note: the “Design Rain Event” indicated on **Figure 5-3** *is the projected 2070, 10-year, 24-hour rain event as described in Section 2 of this report. The axis on the righthand side of the figure depicts current return 24-hour event return periods based on NOAA Atlas 14.*

Several measures to adapt concepts to more intense rainfall and higher sea levels could be applied universally to all concept as described below:

- For concepts that do not include a pump station, the addition of a pump station can allow the concept to function under more intense conditions.
- For concepts with a pump station, increasing the storage volume can allow the pump station to function under a wider variety of conditions.
- For concepts with a pump station, increasing the flow rate, or number of pumps within the concept.
- Utilize large pumps for higher discharge elevations.
- Operate standby pumps alongside duty pumps during an extreme storm event.
- Construct larger peak shaving/storage tanks.
- Increase catch basin and system conveyance capacity in conjunction with larger downstream pumping systems to accommodate increased rainfall.

The following subsections of this section describe the design of individual concepts (including site specific adaptability measures).

5.4 Airport Pump Station

5.4.1 Concept Overview

The Airport Pump Station concept is located at the southwest corner of Boston Logan Airport, as shown in **Figure 5-4**. If a high tide level begins to reduce the ability of existing outfall 24NCSO003 to discharge by gravity, the existing storm sewer will begin to surcharge. The concept design, as shown in **Figure 5-5**, includes a stormwater storage (peak flow shaving) tank and pump station to discharge excess wet weather flow when tide levels are high. A diversion structure with a static weir discharging to a 144-in connecting pipe directs excess flow from the existing sewer to the storage tank. The storage tank is connected directly to the pump station. An additional stormwater outfall owned by Massport is located near the existing Commission owned outfall; the feasibility of adding this outfall to the concept could be evaluated in the future.

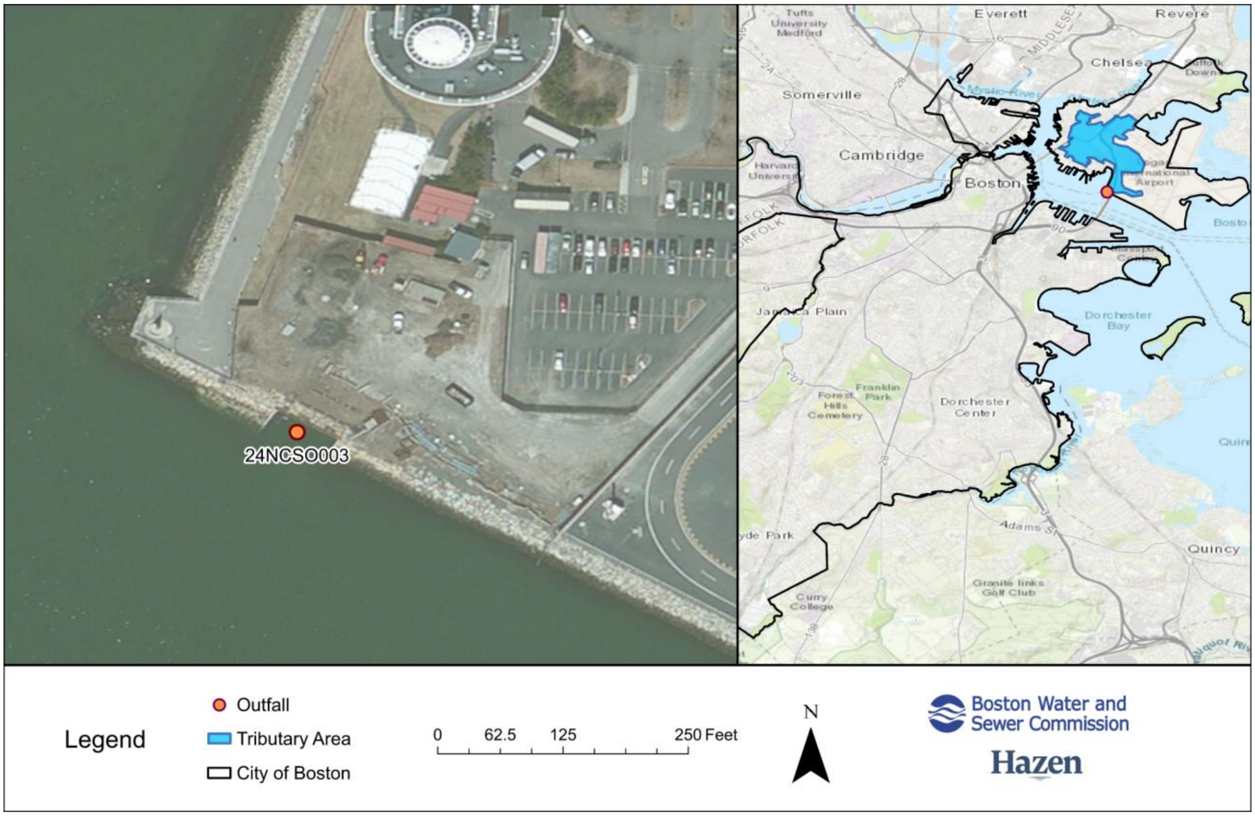


Figure 5-4: Airport Pump Station Concept Location

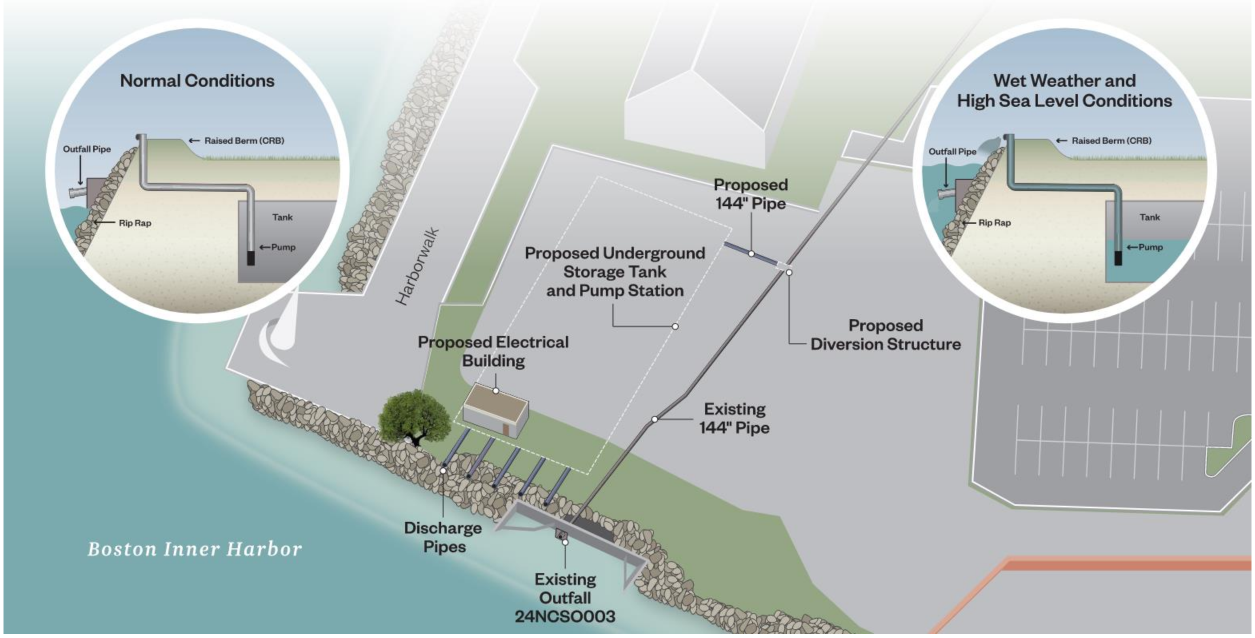


Figure 5-5: Graphic Representation of Airport Concept

5.4.2 Basis of Design

Model simulations were conducted to determine the maximum current-day HGL that occurs at Outfall 24NCSO003 with the representative tide data used in the City's PCSWMM model. Analyses were then conducted to determine the acceptable combinations of storage volume and pumping rate required to maintain the representative current-day HGL with 2070 projected sea level rise and 100-year storm surge, as shown in **Figure 5-6**.

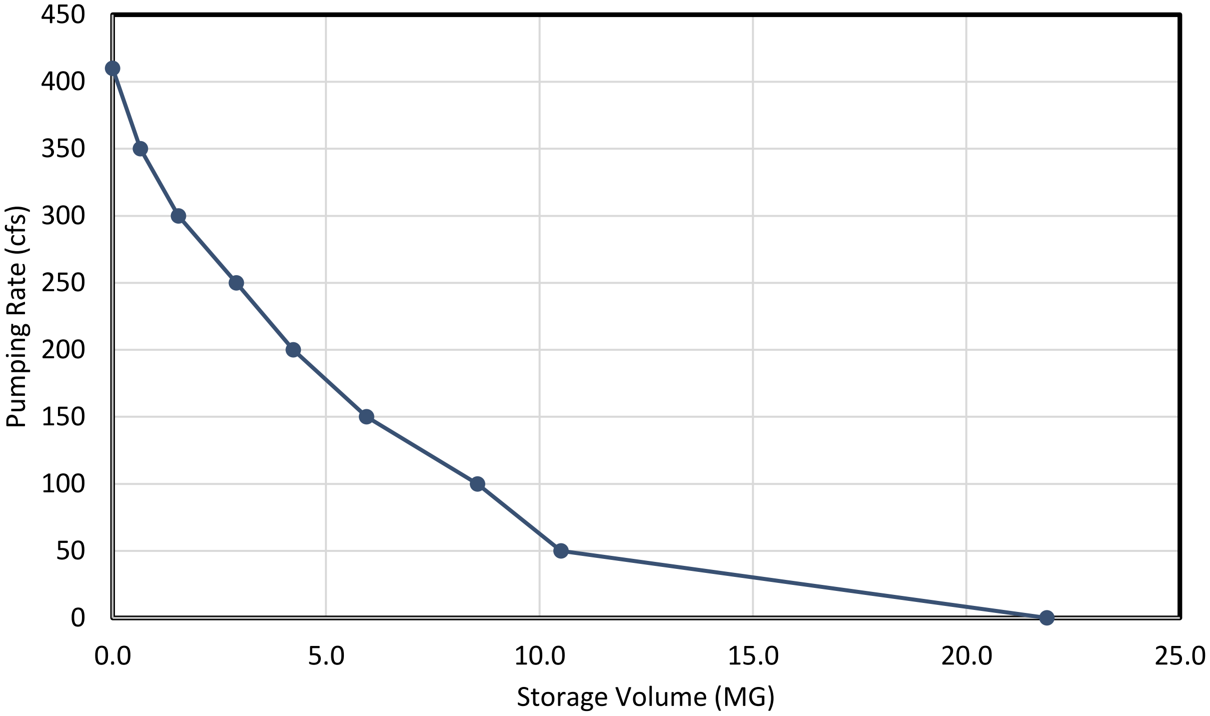


Figure 5-6: Outfall 24NCSO003 Pumping vs. Storage

The City of Boston's Parcel database was used to identify publicly owned parcels near the existing outfall. An analysis of the pump station was performed to identify a pump rate and physical dimensions that are hydraulically viable. It was found that a 1.2 Million Gallon (MG) storage tank approximately 26 ft deep could fit within the property with a 320 CFS pump station. The pump station and storage tank occupy an area of 8,750 ft^2. The pump station utilizes four duty pumps, one standby pump, and two dewatering pumps. The pump station is configured with vertical, axial electric submersible pumps in parallel bays. The pumps are configured to discharge into individual, non-manifolded force mains, which travel horizontally underground from the pump station to the proposed elevated shoreline project (TBD by CRB), at which point they discharge into the harbor onto an energy dissipation structure.

5.4.3 Flooding Analysis

The flood reduction benefits of the Airport Pump Station concept were evaluated using the Commission’s 2D Inundation Model by simulating a 100-year tropical storm event with 2070 SLR and storm surge. **Figure 5-7** below depict the peak flooding that was predicted in the Airport Pump Station drainage area with shoreline protection only and with the pump station and tide gates on all vulnerable BWSC owned outfalls.

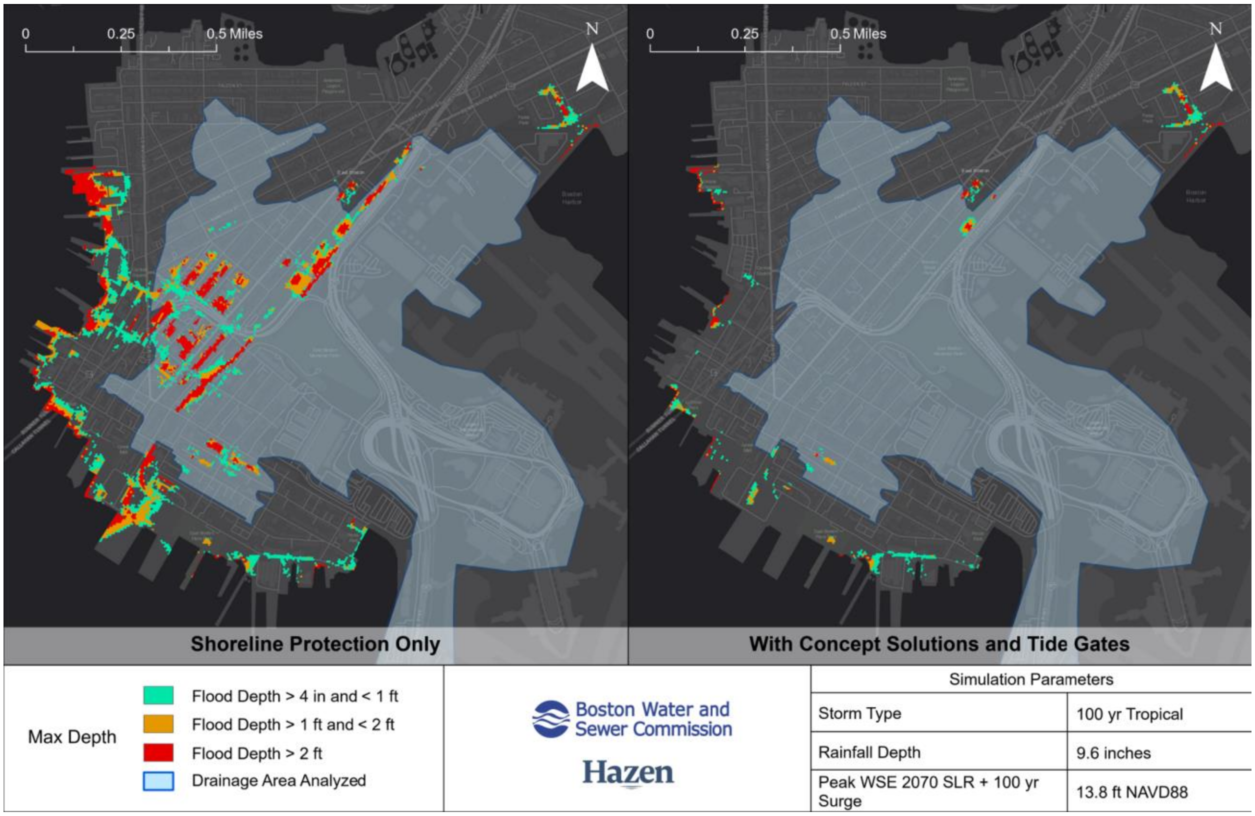


Figure 5-7: Airport Pump Station Flood Model Results

Note: **Figure 5-7** *includes a polygon labeled as "drainage area analyzed". This area represents the area which was included in the economic damage/loss analysis described in* **Section 7** *of this report.*

5.4.4 Adaptability and Implementation

The following measures could be implemented to adapt the concept to more severe conditions (additional SLR, more intense rainfall, etc.) in the future:

- Increase the size of installed electric submersible pumps.
- Utilize the standby pump as a duty pump during extreme conditions.
- Increase the size of the peak shaving tank.
- Consider construction of a larger storage and pump facility at the large privately owned parking lot nearby.
- Increase the size of the concept to manage wet weather flow from the adjacent outfall owned by Massport.

Implementation of the concepts presented for the Airport Pump Station require consideration of the following:

- Coordination with CRB is necessary to implement shoreline protection. The pump station should not be implemented without shoreline protection to prevent coastal flooding within the area tributary to it. The discharge structure may need to be modified depending on the exact nature of the shoreline protection chosen by CRB.
- Coordination with Massport would be necessary to construct the pump station. The concept could be modified to manage wet weather flow from the adjacent outfall owned by Massport.
- The Airport Pump Station currently serves a Combined Sewer Overflow (CSO) outfall. It is the Commission’s intention to separate the drainage area and use the outfall for stormwater flow in the future. The size and pump capacity of the facility should be re-evaluated to consider sewer separation in the future.
- The existing outfall receives flow from a large 144-in conduit. Analyses should be conducted to determine if this conduit has excess capacity after planned sewer separation projects are completed. If it is found that there is additional capacity, other storm drains that are connected to coastal flood vulnerable outfalls could be diverted to Outfall 24NCSO003 and the Airport Pump Station.
- A comprehensive permitting evaluation should be conducted to evaluate possible impacts from construction and operation of the pump station to the receiving water.
- Community engagement with stakeholders may help build project support by documenting the need for the storage tank and pump station.

5.5 Constitution Beach Pump Station

5.5.1 Concept Overview

The Constitution Beach concept is located on Constitution Beach in East Boston, as shown in **Figure 5-8**. The concept design, as shown in **Figure 5-9**, includes a subsurface stormwater storage tank and an underground stormwater pump station to discharge wet weather flow from outfalls 29OSDO001, 29PSDO44, and 28PSDO1 when sea levels are too high for the outfalls to discharge by gravity. Flow to the storage tank is diverted from the existing 18-in and 60-in storm sewers with passive diversion weirs and additional conveyance piping to the storage tank. The storage tank is connected directly to the pump station. The location of the pump station discharge at this location is determined primarily by preliminary CRB adaptation plans, which include shoreline elevation and berms along the outer perimeter of the parking lot. During an extreme storm condition, it is anticipated that any area not protected by the berm would be flooded.

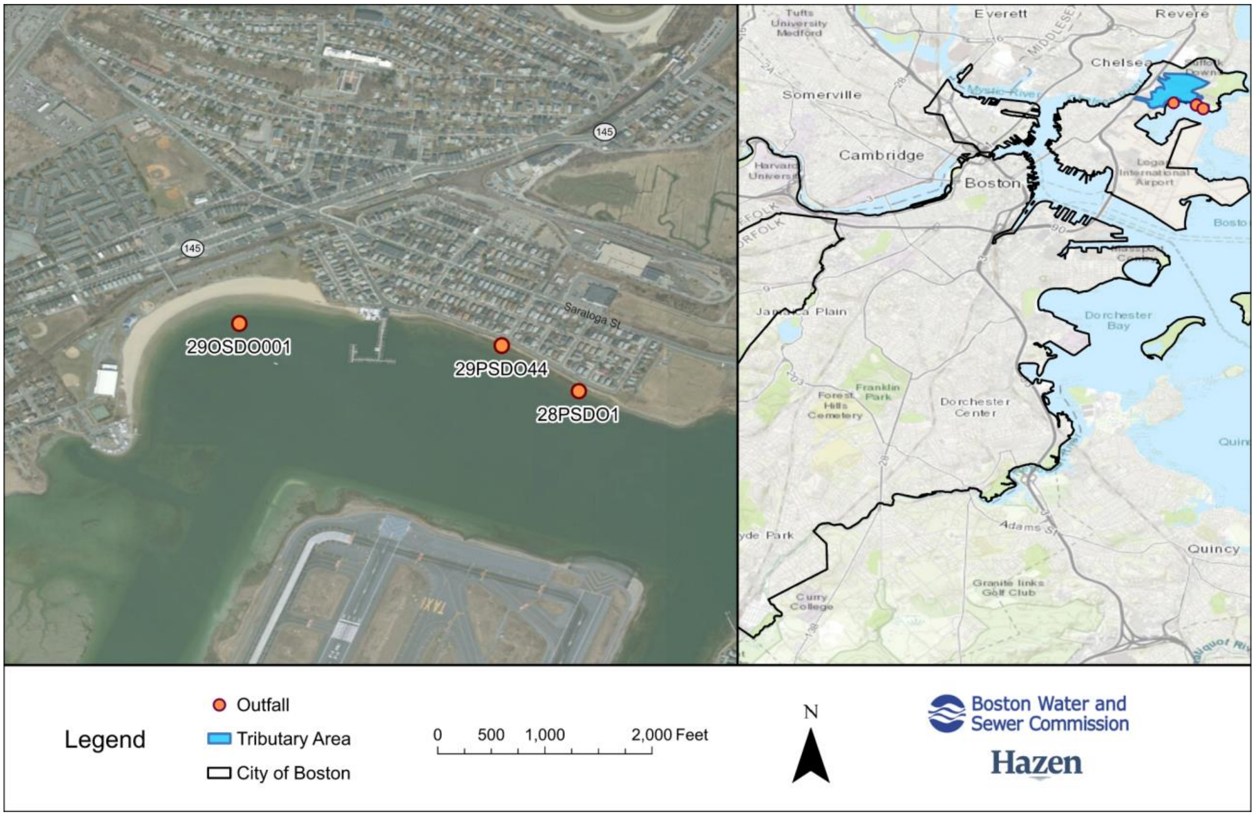


Figure 5-8: Constitution Beach Concept Location

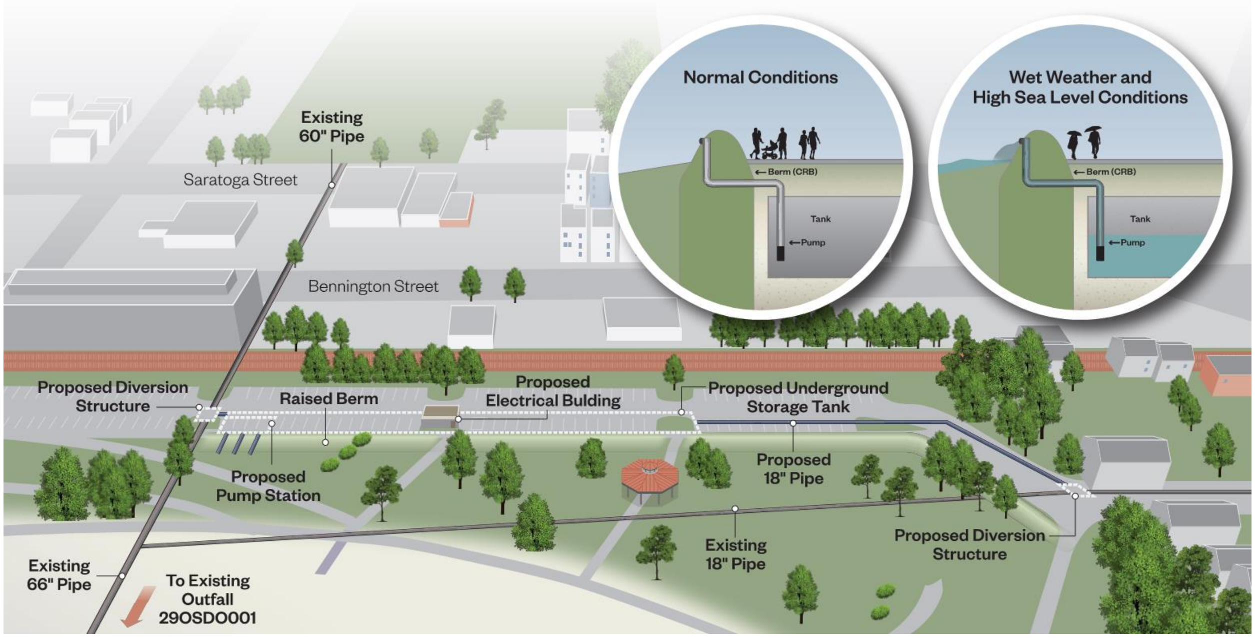


Figure 5-9: Graphic Representation of Constitution Beach Pump Station Concept

5.5.2 Basis of Design

Model simulations were conducted to determine the maximum HGL that occurs at Outfalls 29OSDO001, 29PSDO44, and 28PSDO1 with the representative tide elevation of 3.7 ft NAVD88 used in the City's PCSWMM model. Analyses were then conducted to determine the acceptable combinations of storage volume and pumping rate required to maintain the flooding present during the representative current-day HGL with 2070 projected sea level rise and 100-year storm surge, as shown in **Figure 5-10**.

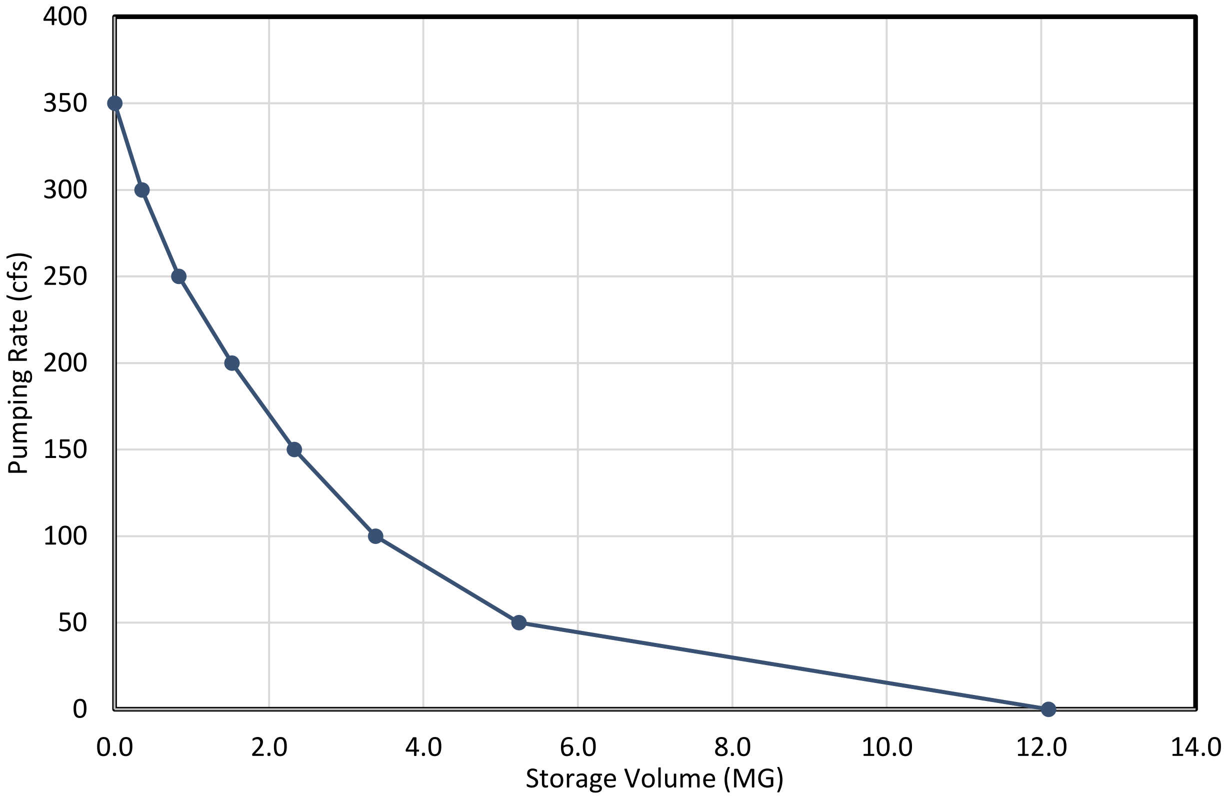


Figure 5-10: Outfall 29OSDO001 Pumping vs. Storage

The City of Boston's Parcel database was used to identify publicly owned parcels near the existing outfall. An analysis of the pump station was performed to identify a pump rate and physical dimensions that are hydraulically viable. It was found that a 1.4 MG storage tank approximately 23 ft deep could fit within the parking lot of the property with a 150 CFS pump station. The storage tank and pump station occupy an area of 11,935 ft^2. The Constitution Beach pump station utilizes two duty pumps, one standby pump, and two dewatering pumps. The pump station is configured with vertical, axial electric submersible pumps in parallel bays. Each pump has its own, non-manifold, discharge force main which carries water to the proposed CRB berm alternative (located next to the parking lot based on current CRB documentation). During extreme storm conditions a portable generator could be parked within the parking lot to provide a backup power supply in the event of a power outage.

5.5.3 Flooding Analysis

The flood reduction benefits of the Constitution Beach concept were evaluated using the Commission’s 2D Inundation Model by simulating a 100-year tropical storm event with 2070 SLR and storm surge. **Figure 5-11** depicts the peak flooding that was predicted in the Constitution Beach drainage area with shoreline protection only and with the pump station and tide gates on all vulnerable BWSC owned outfalls.

Simulation Parameters	
Storm Type	100 yr Tropical
Rainfall Depth	9.6 inches
Peak WSE 2070 SLR + 100 yr Surge	13.8 ft NAVD88

Figure 5-11: Constitution Beach Pump Station Flood Model Results

Note: **Figure 5-11** *includes a polygon labeled as "drainage area analyzed". This area represents the area which was included in the economic damage/loss analysis described in* **Section 7** *of this report.*

5.5.4 Adaptability and Implementation

The following measures could be implemented to adapt the concept to more severe conditions (additional SLR, more intense rainfall, etc.) in the future:

- Increase the size of installed electric submersible pumps
- Utilize the standby pump as a duty pump during extreme conditions
- Increase the size of peak shaving tank

Implementation of the concepts presented for the Constitution Beach Pump Station require consideration of the following:

- Coordination with CRB is necessary to implement shoreline protection. The pump station should not be implemented without shoreline protection to prevent coastal flooding within the area tributary to it.
- The location of the pump station and discharge should be adapted based as CRB continues to evolve its plan for shoreline protection in this area. The pump station should be located in the

"protected" area behind the shoreline adaptation, and the pump station discharge should be incorporated with the shoreline project.

- At present, CRB planning documents indicate that a berm could be constructed between the beach and parking lot. Based on this, the current concept includes a discharge in the same area. It is anticipated that the pump station would only be operated during extreme storm events when the beach is flooded. If the pump station were operated during a non-flood condition, discharge from the pump station would create beach erosion and be a hazard to beach occupants.
- A comprehensive permitting evaluation should be conducted to evaluate possible impacts from construction and operation of the pump station to the receiving water.
- Planting of native plant species and other green features will provide an improved public amenity and preserve the "look and feel" of the parking lot and surrounding park.
- Community engagement with stakeholders may help build project support by illustrating the flood control benefits of the pump station.

5.6 East Boston Waterfront Stormwater Diversion and Pump Station

5.6.1 Concept Overview

The East Boston Waterfront concept location is shown in **Figure 5-12**. The concept design, as shown in **Figure 5-13**, is a stormwater outfall consolidation project with proposed conveyance pipes and a pump station. The proposed pipes collect excess wet weather flow from Outfalls 26LSDO109, 26LSDO084, 26LSDO108, 25MSDO007, and 25MSDO006, using passive weirs to divert flow into a new conduit network for conveyance to a pump station.

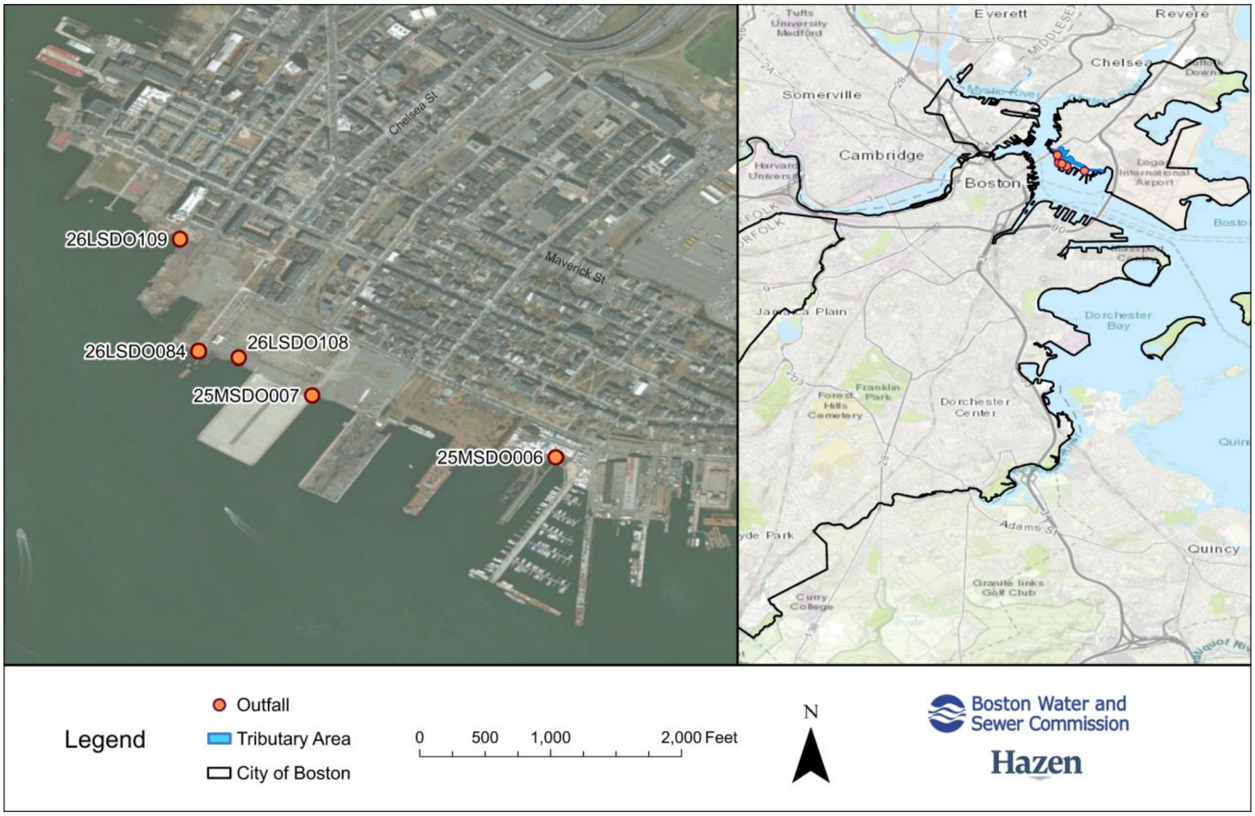


Figure 5-12: East Boston Waterfront Concept Location

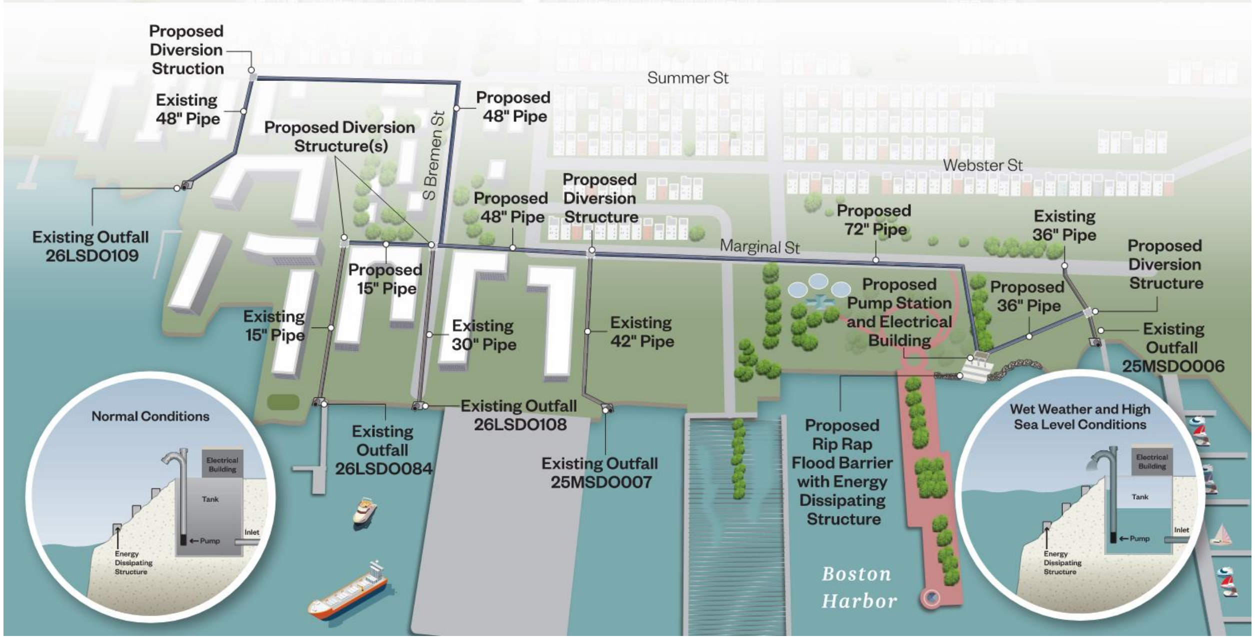


Figure 5-13: Graphic Representation of East Boston Waterfront Concept

5.6.2 Basis of Design

Model simulations were conducted to determine the maximum HGL that occurs at Outfalls 26LSDO109, 26LSDO084, 26LSDO108, 25MSDO007, and 25MSDO006 with the representative tide elevation of 3.7 ft NAVD88 used in the City's PCSWMM model. Analyses were then conducted to determine the acceptable combinations of storage volume and pumping rate required to maintain the representative current-day HGL with 2070 projected sea level rise and 100-year storm surge, as shown in **Figure 5-14**.

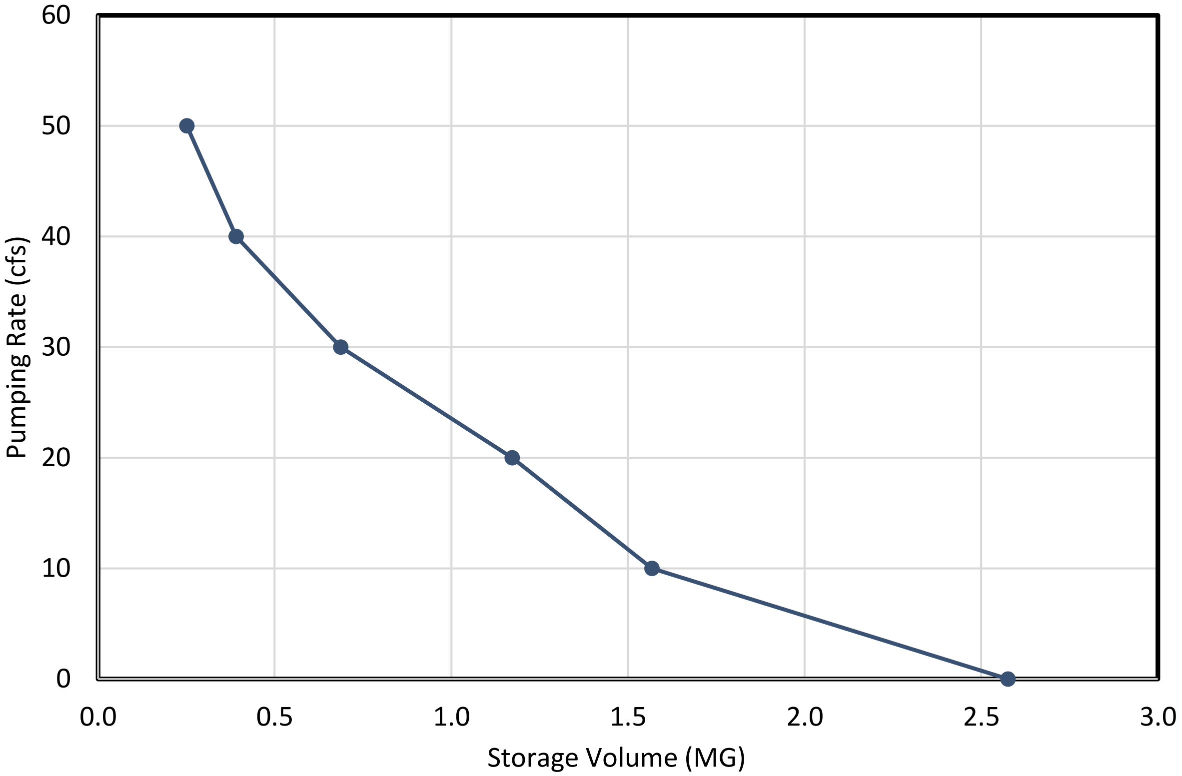


Figure 5-14: East Boston Waterfront Outfalls Pumping vs. Storage

The City of Boston's Parcel database was used to identify publicly owned parcels near the existing outfalls. A suitable location was not available for all outfalls, so an outfall consolidation approach was used. Piers Park at 95 Marginal Street was identified as a suitable, publicly owned parcel to be the location for the pump station, and a pipe alignment was designed to transfer flow from all five outfalls to the pump station, as shown in **Figure 5-15**.

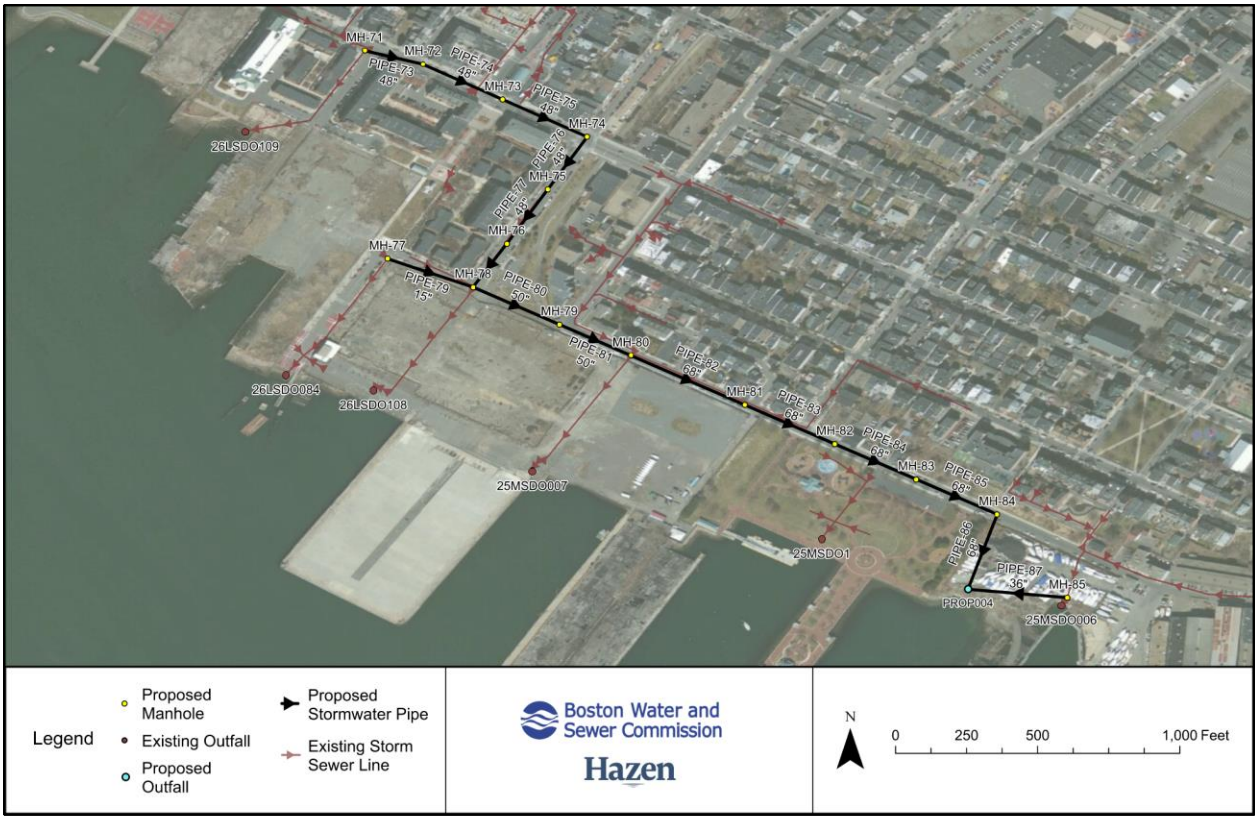
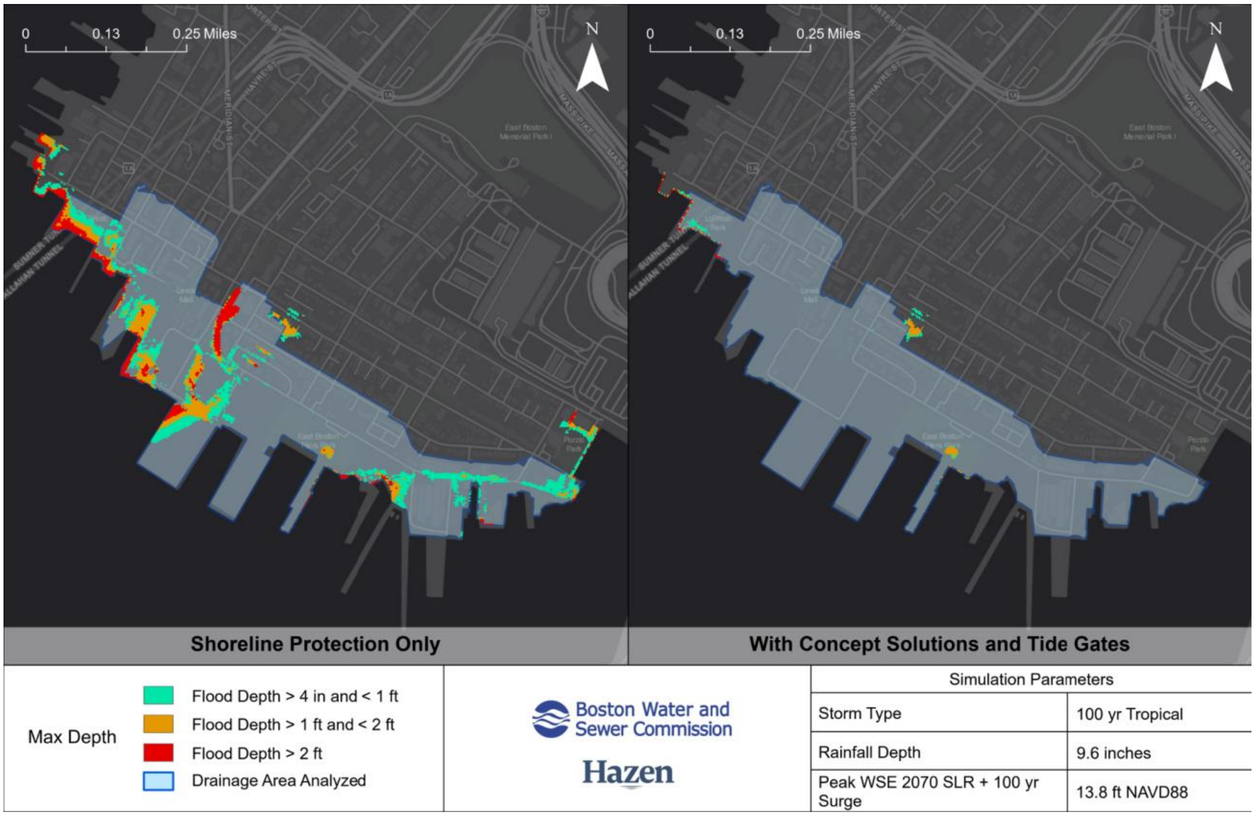


Figure 5-15: East Boston Waterfront Outfall Diversion Proposed Pipeline

An analysis of the pump station was performed to identify a pump rate and physical dimensions that are hydraulically viable. It was found that a significant storage tank is not required, as the proposed pipes needed to divert flow from the outfalls would have sufficient storage when combined with a 40 CFS pump station. The pump station and storage tank occupy an area of 635 ft^2. The proposed pipes have an inline storage volume of 0.44 MG. The pump station utilizes one duty pump, one standby pump, and two dewatering pumps, all with separate, non-manifold, discharges. The pumps discharge directly into Boston Harbor, with an energy dissipating structure along that section of coastline to prevent erosion. The pump station is configured with vertical, axial electric submersible pumps in parallel bays.

5.6.3 Flooding Analysis

The flood reduction benefits of the East Boston Waterfront concept were evaluated using the Commission's 2D Inundation Model by simulating a 100-year tropical storm event with 2070 SLR and storm surge. **Figure 5-16** on the following page depicts the peak flooding that was predicted in the East Boston Waterfront drainage area with shoreline protection only and with the concept implemented.



Simulation Parameters	
Storm Type	100 yr Tropical
Rainfall Depth	9.6 inches
Peak WSE 2070 SLR + 100 yr Surge	13.8 ft NAVD88

Figure 5-16: East Boston Waterfront Stormwater Consolidation Flood Model Results

Note: **Figure 5-16** *includes a polygon labeled as "drainage area analyzed". This area represents the area which was included in the economic damage/loss analysis described in* **Section 7** *of this report.*

5.6.4 Adaptability and Implementation

The following measures could be implemented to adapt the concept to more severe conditions (additional SLR, more intense rainfall, etc.) in the future:

- Increase the size of installed electric submersible pumps
- Utilize the standby pump as a duty pump during extreme conditions
- Increase the size of the pump station to increase pumping capacity
- Increase the size of the pump station to add more peak-shaving storage volume
- Divert additional flow into the new consolidation conduit

Implementation of the concepts presented for the East Boston Waterfront Diversion and Pump Station require consideration of the following:

- Coordination with CRB (and other relevant stakeholders) to construct adequate shoreline protection around the East Boston Waterfront is essential for successful implementation of this concept. To function as designed, the region must be fully isolated from high sea levels; as such, careful coordination with CRB is essential at this location.

- The portions of existing pipelines downstream from the proposed diversion structures are designed to surcharge to allow flow to back up enough to be diverted at the diversion structures. As such, under design conditions, it is important that manhole covers along those portions of the existing pipelines are watertight and securely bolted or fastened in place to prevent flooding.
- Regional stormwater pipes should not be directly connected to the diversion pipeline, as there is currently no way for flow within the pipeline to be discharged without the pump station; therefore, the diversion pipeline should only be configured to accept flow from stormwater outfall pipes that are surcharging.
- A careful analysis of constructability, and design efforts to minimize disruptions from large diameter pipe construction, should be completed.
- Tide gates could be added on the included outfalls a near term measure to prevent backflow during higher tide conditions.

5.7 East Boston Greenway Pump Station

5.7.1 Concept Overview

The East Boston Greenway concept is located along the East Boston Greenway in close proximity to Wood Island Bay Edge Park, as shown in **Figure 5-17**. The concept design, as shown in **Figure 5-18,** includes a small stormwater storage (peak flow shaving) tank and pump station to discharge wet weather flow when tide levels are high. If a high tide level begins to reduce the ability of existing outfall 28NSDO207 to discharge by gravity the existing storm sewer will begin to surcharge. A diversion structure with a static weir directs excess flow via a 60-inch conduit to a small storage tank that is connected directly to the pump station.

Figure 5-17: East Boston Greenway Concept Location

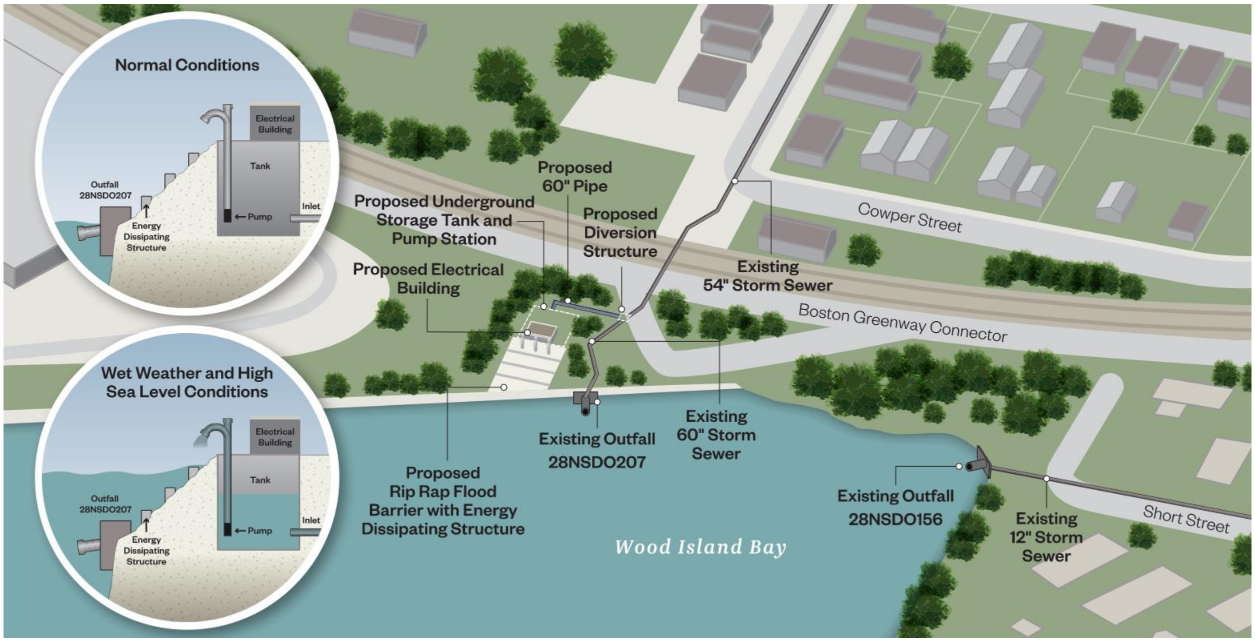


Figure 5-18: Graphic Representation of East Boston Greenway Concept

Given the high public visibility of this location, this solution could provide educational opportunities about resilient stormwater infrastructure and incorporate nature-based features (such as native plantings) to minimize the impact of new infrastructure. The pump station concept is also sized to accept flow from the nearby outfall 28NSDO156 if it becomes necessary to adapt that outfall in the future.

5.7.2 Basis of Design

Model simulations were conducted to determine the maximum HGL that occurs at Outfall 28NSDO207 with the representative tide elevation of 3.7 ft NAVD88 used in the City’s PCSWMM model. Analyses were then conducted to determine the required volume of storage and rate of pumping required to maintain the benchmark maximum current-day HGL with 2070 projected sea level rise, as shown in **Figure 5-19**.

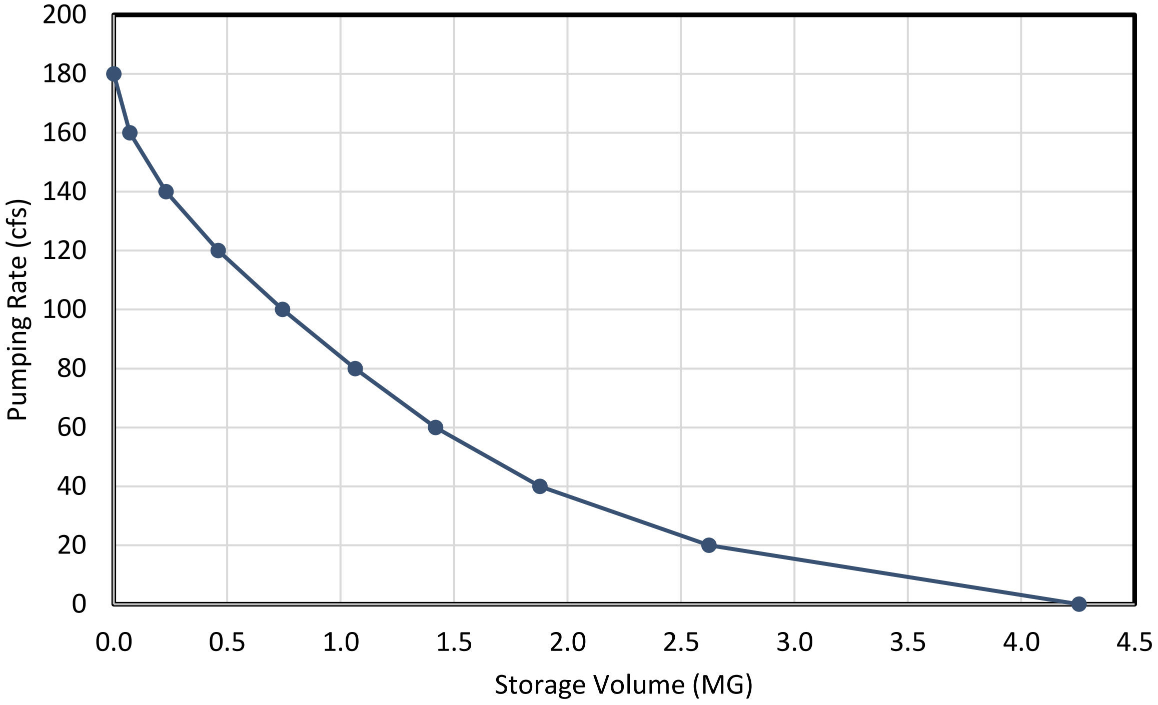


Figure 5-19: Outfall 28NSDO207 Pumping vs. Storage

The Commission’s databased was used to identify a publicly owned parcel near the existing outfall. It was found that a 0.15 MG storage tank at ~26 ft deep could fit on the property with a 150 CFS pump station. The pump station includes two duty pumps, one standby pump, and two dewatering pumps, which discharge onto an energy dissipating structure to prevent shoreline erosion. The pump station utilizes vertical, axial electric submersible pumps in parallel bays. During extreme storm conditions a portable generator could be parked along the Greenway to provide a backup power supply in the event of a power outage.

5.7.3 Flooding Analysis

The flood reduction benefits of the East Boston Greenway pump station were evaluated using the Commission’s 2D Inundation Model by simulating a 100-year tropical storm event with 2070 SLR and storm surge. **Figure 5-20** on the following page depict the peak flooding that was predicted in the drainage area tributary to the East Boston Greenway pump station with shoreline protection only and with the pump station concept implemented.

Simulation Parameters	
Storm Type	100 yr Tropical
Rainfall Depth	9.6 inches
Peak WSE 2070 SLR + 100 yr Surge	13.8 ft NAVD88

Figure 5-20: East Boston Greenway Pump Station Flood Model Results

Note: **Figure 5-20** *includes a polygon labeled as "drainage area analyzed". This area represents the area which was included in the economic damage/loss analysis described in* **Section 7** *of this report.*

5.7.4 Adaptability and Implementation

The following measures could be implemented to adapt the concept to more severe conditions (additional SLR, more intense rainfall, etc.) in the future:

- Increase the size of installed electric submersible pumps
- Utilize the standby pump as a duty pump during extreme conditions
- Increase the size of peak shaving tank
- Consider construction of a larger storage and pump facility at the large privately owned vacant parcel between Short Street and Byron Street.
- Flow from Outfall 28NSDO156 could be redirected to the pump station if it is found that the existing outfall is a source of flooding. The East Boston greenway pump station concept is designed to accommodate this additional flow.

Implementation of the East Boston Greenway concept requires consideration of the following:

- Coordination with CRB is necessary to implement shoreline protection. The pump station should not be implemented without shoreline protection to prevent coastal flooding within the area tributary to it.
- A comprehensive permitting evaluation should be conducted to evaluate possible impacts from construction and operation of the pump station to the receiving water (marsh area).
- Constructability of the currently proposed concept should be analyzed in greater detail to determine possible impacts to the Greenway. If necessary, the design could be modified to mitigate potential impacts to Greenway users.
- Planting of native plant species and other green features will provide an improved public amenity and preserve the “look and feel” of the greenway.
- Community engagement with stakeholders may help build project support by illustrating the flood control benefits of the pump station.
- Compared to other coastal stormwater concepts, the East Boston Greenway Pump station is smaller in size and cost. This project could provide a “pilot” opportunity to implement a coastal stormwater project and shoreline adaptation in parallel.

5.8 Charlestown Schrafft Center

5.8.1 Concept Overview

The Charlestown Schrafft Center concept location is shown in **Figure 5-21**. The concept design solution, as shown in **Figure 5-22,** includes two storage (peak flow shaving) tanks and pump stations to discharge wet weather flow and combined flow when tide levels are high. The tanks and pump stations are located within the Schrafft City Center parking lot in Charlestown. This conceptual solution was developed to adapt two adjacent outfalls, 29JSDO212 and 29JCSO017. If a high tide level begins to reduce the ability of existing outfalls 29JSDO212 and 29JCSO017 to discharge by gravity, the existing storm and combined sewers will begin to surcharge, diverting flow into their respective storage tanks. Both storage tanks are designed with a diversion structure with a static weir to direct excess flow to a storage tank that is connected directly to the pump station.

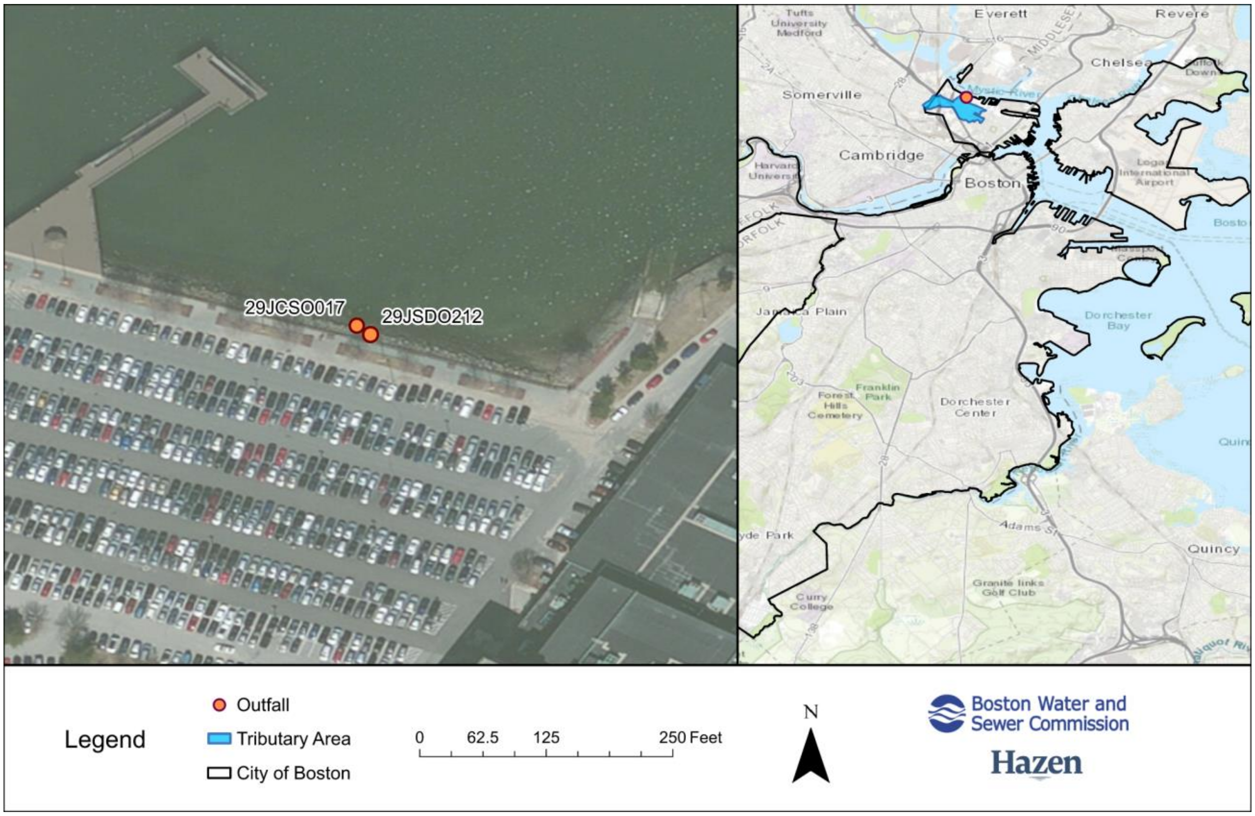


Figure 5-21: Charlestown Schrafft Center Concept Location

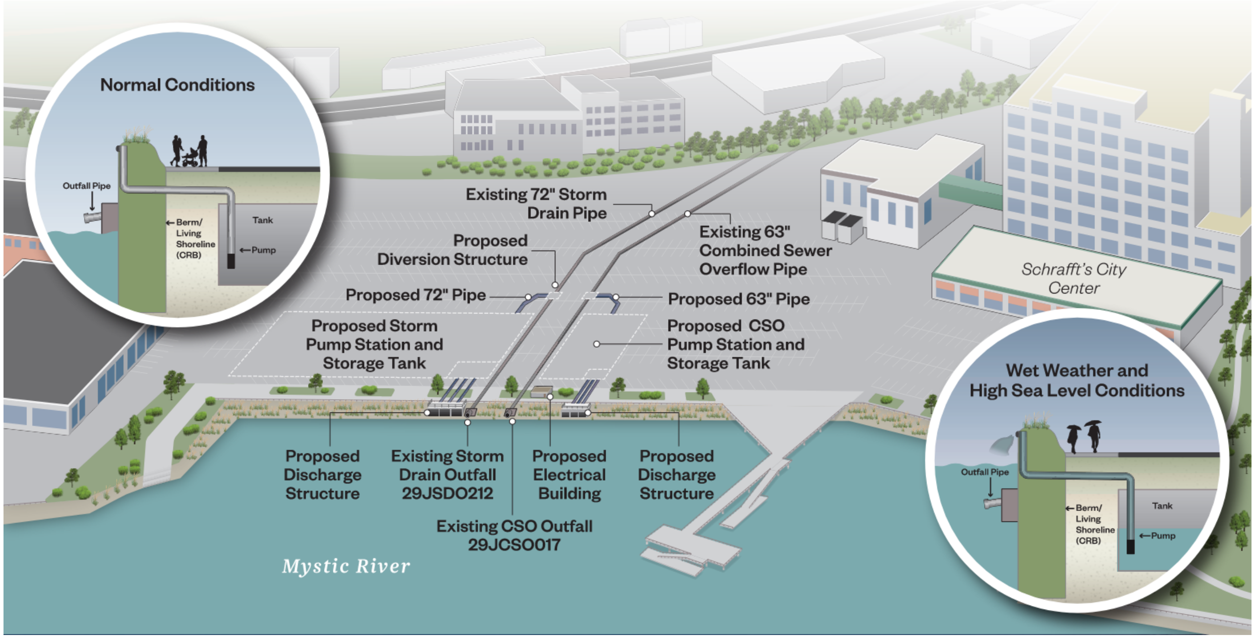


Figure 5-22: Graphic Representation of Charlestown Schrafft Center Concept

5.8.2 Basis of Design

Model simulations were conducted to determine the maximum HGL that occurs at Outfalls 29JCSO017 and 29JSDO212 the representative tide elevation of 3.7 ft NAVD88 used in the City’s PCSWMM model. Analyses were then conducted to determine the acceptable combinations of storage volume and pumping rate required to maintain the representative current-day WSE with 2070 projected sea level rise, as shown in **Figure 5-23** and **Figure 5-24**.

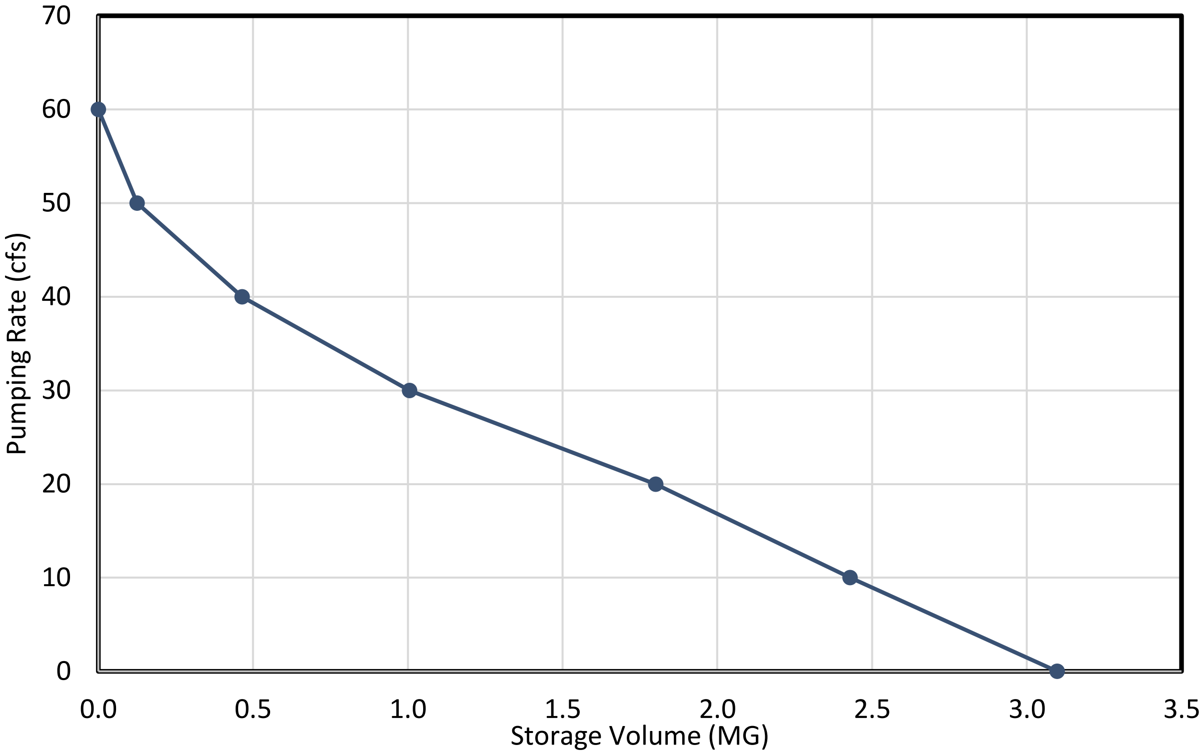


Figure 5-23: 29JCSO017 Pumping vs. Storage

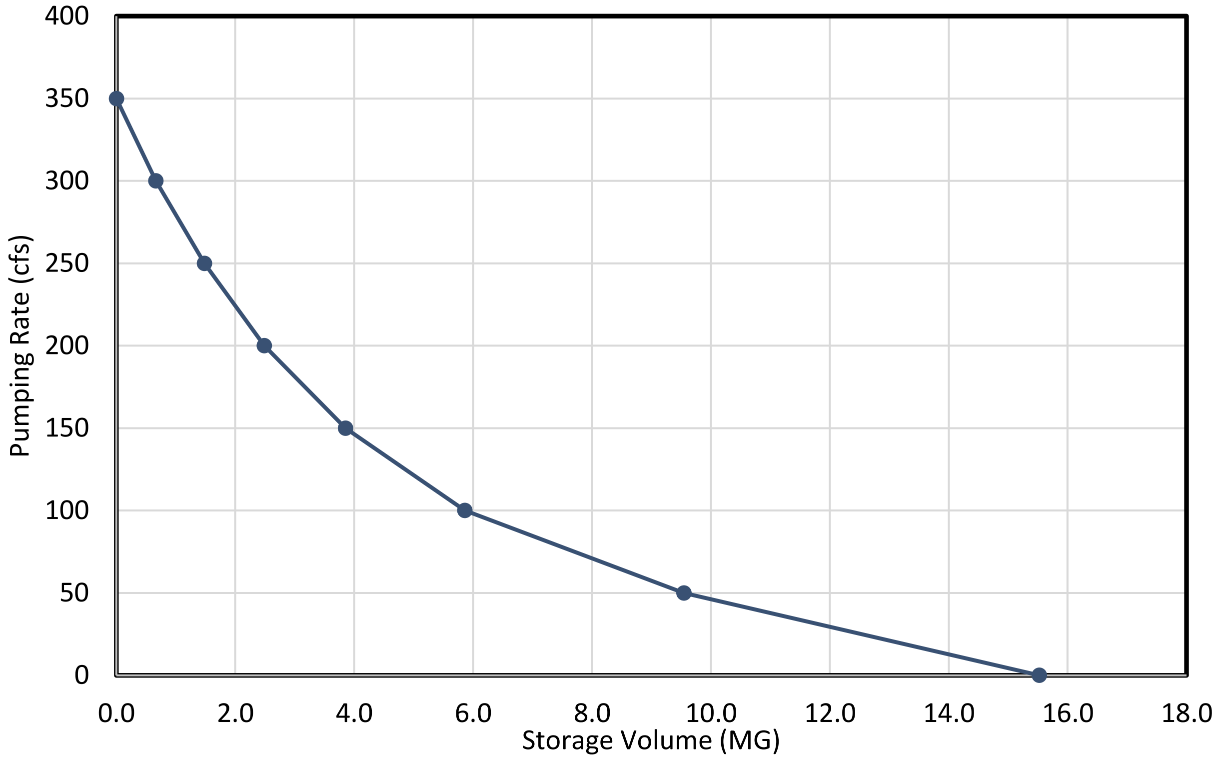
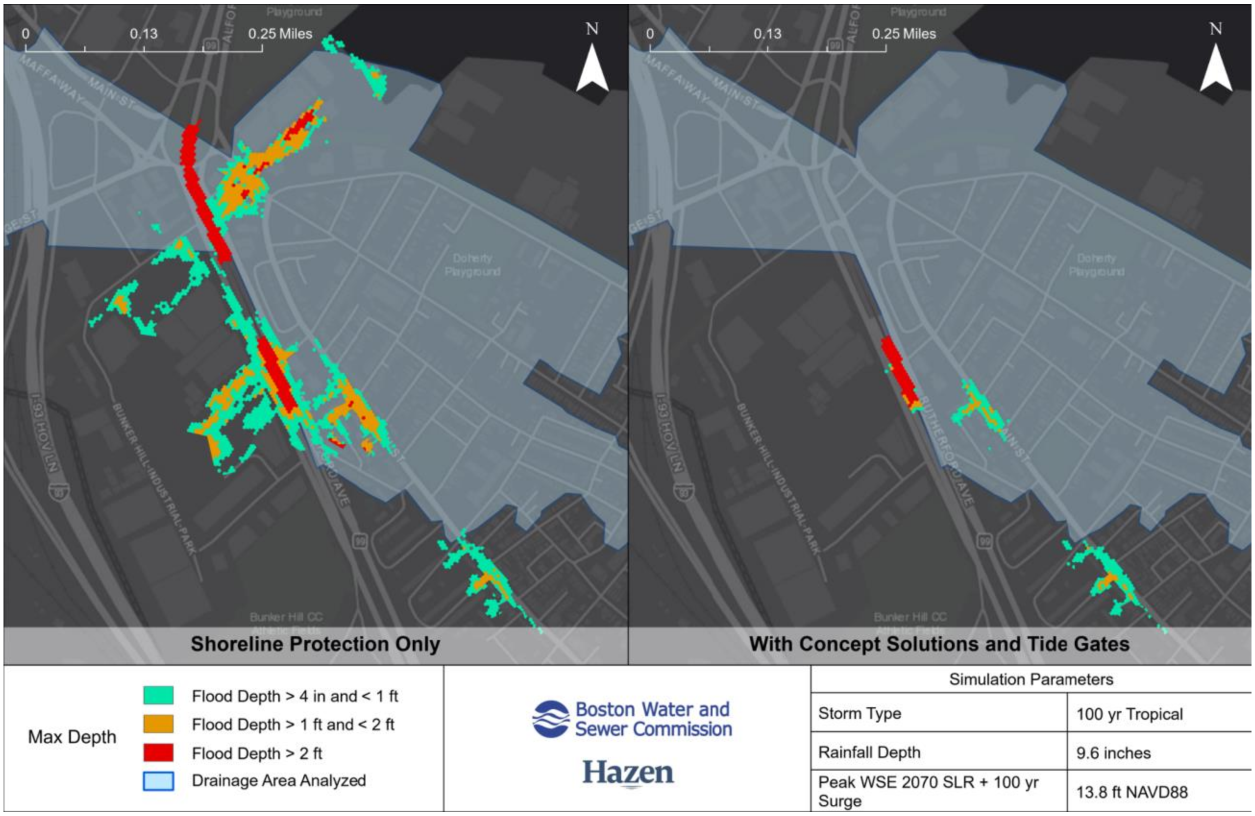


Figure 5-24: 29JSDO212 Pumping vs. Storage

The City of Boston's Parcel database was used to identify publicly owned parcels near the existing outfall. No suitable publicly owned parcels were available. A private parking lot was selected as a reasonable substitute for public land. It was found that, for Outfall 29JCSO017, a 0.5 MG storage tank at ~12 ft deep could fit on the property with a 40 CFS pump station. The CSO pump station and storage tank would occupy an area of 5,885 ft^2. It was found that, for Outfall 29JSDO212, a 2.5 MG storage tank at ~15 ft deep could fit on the property with a 200 CFS pump station. The Storm Drain Overflow (SDO) storage tank and pump station would occupy an area of 25,500 ft^2. Both stations utilize two duty pumps, one standby pump, and two dewatering pumps, and are configured with vertical, axial electric submersible pumps in parallel bays. The pumps are configured to discharge into individual, non-manifolded force mains, which travel horizontally underground from the pump station to the proposed elevated shoreline project (TBD by CRB), at which point they discharge into the harbor onto an energy dissipation structure. The storage tanks for both stations could be constructed as a single structure with a dividing wall. During extreme storm conditions a portable generator could be parked within the parking lot to provide a backup power supply for the two pump stations in the event of a power outage.

5.8.3 Flooding Analysis

The flood reduction benefits of the Charlestown Pump Station concept were evaluated using the Commission’s 2D Inundation Model by simulating a 100-year tropical storm event with 2070 SLR and storm surge. **Figure 5-25** depicts the peak flooding that was predicted in the Charlestown Schrafft Center drainage area with shoreline protection only and with the pump station and tide gates on all vulnerable BWSC owned outfalls.



Simulation Parameters	
Storm Type	100 yr Tropical
Rainfall Depth	9.6 inches
Peak WSE 2070 SLR + 100 yr Surge	13.8 ft NAVD88

Figure 5-25: Charlestown Schrafft Center Pump Station Flood Model Results

Note: **Figure 5-25** *includes a polygon labeled as "drainage area analyzed". This area represents the area which was included in the economic damage/loss analysis described in* **Section 7** *of this report.*

5.8.4 Adaptability and Implementation

The following measures could be implemented to adapt the concept to more severe conditions (additional SLR, more intense rainfall, etc.) in the future:

- Increase the size of installed electric submersible pumps
- Utilize the standby pumps as a duty pump during extreme conditions
- Increase the size of the peak shaving tanks
- Combine the CSO and SDO pump stations or control flow to each station with active controls to maximize system efficiency

Implementation of the Charlestown Schrafft Center concept requires consideration of the following:

- Coordination with CRB is necessary to implement shoreline protection. The pump station should not be implemented without shoreline protection to prevent coastal flooding within the area tributary to it.
- Coordination with the property manager at Shrafft Center should be conducted to plan for temporary loss of parking during construction.
- If sewer separation is planned in the area tributary to the CSO outfall leading to it being converted to a storm drain outfall, a single tank and pump station could be constructed to manage flow from both outfalls.
- A comprehensive permitting evaluation should be conducted to evaluate possible impacts from construction and operation of the pump station to the receiving water.
- Community engagement with stakeholders may help build project support by illustrating the flood control benefits of the pump station.

5.9 Christopher Columbus Waterfront Park

5.9.1 Concept Overview

The Christopher Columbus Waterfront Park concept is located in Downtown Boston, as shown in **Figure 5-26**. The concept design is shown in **Figure 5-27** and includes a stormwater storage (peak shaving) tank and pump station to discharge wet weather flow when water levels are too high in the harbor for the outfall to discharge by gravity. The tank and pump station are located beneath Christopher Columbus Park. If water surface conditions in the harbor prevent the outfall from discharging, a static diversion weir redirects flow via an 84-in pipe to the underground storage tank. The storage tank is directly connected to the pump station.

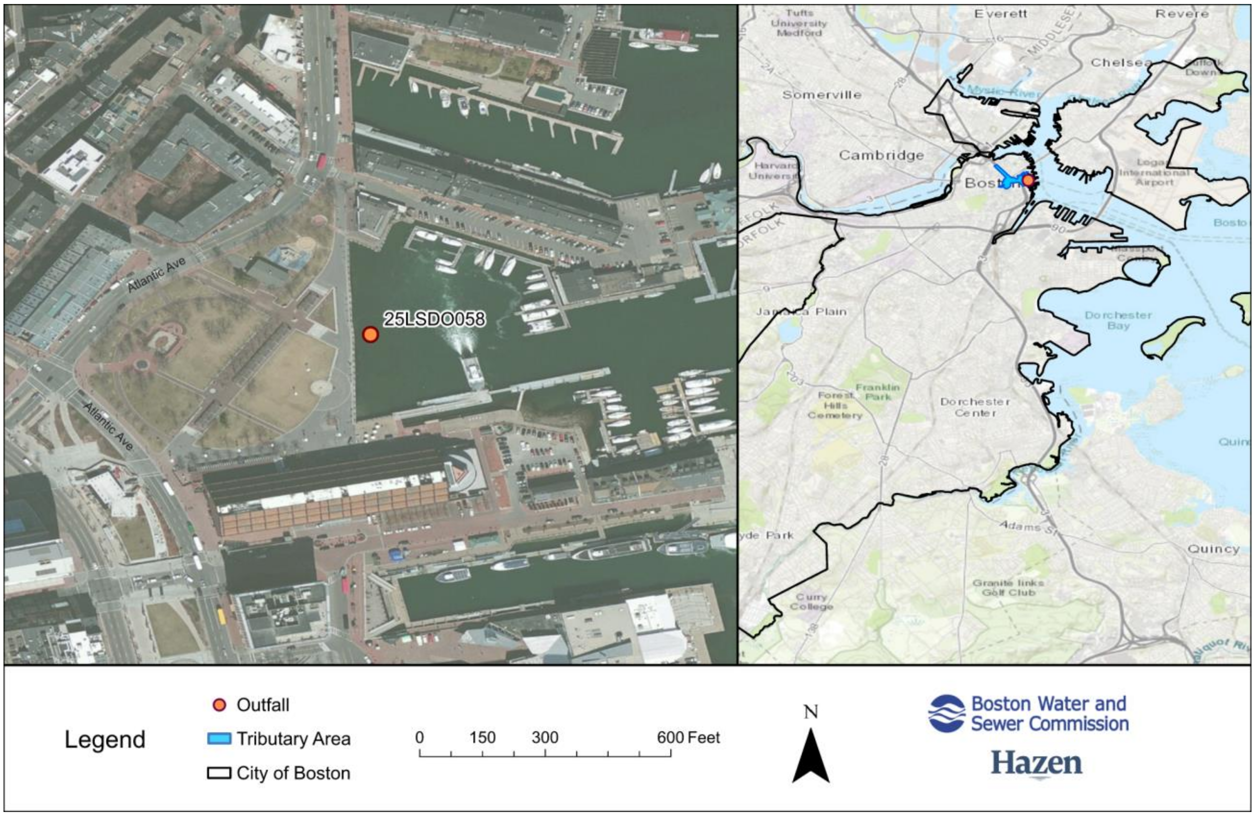


Figure 5-26: Columbus Park Concept Location

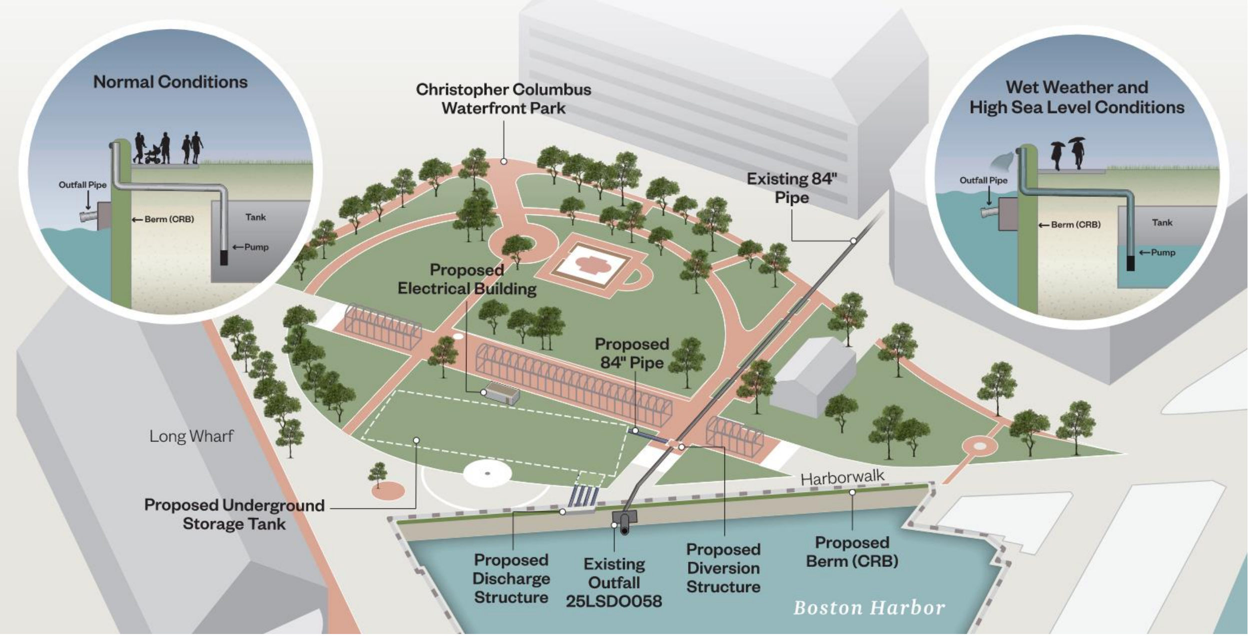


Figure 5-27: Graphical Representation of Columbus Park Concept

5.9.2 Basis of Design

Model simulations were conducted to determine the maximum HGL that occurs at Outfall 25LSDO058 with the representative tide elevation of 3.7 ft NAVD88 used in the City's PCSWMM model. Analyses were then conducted to determine the acceptable combinations of storage volume and pumping rate required to maintain the representative current-day HGL with 2070 projected sea level rise and 100-year storm surge, as shown in **Figure 5-28**.

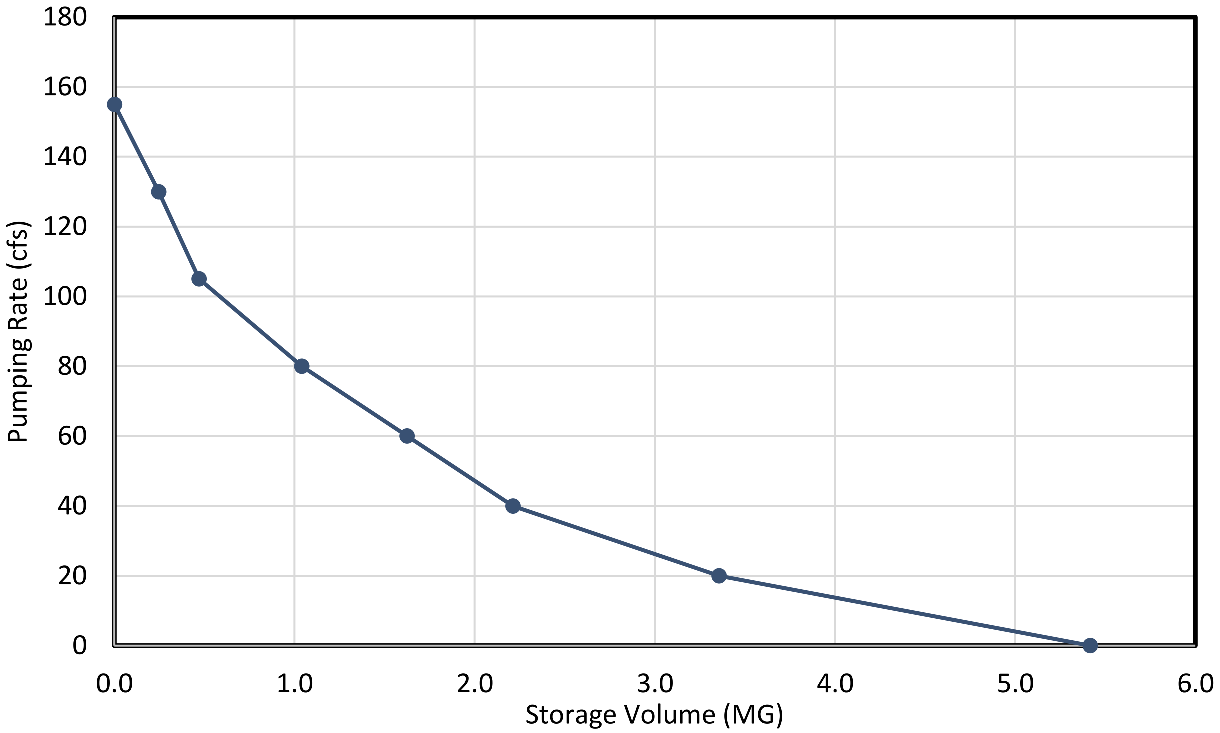


Figure 5-28: Outfall 25LSDO058 Pumping vs. Storage

The City of Boston's Parcel database was used to identify publicly owned parcels near the existing outfall. An analysis of the pump station was performed to identify a pump rate and physical dimensions that are hydraulically viable. It was found that a 1.27 MG, storage tank ~13.3 ft deep could fit within the property with an 80 CFS pump station. The storage tank and pump station occupy and area of approximately 13,000 ft^2. The Columbus Park pump station utilizes one duty pump, one standby pump, and two dewatering pumps. The pump station is configured with vertical, axial electric submersible pumps in parallel bays. The pumps are configured to discharge into individual, non-manifolded force mains, which travel horizontally underground from the pump station to the proposed elevated shoreline project (TBD by CRB), at which point they connect to a singular discharge structure with a fixed weir and discharge into the harbor onto an energy dissipation structure.

5.9.3 Flooding Analysis

The flood reduction benefits of the Columbus Park Pump Station concept were evaluated using the Commission’s 2D Inundation Model by simulating a 100-year tropical storm event with 2070 SLR and storm surge. **Figure 5-29** depicts the peak flooding that was predicted in the Columbus Park drainage area with shoreline protection only and with the pump station and tide gates on all vulnerable BWSC owned outfalls.

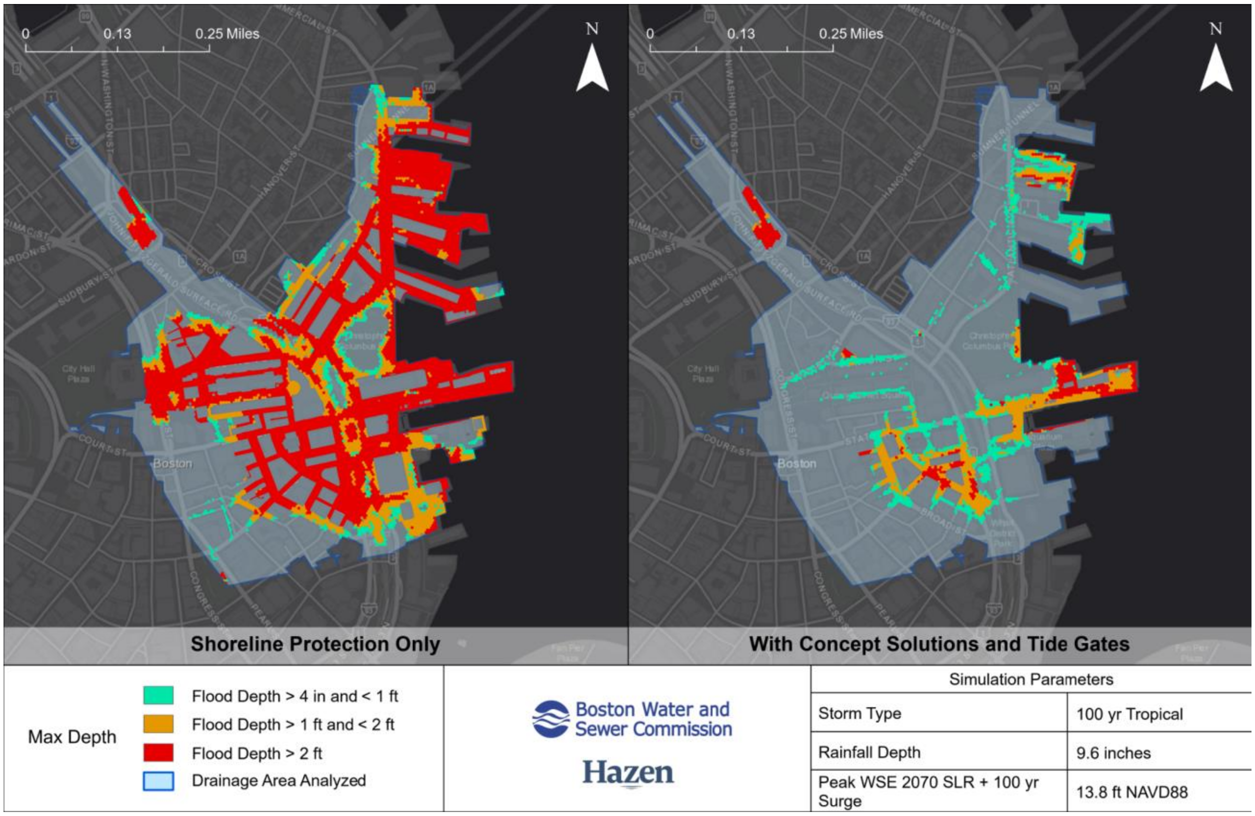


Figure 5-29: Columbus Park Pump Station Flood Model Results

Note: **Figure 5-29** *includes a polygon labeled as "drainage area analyzed". This area represents the area which was included in the economic damage/loss analysis described in* **Section 7** *of this report.*

5.9.4 Adaptability and Implementation

The following measures could be implemented to adapt the concept to more severe conditions (additional SLR, more intense rainfall, etc.) in the future:

- Increase the size of installed electric submersible pumps
- Utilize the standby pump as a duty pump during extreme conditions
- Increase the size of the peak shaving tank

Implementation of the Columbus Park concept requires consideration of the following:

- Coordination with CRB is necessary to implement shoreline protection. The pump station should not be implemented without shoreline protection to prevent coastal flooding within the area tributary to it. The discharge structure may need to be modified depending on the exact nature of the shoreline protection chosen by CRB.
- Given the high public visibility location of this concept, coordination with CRB should occur to construct shoreline adaptations at the same time to avoid separate construction projects.

- A comprehensive permitting evaluation should be conducted to evaluate possible impacts from construction and operation of the pump station to the receiving water.
- A careful analysis of constructability and sequencing will need to be performed to minimize impacts to the existing park.
- If construction of the storage tank results in modifications to the existing park, the design should be made compliant with the Americans with Disabilities Act to address accessibility.
- Community engagement with stakeholders may help build project support by documenting the need for the storage tank and pump station.

5.10 Fort Point Channel

5.10.1 Concept Overview

The Fort Point Channel (FPC) Concept is located between Boston Downtown and South Boston, as shown in **Figure 5-30**. Previous evaluations, including results from the *Inundation Model* project that the Commission completed in 2020, have indicated that the Fort Point Channel is a point of vulnerability for the City, and that high water levels in the channel allow coastal inundation to propagate inland. In addition, outfalls that discharge into the Fort Point Channel provide drainage for approximately 30% of the flood vulnerable (below the projected 100-year flood elevation in 2070, 13.8 ft NAVD88) area within the City. In consideration of the need to maintain a sufficiently low tailwater elevation at the outfalls in the FPC (thereby providing drainage to ~30% of the flood vulnerable portion of the City), *and* protect against overland coastal flooding via the Fort Point Channel, the concept described in this section describes alternatives for a storm surge barrier (SSB) and pump station at the mouth of the FPC. This concept provides the following benefits:

- Exclusion of storm surge during extreme storm events, effectively mitigating the flood vulnerability for areas tributary to the FPC.

- Up to 160 MG of storage for discharges from the Commission’s outfalls for periods when tidal /storm surge conditions prevent gravity discharge. Pumping can be provided to significantly increase the volume of water that can be discharged to the FPC during an extreme storm event.

- Ability to maintain a sufficiently low tailwater elevation at outfalls to prevent storm sewer backups and flooding by utilizing a combination of storage and pumping.

- Unimpeded FPC navigation during non-storm conditions via a navigable gate structure that can be placed into “open” (normal) or “closed” (extreme storm) positions

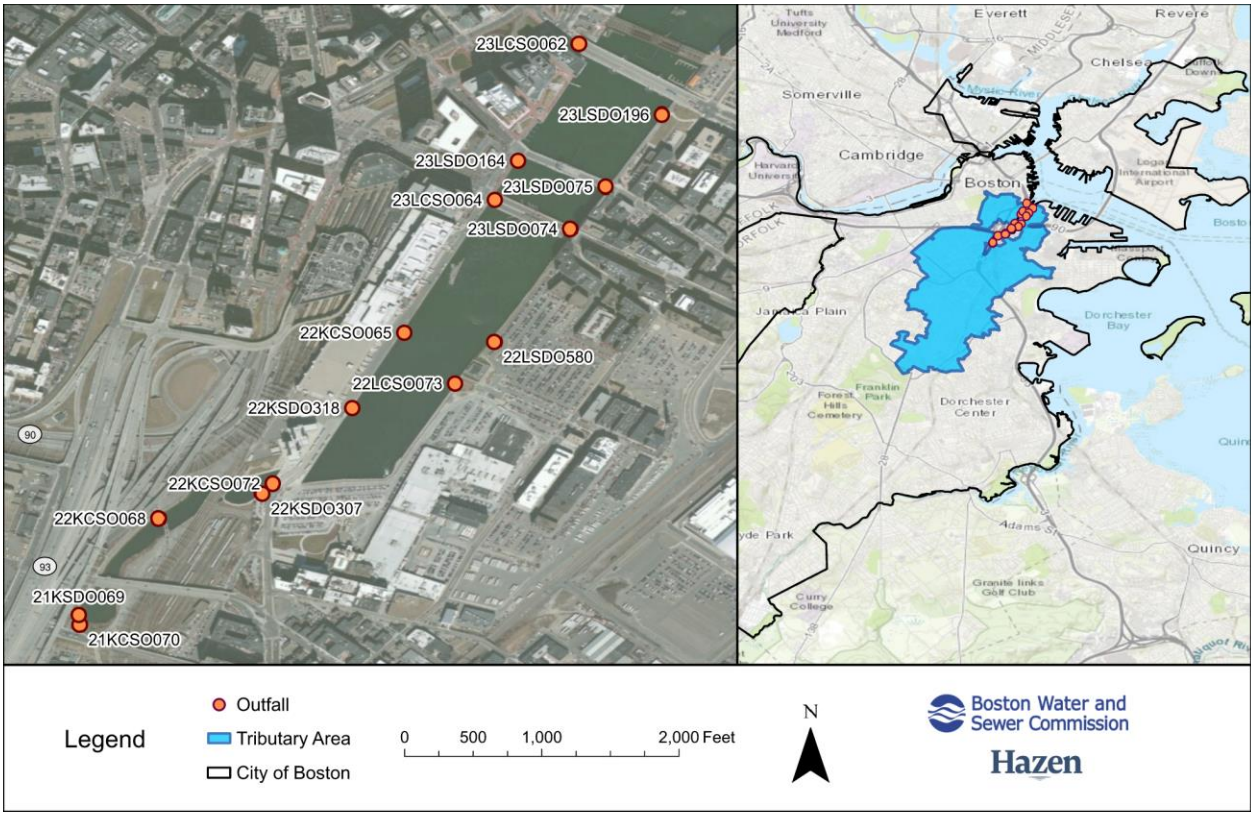


Figure 5-30: Fort Point Channel Concept Location

The FPC storm surge barrier, as shown in **Figure 5-31**, is a concept that utilizes that natural storage capacity of the Fort Point Channel, in combination with a pump station, to isolate outfalls from high sea levels. The storm surge barrier and navigable gate structure would remain open under typical conditions. In the open position, normal tidal flow into and out of the channel and marine traffic are not impeded. If a large storm event with high sea levels is expected, the gate structures could be closed at low tide, effectively isolating the FPC from higher sea levels. Under present-day conditions, timing the closing of the FPC SSB is sufficient to protect the region from flooding. Under future, higher, sea levels, some amount of “pre-pumping” may be needed to draw down the water level in the FPC before a storm to achieve the same volume of storage that exists under present-day conditions. A pump station utilizing electric submersible pumps is incorporated with the SSB. The pump station can help prevent the FPC from overflowing or causing backups into combined sewer and stormwater conduits that drain into the channel.

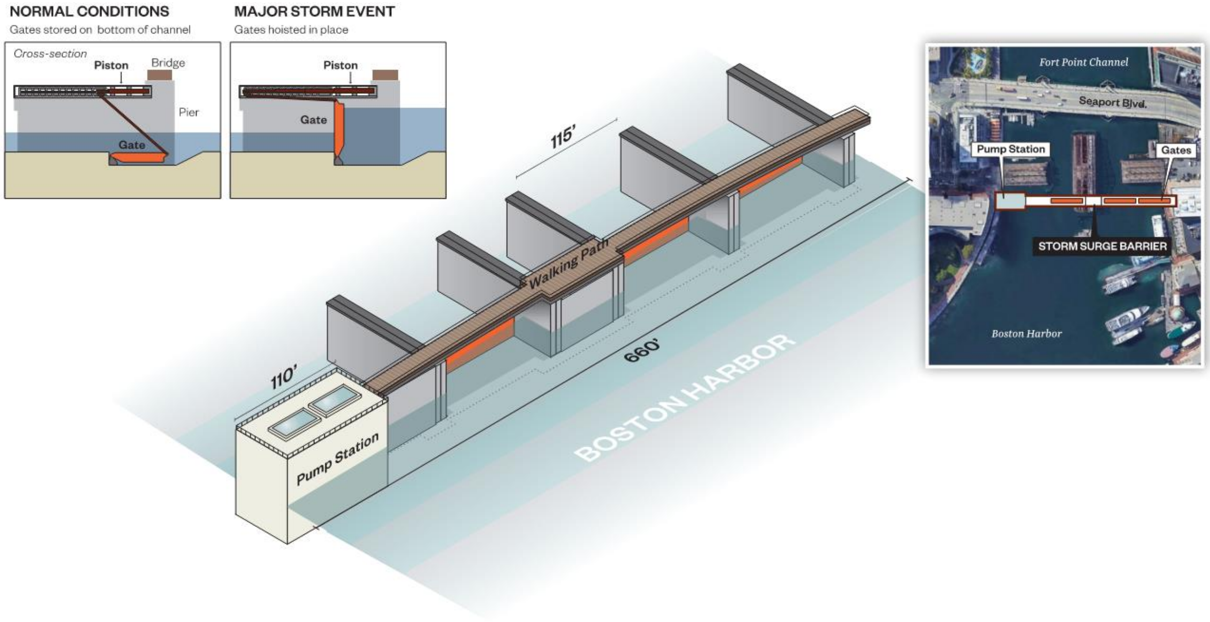


Figure 5-31: Graphic Representation of Fort Point Channel Storm Surge Barrier - Submerged Axis Flap Gate Alternative

The FPC SSB concept would “protect” 36 Commission owned outfalls, and numerous privately owned outfalls located in the FPC, as shown in **Figure 5-32**. It is important to recognize that the SSB concept provides dual benefits by utilizing the FPC as a natural storage basin for storage of stormwater (thereby providing the ability to maintain a sufficiently low tailwater elevation at outfalls), *and* by isolating the FPC from storm surge that could cause flooding throughout the City.

Shoreline elevation alone along the perimeter of the FPC has the potential to prevent overland flooding due to storm surge, but does not have the ability to mitigate the effect of high tailwater (sea levels) on the Commission’s crucial outfalls. As a result, under some conditions, rainfall runoff from the area tributary to the FPC cannot be discharged during extreme storm events, potentially leading to flooding in 30% of the flood vulnerable parts of the City, even if overland coastal flooding is prevented by elevated shorelines. Regardless, shoreline elevation is an important adaptation to prevent “sunny day flooding” due SLR alone (*the FPC SSB concept is not intended to protect against this type of flooding; the SSB is only intended to be closed during severe storm events with substantial rainfall and storm surge*).

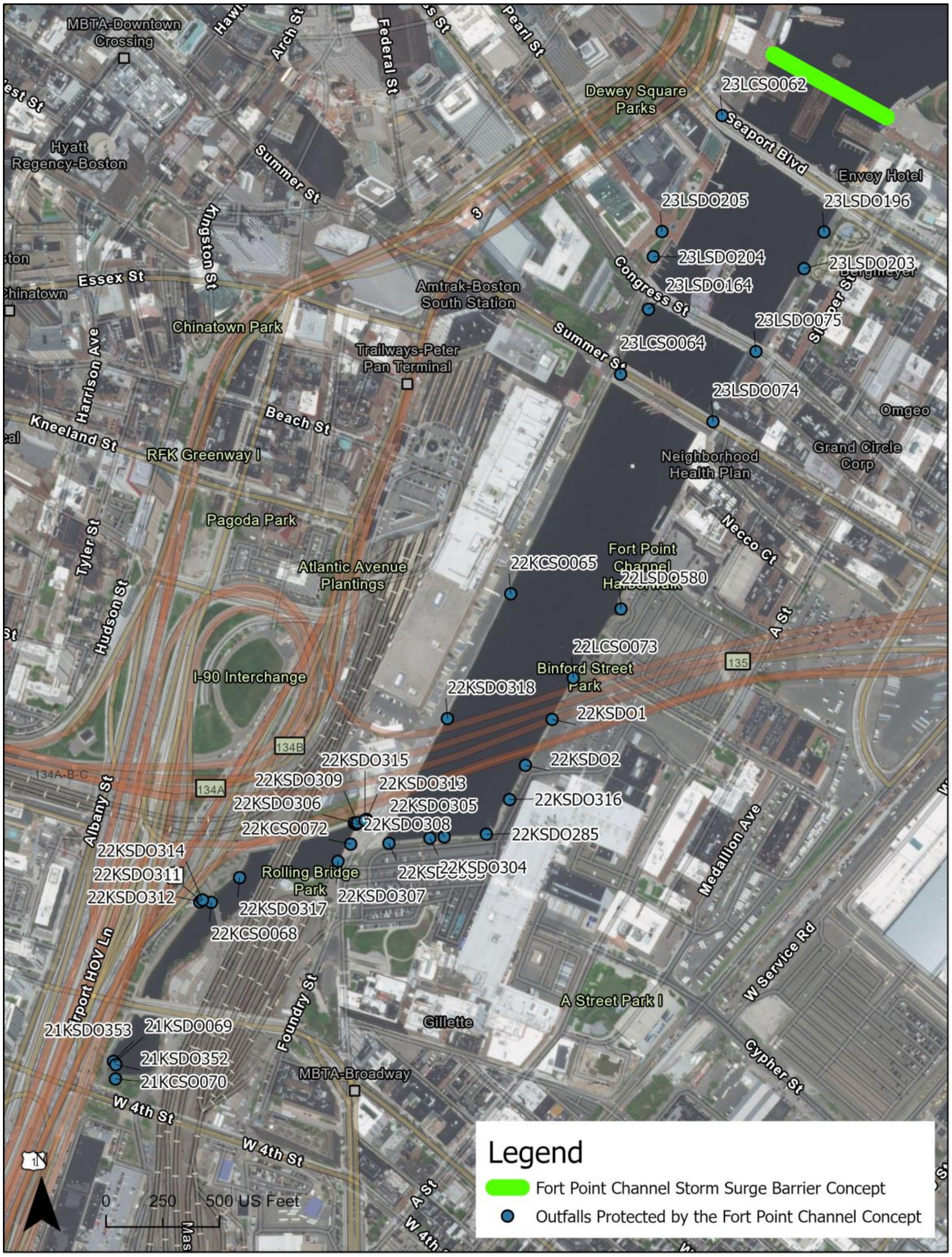


Figure 5-32: Outfalls Protected by FPC SSB Concept

5.10.2 Basis of Design and Gate Alternatives

The storage capacity of the FPC was estimated under present day and 2070 conditions based on 4.3 ft of sea level rise projected in the MC-FRM. The usable storage volume was calculated by utilizing a stage storage curve (provided by BWSC) and determining the volume between Mean Low Water (MLW) and the approximate upper rim elevation of the FPC (approximately 7.0 ft NAVD88). For design and analysis purposes, a usable storage volume of 100 MG (2070 conditions) was calculated from the stage storage data. Additional storage could be obtained by drawing down the water level (below the future low tide level) with the proposed pumps. The present-day usable storage is approximately 160 MG. For the purpose of this analysis, it was assumed that the current-day mean low water is the lowest water surface elevation allowable within the channel; future geotechnical and structural analysis may indicate that it is possible to pump to even lower water levels if needed (and generate even more storage benefits).

Note: FPC storage volume was estimated using a stage storage curve contained a Technical Memorandum obtained from the Commission titled "Fort Point Channel Capacity Analyses", prepared by Stantec in 2019.

The concept solution includes a storm surge barrier to isolate the Fort Point Channel with navigable gate structures. Several navigable gate types were explored for the Fort Point Channel concept, with two alternative navigable gate concepts chosen for design based on the geometric restrictions of the Fort Point Channel, outlined in **Appendix I**:

1. Vertical Lift Gate alternative: Lower cost alternative, but higher visual impacts (See **Section 5.10.2.2**).
2. Submerged Axis Flap Gate alternative: Higher cost alternative with minimal visual impacts (See **Section 5.10.2.3**).

The other gates that were considered for this project are as follows:

1. Vertical Rising Gate: Vertical rising gates are stored beneath the sill when in the open position and lift vertically to activate the barrier. There is opportunity for a large gate span and little upland space is required, but there may be challenges with inspection, maintenance, and high sensitivity.
2. Tainter Gate: Tainter gates rotate around a horizontal axis. When open, the gate is in the lifted position, and when closed, the gate rests on the sill. This is a proven concept with controlled operation and opportunity for large gate span, however this type of gate is not typically used in areas with high maritime traffic due to limited clearance.
3. Submerged Tainter Gate: The submerged tainter gate also operated around a horizontal axis but differs from the standard tainter gate as when in the open position, the gate is recessed in a submerged gate bay below the channel bottom. Though there is unlimited gate span and clearance for this design, it is complex and may face restrictions from water depth.
4. Rotating Segment Gate: Rotating segment gates rotate about a central horizontal axis. In closed position, the gate rests in a concrete sill in the channel bed, and in the open position it is rotated ninety degrees to create the barrier. There is unrestricted vertical clearance for maritime traffic,

quick deployment time, and above ground maintenance, but the operating system and design is complex and vulnerable to silting.

5. Vertical Sector Gate: Vertical sector gates consist of two circular gates which rotate about a vertical axis. When closed the gates rest on the channel bed, and when open each gate is stored in a recess beside the waterway. These gates provide unrestricted clearance and are appropriate for deep waters, but require a large amount of space, deep excavation, and are vulnerable to siltation.
6. Floating Sector Gate: Floating sector gates consist of double gates which rotate about a spherical hinge. The gates are buoyant and float into place, resting on the channel bed in the closed position and stored in gate housing besides the waterway when open. This is more advantageous than vertical sector gates as it can be operated when the sill is covered in silt but poses similar challenges of high spatial requirements and high hinge loading.
7. Inflatable Gate/Dam: Inflatable gates are sealed, flexible tubes anchored to the sill and walls, inflated with air, water, or a combination of both. These gates are invisible when in use, have few spatial restrictions, and are not sensitive to sediment deposition, but deploy slowly and have considerable responses to wave loads.
8. Barge Gate: Barge gates are made of a caisson stored on the side of the waterway when open. To close, the gate pivots around a vertical axis. These gates are a relatively simple design with unrestricted overhead clearance and large span feasibility, but they are slow to deploy, difficult to control in strong currents, and not well suited to sill sedimentation.
9. Horizontal Rolling Gate: A horizontal rolling gate consists of sliding panels stored adjacent to the waterway. They are rolled into the closed position when necessary. Large gate spans are feasible, there is no vertical clearance restrictions, and there is opportunity for dry dock maintenance, however deployment is slow, they are difficult to control when operating, and they require a large amount of upland area.
10. Miter Gate: Miter gates consist of two leaves mounted on the lock walls. In the closed position each leaf bears on a lock wall and the other leaf, forming a shallow three-hinged arch angled upstream. This is a proven concept that does not restrict flow or maritime traffic when open and is appropriate for deep water but is only feasible for relatively small spans and is difficult to close during appreciable flow.

See **Figure 5-33** below for graphics of each of the considered gates. A more comprehensive description of each of the gates and their advantages and disadvantages can be found in **Appendix I**.

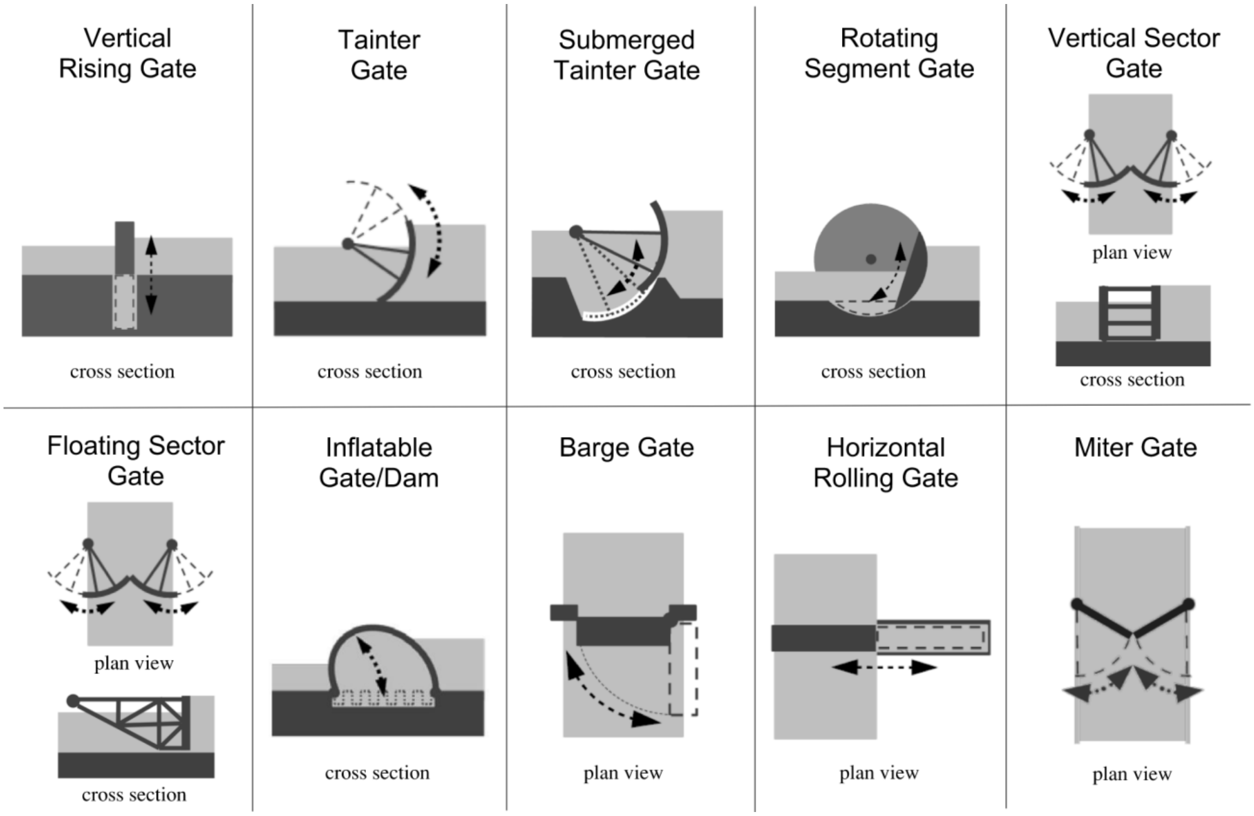


Figure 5-33: Fort Point Channel Storm Surge Barrier Candidate Gate Graphics

An analysis was conducted to determine required pumping capacity by simulating the 10-year, 24-hour design storm with 100-year tropical storm surge under 2070 conditions. The model was used to characterize the HGL in tributary pipelines under existing conditions and evaluate different size pumps under the conditions described above. It was found that 500 CFS of pumping capacity is sufficient to maintain a WSE of 3.7 ft NAVD88 or less within the FPC during these conditions as shown in **Figure 5-34**. This WSE was used to reflect the representative current-day tide elevation of 3.7 ft NAVD88 used in the City’s PCSWMM model.

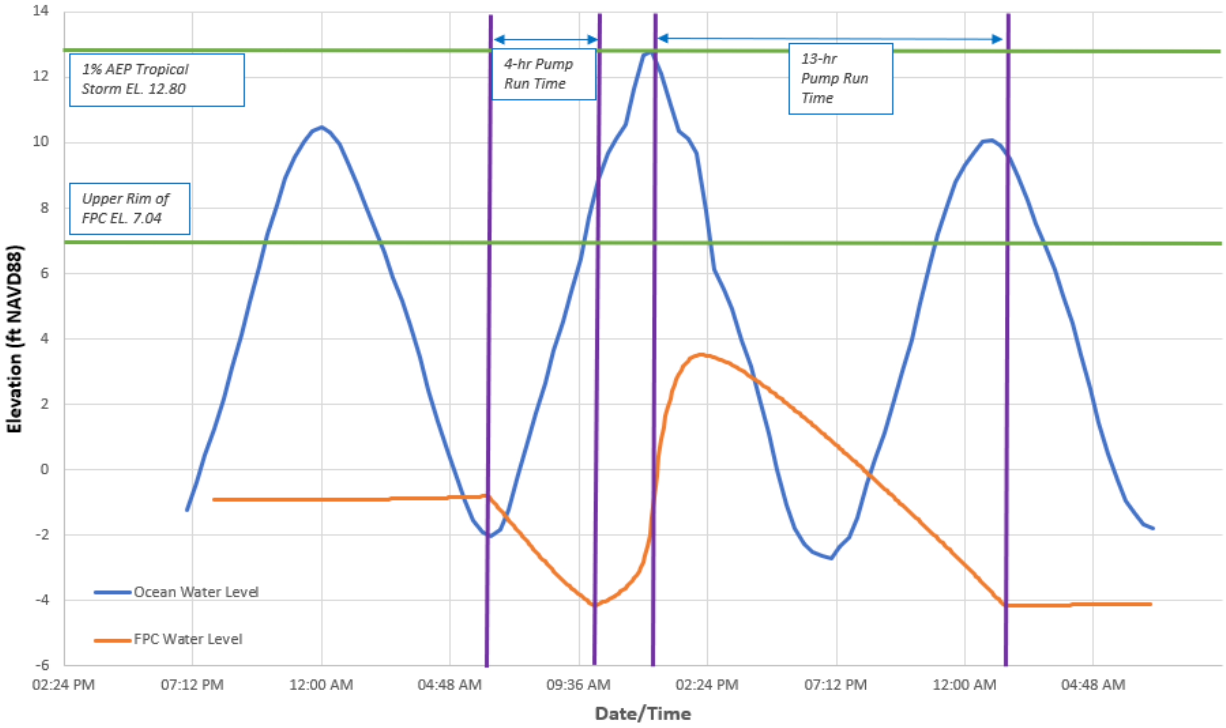


Figure 5-34: Modeled Water Surface Elevation in FPC with 500 CFS Pumping Capacity (2070 Projected 10-year, 24-hour Design Storm with 100-year Storm Surge)

Note: throughout this report the projected 2070 100-year tropical storm flood elevation is stated to be approximately 13.8 feet, NAVD88. The Commission previously received output from the MC-FRM in 11 coastal zones; the precise peak flood elevation varies by zone. The zone which contains the FPC has a maximum flood elevation of approximately 12.8 feet, NAVD88, as shown in figure above.

For this evaluation, it was assumed that SSB gates were closed at low tide before the storm event and that the pumps were run to draw down the water level from the projected 2070 MLW elevation to the current MLW elevation to maximize storage. It was further assumed that gates remained closed throughout the storm event. During an actual storm event it may be possible to open the SSB gates when the exterior tide level drops below the water level in the basin.

Pumps were sized based on the SSB (and surrounding CRB flood barriers) having a crest elevation of 15.5 ft NAVD88 (for consistency with CRB), with a discharge centerline at 17.0 ft NAVD88. The pump station utilizes 3 duty and 2 standby pumps, each with a capacity of approximately 167 CFS and static head range of 21 ft (low water level) to 4 ft (high-high water level, basin overflowing). The approximate footprint of the pump station is 5,700 ft^2. Formed suction inlets (FSIs) were designed for each pump within rectangular pump bays. The separating walls between each FSI may not be necessary but can be beneficial in preventing flow regimes that are suboptimal for pump performance. Additional hydraulic analysis, potentially including physical modeling, will be required to finalize the inlet design for the pump station.

Several alternatives for the FPC pump station were analyzed including use of diesel engine driven pumps, electric submersible pumps, electric non-submersible pumps, and construction of an offsite pumping station. The concept herein utilizes electric submersible pumps with a temporary offsite emergency power supply (i.e., use of portable diesel generators driven to the site on a trailer) on the basis of minimized visual impacts and minimized permitting challenges (e.g., no need for extensive air permits).

The FPC concept electrical design was advanced to the stage of a line diagram, shown in the concept sheet for FPC in **Appendix G**. An estimate for the size of the off-site electrical building was developed, and found to be approximately 800 square feet, with a 12-ft ceiling. No specific location was chosen for the electrical building at this stage of design.

5.10.2.1 Off-Site Pump Station Alternative

To reduce the visual impacts of a SSB/pump station complex located at the mouth of the FPC, an analysis of alternate pump station locations was conducted. **Figure 5-35** depicts an offsite pump station that located on undeveloped (no buildings), publicly owned land (A-Street Park). This alternative, as shown in the figure below, has multiple possible discharge points. Two options considered for discharge locations were the back of the Reserved Channel and a section of Boston Harbor near the mouth of the Fort Point Channel.

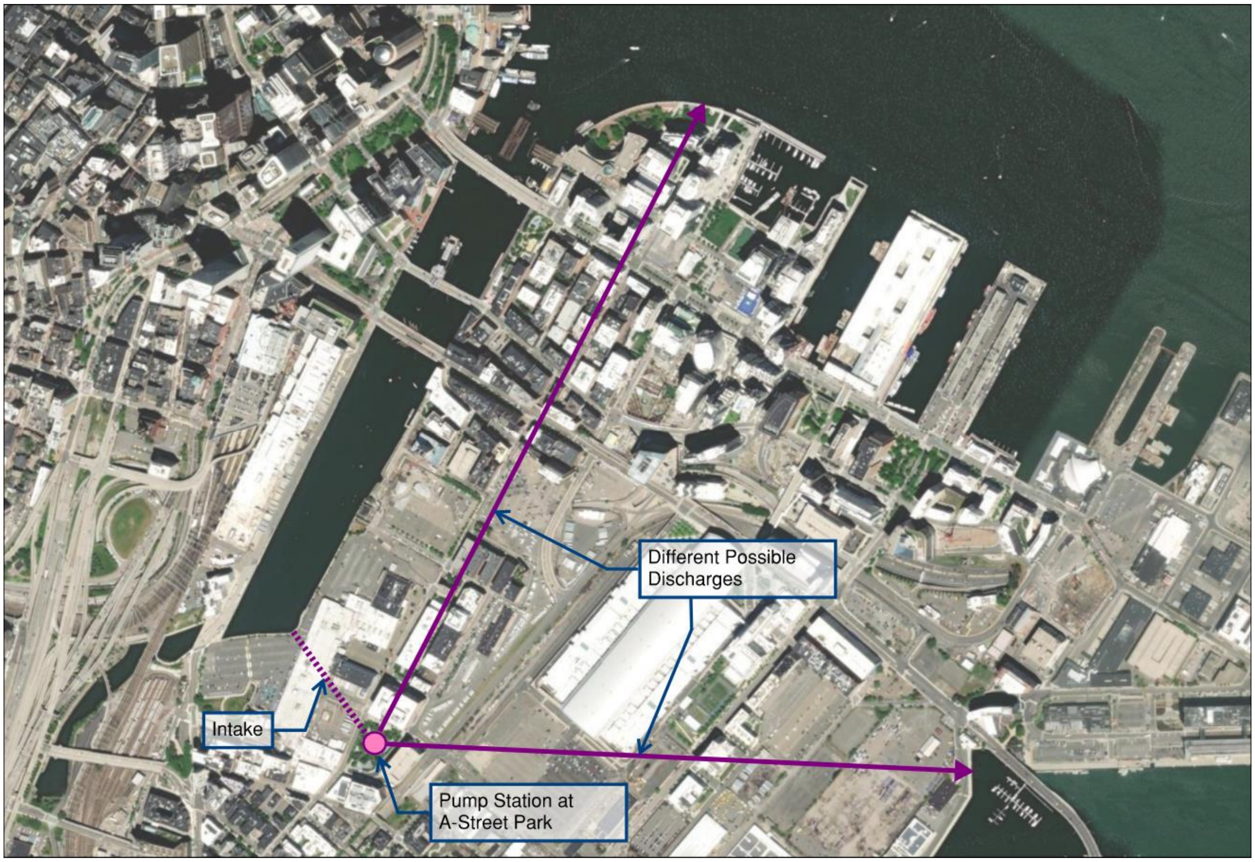


Figure 5-35: FPC Alternative Discharge Locations

Utilizing an off-site pump station for the FPC SSB concept presents several advantages, such as increased navigable space at the SBB, minimizing viewshed impacts from the pump station to nearby properties, and simplified construction for the pump station (temporary coffer dams not required for pump station construction). However, there are also significant disadvantages associated with such an alternative, including requiring a large portion of the land within the A-Street park, increased operations and maintenance costs associated with discharge pipelines, and an increased construction complexity due to the size and scope of tunneling and/or significant street construction required to build the discharge pipes. Additionally, discharging from the Fort Point Channel into the Reserved Channel could potentially make the process of protecting the several BWSC-owned coastal flood-vulnerable outfalls within the Reserved Channel more difficult in the future. Based on these factors, it was decided that off-site pumping of the FPC was not the selected alternative at the time of this project.

5.10.2.2 Vertical Lift Gate Alternative

Two alternatives for navigable gate structures at the FPC SSB were developed. As shown in **Figure 5-36** and **Figure 5-37**, the vertical lift gate alternative utilizes four 115-ft-wide gate sections that are stowed in the air (above the storm surge barrier superstructure) when in the open position. A navigable passage is provided in addition to three auxiliary flow gates. When open, the storm surge barrier does not impede existing navigation. The gates can be lowered into the “closed” position ahead of an extreme storm event to isolate the FPC.

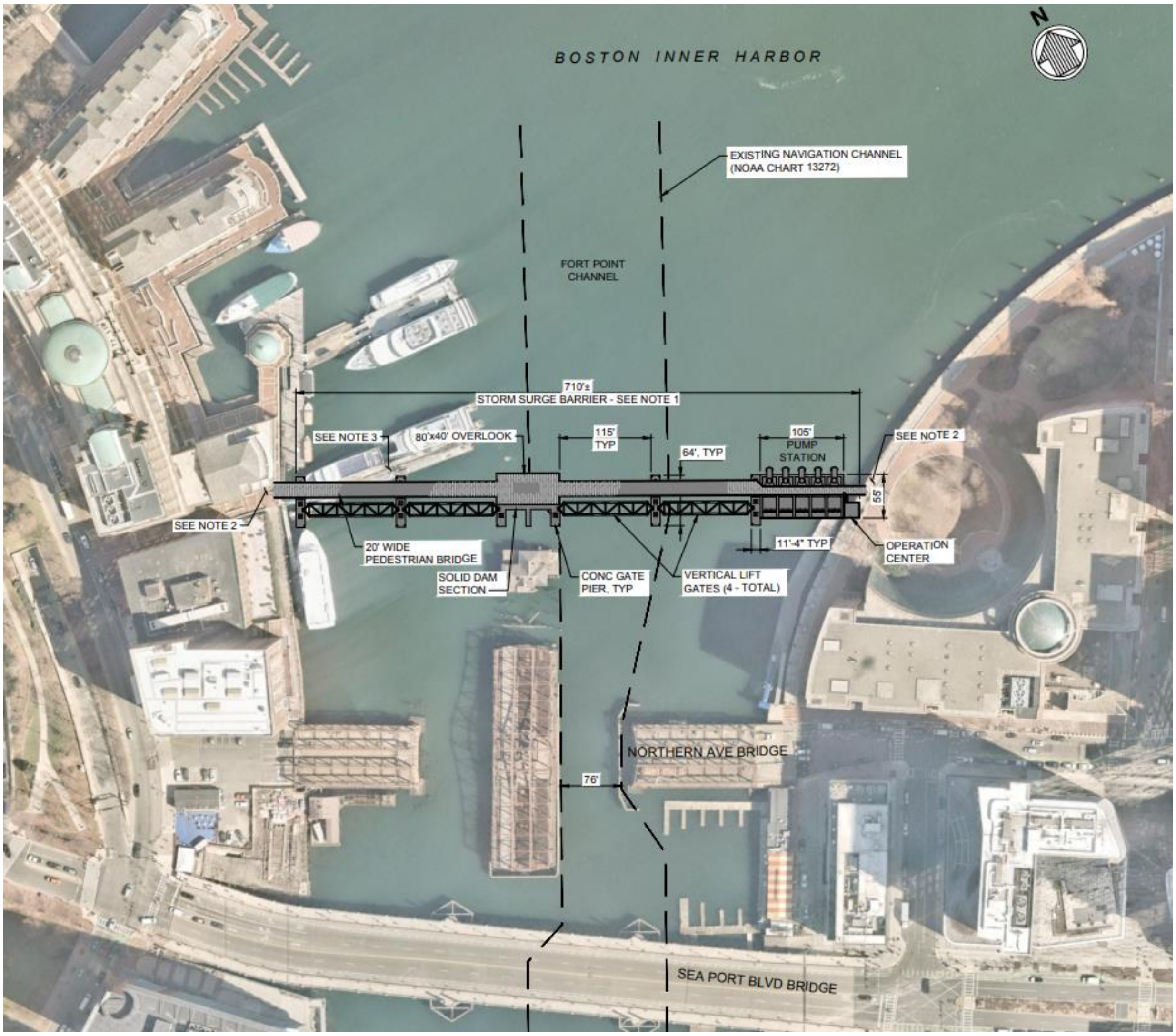


Figure 5-36: Vertical Lift Gate Alternative

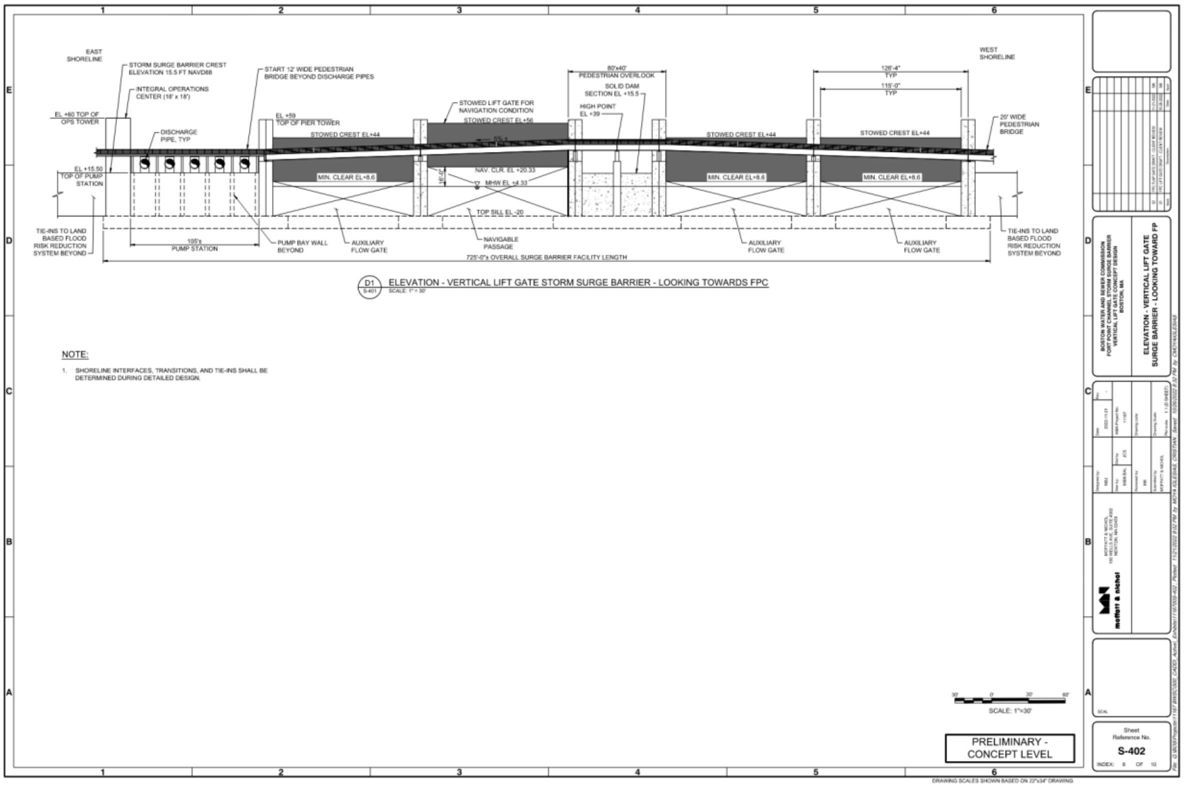


Figure 5-37: Vertical Lift Gate Alternative Profile

The vertical lift gate alternative is associated with high visual impacts and lower cost compared with the submerged axis flap gate alternative.

5.10.2.3 Submerged Axis Flap Gate Alternative

As shown in **Figure 5-38** and **Figure 5-39**, the submerged axis flap gate alternative utilizes four 115-ft-wide gate sections that are stored on the channel bottom recessed in a reinforced concrete pier foundation/sill. A navigable passage is provided in addition to three auxiliary flow gates. When open, the storm surge barrier does not impede existing navigation. The gates can be lifted into the "closed" position with telescoping hydraulic drive cylinders and trolley attached to the gate arm before an extreme storm event to isolate the FPC.

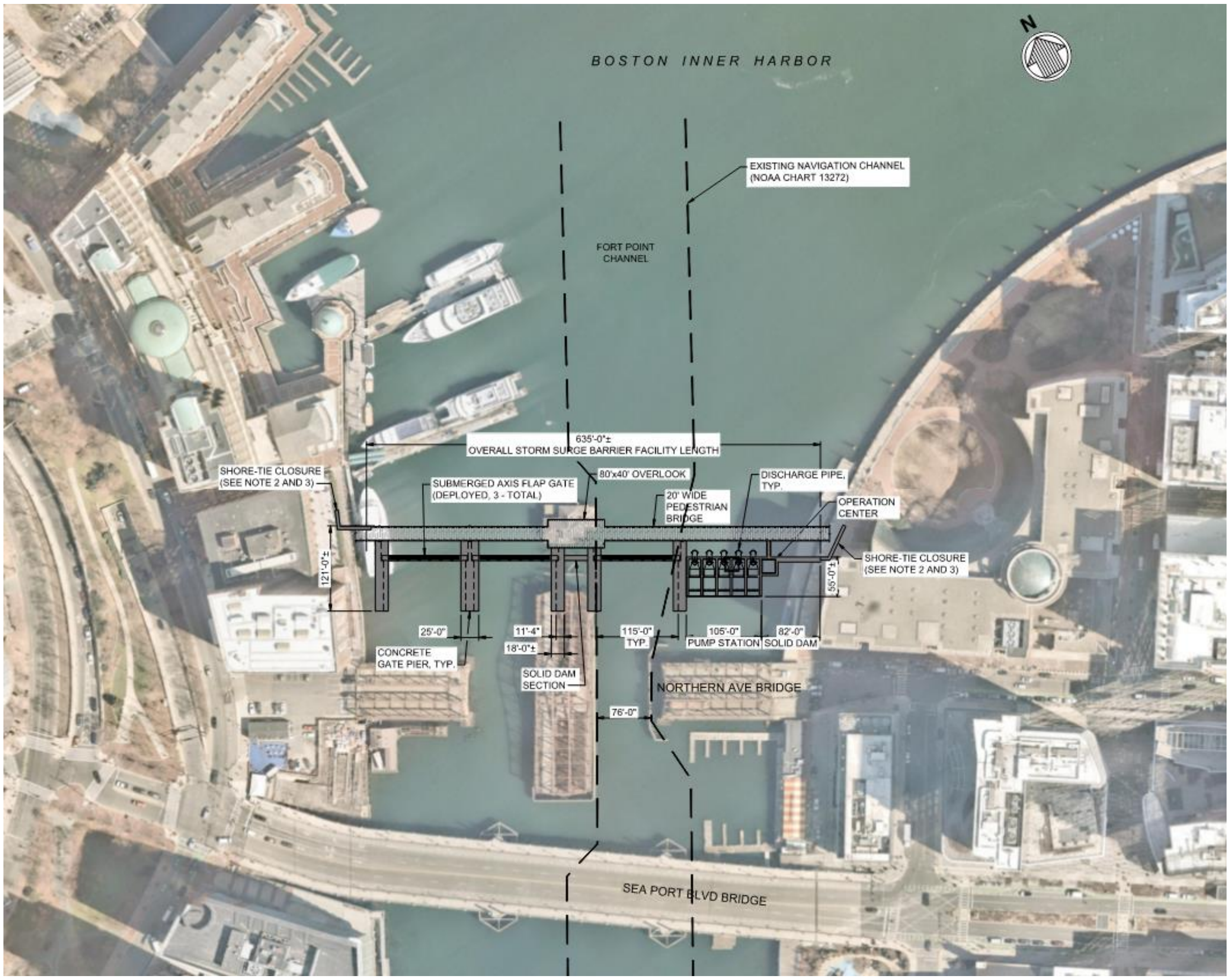


Figure 5-38: Submerged Axis Flap Gate Alternative

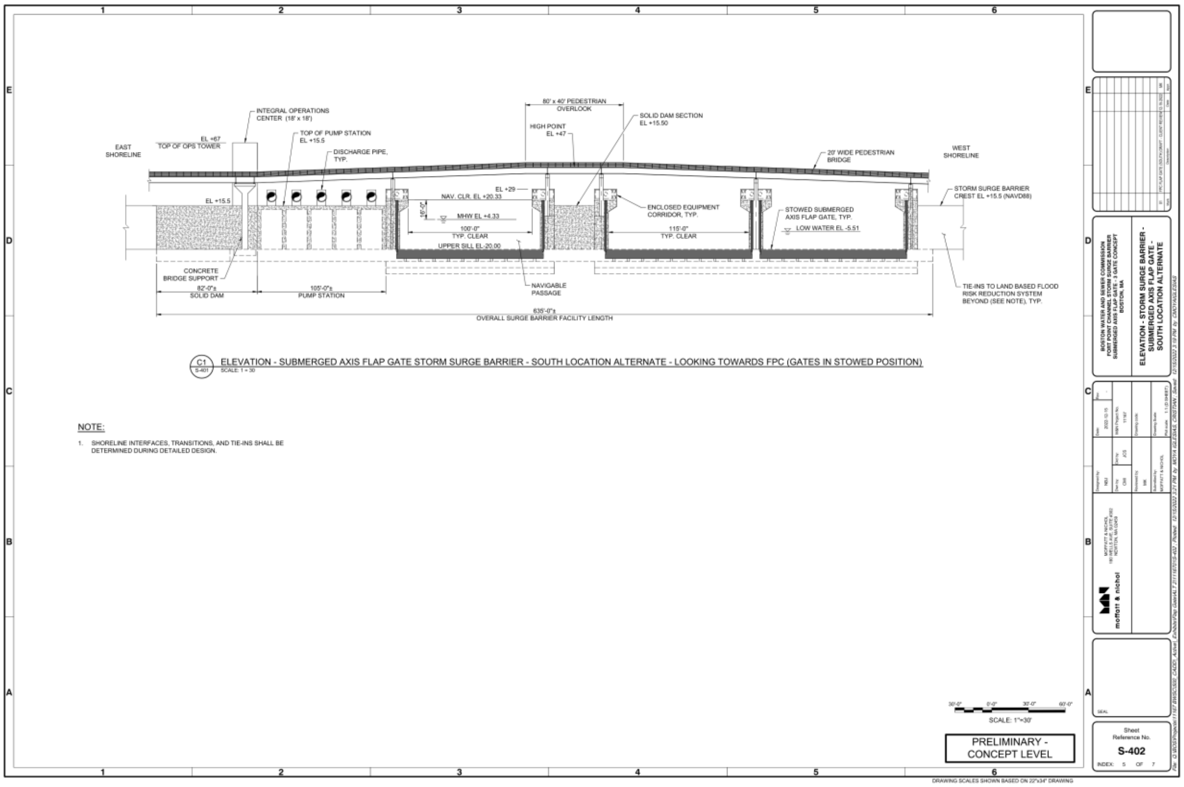


Figure 5-39: Submerged Axis Flap Gate Alternative Profile

The submerged axis flap gate offers minimized viewshed impacts compared to the vertical lift gate alternative, but is associated with a greater Operations and Maintenance (O&M) burden, additional complexity, and higher cost.

5.10.2.4 Northern Avenue Bridge Storm Surge Barrier Integrated Alternative

Currently, the design for a replacement for the Northern Avenue Bridge, which is in the mouth of the Fort Point Channel, is being finalized. The bridge project was scheduled to be in its construction phase by 2021, but progress has been delayed due to the COVID-19 pandemic and other factors. As of November 2021, the project was still in its permitting stage, and has not entered the construction phase. Given the close proximity of the planned bridge replacement to the FPC SSB concept, integration of these structures should be considered.

There are several benefits to integrating the storm surge barrier with the Northern Avenue Bridge project. Combining the projects yields fewer separate construction activities within the region, reducing possible construction conflicts and community disruption. Additionally, combining the projects will improve public waterfront access (via the combined bridge/SSB complex). Further, viewshed impacts associated with the SSB would be minimized or eliminated. The current design for the new Northern Avenue Bridge includes both a promenade deck and a viewing platform underneath the main bridge deck. The feasibility of constructing the SSB and pump station beneath the bridge structure should be evaluated.

A preliminary illustration of a combined Northern Avenue Bridge / FPC SSB project with the barrier open is shown below in **Figure 5-40**. The mechanical systems are similar to the other concepts shown previously. An integrated project would offer an opportunity for Boston and the Commission to implement an iconic adaptation project, with multiple community benefits, that could catalyze funding and coordination for further adaptation efforts.

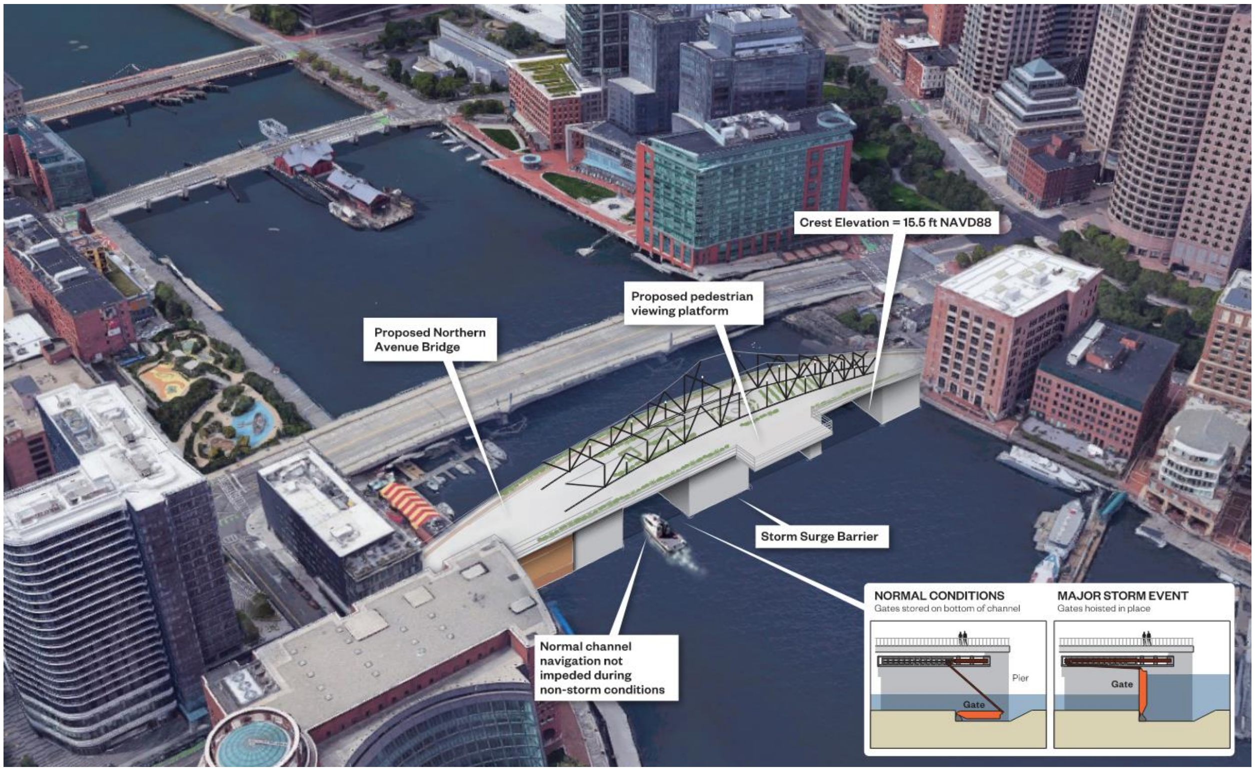
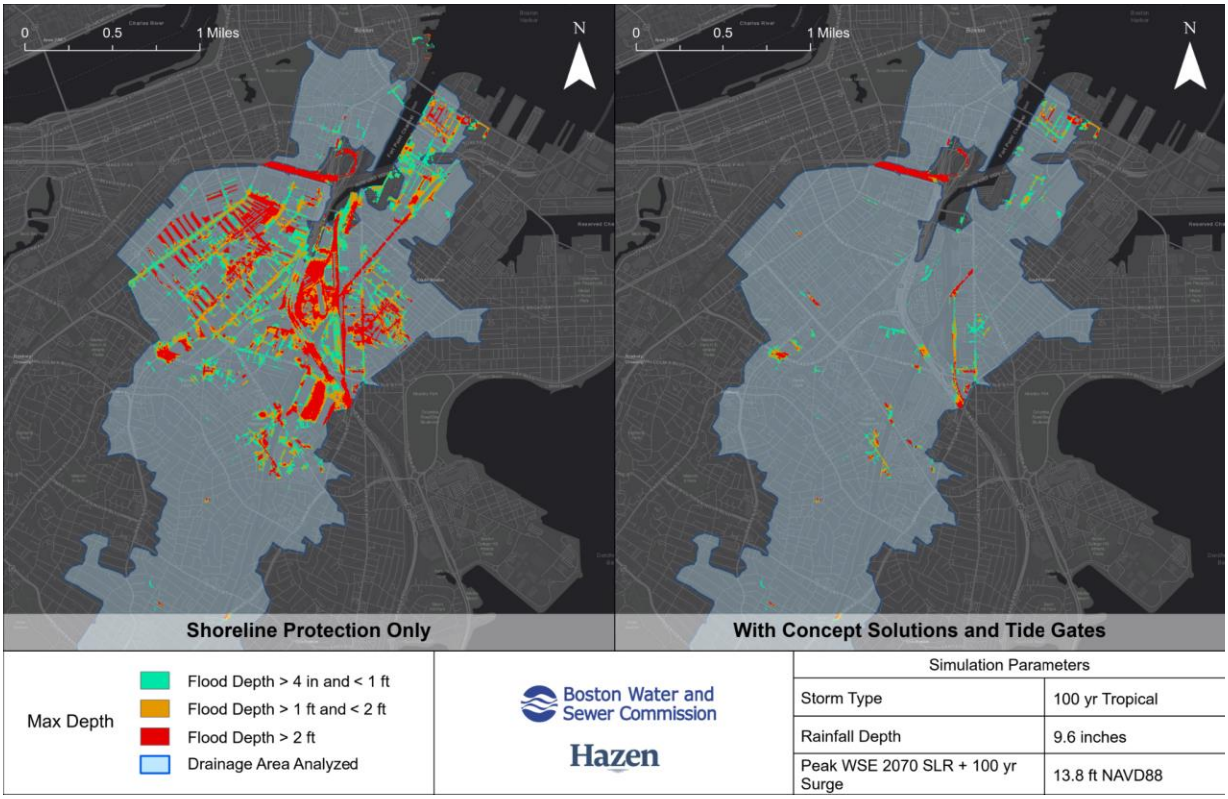


Figure 5-40: Northern Avenue Bridge-Integrated SSB Alternative (Graphical Rendering)

5.10.3 Flooding Analysis

The flood reduction benefits of the FPC SSB concept were evaluated using the Commission’s 2D Inundation Model by simulating a 100-year tropical storm event with 2070 SLR and storm surge. **Figure 5-41** depicts the peak flooding that was predicted in the drainage area tributary to the FPC with shoreline protection only and with the FPC SSB and tide gates on all vulnerable BWSC owned outfalls.



Simulation Parameters	
Storm Type	100 yr Tropical
Rainfall Depth	9.6 inches
Peak WSE 2070 SLR + 100 yr Surge	13.8 ft NAVD88

Figure 5-41: Fort Point Channel Flood Model Results

Note: **Figure 5-41** *includes a polygon labeled as "drainage area analyzed". This area represents the area which was included in the economic damage/loss analysis described in* **Section 7** *of this report.*

5.10.4 Adaptability and Implementation Considerations

The following measures could be implemented to adapt the concept to more severe conditions (additional SLR, more intense rainfall, etc.) in the future:

- Convert a standby pump to a duty pump for additional capacity
- Increase the size of each FPC pump unit (*Note: To some extent, it may be possible to increase the size of each FPC pump without increasing the size of the pump bays, pending physical modeling. If the ability to switch to larger pumps in the future is desired, the pump bays could be oversized.)*
- Redirect additional vulnerable outfalls to discharge into the FPC behind the SSB

Implementation of the Fort Point Channel concept requires consideration of the following:

- Given the criticality of this pump station's performance it would also be advisable to provide dual power feeders fed from different electrical substations. In the event that one substation is lost for any reason (e.g., substations were lost in NYC during Superstorm Sandy), the second substation can provide the necessary power to keep pumps operational during a storm (before needing to switch to onsite backup generators).

- A one-line diagram was developed and dimensions for an electrical equipment enclosure (see concept sheets in Appendix G). Electrical motors to move the SSB gates were sized based on the lift gate alternative, and an estimated weight of 840 kips per gate. This results in dual 30 HP motors per gate (with allowances for weight of sediment accretion, friction, etc.).

- It is estimated that the backup power supply (portable generator) should be capable of supplying 2 megawatts to operate the FPC pumps, as currently designed.

- Coordination with CRB (and other relevant stakeholders) to construct adequate shoreline protection to prevent flanking of the SSB.

- Coordination with the Northern Avenue Bridge replacement team could facilitate integration of these structures. Construction of an “integrated” structure could reduce construction costs, minimize viewshed impacts, and provide additional public amenities.

- Shoreline elevation projects along the interior of the FPC should still be evaluated since the FBC SSB is not designed to isolate the basin from “day-to-day” high tide levels.

- Deauthorization of the federally authorized navigation channel would be a significant undertaking. It is recommended that future development of this concept preserve the existing navigation function unless the project is undertaken at the federal level.

- A thorough permitting evaluation of the FPC SSB should be conducted. Although the SSB concept was developed to maximize tidal exchange between the FPC and Boston Harbor, a thorough environmental impact assessment should be conducted to evaluate possible impacts of constructing an SSB.

- At a further stage of the design process, consideration should be given to mitigating the possible hazard caused by the high-flow discharges of the pump station to small boats, swimmers, and other harbor users.

- Additional outfalls could be redirected to discharge behind the FPC SSB and pump station to mitigate the effect of higher sea levels – this would increase the regional utility and benefits of the concept in the future. Consideration should be given to redirecting privately owned outfalls proximal to the FPC concept as well as outfalls owned by the Commission.

- GIS data for the FPC shows several private outfalls within the channel. More research and coordination are needed to quantify the number and impact of private outfalls, and determine how their discharges impact the effectiveness of the FPC concept under different storm conditions.

- 2D modeling was conducted to evaluate the incremental benefit of adding tide gates to all BWSC owned outfalls that discharge into the FPC in addition to shoreline elevation. It was found that additional tide gates have a substantial flood reduction benefit compared to shoreline elevation alone. Installation of tide gates on all BWSC owned outfalls could be considered as an interim measure before construction of the SSB and pump station. It is important to note that, for some outfalls, the sole addition of a tide gate will not prevent inland flooding due to insufficient stormwater discharge. In these cases, local stormwater best management practices may also be required to mitigate inland flooding.

- The FPC SSB pump station uses a temporary backup power supply; as such, it is important to coordinate availability of backup power several days before an anticipated extreme storm event.

5.11 Davenport Creek Stormwater Park

5.11.1 Concept Overview

The Davenport Creek Stormwater Park concept is located in Dorchester, as shown in **Figure 5-42**. The concept design is shown in **Figure 5-43** and includes a “natural” (surface) storage system with a pump station that can be used during larger storm events. This concept is designed to maintain sufficiently low water levels at Outfall 10LSDO094 by isolating the outfall from high tide levels with a tide gate and providing a large storage area for temporary detention of stormwater in an above ground area.

Figure 5-42: Davenport Creek Concept Location

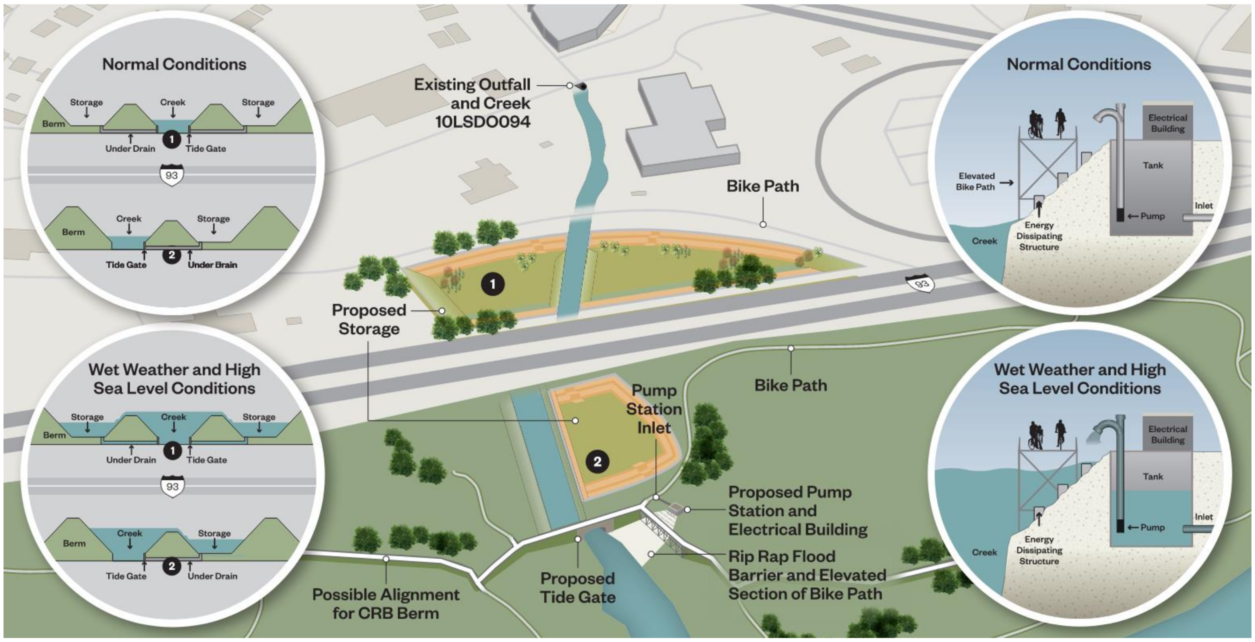


Figure 5-43: Illustration of Davenport Creek Concept

During rain events which occur at high tide (triggering closure of a tide gate that could be installed to the west of Interstate 93), stormwater discharged from Outfall 10LSDO094 can overflow proposed berms alongside Davenport Creek into the above ground storage areas. These storage areas would typically remain dry during normal conditions and feature water tolerant native plant species and public access along the existing Neponset Trail. During larger storm events, flow exceeding the capacity of the storage areas can enter a stormwater pump station that discharges into Davenport Creek near its confluence with the Neponset River. Due to the high flood vulnerability of this location, it is essential that berms (or other shoreline protection measures) be constructed around the pump station and storage areas to prevent coastal flooding. In addition to constructing the storage area and pump station, proposed storm water conveyance piping is required to divert higher elevation areas upstream directly to existing outfall 9LSDO095.

5.11.2 Basis of Design

Model simulations were conducted to determine the maximum HGL that occurs at Outfall 10LSDO094 with the representative tide elevation of 3.7 ft NAVD88 used in the City's PCSWMM model. Analyses were then conducted to determine the required volume of storage and rate of pumping required to maintain the benchmark maximum current-day HGL with 2070 projected sea level rise, as shown in **Figure 5-44**. The City of Boston's Parcel database was used to identify publicly owned parcels near the existing outfall. It was assumed that flow from the higher elevation portion of the Davenport Creek tributary area will be diverted as shown in **Figure 5-45**.

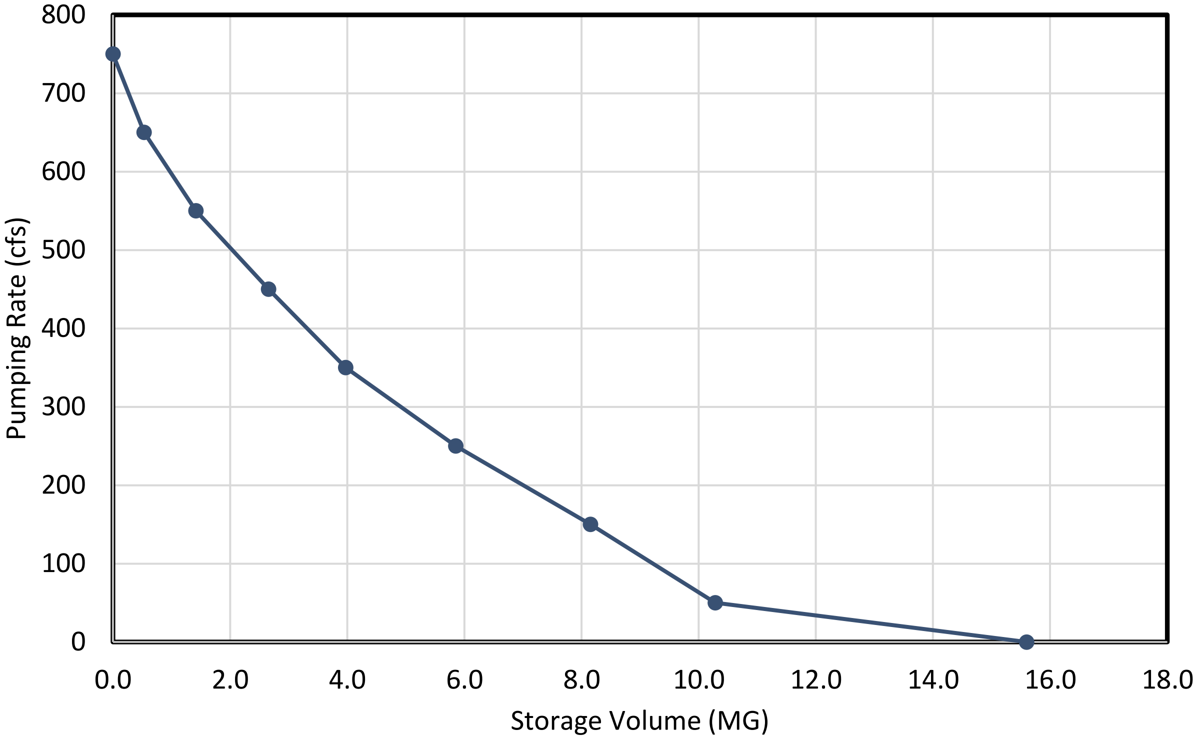


Figure 5-44: Pumping vs. Storage

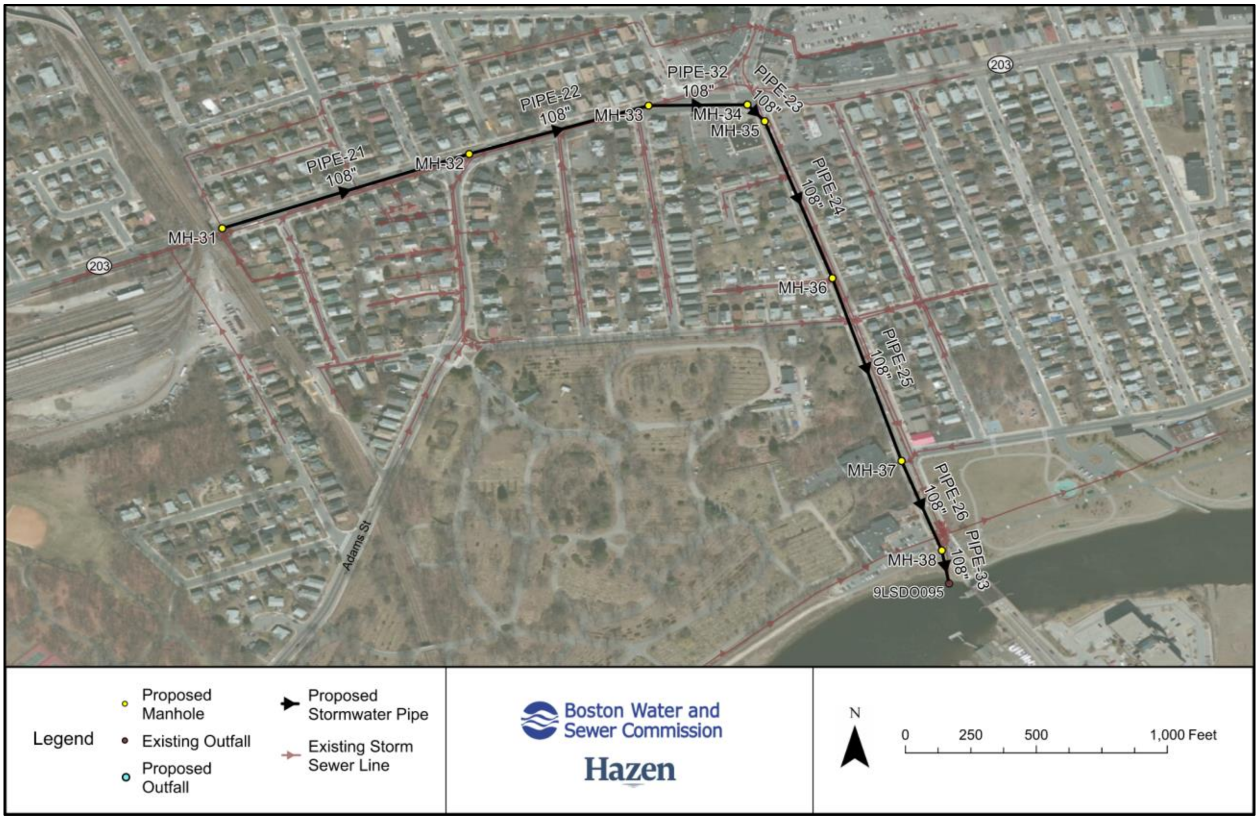


Figure 5-45: Davenport Creek Stormwater Park High Elevation Diversion Pipeline

Based on a maximum acceptable depth of 7.5 ft in the above ground storage areas (depicted on the next page) with a sidewall slope of 1:1, it was found that the above ground storage areas can detain approximately 6 MG, requiring a 250 CFS pump station. The pump station occupies an area of 2,465 ft^2. The detention basins occupy an area of 115,900 ft^2. After a wet weather event when the tide level recedes, the storage areas are designed to drain by gravity into Davenport Creek via underdrains. The pump station utilizes three duty pumps, one standby pump, and two dewatering pumps. All pumps are axial electric submersible pumps, arranged in parallel bays. The pump station discharges onto an energy dissipation structure located underneath a raised section of mixed-use path (a “bike bridge”).

5.11.3 Flooding Analysis

The flood reduction benefits of the Davenport Creek Stormwater Park concept were evaluated using the Commission’s 2D Inundation Model by simulating a 100-year tropical storm event with 2070 SLR and storm surge. **Figure 5-46** on the following page depicts the peak flooding that was predicted in the drainage area tributary to Davenport Creek with shoreline protection only and with the concept implemented.

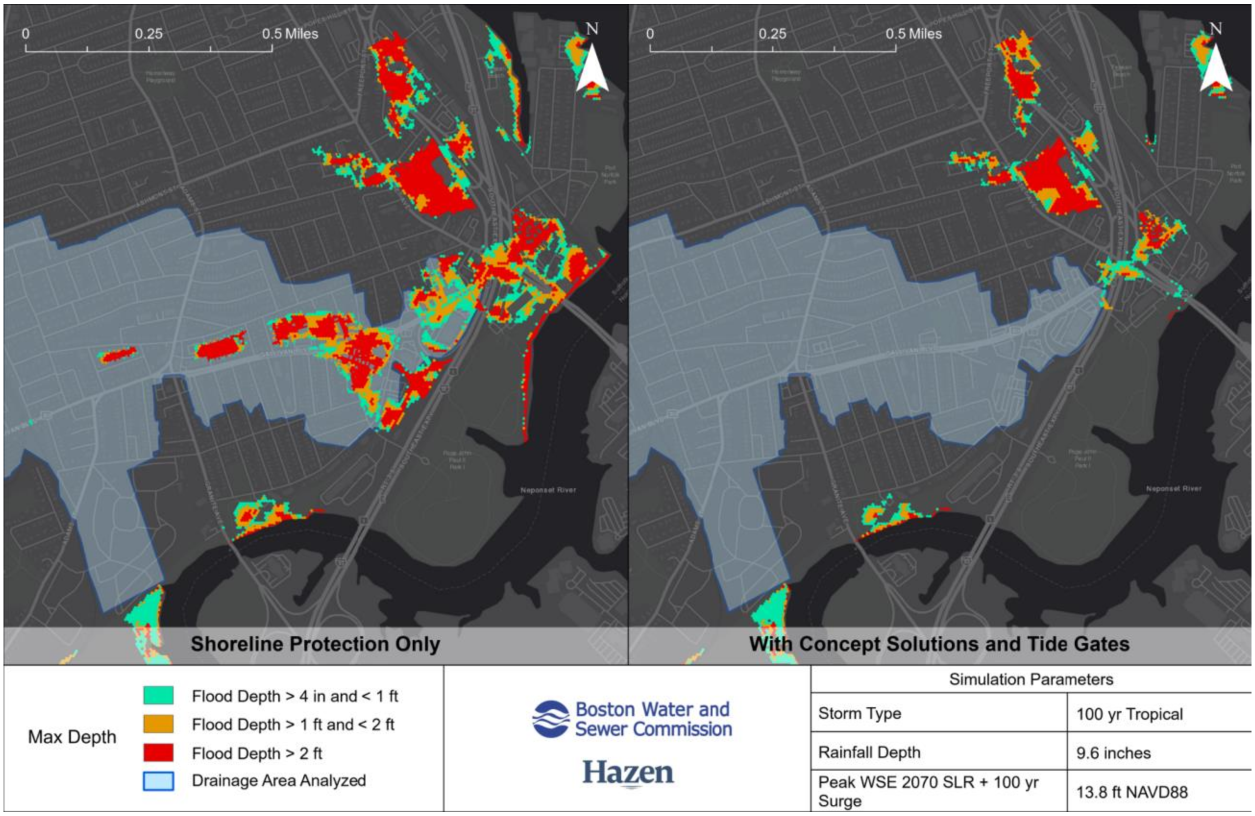


Figure 5-46: Davenport Creek Stormwater Park Flood Model Results

Note: **Figure 5-46** *includes a polygon labeled as "drainage area analyzed". This area represents the area which was included in the economic damage/loss analysis described in* **Section 7** *of this report.*

5.11.4 Adaptability and Implementation

The conditions that were used to design and analyze and design the Davenport Creek Stormwater Park are conservative and represent more extreme conditions than have occurred historically. Considering this, it is expected that the Davenport Creek Stormwater Park will function as a storage only facility (not requiring pumping) during most storm events. Regardless, if additional storage or pumping capacity is required in the future, the following options could be considered:

- The pump station could be expanded to increase pumping capacity if more intense rainfall causes larger than predicted inflows.
- The storage area could be expanded into the adjacent athletic fields in Pope John Paul II Park. If this larger storage area is implemented flow from other adjacent outfalls could be diverted into the storage area.

Implementation of the Davenport Creek concept requires consideration of the following:

- Coordination with CRB (and other relevant stakeholders) to construct adequate shoreline protection around the Davenport Creek Stormwater Park is essential for successful implementation of this concept.
- Coordination with residents and stakeholders could be conducted to determine preferences for features to be included in the above ground storage areas.
- The new pipelines that drain higher elevation portions of the tributary areas are designed only to convey flow from areas upstream of their origin. Lower elevation areas with higher flood vulnerability along these pipelines should not be connected to the new pipelines.
- Before beginning the final design process geotechnical investigations should be conducted to determine the groundwater elevation in the proposed storage areas; high groundwater levels could significantly reduce the usable storage volume.
- Based on elevation, it is possible to place the pump station on the other side of the bike path (i.e., closer to the ocean). This configuration may be simpler from an outfall configuration perspective, but it may introduce additional difficulties for geotechnical design and constructability, as the pump station would be closer to the ocean and would be partially below the design flood elevation.
- The Neponset River is federally designated superfund site. A survey of hazardous materials, and detailed list of required permits, should be developed before beginning the final design process.

5.12 Dorchester Bay Basin

5.12.1 Concept Overview

The Dorchester Bay Basin concept location is shown in **Figure 5-47**. The concept design, as shown in **Figure 5-48**, utilizes the existing shoreline geometry to store stormwater in the Dorchester Bay Basin (DBB). Available storage in the basin could be used to completely store outfall discharges during small rain events or attenuate the peak rate of pumping that could be required during larger rain events. By utilizing a vertical lift gate and storm surge barrier (which could be located near the Castle Island Drawbridge on Morrissey Boulevard), the DBB could be closed at low tide before a predicted coastal storm event. Details about the proposed storm surge barrier can be found in **Appendix J**.

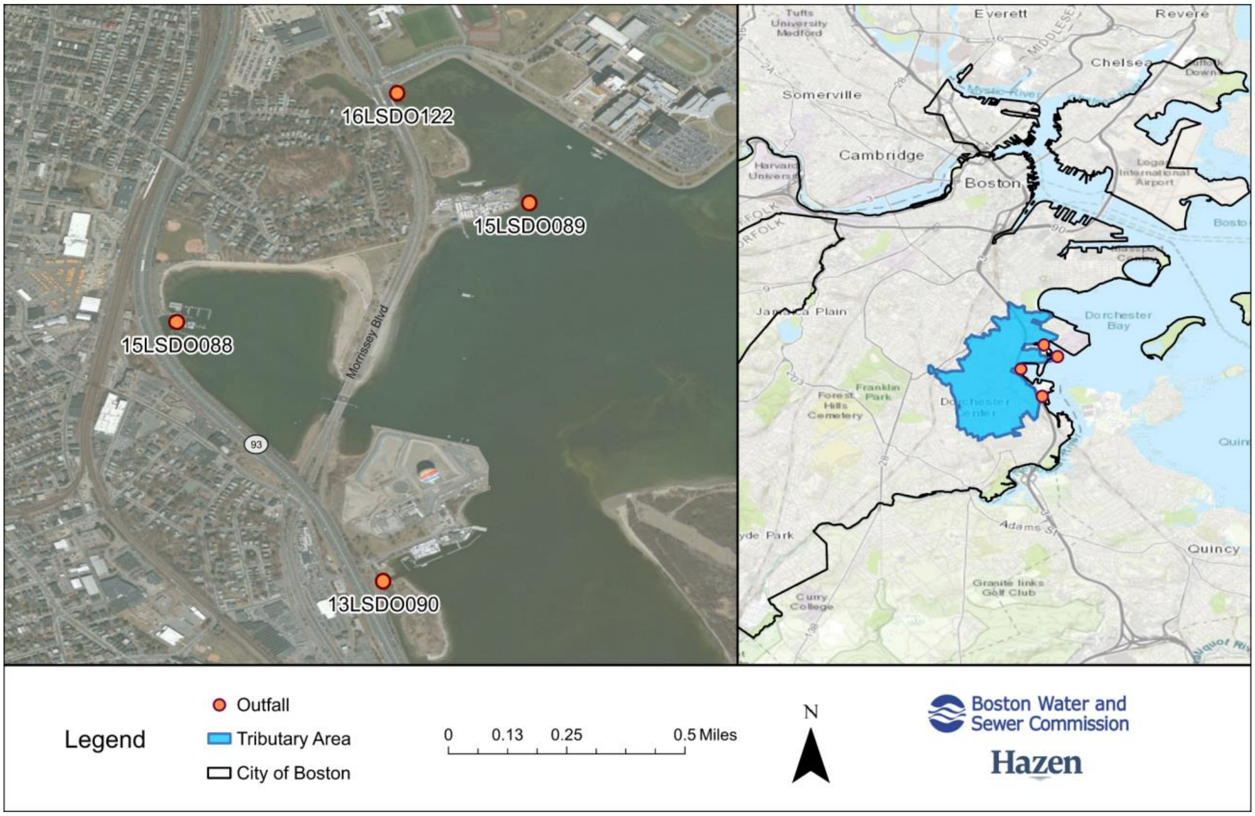


Figure 5-47: Dorchester Bay Basin Concept Location

Figure 5-48: Graphic Representation of Dorchester Bay Basin Concept

Under present day conditions, the basin could store approximately 160 MG before overflowing; by 2070 (assuming 4.3 ft of sea level rise) the basin's storage capacity would be reduced to 100 MG. The Storm Surge Barrier concept at the DBB utilizes a single 66-ft-wide navigation gate and an auxiliary flow gate. The gates, when open, are stored above the storm surge barrier superstructure. When open, free access for navigation is available between the DBB and the Boston Harbor. The gates can be lowered into the closed position ahead of an extreme storm event to isolate the DBB.

In addition to protecting outfalls 15LSDO088 and 15LSDO089, this concept protects outfalls 13LSDO090 and 16LSDO0122 with the use of diversion structures that can redirect flow to the basin by gravity through new conduits if high sea levels are predicted. Higher elevation portions of the areas tributary to these outfalls are not vulnerable to flooding from higher sea levels; this concept also includes new pipeline to separately drain these higher elevation areas directly to the receiving waters. By providing separate drainage conduits ("express" pipelines) for these high elevation areas, flow into the DBB is reduced sufficiently to avoid the need for a pump station under the conditions analyzed. A pump station could be constructed in the future if necessary to maintain sufficiently low water surface elevations in the basin to allow for gravity discharge and storage if conditions change in the future.

5.12.2 Basis of Design

5.12.2.1 Basin Storage Capacity

The storage capacity of the DBB was analyzed under present day and 2070 conditions based on 4.3 ft of sea level rise projected in the MC-FRM. The usable storage volume was calculated by developing a stage storage curve from a topobathymetric Digital Elevation Model (DEM) obtained for the DBB from the Continuously Updated Digital Elevation Model (CUDEM) project from NOAA and determining the volume between MLW and the approximate upper rim elevation of the existing DBB. For the purposes of this preliminary investigation, the upper rim (bounding region) of the basin was defined as the highest contour line which stayed within the boundary of the intertidal zone of the basin and did not interfere with buildings or roads. For the DBB, this was approximately 5 ft NAVD88, close to the mean higher high-water level of 4.77 ft. Landscaping and/or building a seawall would allow for a higher "upper rim" to the basin (i.e., additional storage volume within the basin).

Note that the upper bound for water storage for this project is slightly above the maximum WSE of 3.7 (ft, NAVD88) chosen for other concepts, as the tidal basin regularly experiences higher WSEs than 3.7 ft during daily tide cycles. Local drainage improvements and/or additional tide gates may be required to allow the DBB concept to function without inducing additional local flooding. Further field investigations and modeling analysis is required to determine the maximum WSE for storage within the DBB that does not induce additional local flooding. **Table 5-3** and **Figure 5-49** contain a summary of the present day and projected usable DBB storage volume. Localized sea level datums are relative to NAVD88 and were determined based on information from NOAA buoy number 8443970, located in Boston in the Fort Point Channel, less than 3.5 miles away from the study region.

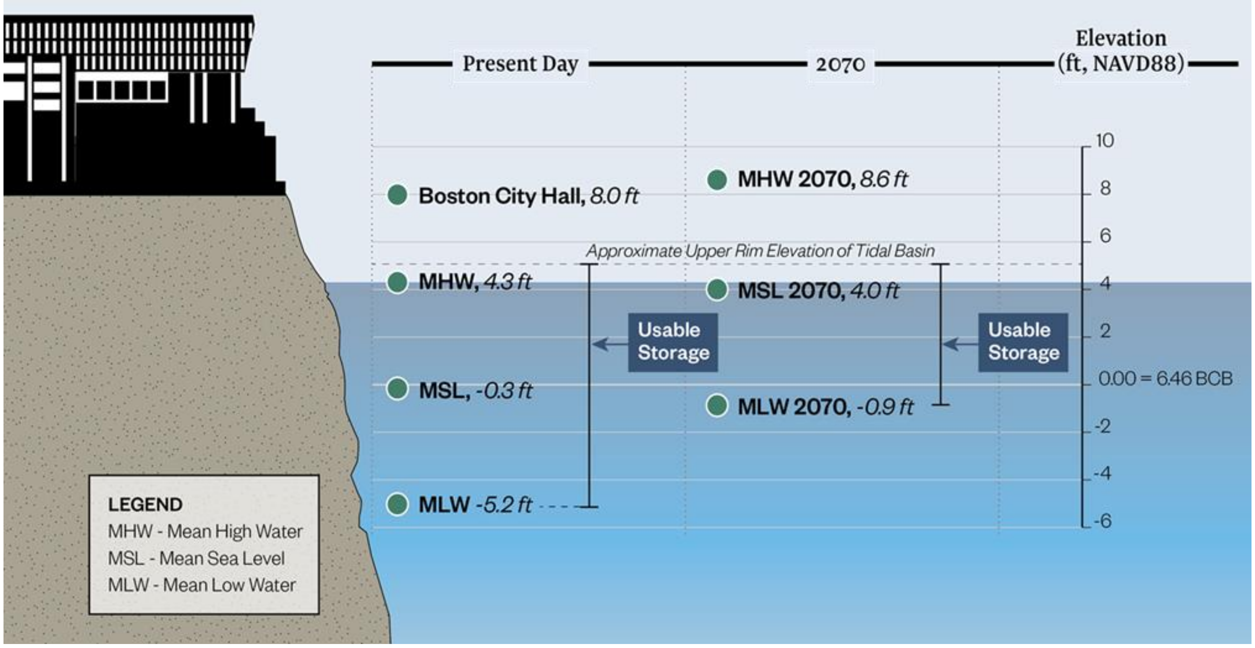


Figure 5-49: Present Day and 2070 Projected Estimated DBB Storage Capacity

Table 5-3: Present Day and 2070 Projected Estimated DBB Storage Capacity

Scenario	**Mean Low Water (ft, N**AVD88)	**Mean High Water (ft, NAVD88)**	**Usable DBB** Storage Capacity (million gallons)
Present Day	-5.2	4.3	160
Projected 2070 SLR	-0.9	8.6	100

Figure 5-50 depicts the stage storage curve that was developed to determine the DBB storage capacity. For design and analysis purposes, a usable storage volume of 100 MG (2070 conditions) was calculated.

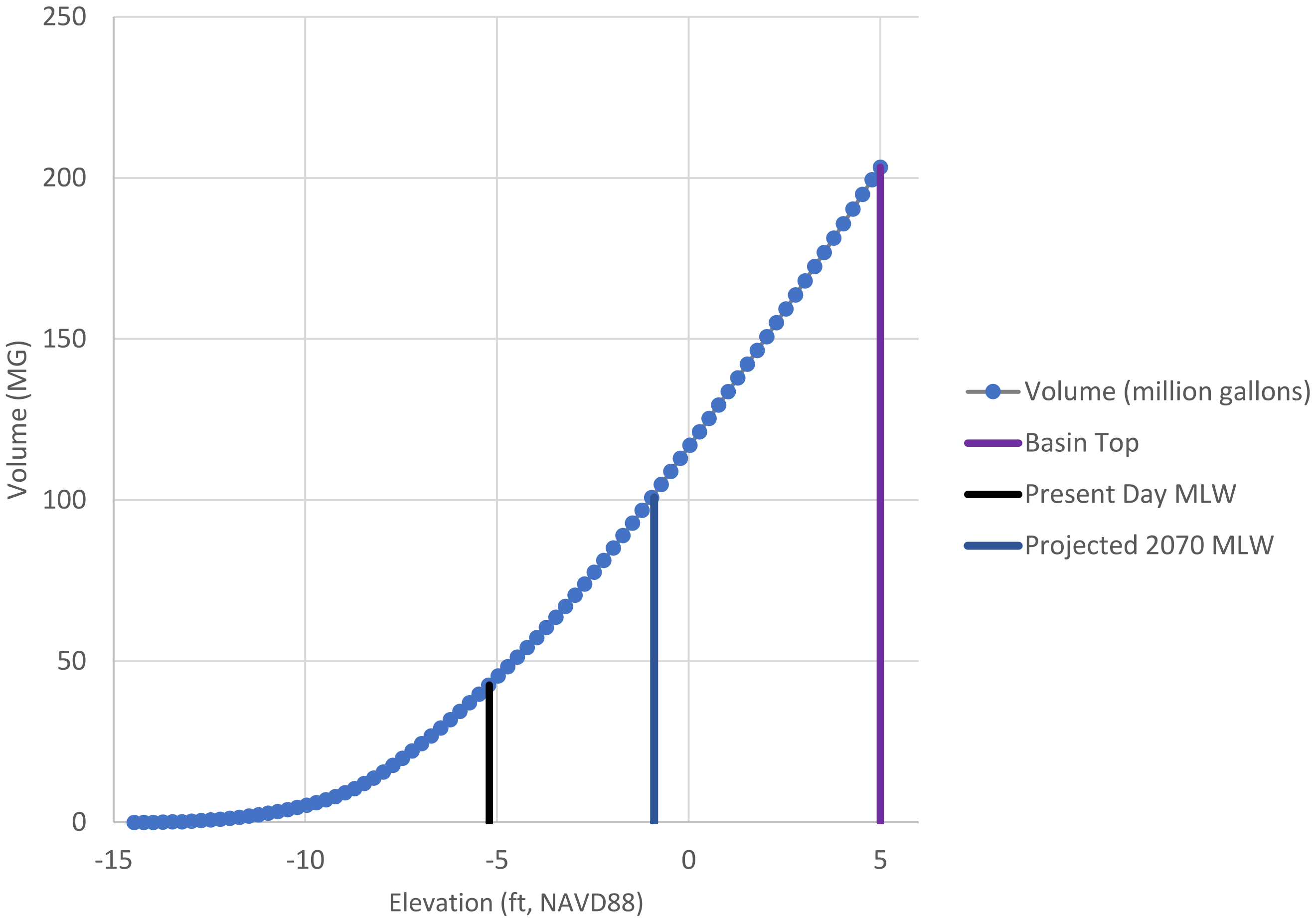


Figure 5-50: DBB Stage Storage Curve

5.12.2.2 Pumping Evaluation and Storage Capacity

A series of simulations were conducted using the Commission's Inundation Model to determine the volume of water discharged into the DBB during the 10-year, 24-hour design storm and 100-year tropical storm under 2070 conditions. This analysis was conducted to evaluate the potential for the basin to overflow (exceed elevation 5.0 ft NAVD88) and determine if pumping is required to prevent the basin from overflowing. The simulation included the high elevation gravity diversions shown in **Section 5.12.2.3** and it was assumed that the basin was isolated from the Neponset River (by the proposed storm surge barrier) for the duration of the simulation (water was not discharged from the basin). **Figure 5-51** depicts the WSE in the basin during the projected 10-year, 24-hour design storm event.

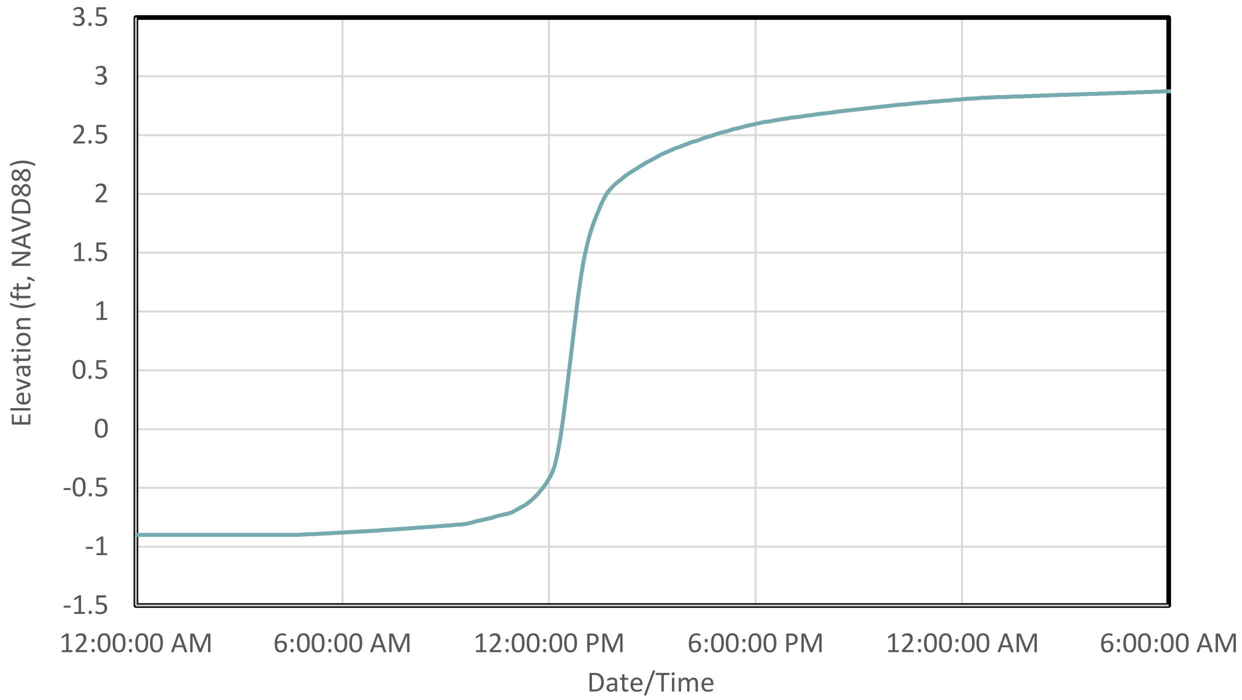


Figure 5-51: Model Predicted WSE in DBB (2070 Projected 10-year, 24-hour Design Storm)

Based on the results of these simulations, summarized in **Table 5-4**, it was determined that the DBB Storage Concept does not require a pump station under the conditions simulated. During the final design process, detailed survey can be conducted to verify the available storage volume in the basin with more accuracy. A pump station could be added to the concept in the future if larger storm events result in inflow volumes that exceed the storage capacity of the basin. It should be noted that these simulations utilized a MLW elevation based on projections for 4.3 ft of SLR by 2070; under present day conditions the basin has approximately 60% more storage capacity than this projected 2070 condition.

Table 5-4: DBB Storage Simulation

Scenario	Initial WSE (ft, NAVD88)	Final WSE (ft, NAVD88)	Volume Stored (MG)	Percent Full
10-year, 24-hour Design Storm (2070)	-0.9	2.9	64	64%
100-year Tropical Storm (2070)	-0.9	4.7	97	97%

5.12.2.3 *Proposed Conveyance Pipelines*

As noted in **Section 5.12.1**, new conveyance pipelines have been designed to divert stormwater flows from outlets that may be impacted by higher sea levels. It is important to recognize that portions of these new pipelines are designed to surcharge during extreme storm conditions; it was assumed that bolted, or otherwise secured, manhole covers would be provided to prevent flooding during peak flow conditions.

5.12.2.3.1 Outfall 16LSDO122 Diversion to Dorchester Bay Basin

This new pipeline, shown in **Figure 5-52**, consists of a 144-in diameter conduit connected via a diversion structure to the existing storm drain at the intersection of Morrissey Boulevard and Bianculli Boulevard. At this location, under low sea level conditions, the storm drain discharges to Outfall 16LSDO122 at Savin Hill Cove. The new pipeline would convey excess flows that cannot discharge from Outfall 16DO122 under higher sea level conditions to along Morrissey Boulevard and the Dorchester Bay Basin at Malibu Beach and discharge to a new Outfall PROP001 between Savin Hill Beach and Malibu Beach.

Figure 5-52: Outfall 16LSDO122 Diversion to Dorchester Bay Basin

5.12.2.3.2 Outfall 13LSDO090 Diversion to Dorchester Bay Basin

This new pipeline, shown in **Figure 5-53**, consists of a 144-in diameter conduit connected via a diversion structure to the existing storm drain system at Victory Road and Freeport Street. At this location, under low sea level conditions, the existing storm drain system discharges to Outfall 13LSDO090 to a channel adjacent to the Dorchester Shores Reservation and the Neponset River. The new pipeline would convey excess flows that cannot discharge to Outfall 13LSDO090 under higher sea level conditions to the Dorchester Bay Basin via Freeport Street to Everdean Street and then crossing the Southeast Expressway and discharging at a new Outfall PROP002 at Savin Hill Cove.

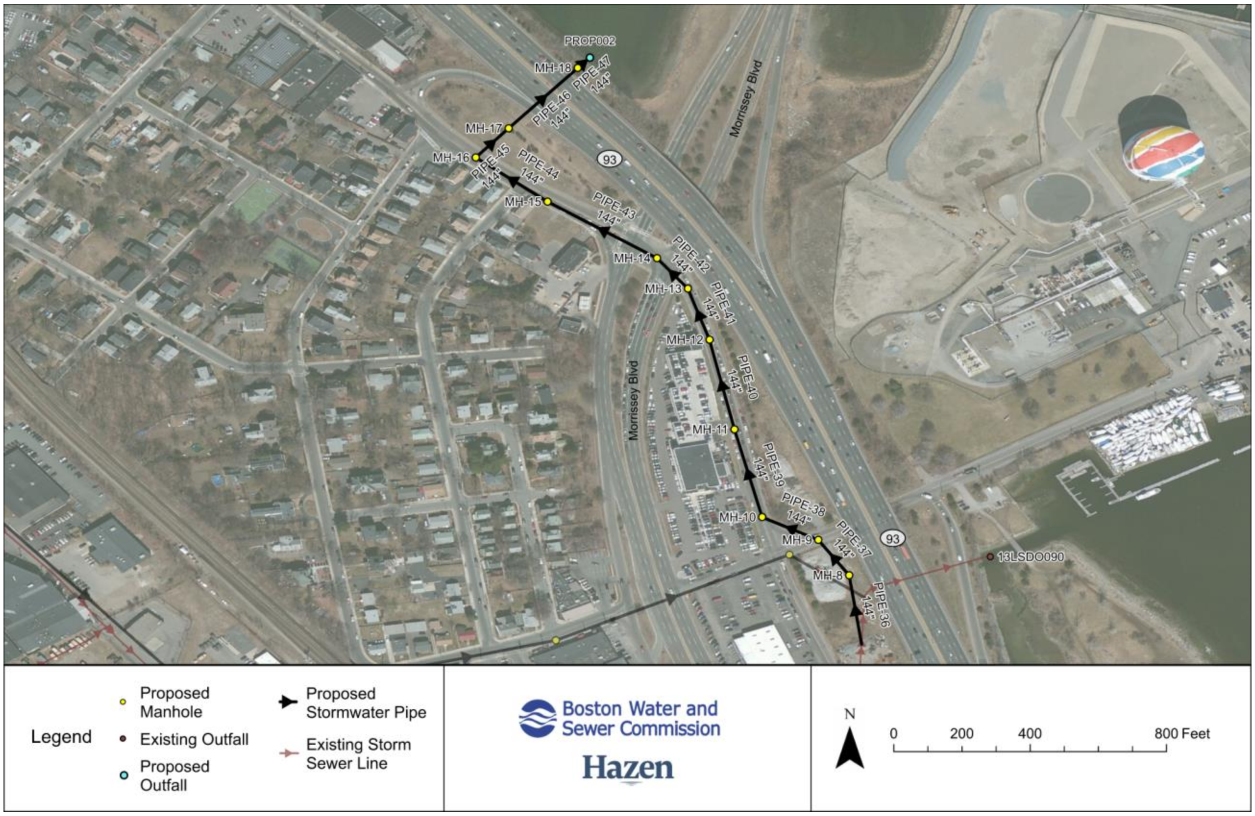


Figure 5-53: Outfall 13LSDO090 Diversion to Dorchester Bay Basin

5.12.2.3.3 New Pipelines for Drainage of High Elevation Areas

New high elevation diversion conveyance (“express”) pipelines are proposed to augment the existing system and promote adequate drainage of the upper tributary areas including the following:

New Pipeline No. 1 – This pipeline, shown in **Figure 5-54**, consists of a 90-in storm drain connected via a diversion structure to the existing storm drain located at the Hancock Street and Bowdoin Street intersection. This connection point avoids the existing weir structure which currently diverts regular storm flow to outfall 15LSDO089. To allow existing local flow to drain to the Dorchester Bay Basin, the existing weir will need to be removed. The new storm drain alignment would follow Hancock Street across Dorchester Avenue to Freeport Street parallel to the existing storm drain that crosses the MBTA rail lines and the Southeast Expressway. It will connect to the system on Morrissey Boulevard upstream of Outfall 15LSDO88 that discharges at the Dorchester Yacht Club and connecting to the existing storm drain that ultimately discharges to Outfall 15LSDO089 at Savin Hill Yacht Club.

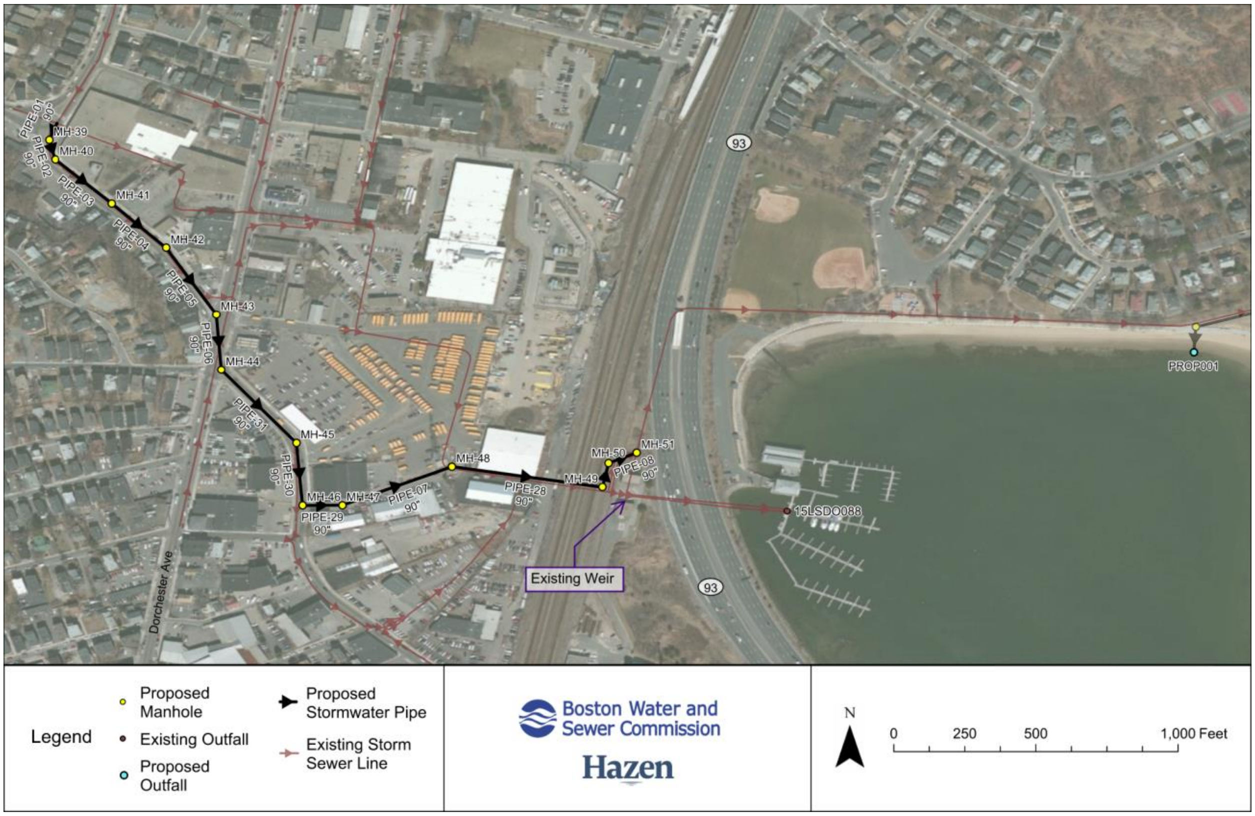


Figure 5-54: Dorchester Bay Basin High Elevation Diversion Pipeline No. 1

New Pipeline No. 2 – This pipeline, shown in **Figure 5-55**, consists of two new storm drains. The first consists of a short section of 48-in pipe located on Adams Street at the intersection of Victory Road that connects to a manhole located at Dix Street. A short section of 84-in pipe on Dix Street also connects to this manhole. From this manhole, a 96-in storm drain will continue down Adams Street to Neponset Avenue where it will be connected to a new 108-in pipe extending east on Dorchester Avenue to Christopher Street that follows the existing storm drain alignment. At Christopher Street, the pipeline diameter will be increased to 144 in and continue across Bispham Street passing through the parking areas of three private properties to Adams Street. From this point, the storm drain will continue down Christopher Street across Sturtevant Street to Mapes Street to Victory Road, crossing the MBTA rail lines and continuing down Victory Road to its connection point to the existing storm drain system upstream of 13LSDO090.

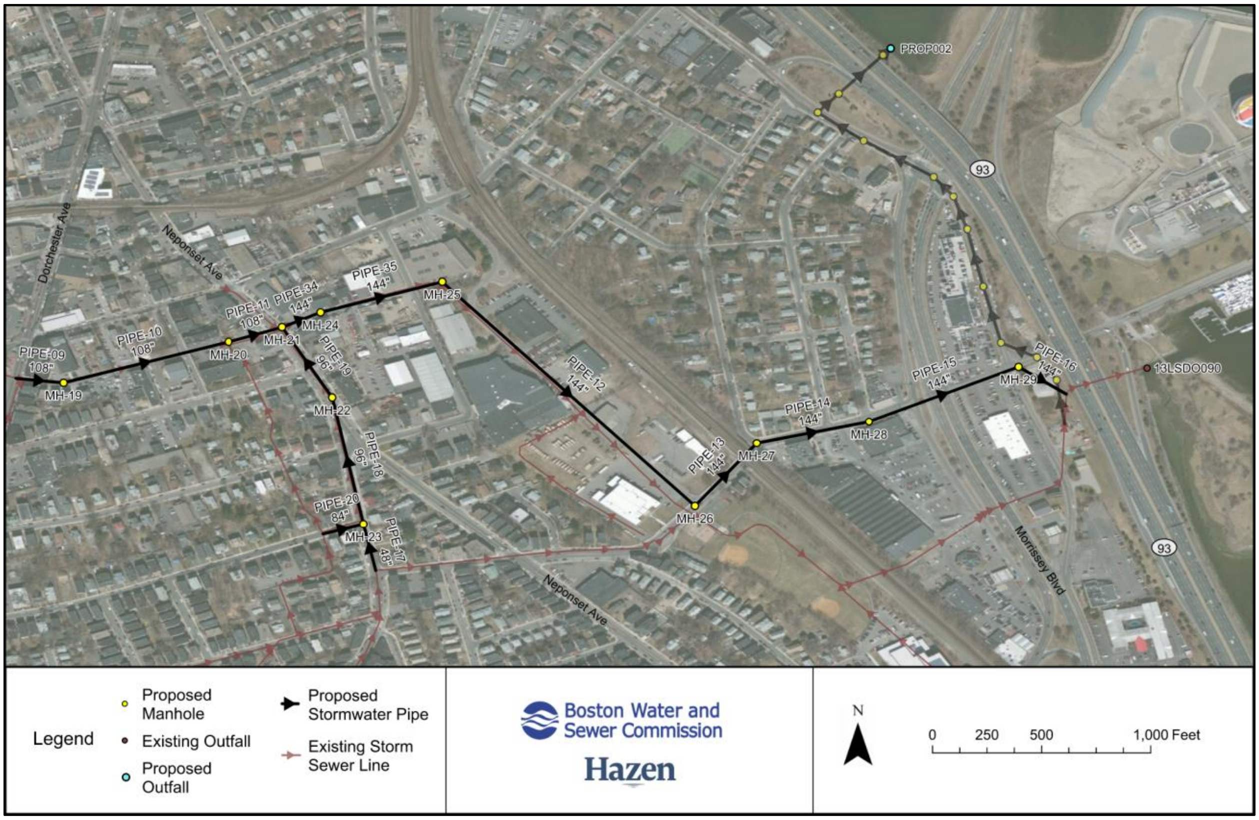
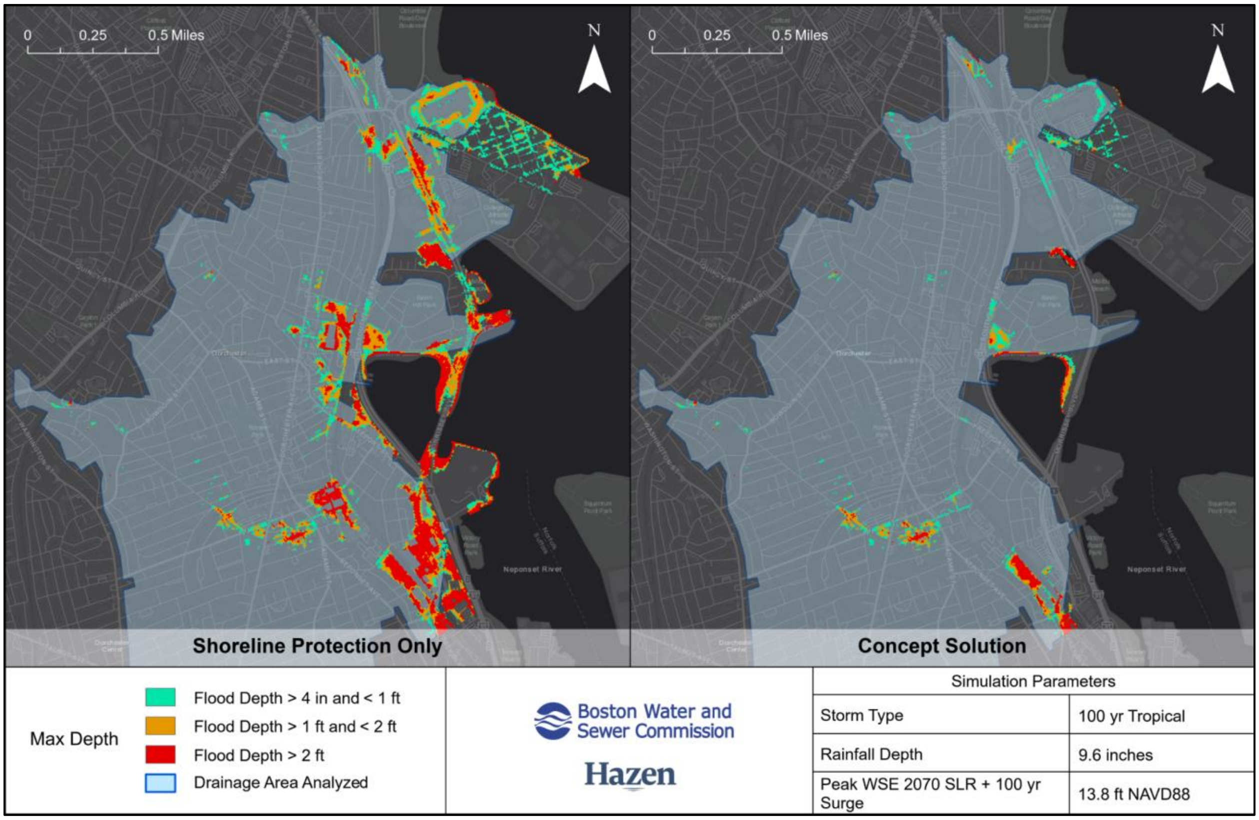


Figure 5-55: Dorchester Bay Basin High Elevation Diversion Pipeline No. 2

5.12.3 Flooding Analysis

The flood reduction benefits of the DBB concept were evaluated using the Commission’s 2D Inundation Model by simulating a 100-year tropical storm event with 2070 SLR and storm surge. **Figure 5-56** below depicts the peak flooding that was predicted in the drainage area tributary to the DBB with shoreline protection only and with the DBB concept implemented.



Simulation Parameters	
Storm Type	100 yr Tropical
Rainfall Depth	9.6 inches
Peak WSE 2070 SLR + 100 yr Surge	13.8 ft NAVD88

Figure 5-56: Dorchester Bay Basin Flood Model Results

Note: **Figure 5-56** *includes a polygon labeled as "drainage area analyzed". This area represents the area which was included in the economic damage/loss analysis described in* **Section 7** *of this report.*

5.12.4 Adaptability and Implementation

The conditions that were used to analyze and design the DBB storage concept are conservative and represent more extreme conditions than have occurred historically. As such, it is likely that the DBB storage concept will function without the need for a pump station in the future under many conditions. Regardless, the following measures could be implemented to adapt the concept to more severe conditions (additional SLR, more intense rainfall, etc.) in the future:

- Construct a pump station to maintain lower water levels during a storm event
- Construct a pump station to draw down water levels (maximize storage capacity) in DBB before a forecast storm event
- In conjunction with a pump station, dredge DBB to obtain additional usable storage

Implementation of the concepts presented for the DBB require consideration of the following:

- Coordination with CRB (and other relevant stakeholders) to construct adequate shoreline protection around the DBB is essential for successful implementation of this concept. To function as designed, the DBB must be fully isolated from high sea levels when the gate is closed; as such, careful coordination with CRB is essential at this location. The maximum WSE in the DBB is determined by the hydraulics of the connected outfalls; it is not impacted by the design flood elevation of coastal protection structures. As such, coastal flood protection modifications to planned flood protection structures that result in higher elevations do not impact the efficacy of this concept.

- Coordination with the Dorchester Yacht Club should be conducted to help make sure gates are sufficiently large to accommodate all anticipated boat traffic.
- Consideration of the hydraulic impacts on the physical design of the new storm drain system is critical. The new pipelines that convey flow from adjacent outfalls to the DBB are designed to surcharge. As such, under design conditions, it is important that manhole covers are watertight and securely bolted or fastened in place to prevent surface flooding.
- The new pipelines that drain higher elevation portions of the tributary areas are designed only to convey flow from designated areas upstream of their origin. Lower elevation areas with higher flood vulnerability along these pipelines should not be connected to the new pipelines.
- The new pipelines that divert flow into the DBB from adjacent outfalls are designed to surcharge under extreme storm conditions. Bolted/secured watertight manhole covers should be provided to prevent flooding during peak flow conditions.
- The Commission’s PCSWMM model indicates that the weir/regulator structure that controls flow between outfalls 088 and 089 is a significant hydraulic restriction. Removal of this restriction is an important element of this concept to facilitate flow into the DBB.
- Active flow control gates at proposed diversion structures could be used to divert flow into the DBB during “normal” tide conditions; this could help prevent sediment deposition in the pipelines.
- Modifications may need to be made to local drainage infrastructure at low elevation near the DBB to accommodate for the high WSE used as the upper bound of storage within the basin.
- GIS data for the DBB shows several private outfalls within the basin. More research and coordination is needed to quantify the impact of private outfall discharges on the effectiveness of the DBB concept under different storm conditions.
- The Neponset River is federally designated superfund site. A survey of hazardous materials, and detailed list of required permits, should be developed before beginning the final design process.

5.13 Joseph Finnegan Stormwater Park

5.13.1 Concept Overview

The Joseph Finnegan Park concept is located in Dorchester as shown in **Figure 5-57**. The concept design, as shown in **Figure 5-58,** includes a storage basin that is a hybrid "natural" (above ground) storage system with a pump station that can be used during larger storm events. The basin and pump station are located inside Joseph Finnegan Park and next to the Neponset River. The basin has a rectangular perimeter and walls that slope inward at a 1:4 slope. During dry weather or low tide rain events, the basin functions as walkable recreation space. During rain events, if a high tide level begins to reduce the ability of existing outfalls 12LSDO092 and 11MSDO093 to discharge by gravity, then two diversion structures each with a static weir directs excess flow via a 78-in pipe connected to the 12LSDO092 outfall pipe and a 48-in pipe connected to the 11MSDO093 outfall pipe to the park storage basin. The storage basin is connected to the pump station, which sits near the shoreline and can pump water into the Neponset River.

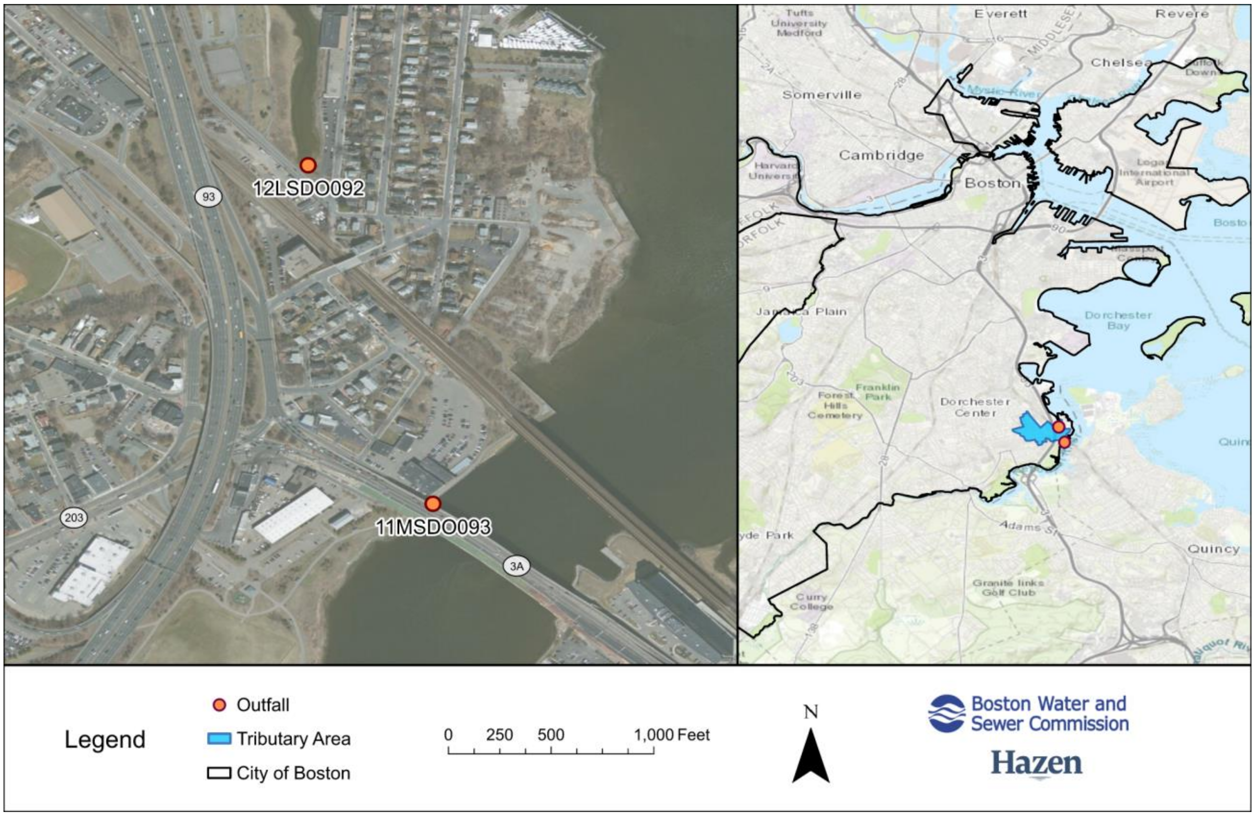


Figure 5-57: Finnegan Park Concept Location

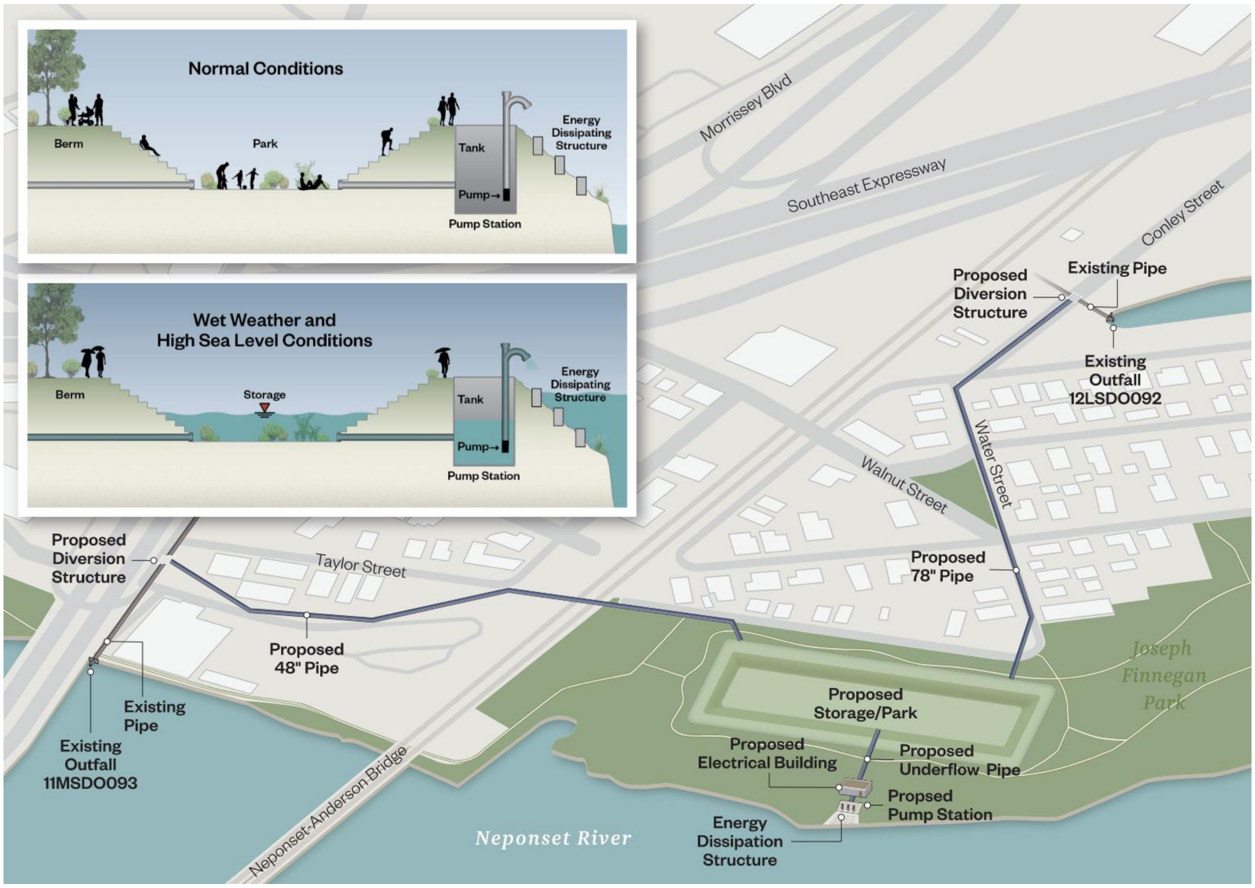


Figure 5-58: Graphic Representation of Joseph Finnegan Stormwater Park Concept

5.13.2 Basis of Design

Model simulations were conducted to determine the maximum HGL that occurs at Outfalls 12LSDO092 and 11MSDO093 with the representative tide elevation of 3.7 ft NAVD88 used in the City's PCSWMM model. Analyses were then conducted to determine the acceptable combinations of storage volume and pumping rate required to maintain the benchmark maximum current-day HGL with 2070 projected sea level rise and 100-year storm surge, as shown in **Figure 5-59**.

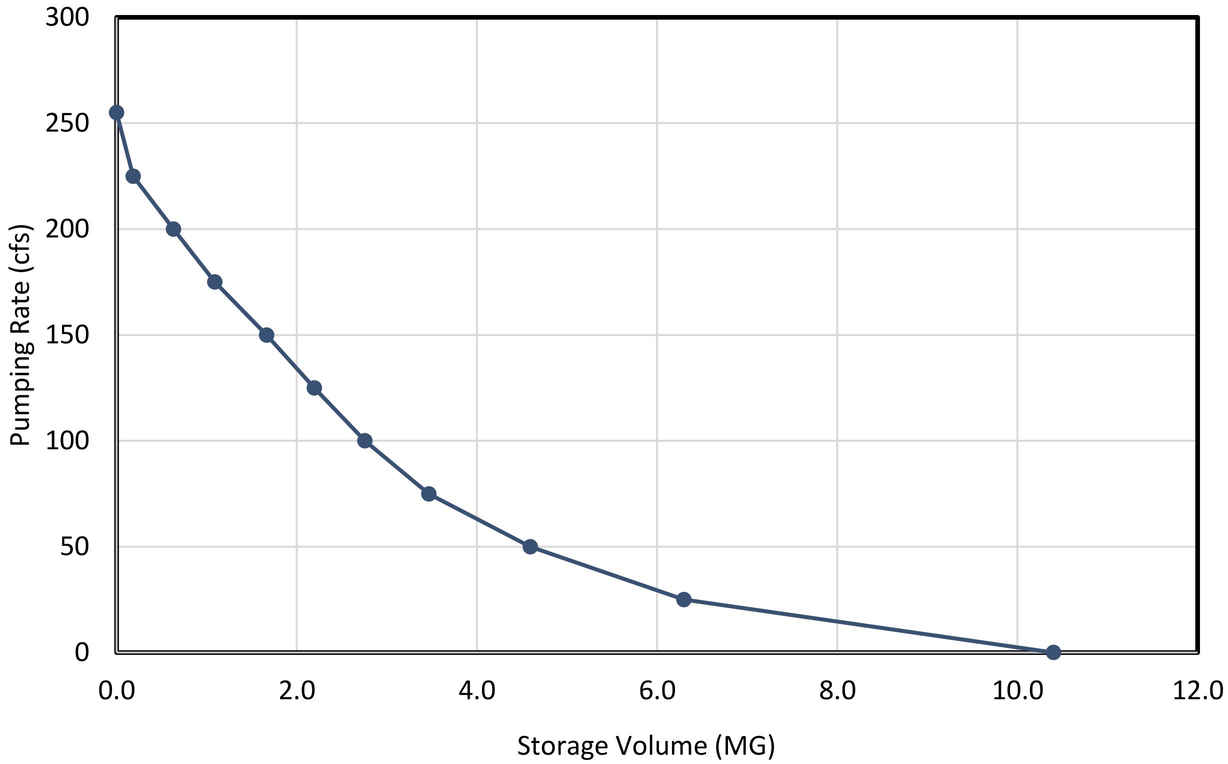
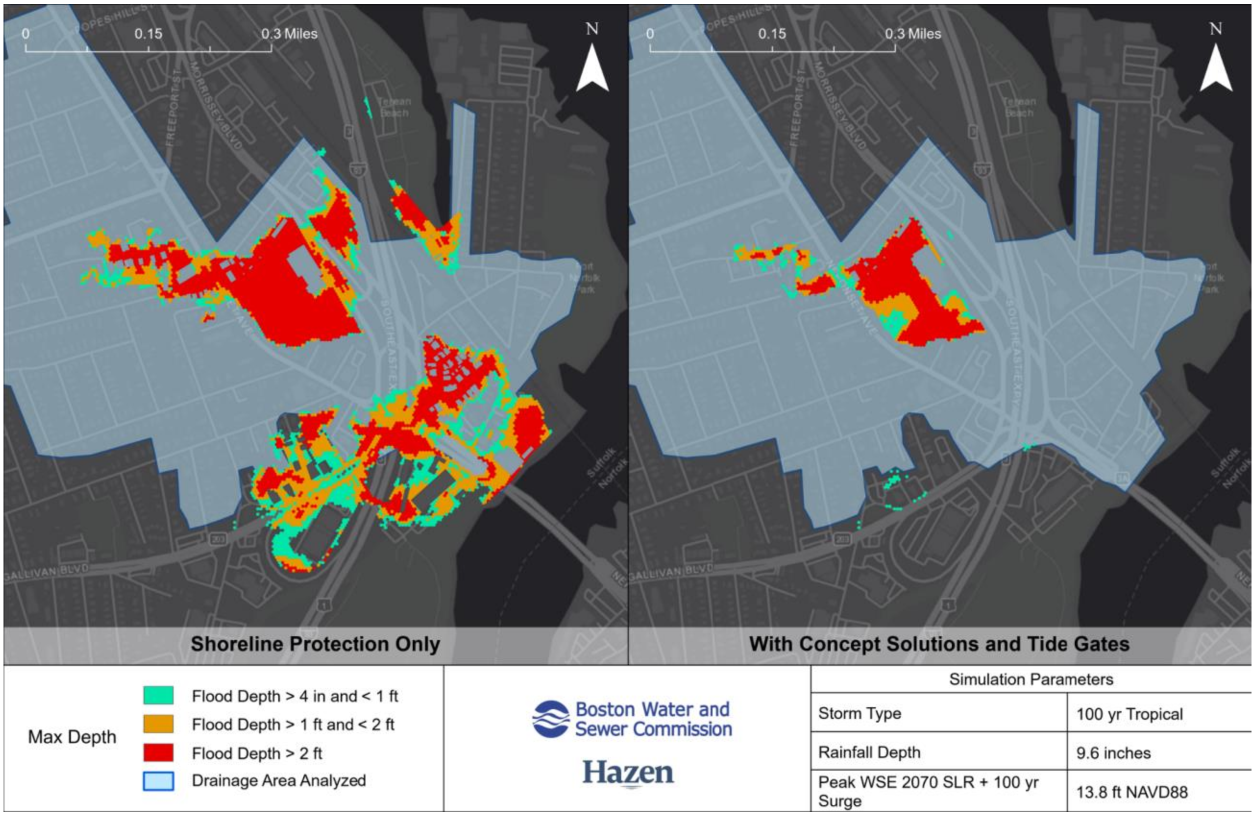


Figure 5-59: Finnegan Park Outfalls Pumping vs Storage

The City of Boston's Parcel database was used to identify publicly owned parcels near the existing outfall. An analysis of the pump station was performed to identify a pump rate and physical dimensions that are hydraulically viable. It was found that a 10 MG storage basin and a 50 CFS pump station ~20.5 ft deep could fit within the property. The storage tank and pump station occupy an area of 133,020 ft^2. The storage basin has a rectangular perimeter and walls that slope inward at a 1:4 slope. During dry weather or low tide rain events, the basin functions as walkable recreation space. During rain events, if a high tide level begins to reduce the ability of existing outfalls 12LSDO092 and 11MSDO093 to discharge by gravity, then a diversion structure with a static weir directs excess flow to the park storage basin. The storage basin is connected to the pump station, which sits near the shoreline and can pump water into the Neponset River. The Finnegan Park pump station utilizes one duty pump, one standby pump, and two dewatering pumps. The pump station is configured with vertical, axial electric submersible pumps in parallel bays. Each pump has a separate, non-manifold discharge.

5.13.3 Flooding Analysis

The flood reduction benefits of the Joseph Finnegan Park concept were evaluated using the Commission’s 2D Inundation Model by simulating a 100-year tropical storm event with 2070 SLR and storm surge. **Figure 5-60** on the following page depict the peak flooding that was predicted in the Joseph Finnegan Park drainage area with shoreline protection only and with the pump station and tide gates on all vulnerable BWSC owned outfalls.



Simulation Parameters	
Storm Type	100 yr Tropical
Rainfall Depth	9.6 inches
Peak WSE 2070 SLR + 100 yr Surge	13.8 ft NAVD88

Figure 5-60: Finnegan Park Pump Station Flood Model Results

Note: **Figure 5-60** *includes a polygon labeled as "drainage area analyzed". This area represents the area which was included in the economic damage/loss analysis described in* **Section 7** *of this report.*

5.13.4 Adaptability and Implementation

The following measures could be implemented to adapt the concept to more severe conditions (additional SLR, more intense rainfall, etc.) in the future:

- Expand the pump station to maintain lower water levels during a storm event
- Deepen the storage basin and redesign the pump station to obtain additional usable storage
- Other interior drainage improvements could be made to convey additional flow to the Finnegan Park storage concept

Implementation of the Joseph Finnegan Park concept requires consideration of the following:

- Coordination with CRB (and other relevant stakeholders) to construct adequate shoreline protection around Finnegan Park is essential for successful implementation of this concept. To function as designed, Finnegan Park must be fully isolated from high sea levels; as such, careful coordination with CRB is essential at this location.

- Coordination with park planners and users of the park should be conducted to address the risks associated with having significant topographic variation, such as determining locations where activities such as throwing frisbees and balls is discouraged. The design should be modified as necessary to help make sure the park area is compliant with the Americans with Disabilities Act and fully accessible.

- On-site signage and community outreach will be required to adequately inform the public that the park will be a drowning hazard for children and people with physical disabilities during wet weather events.

- Planting of native plant species and other green features will provide an improved public amenity and preserve the "look and feel" of the park.

- Portions of existing and proposed pipelines may flow under surcharge conditions during certain wet weather conditions. As such, under design conditions, it is important that manhole covers along those portions of the pipelines are watertight and securely bolted or fastened in place to prevent flooding. Additional field investigation is required to accurately determine the extent of this requirement.

- Active flow control gates at proposed diversion structures could be used to divert flow into Finnegan Park during low-intensity rain events; this could help prevent sediment deposition in the pipelines.

- A comprehensive permitting evaluation should be conducted to evaluate possible impacts from construction and operation of the pump station to the receiving water.

- A portion of the Neponset River is federally designated as a superfund site. A survey of hazardous materials, and detailed list of required permits, should be developed before beginning the final design process.

- Community engagement with stakeholders may help build project support by illustrating the flood control benefits of the storage basin and pump station.

5.14 Old Harbor Park

5.14.1 Concept Overview

The Old Harbor Park concept is located in Dorchester, as shown in **Figure 5-61**. The concept design, as shown in **Figure 5-62,** includes a stormwater storage (peak flow shaving) tank and pump station to discharge wet weather flow when tide levels are high. The tank and pump station are located at Old Harbor Park. If a high tide level begins to reduce the ability of existing outfall 17MSDO33 to discharge by gravity the existing storm sewer will begin to surcharge. A diversion structure with a static weir directs excess flow from the existing sewer via a 72-in pipe to the storage tank. The storage tank is connected directly to the pump station.

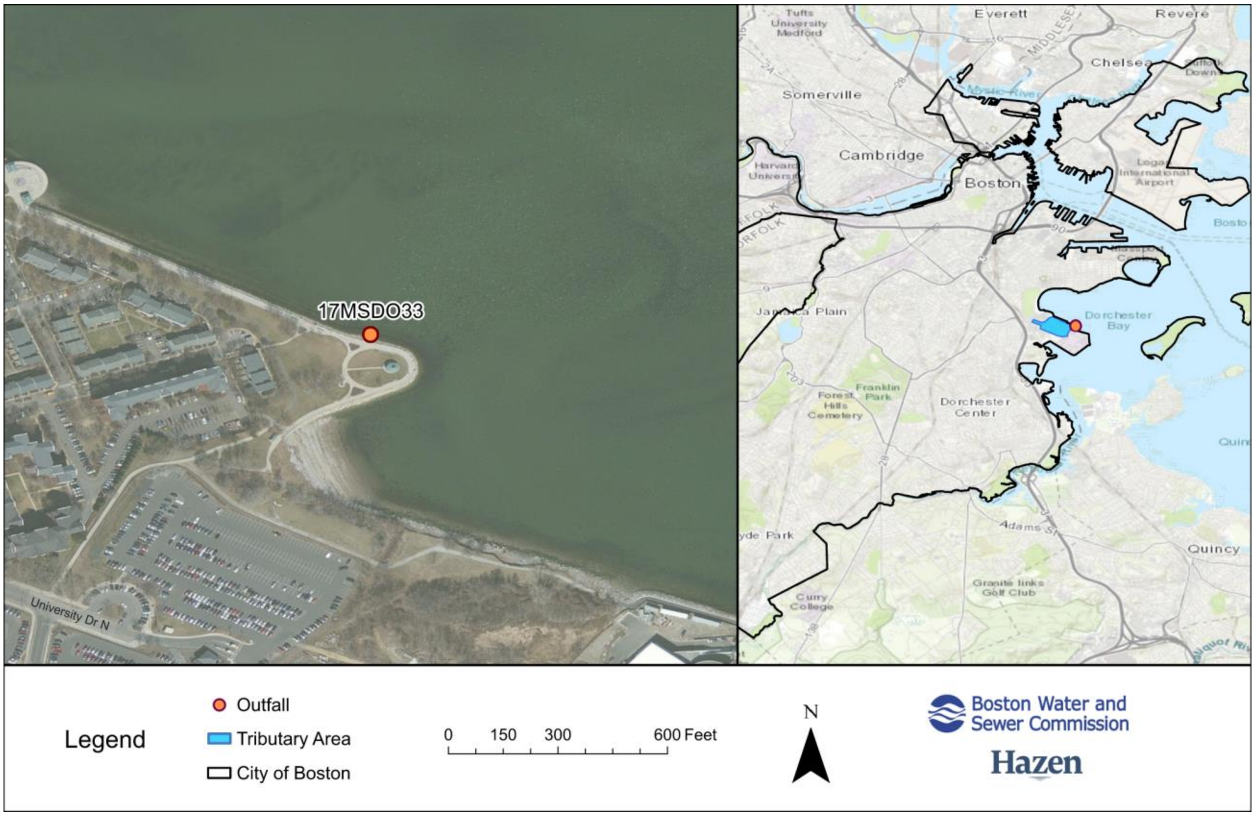


Figure 5-61: Old Harbor Park Concept Location

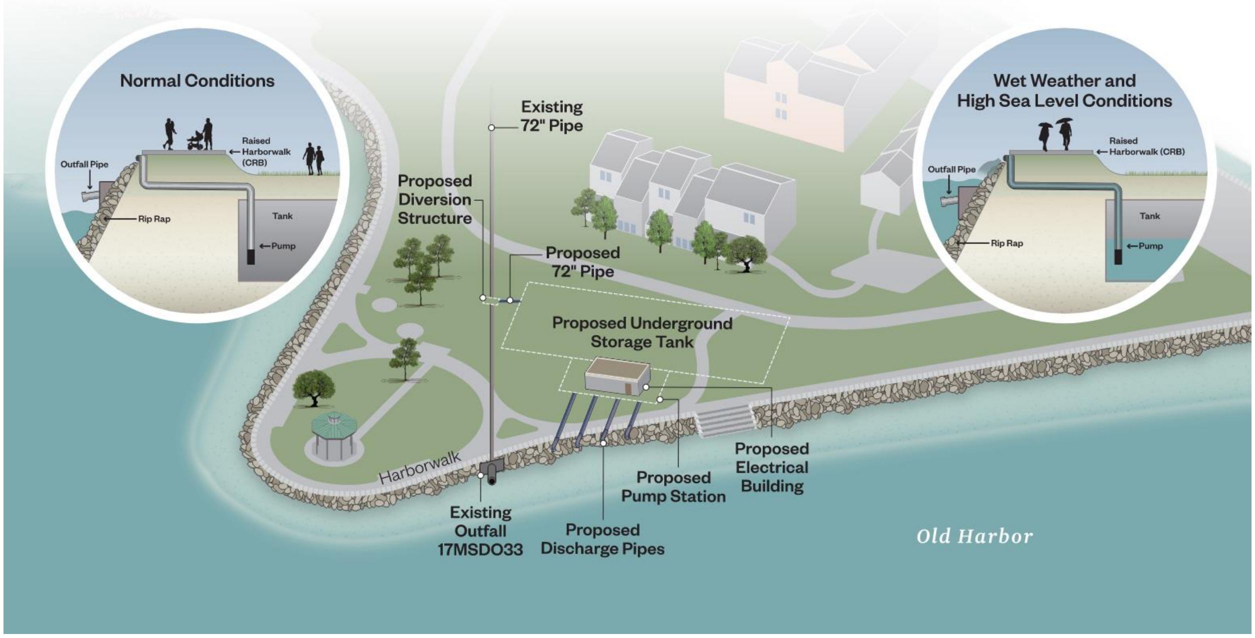


Figure 5-62: Graphic Representation of Old Harbor Park Concept

5.14.2 Basis of Design

Model simulations were conducted to determine the maximum HGL that occurs at Outfall 17MSDO033 with the representative tide elevation of 3.7 ft NAVD88 used in the City's PCSWMM model. Analyses were then conducted to determine the acceptable combinations of storage volume and pumping rate required to maintain the benchmark maximum current-day HGL with 2070 projected sea level rise and 100-year storm surge, as shown in **Figure 5-63**.

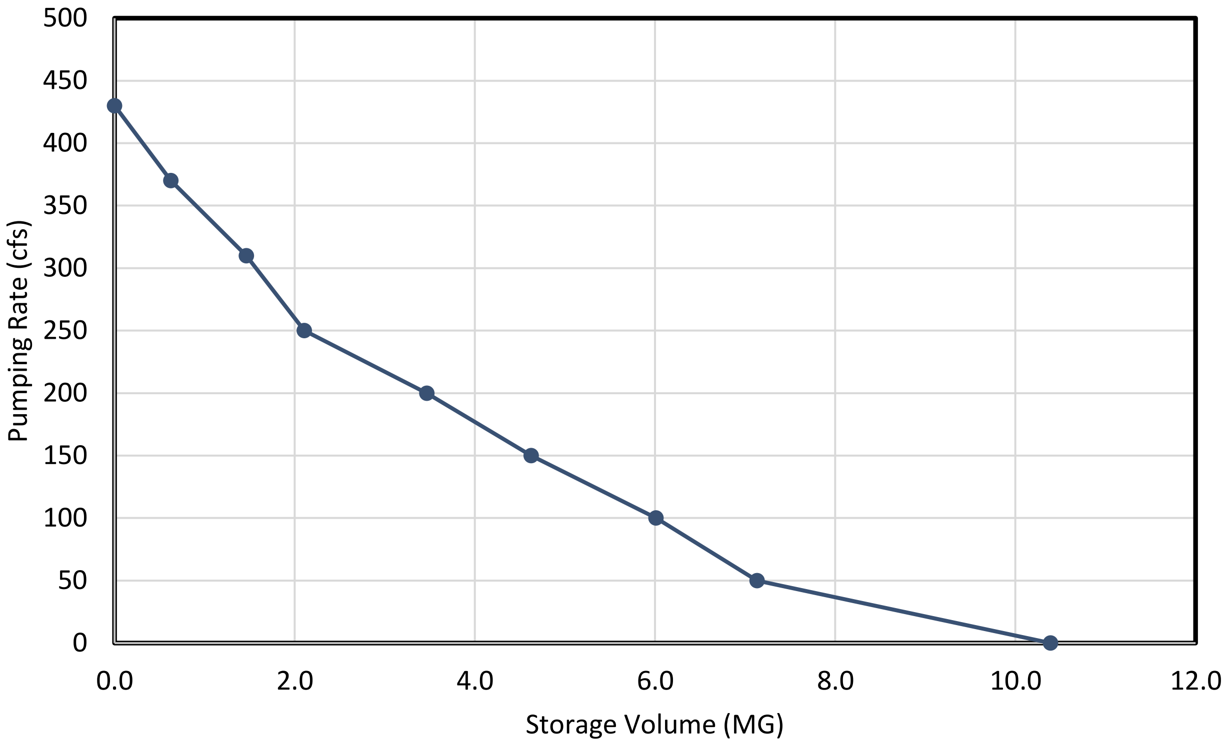
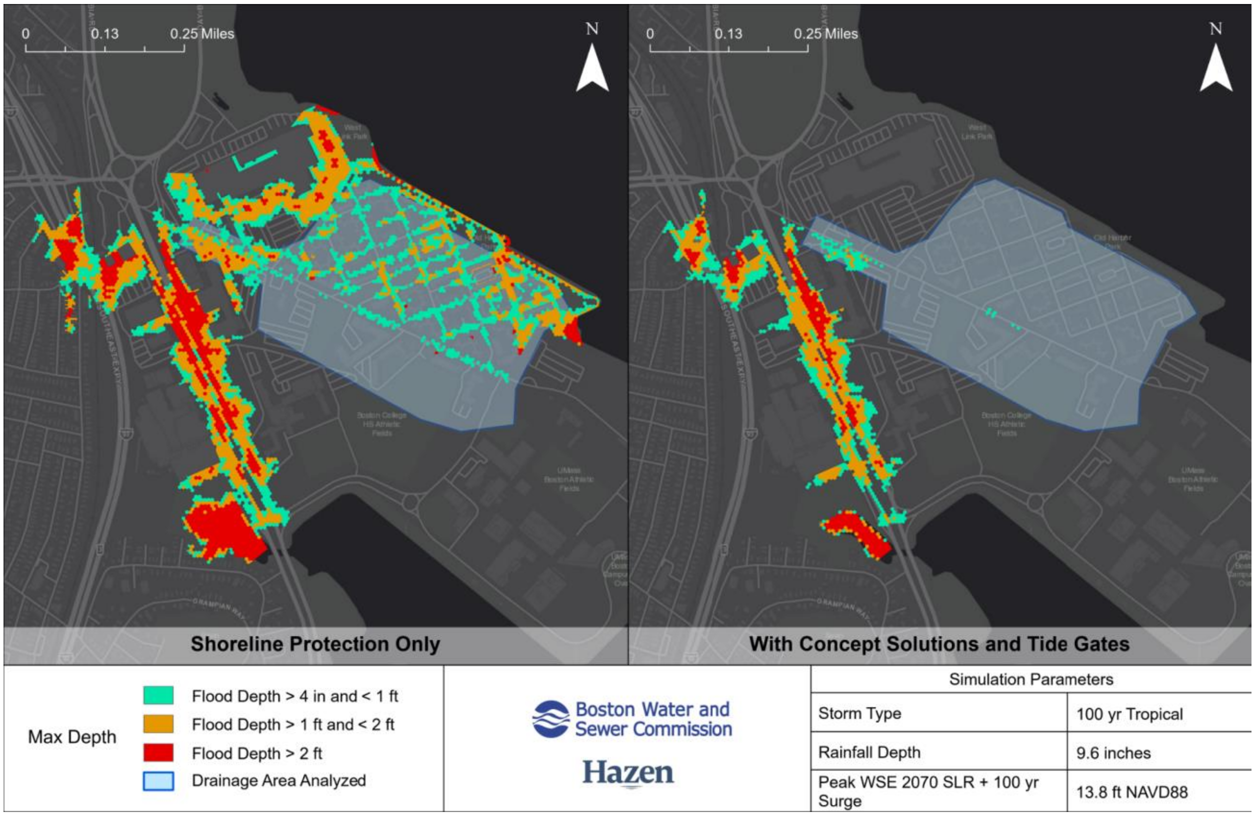


Figure 5-63: Outfall 17MSDO033 Pumping vs. Storage

The City of Boston's Parcel database was used to identify publicly owned parcels near the existing outfall. An analysis of the pump station was performed to identify a pump rate and physical dimensions that are hydraulically viable. It was found that a 1.4 MG storage tank ~25 ft deep could fit within the property with a 306 CFS pump station. The pump station and storage tank occupy an area of 11,260 ft^2. The pump station utilizes three duty pumps, one standby pump, and two dewatering pumps. The pump station is configured with vertical, axial electric submersible pumps in parallel bays. The pumps are configured to discharge into individual, non-manifolded force mains, which travel horizontally underground from the pump station to the proposed elevated shoreline project (TBD by CRB), at which point they discharge into the harbor onto an energy dissipation structure.

5.14.3 Flooding Analysis

The flood reduction benefits of the Old Harbor Park Pump Station concept were evaluated using the Commission’s 2D Inundation Model by simulating a 100-year tropical storm event with 2070 SLR and storm surge. **Figure 5-64** on the following page depicts the peak flooding that was predicted in the Old Harbor Park drainage area with shoreline protection only and with the pump station and tide gates on all vulnerable BWSC owned outfalls.



Simulation Parameters	
Storm Type	100 yr Tropical
Rainfall Depth	9.6 inches
Peak WSE 2070 SLR + 100 yr Surge	13.8 ft NAVD88

Figure 5-64: Harbor Park Pump Station Flood Model Results

Note: **Figure 5-64** *includes a polygon labeled as "drainage area analyzed". This area represents the area which was included in the economic damage/loss analysis described in* **Section 7** *of this report.*

5.14.4 Adaptability and Implementation

The following measures could be implemented to adapt the concept to more severe conditions (additional SLR, more intense rainfall, etc.) in the future:

- Increase the size of installed electric submersible pumps
- Utilize the standby pump as a duty pump during extreme conditions
- Increase the size of peak shaving tank

Implementation of the Old Harbor Park concept requires consideration of the following:

- Coordination with CRB is necessary to implement shoreline protection. The pump station should not be implemented without shoreline protection to prevent coastal flooding within the area tributary to it.
- A comprehensive permitting evaluation should be conducted to evaluate possible impacts from construction and operation of the pump station to the receiving water (recreation area).

- A thorough analysis of constructability should be conducted at this location. Methods to minimize disruptions to residents should be considered during the design process.
- Planting of native plant species and other green features will provide an improved public amenity and preserve the “look and feel” of the greenway.
- Community engagement with stakeholders may help build project support by illustrating the flood control benefits of the pump station.

6. Opinion of Probable Construction Cost

6.1 Basis of Cost

Construction cost opinions include estimates that are considered to be AACE (Association for the Advancement of Cost Estimating) International Class 4, which has a typical accuracy range of -30% to -15% on the low side and +20% to +50% on the high side.

Table 6-1 presents total project costs (including an approximation of design and construction engineering) for each location. The costs in **Table 6-1** for Fort Point Channel and Dorchester Bay Basin exclude the storm surge barriers. Design and Construction Administration costs are calculated based on 20% of the total cost (less design continency).

Table 6-2 presents sub-totals for the storm surge barriers alone, including two different types of barriers for the Fort Point Channel location.

Appendices L and M include detailed cost estimate backup data.

The estimates are comprised of unit costs calculated from a combination of detailed takeoff, forced takeoff, factoring, and allowances. Design contingency carried is at 50% based on the status of the design, the nature of the project, the estimate classification, and estimator judgment for most locations and features, except for the Fort Point Channel and Dorchester Bay Basin storm surge barriers, which carried a 35% contingency. The reason for the difference in estimating level is that the storm surge barrier designs needed to be advanced to a slightly higher level of detail in order to accurately capture the potential construction costs (including temporary costs, such as cofferdam construction).

The estimates include direct and indirect construction costs, as well as markups that represent contractor and subcontractor overhead and profit, escalation to midpoint of construction for labor and materials, bonds/insurance, and contract allowances. The assumed timeframe for construction work is late-2030’s, evident in our assumed escalation (based on 15 years from date of pricing to expected midpoint of construction).

Some items are excluded in the cost estimate, including:

- Land/property easements/purchase/transfers
- Microtunneling or other costs related to railroad or major highway crossings (applies to Dorchester Bay Basin storm sewers)
- Improvements related to Climate Ready Boston projects (shoreline protection)
- Site restoration above and beyond current site conditions

Table 6-1: Concept Cost Estimate Subtotals (Exclusive of Storm Surge Barriers)

	Airport	Charlestown Schrafft Center	Columbus Park	Constitution Beach	Davenport Creek	Dorchester Bay Basin[2]	East Boston Greenway	East Boston Waterfront	Fort Point Channel[1]	Old Harbor Park	Joseph Finnegan Park
Direct Construction Costs	$7,236,248	$11,596,079	$4,731,915	$7,615,841	$17,902,197	$48,774,375	$2,936,938	$6,256,022	$8,968,000	$7,012,000	$9,246,000
Indirect Construction Costs	$1,447,250	$2,319,216	$946,383	$1,523,168	$3,580,439	$9,754,875	$587,388	$1,251,204	$1,794,000	$1,402,000	$1,849,000
Mark-Up (incl. escalation)	$9,645,964	$15,544,944	$6,366,233	$10,209,454	$24,110,121	$65,740,034	$3,926,783	$8,373,533	$11,858,649	$9,319,302	$12,443,046
Construction Sub-total	**$18,329,462**	**$29,460,239**	**$12,044,521**	**$19,348,463**	**$45,592,757**	**$124,269,284**	**$7,451,109**	**$15,880,759**	**$22,620,649**	**$17,733,302**	**$23,538,046**
Design Continency	$8,833,538	$14,197,762	$5,804,479	$9,324,537	$21,972,243	$59,888,716	$3,590,892	$7,653,220	$10,901,147	$8,545,899	$11,343,712
Sub-total	**$27,163,000**	**$43,658,001**	**$17,849,000**	**$28,673,000**	**$67,565,000**	**$184,158,000**	**$11,042,001**	**$23,533,979**	**$33,521,796**	**$26,279,201**	**$34,881,758**
Design & Construction Administration	$3,666,000	$5,893,000	$2,409,000	$3,870,000	$9,119,000	$24,845,000	$1,491,000	$3,177,000	$4,524,000	$3,547,000	$4,708,000
Total Project Cost	**$30,829,000**	**$49,551,001**	**$20,258,000**	**$32,543,000**	**$76,684,000**	**$209,003,000**	**$12,533,001**	**$26,710,979**	**$38,045,796**	**$29,826,201**	**$39,589,758**

Notes:

3. Fort Point Channel location excludes the storm surge barrier estimate; includes only the pump station
4. Dorchester Bay Basin location excludes the storm surge barrier estimate; includes only the conveyance and diversion structures

Table 6-2: Storm Surge Barrier Cost Estimate Subtotals

	Fort Point Channel[1]			**Dorchester Bay Basin**
	Submerged Axis Flap Gate *(4 gates)*	**Submerged Axis Flap Gate - South Location** *(3 gates)*	**Vertical Lift Gate**	**Vertical Lift Gate**
Remaining Design Development & BWSC Construction Administration	$60,553,000	$49,851,000	$36,350,000	$14,169,000
Direct & Indirect Construction Costs Total (Marked-up)*	$329,465,000	$271,236,000	$197,328,000	$76,917,000
Escalation (15 Years)	$240,119,000	$197,682,000	$143,867,000	$56,078,000
Design Contingency	$136,506,000	$112,381,000	$81,788,000	$31,881,000
Total	**$766,643,000**	**$631,150,000**	**$459,333,000**	**$179,045,000**

Notes:

2. Fort Point Channel location excludes the pump station estimate; includes only the storm surge barrier portion of the cost.

7. Damage Analysis

Hazen and its subconsultant, risQ, Inc. (recently acquired by Intercontinental Exchange, Inc.), developed estimates of economic impact (i.e., damage) on the physical environment (i.e., buildings, etc) due to flooding under the scenarios described in Section 4.2 (and shown throughout Section 5 for each concept), through calculations of three metrics:

- Replacement value (of buildings) – total value of the impacted buildings in each area, based on rebuild cost; this is a conservative number as it assumes the entire structure needs to be rebuilt regardless of flood depth/duration; a structure is included in the cost if flooding is predicted to encroach it
- Physical damage (to buildings) – presented as both minimum, maximum values (and a simple average of the two numbers)
    - Minimum values are based on the affected buildings as indicated by the minimum predicted depth of flooding in the area and the lower value of replacement cost estimates (a range was evaluated)
    - Maximum values are based on the affected buildings as indicated by the maximum predicted depth of flooding in the area and the higher value of replacement cost estimates (a range was evaluated)
- Lost Usage - Gross Domestic Product (GDP) impairment, presented as both minimum, maximum (and a simple average of the two numbers); includes:
    - Business interruption for commercial and industrial properties
    - Lost rental income and property taxes for residential properties

Model-predicted flooding data (in the form of GIS shapefiles) from the 2D Inundation Model simulations, for the 100-year tropical storm event, were input into risQ's economic database/framework. Two scenarios were evaluated: 1) Shoreline protection only (CRB proposed projects), and 2) Shoreline protection + conceptual solution (flood mitigation). Economic impacts before and after the solutions are implemented were calculated, for each "area of interest", which correspond to the outfall tributary areas at each conceptual design location.

This Section provides a concise summary of the economic damage analysis performed, but for additional detail please refer to **Appendix K** for the full report. Values reported in **Table 7-1** are shown in 2022 dollars and are reported in thousands for simplicity.

A database of building locations and their physical attributes was created for the areas of interest impacted by the simulated storm events. To enable data sharing, open-source data obtained from the Boston Planning and Development Agency, together with data from the City of Boston Tax Assessor Department were used. Modeling of flood-induced damage to buildings considered foundation type and the presence or absence of a basement, which were the main drivers of resulting damage.

Various modeling techniques were used in allocating the physical building attributes, which required validation via random sampling and manual inspection. These techniques and results are presented. The modeled output from the storm surge simulations included gridded physical flood parameters such as ground surface water elevations, flow velocity, and depths. The horizontal spatial resolution of the hexagonal grids was approximately 10 meters.

Damage was estimated by applying standard physical risk loss modeling techniques, where hazard intensities are linked to building damages using vulnerability functions. The vulnerability functions provide potential individual building damage estimates as percentages of a building's replacement costs for a given intensity. The functions used accounted for both flood depth and velocity, and distinguish damage by building occupancy, height, and foundation type. Uncertainty in the calculation of building replacement costs and flood parameters impacting each building are also accounted for. This enables a range of loss estimates for each area of interest's scenario.

Although location-level individual building data is used to model damages for each scenario, it should be made clear that the approach, and vulnerability functions used in the modeling process, can only provide typical expected losses. For more accurate, actual building specific loss to be calculated much more detail in terms of the individual buildings physical characteristics would be required. This statement is particularly true for the engineered mid-and high-rise structures, and structures servicing more complex occupancies within the areas of interest. Damage to infrastructure including bridges, roads, train tracks & stations, utility infrastructure (e.g., power lines, substations, communication networks, and water treatment plants) were not included.

In all areas of interest evaluated, it can be concluded that a significant benefit could be realized by implementation of the proposed concepts, in terms of risk of damage avoided.

Table 7-1: Economic Damage Analysis Results (Thousands of Dollars)

Area	Scenario	Replacement Value of Impacted Buildings	Min Physical Damage	Max Physical Damage	Average Physical Damage	Min Lost Usage	Max Lost Usage	Average Lost Usage
Fort Point Channel	Shoreline Protection Only	20,470,236	2,938,938	5,105,728	4,022,333	1,842,013	3,894,824	2,868,419
Fort Point Channel	Conceptual Solution	4,616,728	676,619	1,145,390	911,005	86,588	225,193	155,891
Joseph Finnegan Park	Shoreline Protection Only	152,077	24,789	41,516	33,153	46,119	77,888	62,004
Joseph Finnegan Park	Conceptual Solution	30,029	4,290	7,025	5,658	12,606	21,034	16,820
Old Harbor Park	Shoreline Protection Only	310,681	45,805	76,698	61,252	27,815	76,874	52,345
Old Harbor Park	Conceptual Solution	0	0	0	0	0	0	0
East Boston Waterfront	Shoreline Protection Only	482,821	69,255	115,439	92,347	7,805	22,399	15,102
East Boston Waterfront	Conceptual Solution	6,789	987	1,665	1,326	8	29	19
Constitution Beach	Shoreline Protection Only	519,621	52,906	89,495	71,201	22,837	42,692	32,765
Constitution Beach	Conceptual Solution	166,283	2,382	3,991	3,187	6,055	10,115	8,085
East Boston Greenway	Shoreline Protection Only	12,754	2,008	3,392	2,700	20	54	37
East Boston Greenway	Conceptual Solution	0	0	0	0	0	0	0

Area	Scenario	Replacement Value of Impacted Buildings	Min Physical Damage	Max Physical Damage	Average Physical Damage	Min Lost Usage	Max Lost Usage	Average Lost Usage
Dorchester Bay Basin	Shoreline Protection Only	1,408,902	186,031	315,066	250,549	326,320	866,024	596,172
Dorchester Bay Basin	Conceptual Solution	467,912	50,691	84,433	67,562	78,449	225,660	152,055
Davenport Creek	Shoreline Protection Only	161,816	22,380	37,466	29,923	10,053	17,382	13,718
Davenport Creek	Conceptual Solution	0	0	0	0	0	0	0
Columbus Park	Shoreline Protection Only	4,432,483	714,699	1,239,409	977,054	1,232,970	2,281,389	1,757,180
Columbus Park	Conceptual Solution	1,258,120	186,800	324,124	255,462	370,274	867,807	619,041
Charlestown Schrafft Center	Shoreline Protection Only	115,431	14,032	24,831	19,432	8,625	36,397	22,511
Charlestown Schrafft Center	Conceptual Solution	6,281	757	1,262	1,010	0	$2	$1
Boston Logan Airport	Shoreline Protection Only	883,069	125,137	214,588	169,863	74,862	199,502	137,182
Boston Logan Airport	Conceptual Solution	54,545	5,787	10,028	7,908	2,490	8,319	5,405

Notes:

2. Costs are presented in 2022 dollars (no net present value assumed)

8. Implementation Timeline

Although the primary focus of this project was to identify the Commission's most critical and vulnerable outfalls and develop conceptual adaptation solutions at a subset of these outfalls, it is important to recognize that the Commission's stormwater system depends on the functionality of several hundred outfalls that are located throughout the City. To address the outfalls that were not advanced to the conceptual design phase of this project, an Implementation Timeline was developed that can be used as a "roadmap" to adapt these remaining outfalls. The Implementation Timeline is included as **Appendix E**.

8.1 Methodology and Summary

The Implementation Timeline only includes outfalls which are owned by the Commission (based on GIS data provided by the Commission in 2020). Outfalls were further screened based on coastal flood vulnerability. Outfalls with inverts above 13.8 ft NAVD88 (the approximate projected 100-year storm surge elevation in 2070) were considered not coastal flood vulnerable, and excluded from the Implementation Timeline, as shown in **Figure 8-1**.

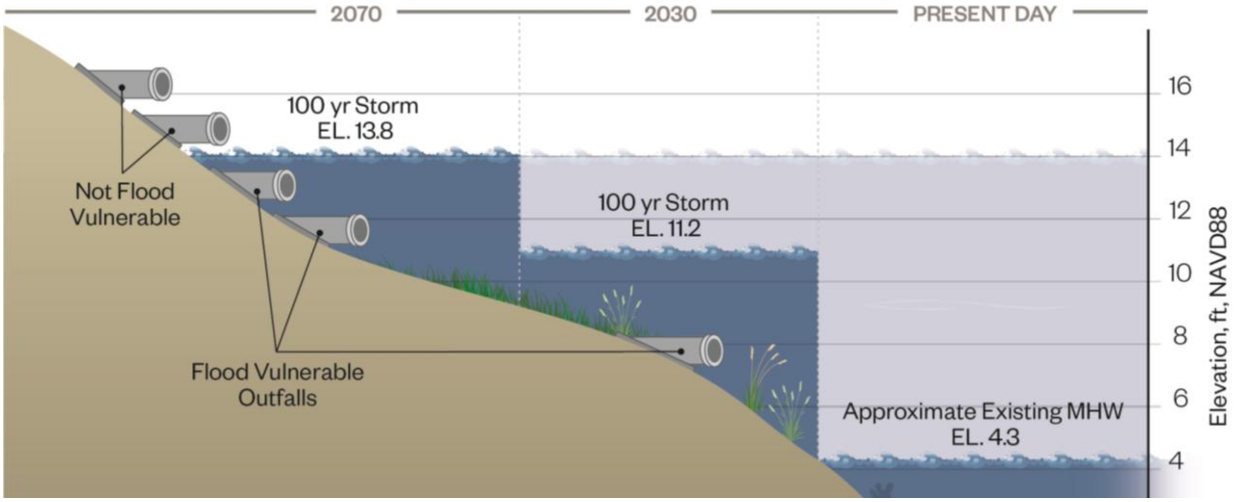


Figure 8-1: Outfall Screening for Implementation Timeline

A second tier of screening was applied by analyzing the approximate drainage areas served by outfalls classified as coastal flood vulnerable and segregating them from outfalls that are not vulnerable. Outfalls which serve higher elevation drainage areas (above 13.8 ft, NAVD88) may be influenced by higher sea levels (at their downstream end), but still function as intended and discharge by gravity without additional modifications required (since they are not vulnerable to the coastal flood conditions evaluated herein). Thus, these outfalls which serve areas with low coastal flood vulnerability (as depicted in **Figure 8-2**) were not included in the Implementation Timeline.

Figure 8-2: Illustration of Coastal Flood Vulnerability

By following this two-tier screening process, a total of 66 outfalls were identified for inclusion in the Implementation Timeline.

A key objective when identifying a potential solution for each of the Implementation Timeline outfalls was replication of the design concepts developed in **Section 5** of this report. The solutions identified in the Implementation Timeline can be classified into the following categories:

- **Pump Station:** electric submersible units installed within wet wells or subsurface storage tanks to discharge stormwater against high tides.
- **Storage:** solutions that utilize natural features or constructed tanks and wetlands to manage flow from outfalls.
- **Storm Surge Barrier:** a structure that blocks higher tide levels and storm surge conditions from entering a protected area to maintain low tailwater elevations. Solutions utilizing a storm surge barrier typically “protect” multiple coastal flood vulnerable outfalls.
- **Conveyance:** modifications to existing pipe networks (or construction of new piping) to facilitate gravity drainage.
- **Consolidation and Pump Station:** new pipelines to intercept flow from multiple outfalls for conveyance to a single pump station.
- **Tide Gate:** devices/structures that prevent backflow of water through outfalls. Other improvements may be required to eliminate residual flooding in the future.
- **Local Stormwater Management:** solutions that temporarily manage excess stormwater “on site” during high tide conditions.

Figure 8-3 depicts the classification of all outfalls included in both the Concept Designs (described in Section 5) and the Implementation Timeline.

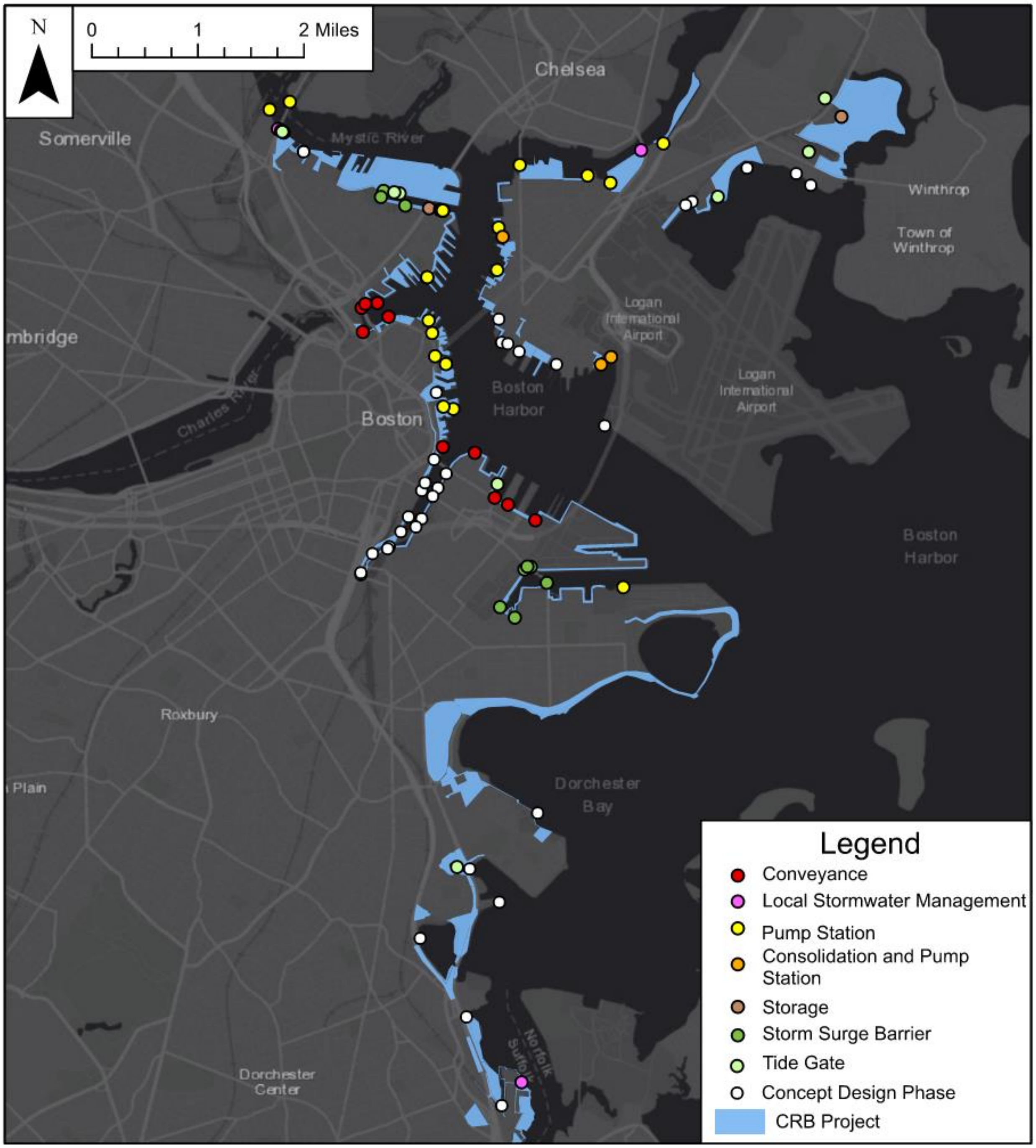


Figure 8-3: Classification of Outfall Concepts

Due to the mostly flat topography of many neighborhoods (including Downtown and parts of East Boston) there are a large number of outfalls that will require adaptation to continue functioning as intended with higher sea levels. For the purposes of this Implementation Timeline, many of these outfalls were classified into the “Pump Station” solution category. Where possible, directly adjacent outfalls were classified as “Consolidation and Pump Station”, indicating that flow from these outfalls could be consolidated and redirected to a single pump station. In dense areas (such as Downtown) where pipeline construction and outfall consolidation could be more disruptive than construction of several separate pump stations, outfalls were added to the “Pump Station” category. A future study should evaluate the feasibility of consolidating outfalls in greater detail to minimize the large number of separate pump stations that would be required without consolidation. This future work could include advancement of an additional group of outfalls to the concept design phase.

8.2 Implementation Timeline “Regional” Solutions

Although most outfalls included in the Implementation Timeline are managed with a specific solution local to each individual outfall, several opportunities for “regional” solutions (similar to the Dorchester Bay Basin and Fort Point Channel concepts) were identified for future consideration. These regional solutions can be broadly categorized as conveyance-based or storm surge barrier-based. As with all other storm surge barrier concepts, additional coordination with Climate Ready Boston is required to determine the interplay between planned shoreline protection projects and coastal barriers. By prioritizing the development of regional solutions, the Commission can develop adaptations that protect large vulnerable portions of the City with a small number of projects and leverage existing coastal geometries to minimize the need for distributed pumping systems and storage facilities throughout the City.

Note: the regional Implementation Timeline solutions documented in this Section are preliminary planning level concepts only. A more detailed assessment (concept design) of feasibility, preliminary design work, and modeling evaluations has not been performed.

8.2.1 Charles River Dam

Currently, outfalls which discharge to the Charles River are considered protected by the Charles River Dam and pump station, which regulate the water level in the river basin during rain and high tide events. Redirection of flow from outfalls which are subject to tidal fluctuations (including SLR and storm surge) to new outfalls behind the Charles River Dam was considered during development of the Implementation Timeline. **Figure 8-4** depicts outfalls located in Charlestown and the North End which could be redirected to new outfalls behind the Charles River Dam.

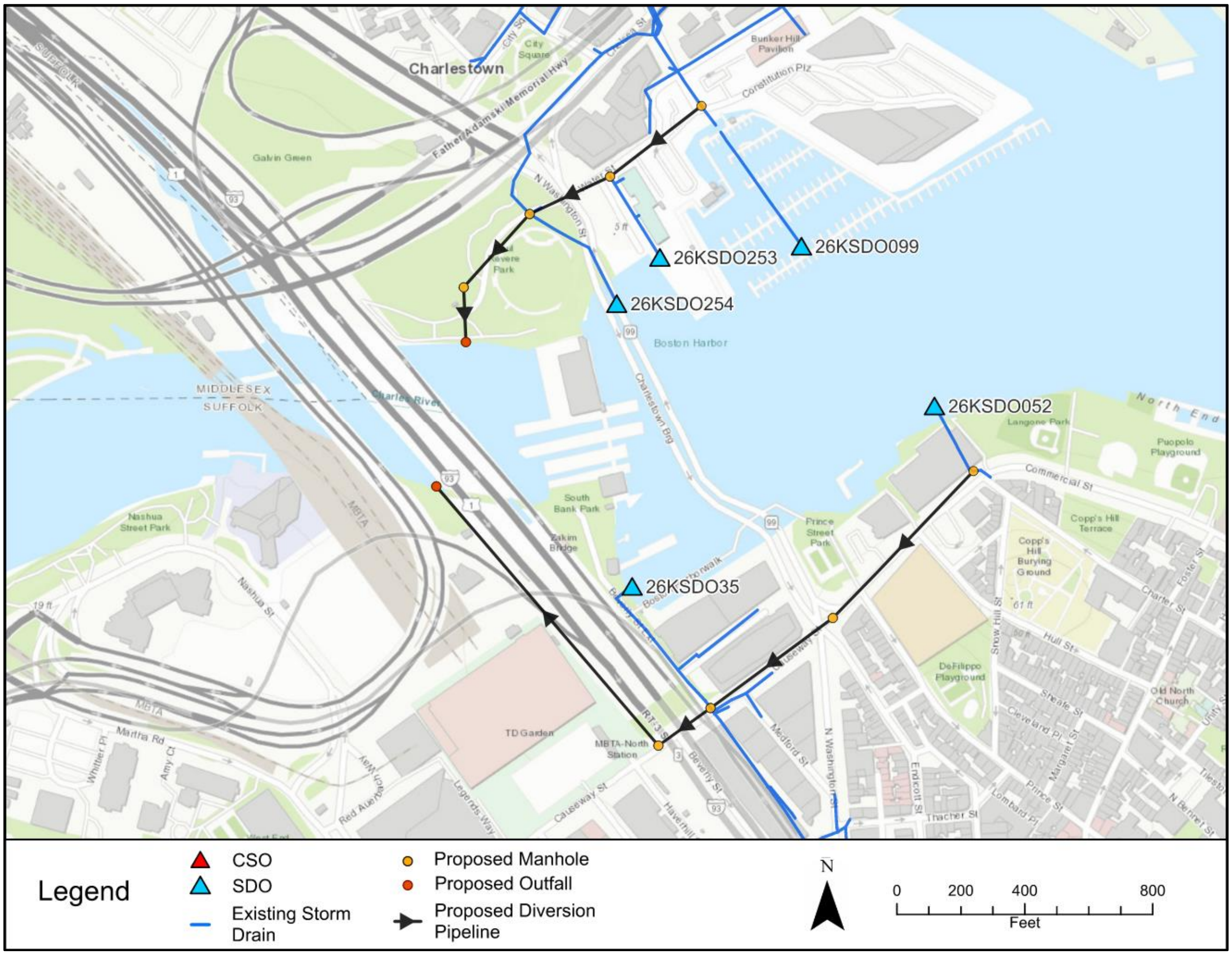


Figure 8-4: Outfall Diversion to Charles River Dam

8.2.2 Little Mystic Channel

Several outfalls that provide drainage to the apartment complexes located along Medford Street in Charlestown and Massport facilities could be protected by a SSB located to the west of the Tobin Bridge, as shown in **Figure 8-5**. Coordination to provide tie-ins (on both sides of the Channel) with Massport would be required to prevent flanking of the SSB.

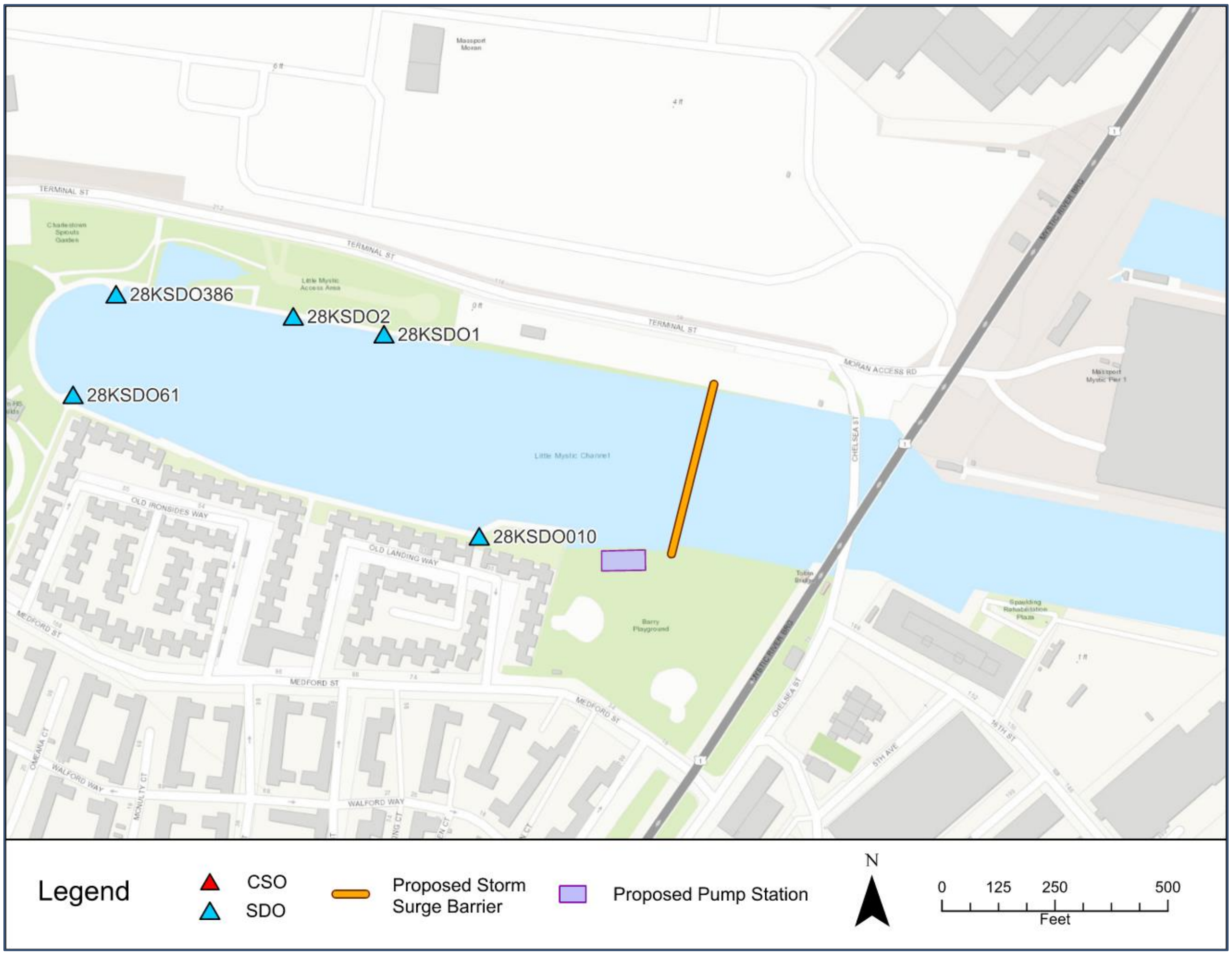


Figure 8-5: Little Mystic Channel Storm Surge Barrier

Five storm drains lie at the mouth of the Little Mystic Channel that could also benefit from flood protection, depending on the placement of the Little Mystic storm surge barrier. An alternative solution for those five outfalls would be to utilize the surrounding publicly owned land and install subsurface storage and a pump station, depicted in **Figure 8-6.**

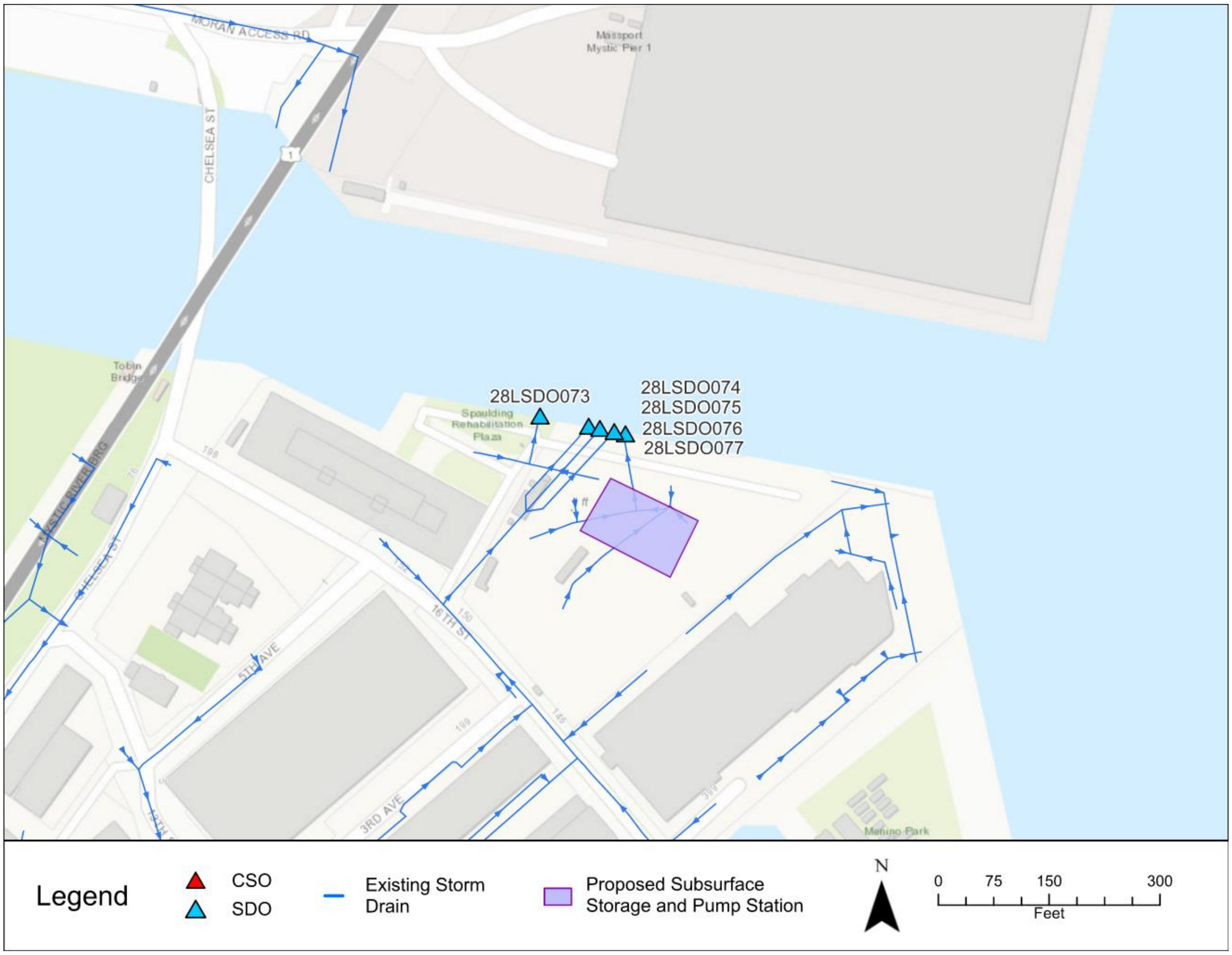


Figure 8-6: Little Mystic Channel Subsurface Storage and Pump Station

8.2.3 Fort Point Channel

As documented in **Section 5** of this report, a SSB constructed in the vicinity of the Northern Avenue Bridge could protect numerous Commission owned outfalls (as well as outfalls that are privately owned or owned by other agencies) from high sea levels. In addition to the outfalls which currently discharge to the region of the FPC that would be protected by the SSB, there are additional outfalls which currently provide drainage service to the Seaport neighborhood that could be consolidated with a new conduit (similar to the East Boston Waterfront solution documented in **Section 5**) and redirected to the "protected" region of the FPC (i.e., behind the SSB proposed there), as shown in **Figure 8-7**. The feasibility of this solution should be considered before advancing the FPC concept to final design, so that the additional inflow is accounted for when advancing the design of the FPC SSB pump station. As documented in **Section 5**, there is flexibility in the current FPC SSB pump station concept to accommodate additional pumping capacity.

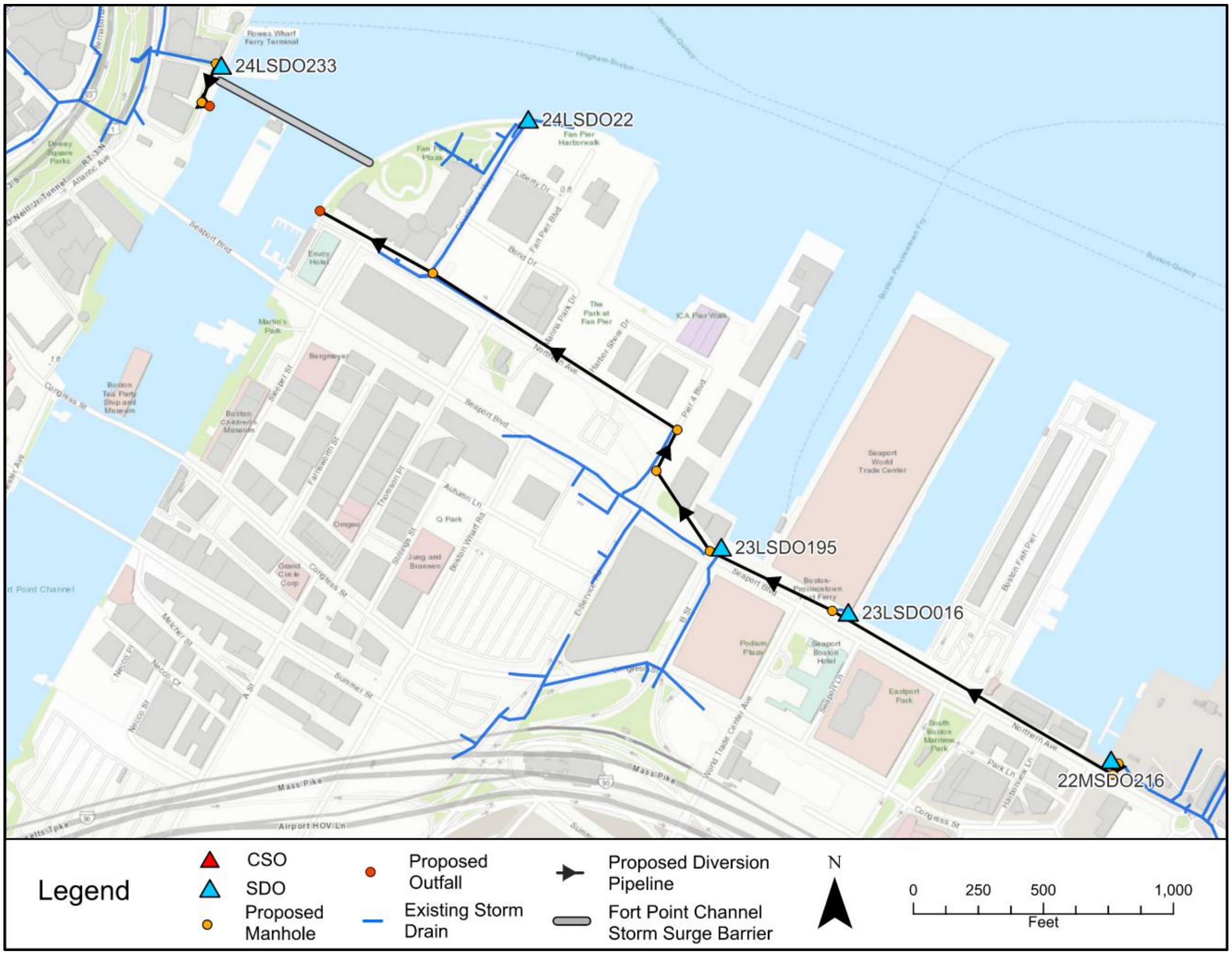


Figure 8-7: Conveyance to the Fort Point Channel Storm Surge Barrier

8.2.4 Reserved Channel

The Reserved Channel is an important waterway in Boston that allows for navigation of large vessels including container and cruise ships. As such, the feasibility of constructing a SSB at the mouth of the channel (similar to the FPC) is limited due the restrictions it would impose on navigation. However, the portion of the channel to the east of the Summer Street bridge is not used for navigation by these large vessels, and could possibly be protected by a SSB, as shown in **Figure 8-8**. This concept would protect six vulnerable outfalls owned by the Commission, as well as providing flood protection to the coastal infrastructure in the region.

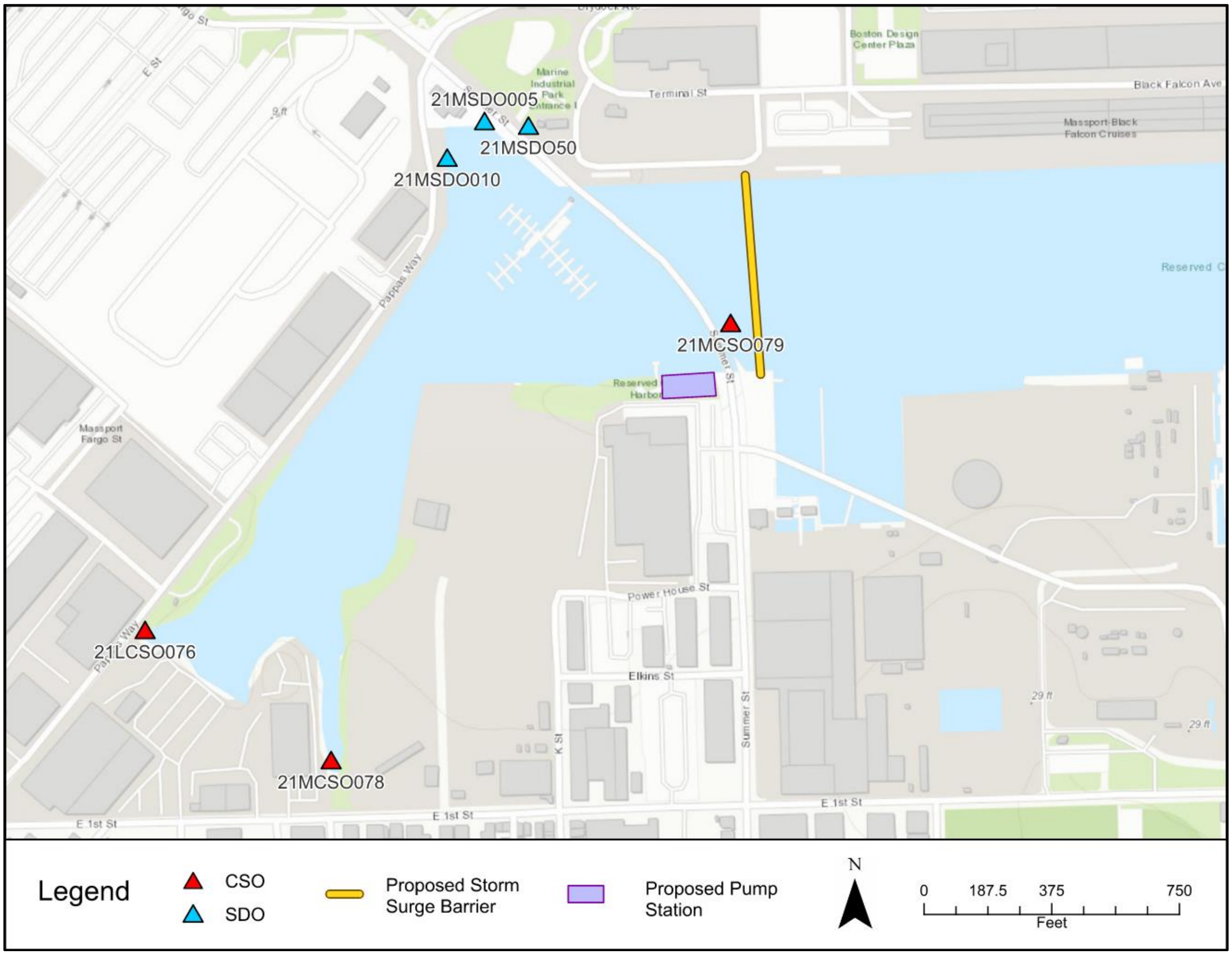


Figure 8-8: Reserved Channel Storm Surge Barrier and Pump Station

8.2.5 Bearse Avenue

Bearse Avenue is a residential street adjacent to the Neponset River Reservation, which provides opportunity for nature-based stormwater management solutions. A detention pond could be installed off Bearse Avenue, collecting flow from nearby outfalls, as shown in **Figure 8-9**. Some construction limitations may be posed by the swamps in the Neponset River Reservation. Note that shoreline protection (by CRB or others) would be essential to the feasibility of this potential solution.

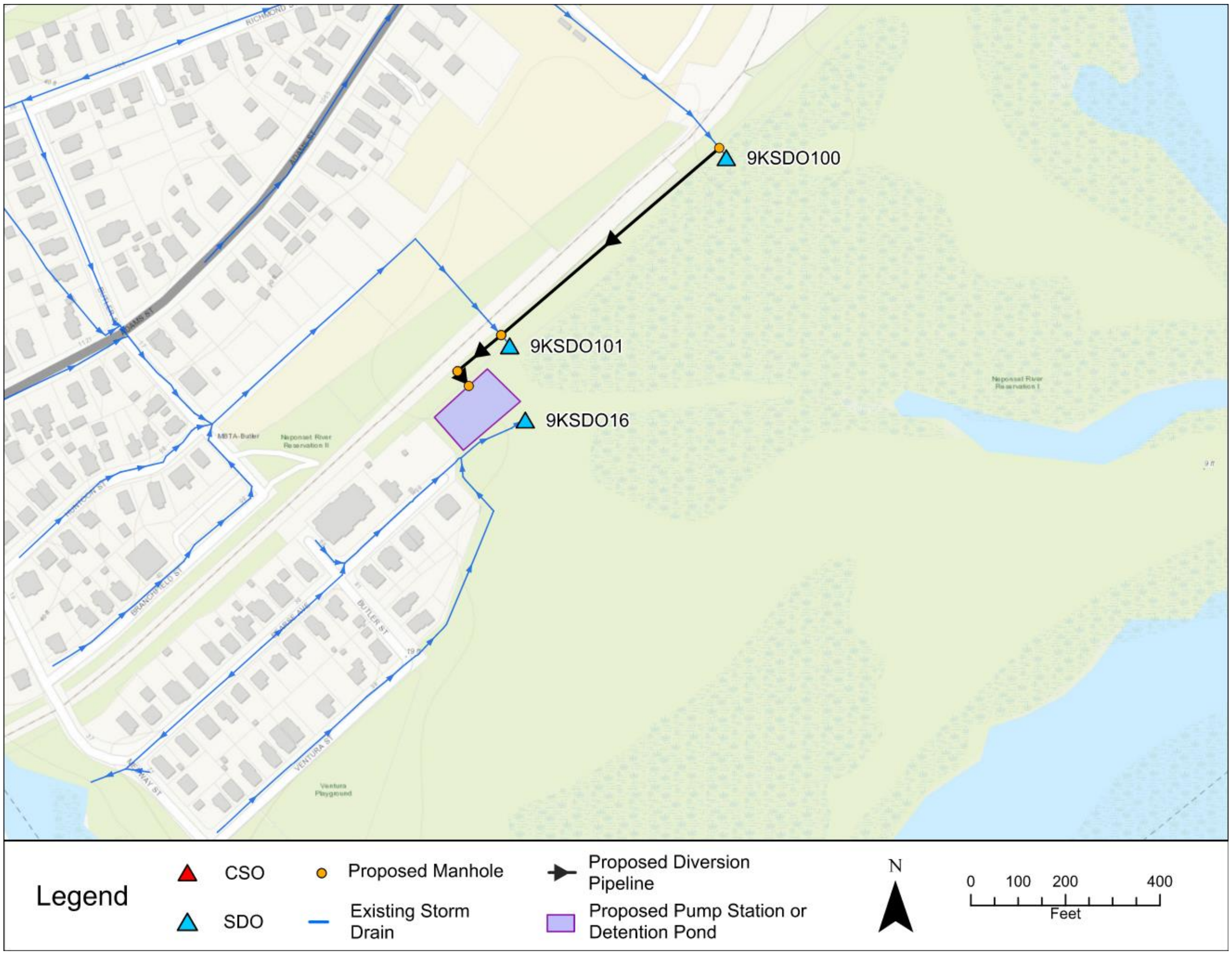


Figure 8-9: Bearse Avenue Detention Pond

8.2.6 Charlestown Naval Shipyard Park

The outfalls located at Charlestown Naval Shipyard Park provide drainage for the residential buildings along Chelsea Street and Bunker Hill Street. The park is publicly owned and provides an opportunity for subsurface storage and a pump station for stormwater management, as shown in **Figure 8-10**.

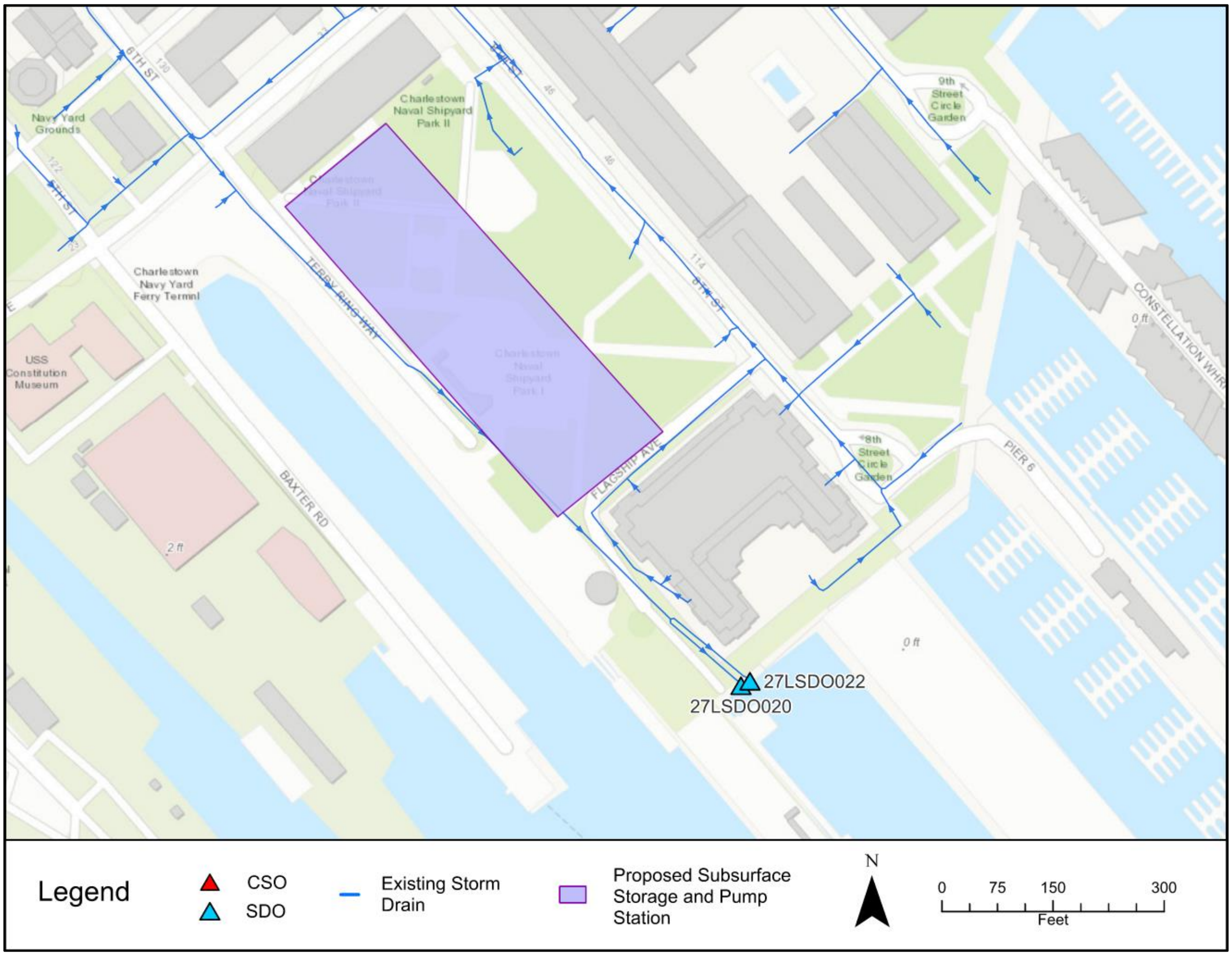


Figure 8-10: Charlestown Naval Shipyard Park Storage and Pump Station

8.2.7 Porzio Park

Porzio Park is a small park on the waterfront of East Boston. Two combined outfalls serve the neighborhood bordering the park and flow into Boston Harbor. These two outfalls could be consolidated, and subsurface storage could be installed in the public land near Porzio Park for stormwater management, as shown in **Figure 8-11.**

It is important to note that outfall 24NCSO004 currently discharges combined sewer overflows. The feasibility of this solution is dependent on sewer separation being constructed and conversation of the CSO outfall to a storm drain outfall.

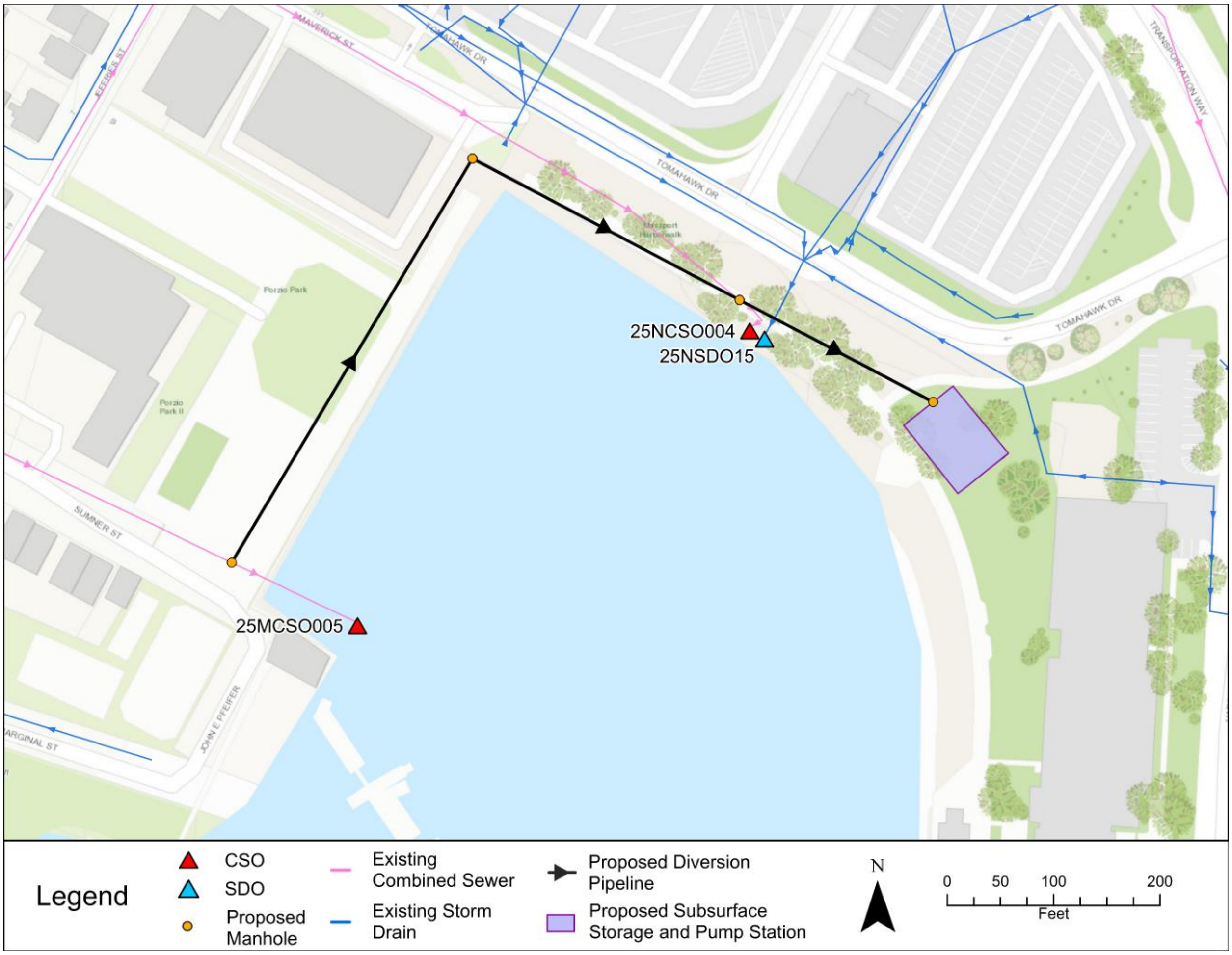


Figure 8-11: Porzio Park Consolidation and Storage

8.3 Replicability

Elements from one or more of the concept designs are applicable to each outfall within the implementation timeline. **Table 8-1** summarizes the design elements of the concept designs and the outfalls in the Implementation Timeline. Note that concepts with the design element ‘Storm Surge Barrier’ also include elements of storage implicit to the SSB. The design element of ‘Storage’ refers to subsurface storage or natural basins at ground level which do not fall into the category of SSBs. More detail and description of the “Implementation Timeline Outfalls” can be found in the full Implementation Timeline report, submitted under a separate cover.

Table 8-1: Replicable Concept Elements

Concept/Outfall	Conveyance	Storage	Pump Station	Tide Gates	Storm Surge Barrier
Coastal Stormwater Design Concepts					
Airport		✓	✓	✓	
Constitution Beach		✓	✓	✓	
East Boston Waterfront	✓		✓	✓	
East Boston Greenway		✓	✓	✓	
Charlestown Schrafft Center		✓	✓	✓	
Columbus Park		✓	✓	✓	
Fort Point Channel			✓	✓	✓
Davenport Creek	✓	✓	✓	✓	
Dorchester Bay Basin	✓			✓	✓
Joseph Finnegan Park		✓	✓	✓	
Old Harbor Park		✓	✓	✓	
Implementation Timeline Outfalls					
10LSDO096				✓	
12MSDO091	✓				
16LSDO097				✓	
21NCSO80		✓	✓	✓	
23LSDO211				✓	
25LCSO057			✓		
24LCSO060			✓	✓	

Concept/Outfall	Conveyance	Storage	Pump Station	Tide Gates	Storm Surge Barrier
26LSDO106		✓	✓		
26LSDO70		✓	✓		
27LCSO10		✓	✓		
28LCSO012		✓	✓		
28LCSO019		✓			
24LSDO244		✓		✓	
25LSDO144		✓	✓		
28LSDO011	✓				
28OSDO25		✓		✓	
29JCSO108			✓	✓	
29JSDO029				✓	
29JSDO129				✓	
29JSDO213				✓	
29JSDO214				✓	
29MCSO013			✓	✓	
29MSDO049		✓	✓		
29NCSO014			✓		
29NSDO015				✓	
29NSDO135		✓	✓		
29PSDO15				✓	
30JSDO19			✓	✓	
30JSDO30			✓	✓	
30PSDO107				✓	
30PSDO062		✓			
8KSDO49		✓		✓	
9LSDO095				✓	
21MCSO078			✓	✓	✓
21MCSO079			✓		✓
21MSDO010			✓		✓
21MSDO005			✓	✓	✓
21MSDO50			✓		✓

Concept/Outfall	Conveyance	Storage	Pump Station	Tide Gates	Storm Surge Barrier
21LCSO076			✓	✓	✓
22MSDO216	✓				✓
23LSDO195	✓				✓
23LSDO016	✓				✓
24LSDO22	✓				✓
24LSDO233	✓				✓
25MCSO005	✓	✓	✓		
25NCSO004	✓	✓	✓	✓	
26KSDO052	✓				
26KSDO099	✓				
26KSDO253	✓				
26KSDO254	✓				
26KSDO35	✓				
27LSDO020		✓	✓		
27LSDO022		✓	✓		
28KSDO010			✓		✓
28KSDO1			✓	✓	✓
28KSDO2			✓	✓	✓
28KSDO386			✓		✓
28KSDO61			✓	✓	✓
28LSDO076		✓	✓		
28LSDO077		✓	✓		
28LSDO073		✓	✓		
28LSDO074		✓	✓		
28LSDO075		✓	✓		
9KSDO100	✓	✓	✓		
9KSDO101	✓	✓	✓		
9KSDO016	✓	✓	✓		

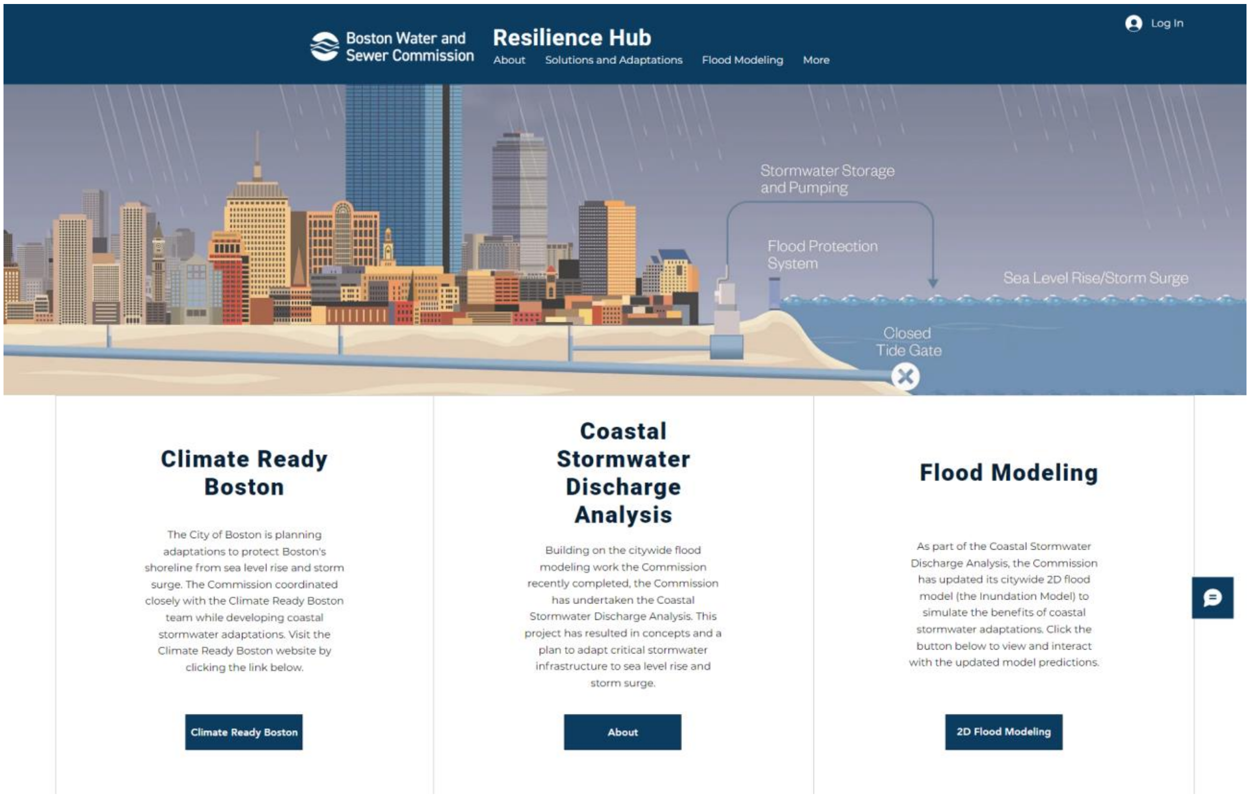
8.4 Other Considerations

It is important to note that the Coastal Stormwater Discharge Analysis project did not evaluate or consider the many outfalls within the City of Boston that are outside of the Commission's jurisdiction. Throughout the City, there are a multitude of coastal flood vulnerable outfalls that are owned privately or by other agencies. At a minimum, a multi-jurisdictional/agency/stakeholder effort should be undertaken to identify these exposed/vulnerable outfalls and determine which should be adapted with installation of tide gates. These unprotected outfalls are a significant vulnerability, and potential source of Citywide flooding during future coastal storm events. If these outfalls are not identified and protected, they have the potential to serve as "holes" in a coastal defense strategy that includes shoreline elevation and adaptation of the Commission's outfalls. The adaptation strategies identified in this document could be modified to include, or replicated at, these non-Commission outfalls.

9. Resilience Hub

The Resilience Hub is an interactive web-based platform that builds upon the work the Commission has done to provide visually-intuitive coastal flood modeling results in the Inundation Model Viewer (www.bwscstormviewer.com). This "Hub" provides additional information beyond flood vulnerability/modeling results.

The home page of the Resilience Hub, shown in **Figure 9-1**, features blurbs about the Coastal Stormwater Discharge Analysis and the Inundation Model, as well as links to the corresponding pages on the website where readers can learn more. The home page also includes a link to the City's Climate Ready Boston website, for the latest information on those efforts to protect the shoreline.



Climate Ready Boston

The City of Boston is planning adaptations to protect Boston's shoreline from sea level rise and storm surge. The Commission coordinated closely with the Climate Ready Boston team while developing coastal stormwater adaptations. Visit the Climate Ready Boston website by clicking the link below.

Coastal Stormwater Discharge Analysis

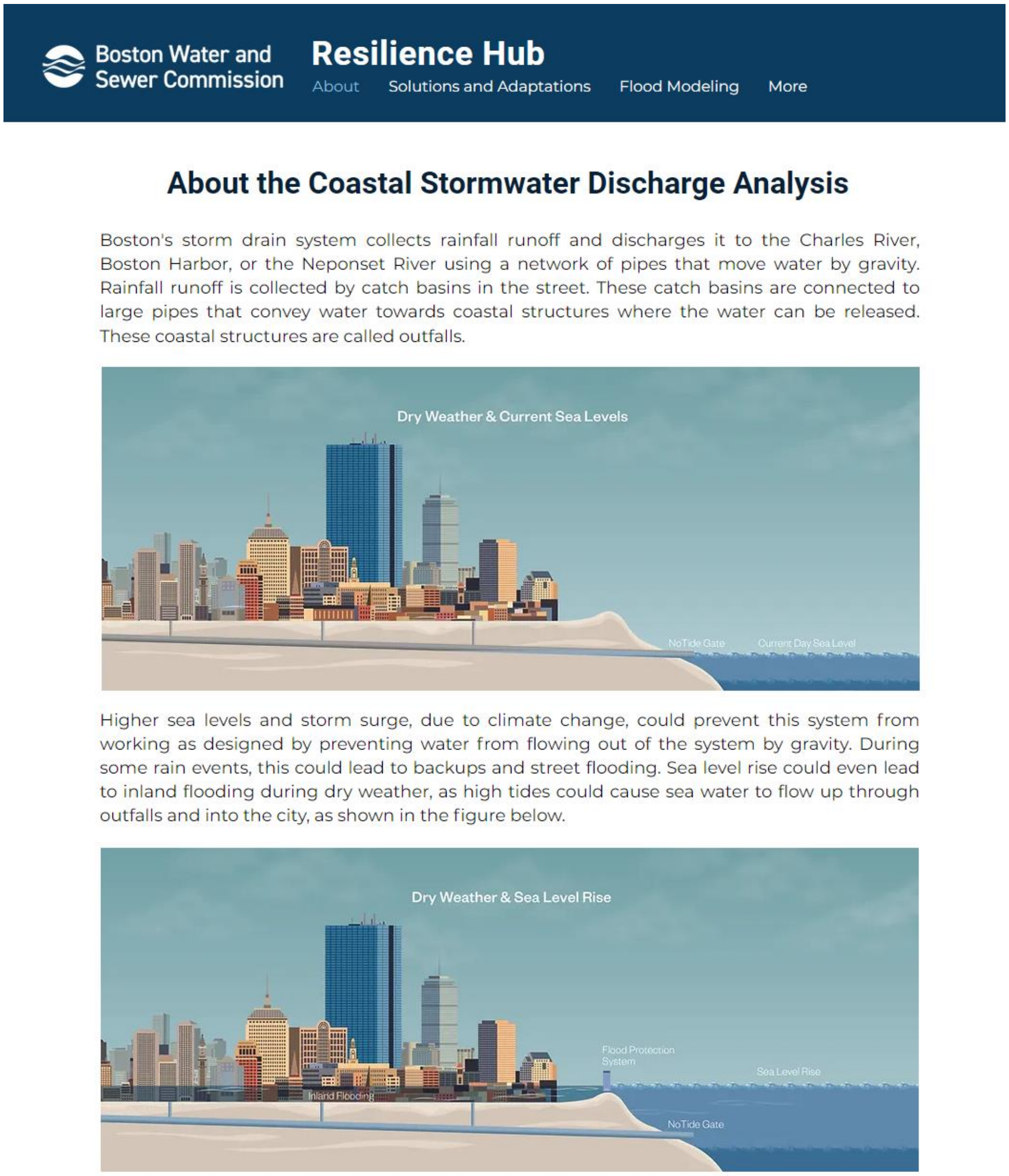
Building on the citywide flood modeling work the Commission recently completed, the Commission has undertaken the Coastal Stormwater Discharge Analysis. This project has resulted in concepts and a plan to adapt critical stormwater infrastructure to sea level rise and storm surge.

Flood Modeling

As part of the Coastal Stormwater Discharge Analysis, the Commission has updated its citywide 2D flood model (the Inundation Model) to simulate the benefits of coastal stormwater adaptations. Click the button below to view and interact with the updated model predictions.

Figure 9-1: Resilience Hub Homepage

The About page, shown in **Figure 9-2**, includes a description, with illustrative figures, of how sea level rise impacts outfalls and can lead to inland flooding. The page then describes the objectives of the Coastal Stormwater discharge analysis and the progress so far on conceptual designs.



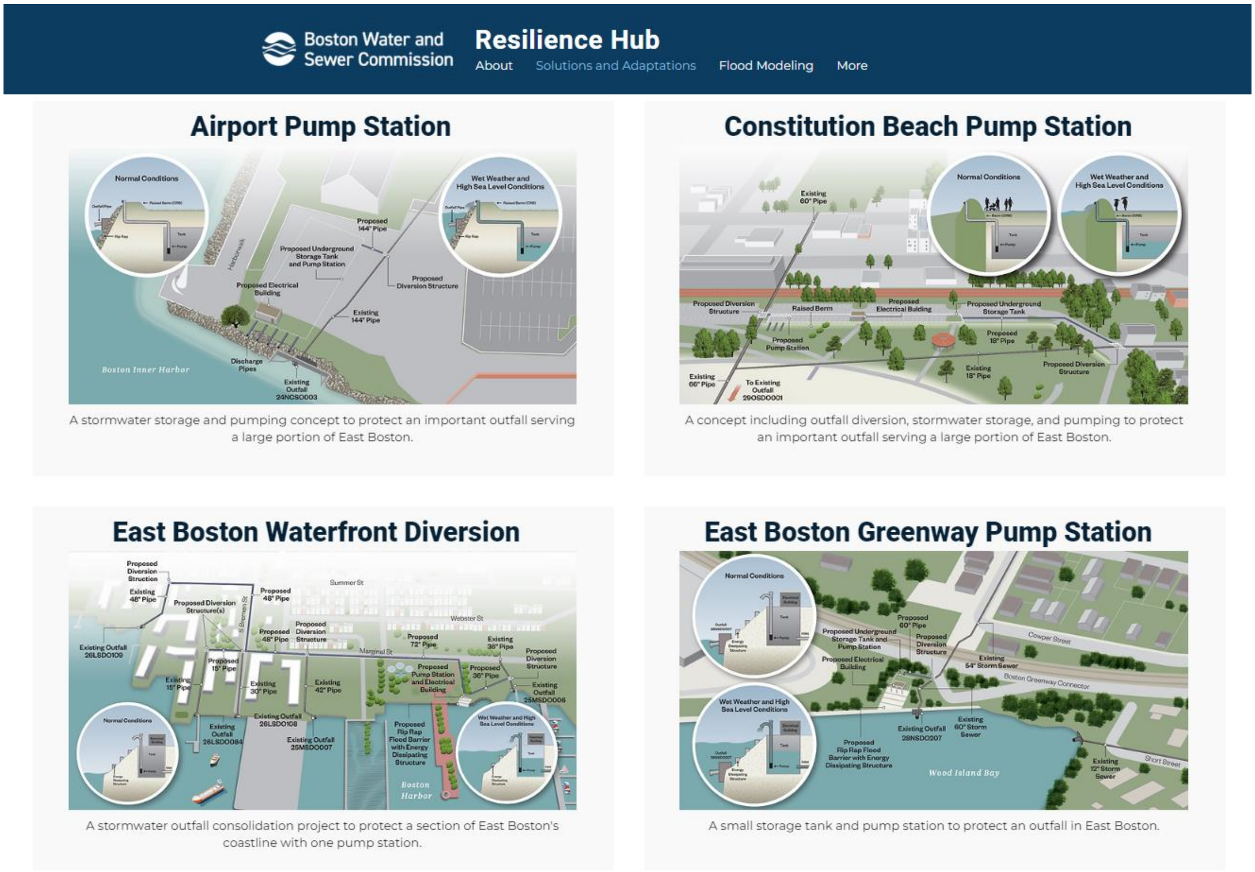
About the Coastal Stormwater Discharge Analysis

Boston's storm drain system collects rainfall runoff and discharges it to the Charles River, Boston Harbor, or the Neponset River using a network of pipes that move water by gravity. Rainfall runoff is collected by catch basins in the street. These catch basins are connected to large pipes that convey water towards coastal structures where the water can be released. These coastal structures are called outfalls.

Higher sea levels and storm surge, due to climate change, could prevent this system from working as designed by preventing water from flowing out of the system by gravity. During some rain events, this could lead to backups and street flooding. Sea level rise could even lead to inland flooding during dry weather, as high tides could cause sea water to flow up through outfalls and into the city, as shown in the figure below.

Figure 9-2: Resilience Hub About Page

The Solutions and Adaptations page, shown in **Figure 9-3**, includes a description of the categories of conceptual solutions: storage, pumping, conveyance, and nature-based solutions. The page then displays illustrative figures of each of the conceptual designs, along with a short description of the design.



Airport Pump Station

A stormwater storage and pumping concept to protect an important outfall serving a large portion of East Boston.

Constitution Beach Pump Station

A concept including outfall diversion, stormwater storage, and pumping to protect an important outfall serving a large portion of East Boston.

East Boston Waterfront Diversion

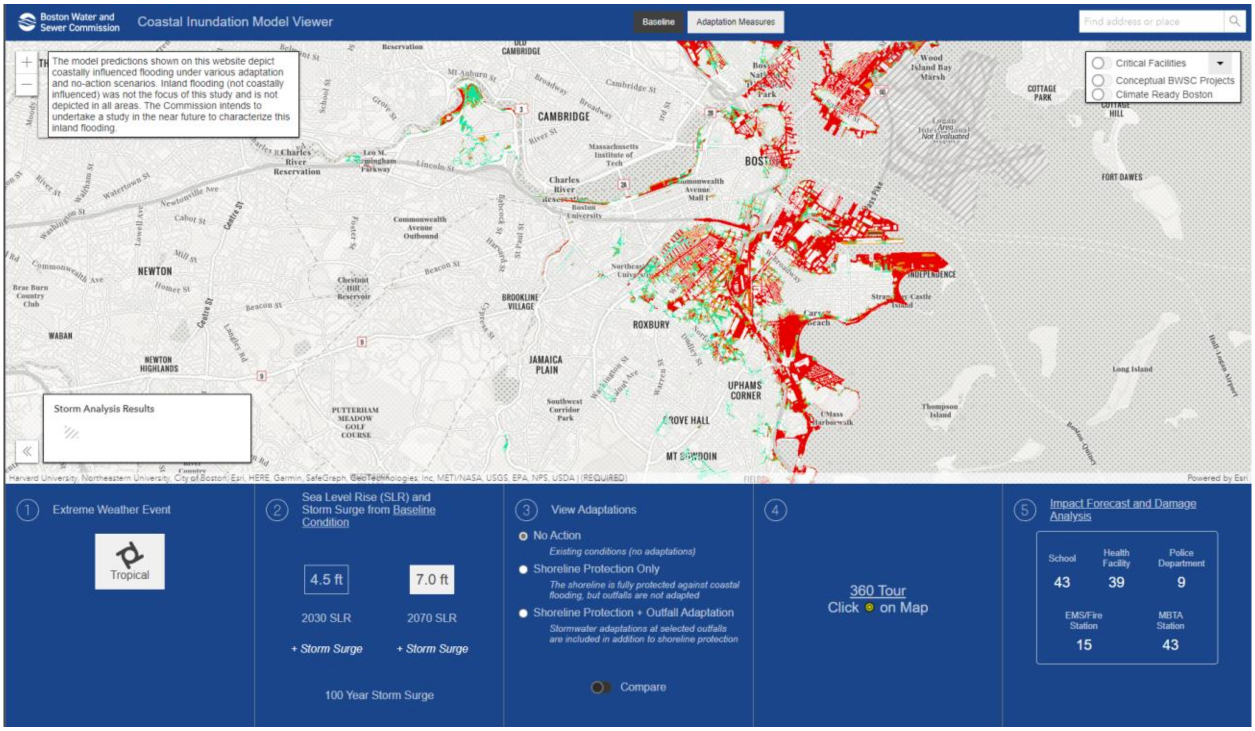
A stormwater outfall consolidation project to protect a section of East Boston's coastline with one pump station.

East Boston Greenway Pump Station

A small storage tank and pump station to protect an outfall in East Boston.

Figure 9-3: Resilience Hub Solutions and Adaptations Page

The Flood Modeling page contains the Inundation Model Viewer, shown in **Figure 9-4**. This tool is a dynamic mapping interface which illustrates coastal inundation model results for current (no action) scenarios. The page includes a revision to the original coastal Inundation Model results viewer to include an “adaptation” mode, where proposed conceptual solutions at outfalls can be understood (i.e., what the Commission has contemplated for solutions the baseline flooding during extreme events). The Inundation Model Viewer also includes 360-degree photo tours with renderings of what the landscape would look like with conceptual solutions in place (i.e., reduced flooding or flooding eliminated as a result of mitigation).



The model predictions shown on this website depict coastally influenced flooding under various adaptation and no-action scenarios. Inland flooding (not coastally influenced) was not the focus of this study and is not depicted in all areas. The Commission intends to undertake a study in the near future to characterize this inland flooding.

Harvard University, Northeastern University, City of Boston, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA | (REQUIRED)

① Extreme Weather Event: Tropical

② Sea Level Rise (SLR) and Storm Surge from Baseline Condition

- 4.5 ft 2030 SLR + Storm Surge
- 7.0 ft 2070 SLR + Storm Surge
- 100 Year Storm Surge

③ View Adaptations

- ● No Action
  Existing conditions (no adaptations)
- ○ Shoreline Protection Only
  The shoreline is fully protected against coastal flooding, but outfalls are not adapted
- ○ Shoreline Protection + Outfall Adaptation
  Stormwater adaptations at selected outfalls are included in addition to shoreline protection
- Compare

④ 360 Tour
Click ● on Map

⑤ Impact Forecast and Damage Analysis

School	Health Facility	Police Department
43	39	9

EMS/Fire Station	MBTA Station
15	43

Figure 9-4: Inundation Model Viewer, Adaptation Measures Mode

The Implementation Timeline page describes how the Implementation Timeline was developed to address outfalls that were not selected for conceptual designs, how outfalls were selected, and how the work of CRB affects the implementation time of potential projects. The page then outlines the categories of solutions (pump station, storage, conveyance, tide gate, etc.) with short descriptions and graphics to aid in reader comprehension. Finally, the page includes an interactive mapping tool, shown in **Figure 9-5**, which displays outfalls and tributary areas included in concept designs and the Implementation Timeline. Map features are color-coded to display their planning phase (near, mid, or long term) and users can click on outfalls and tributary areas to see additional information.

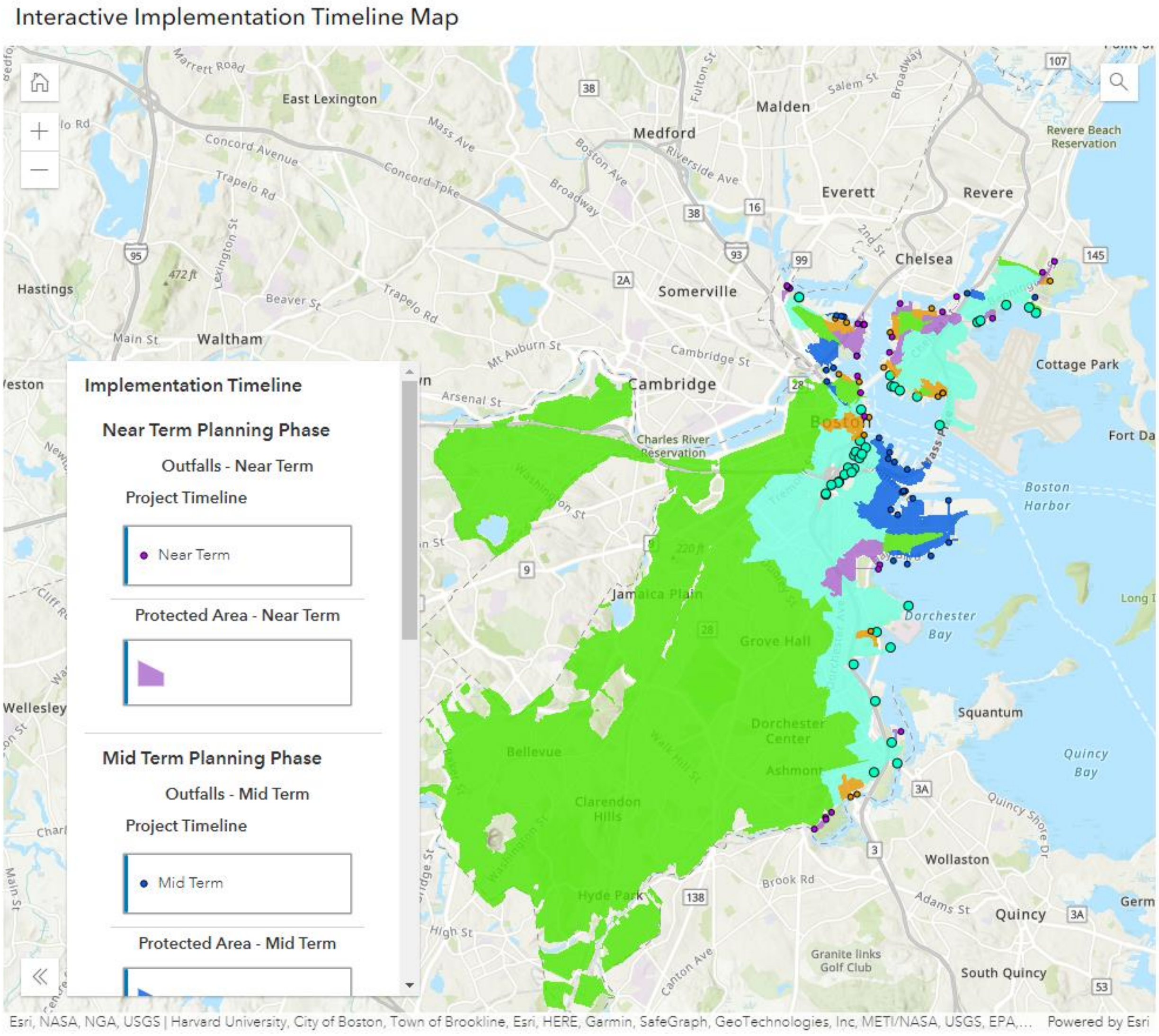


Figure 9-5: Implementation Timeline Interactive Mapping Tool

The Resilience Hub is an updatable public resource that can be used in several ways, including advancing public outreach, engendering stakeholder support through data and visualizations, and providing a centralized location for public access to data about sea level rise and coastal resiliency. As the conceptual designs and implementation timeline projects are advanced, the Resilience Hub can continue to be a resource to provide updates at each stage of the projects, from conceptual design to construction information to real-time operational data of storm surge barriers and pump stations. Additionally, the Resilience Hub includes a Questions and Feedback section at the bottom of each page where stakeholders/public can offer comments/ask questions, which can be used to supplement traditional methods of obtaining public comments during public meetings, allowing for greater-than-usual levels of stakeholder feedback.

10. Next Steps and Considerations

10.1 Project Limitations

The Commission has undertaken the Coastal Stormwater Discharge Analysis project to continue its efforts to prepare for the effects of climate change. As different strategies to respond to climate change are developed, including strategies developed by the City of Boston (i.e., the Climate Ready Boston initiative) and other agencies, it is essential that the Commission’s ability to discharge stormwater is preserved and the challenges posed by sea level rise and storm surge are addressed. Adaptations being planned and designed by other agencies have the potential to influence the Commission’s infrastructure. This Coastal Stormwater Discharge Analysis establishes strategies and conceptual designs that will help make sure that the Commission maintains its ability to discharge stormwater under varied circumstances, despite the impact of these dynamic challenges. It is important to understand the limitations and objectives of this project, including the following:

- This project has advanced several conceptual designs at various locations, but only Commission-owned outfalls are included in this analysis. Outfalls owned by other entities (MassDOT, DCR, private, etc.) are not included in this project, and some of them may be in close proximity to an outfall that has a conceptual design solution developed. Agencies other than the Commission that have vulnerable outfalls should protect outfalls from storm surge and sea level rise to to maximize the effectiveness of flood protection measures in Boston.

- The conceptual designs herein are predicated on the implementation of Climate Ready Boston’s shoreline protection projects. The flooding benefits predicted by the 2D model simulations in this project are dependent on shoreline protection (from coastal surge/sea level rise) being implemented by CRB. All “shoreline protection” scenarios simulated were configured with 100% effective shoreline protection, thereby completely eliminating overland coastal flooding. If effective shoreline protection is not provided alongside the coastal stormwater solutions documented in this report, it is expected that additional flooding beyond model predictions would result, and the effectiveness of the stormwater discharge concepts would be reduced due to additional inflow from coastal flooding.

- The conceptual designs herein are additionally predicated on implementation of effective backflow controls on all outfalls throughout the City, including those which are not owned by the Commission. Extensive inter-agency coordination and negotiation with private entities will need to be performed to adequately prevent inflow entering the Commission’s sewer system.

- Concepts were designed for consistency with CRB proposed adaptations (DFEs) and analyzed based on sea level rise projections in the Massachusetts Coastal Flood Risk Model. The SLR values applied in MC-FRM are consistent with the standards for the Commonwealth of Massachusetts developed by Coastal Zone Management. The MC-FRM utilizes a “High” SLR scenario. This scenario is based on the relative SLR projections under RCP 8.5 (a “worst case scenario” of increasing atmospheric carbon concentrations) and represents elevations that have a 99.5% probability of not being exceeded within the respective timeframes. In 2030, that amounts to an increase of 1.3 ft in Boston from a baseline condition (2008 centered tidal epoch), and in 2070 that amounts to an increase of 4.3 ft. As flood risk models are refined with new data in the future, changes may be needed to the concepts described herein.

- The concepts developed in this project were analyzed using coastal conditions that include 2070 projected SLR and storm surge resulting from a 100-year tropical storm. The peak water surface elevation predicted by the MC-FRM during these conditions is approximately 13.8 ft NAVD88 (varies by location). In mid-2022, the Greater Boston Research Advisory Group issued an updated report with new SLR projections. The report acknowledges that long term SLR projections are associated with significant uncertainty, and that updated projections include less SLR by 2100 (compared to earlier projections in the 2015 BRAG Report). According to the report, the likely range of SLR by 2070 under an RCP 8.5 scenario is 1.4 – 2.8 ft. Based on this information, projections from the MC-FRM that were utilized in this project are conservative and appropriate for long term planning purposes.
- The conceptual level designs developed as part of this project rely on the accuracy of the Commission’s existing GIS records and the assumptions outlined in **Section 3** of this report. It is expected that pipe sizes, inverts, location of tide gates, and other data may differ slightly in GIS records from reality. As such, it is important that detailed survey work be conducted to verify these assumptions before advancing the coastal stormwater design concepts. As the Commission continues to improve and update its GIS records overtime, the assumptions associated with each concept may need to be updated.
- The modeling performed as part of this project was not configured to capture or characterize interior stormwater flooding unrelated to SLR. Non-coastal and localized factors such as catch basin capacity, hydraulic restrictions, bottlenecks, etc. are known to cause flooding during the rain events analyzed during this project. The 2D modeling performed as part of this project did not fully capture these sources of flooding. As such, it is important to analyze the flood model predictions in the context of coastal related flooding only.

10.2 Final Design, Permitting, and Constructability

As stated in **Section 8.4**, this project did not consider or analyze outfalls which are not owned by the Commission. In many cases, these outfalls are located in close proximity to Commission owned outfalls and could be incorporated into the designs documented in this report. Before beginning the final design process, it would be beneficial to identify these outfalls and engage with their owners to consider incorporating the outfalls in the final design. Including additional outfalls in any of these designs may require adjusting some of the design parameters of the concepts, including (without limitation) pump and storage tank sizing.

A thorough permitting evaluation of the concepts summarized in this report has not been performed. Although efforts were made during the design process to avoid concept designs with potentially burdensome permitting requirements (for example, not using diesel engine driven pumps to avoid air permits), it is anticipated that some solutions would encounter meaningful permitting challenges (especially those that discharge into wetlands or involve new SSBs). A prudent next step for concepts being advanced would be to identify specific permits that would be required for construction so that opportunities to minimize permitting challenges could be taken advantage of during the design process.

A thorough analysis of constructability should also be conducted, especially on solutions that involve new conveyance. Challenges such as available space for construction laydown, presence of overhead wires, utility conflicts, and others should be evaluated before beginning the final design process. Construction of large diameter pipelines is challenging due to the size of equipment required, and potential impacts associated with open-cut construction. Optimization of pipe alignments may help alleviate construction impacts to major streets, residents, and intersections. Research into as-built information and field investigations will be required to advance the designs described herein. Public outreach and efforts to build stakeholder support by demonstrating flood reduction benefits may be beneficial early in the design process.

As previously stated Section 5.2.3, it is generally recognized that pump stations impose an additional O&M burden on utilities (such as the Commission) and are not viewed favorably by some stakeholders and residents. As such, where possible, the solutions developed during this project sought to minimize the number and size of pump stations by preferencing solutions relying on conveyance/upstream system optimization and storage. During future studies or design projects, the cost effectiveness of this approach should be considered. Construction of new conveyance systems and storage facilities may be more disruptive and costly than construction and maintenance of a new pump station in some circumstances.

10.3 Stakeholders and Project Funding

The concepts described herein provide benefits beyond the shoreline; the coastal stormwater adaptations in this report could substantially reduce flooding across the City (when paired with shoreline protection) and offer benefits to multiple agencies and sectors. Given the large potential benefits and impact of the concepts, there are many potential auxiliary funding opportunities for these concepts, including potential for federal funding assistance. For example, FEMA BRIC funding prioritizes disadvantaged communities. **Table 10-1** contains a summary of several indicators for the concept tributary areas that could be used help characterize the community for future FEMA funding applications and prioritization of projects that benefit disadvantaged communities.

Given the broad scope and the substantial cost of constructing and maintaining these concepts, it may be prudent to consider the creation of new agency, consisting of multiple agencies/stakeholders (including the Commission) responsible for funding, maintaining, and operating solutions with regional benefits. Possible stakeholder entities for a new “Massachusetts Coastal Defense Agency” are illustrated in **Figure 10-1**.

Figure 10-1: Massachusetts Coastal Defense Agency

Table 10-1: BRIC Metrics (provided by risQ Inc.)

BRIC Variable	Boston Logan Airport	Charlestown Schrafft Center	Columbus Park	Constitution Beach	Davenport Creek	Dorchester Bay Basin	East Boston Greenway	East Boston Waterfront	Fort Point Channel	Joseph Finnegan Park	Old Harbor Park
GINI Index	0.42	0.42	0.53	0.46	0.21	0.22	0.51	0.52	0.4	0.39	0.59
Per Capita Income	$32,827	$81,062	$108,521	$32,899	$40,556	$33,671	$37,917	$39,098	$58,326	$50,749	$19,522
Racial Gap in Income	86%	57%	67%	77%	57%	80%	69%	74%	60%	57%	100%
Below Poverty Line	12%	5%	11%	16%	18%	17%	16%	19%	23%	6%	49%
Median Monthly Housing Costs	$1,683	$2,502	$2,635	$1,342	$1,655	$1,662	$1,559	$1,481	$1,778	$1,816	$2,076
Rent Burdened Population	33%	26%	26%	18%	41%	39%	33%	25%	34%	25%	52%
Food Insecure	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%
Unemployment Rate	6%	2%	4%	11%	5%	7%	5%	6%	8%	4%	6%
Working Poor	8%	4%	0%	7%	13%	10%	5%	12%	13%	2%	25%
Childhood Poverty	19%	5%	5%	32%	29%	23%	22%	26%	27%	5%	52%
Early Education	37%	66%	38%	56%	25%	22%	40%	39%	31%	41%	0%
No High School Degree	29%	3%	3%	19%	12%	18%	14%	20%	16%	8%	12%
Mental Health Challenges	17%	10%	11%	15%	14%	16%	14%	16%	15%	12%	19%
Health Insurance Coverage	91%	99%	98%	92%	98%	95%	93%	94%	96%	98%	96%
Safe Drinking Water Violation	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%

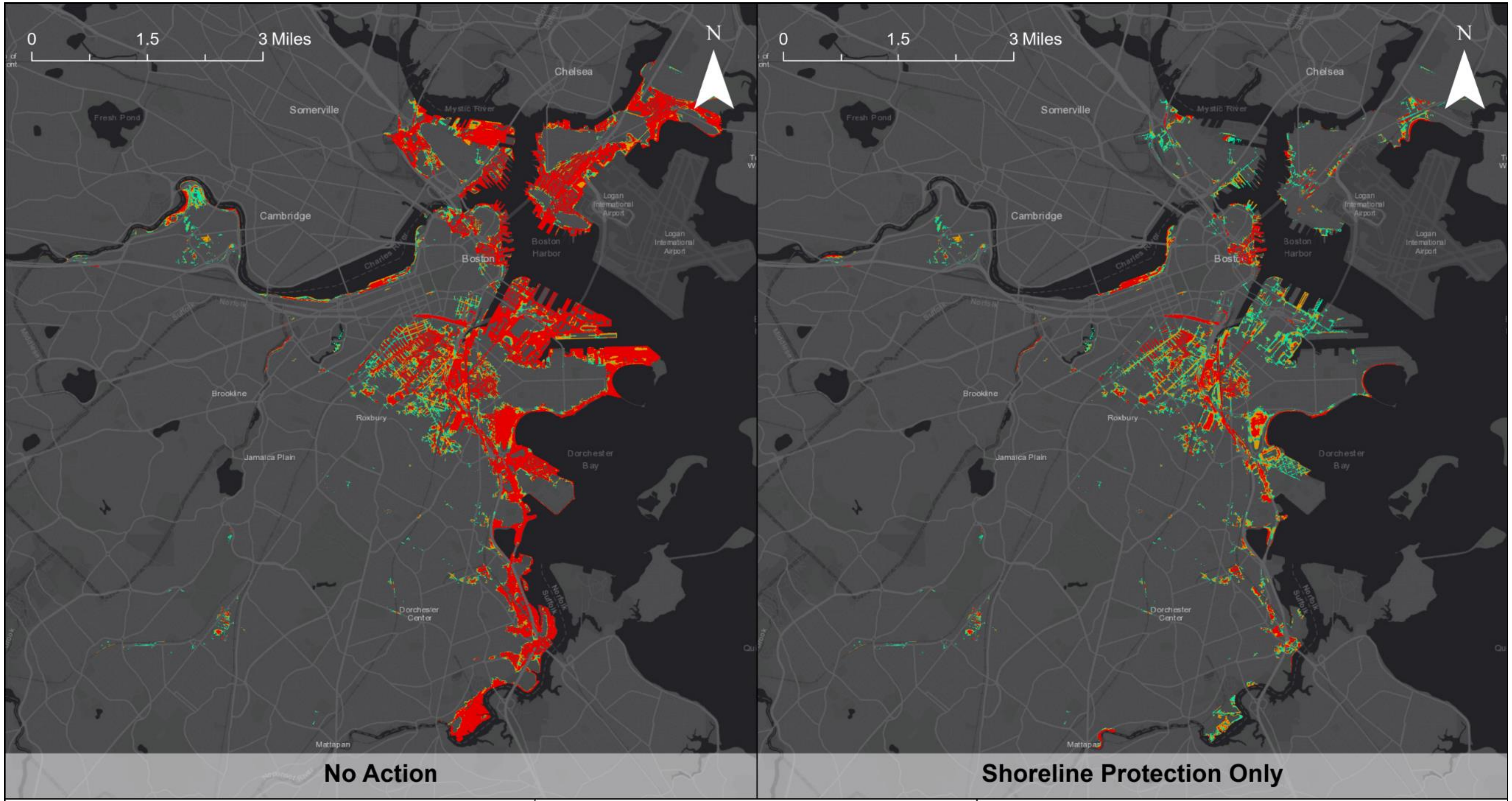
BRIC Variable	Boston Logan Airport	Charlestown Schrafft Center	Columbus Park	Constitution Beach	Davenport Creek	Dorchester Bay Basin	East Boston Greenway	East Boston Waterfront	Fort Point Channel	Joseph Finnegan Park	Old Harbor Park
Asian Popl	3%	6%	7%	4%	6%	17%	5%	8%	13%	9%	29%
Black Popl.	3%	5%	5%	3%	39%	36%	4%	5%	30%	10%	14%
Latinx Popl.	63%	5%	5%	48%	15%	17%	46%	43%	20%	4%	29%
Native American Popl.	1%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
Native Islander Popl.	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%
White Popl.	53%	84%	84%	67%	44%	31%	61%	69%	41%	75%	36%

10.4 Conclusion

At the conclusion of the project, 2D coastal flood model simulations were performed at all conceptual design locations simultaneously to evaluate the cumulative effectiveness of the proposed conceptual solutions.

Figure 10-2 depicts a comparison of “no action” model predictions during a 100-year tropical storm event in 2070 versus a scenario including complete shoreline protection. As this figure illustrates, shoreline protection alone reduces peak flood depths and extents throughout the City but does not fully alleviate substantial flooding in many neighborhoods and drainage areas, including the area tributary to the Fort Point Channel.

Figure 10-3 depicts a comparison of the shoreline protection scenario versus a scenario that includes shoreline protection in addition to the proposed coastal stormwater concepts documented in this report as well as tide gates on all coastal flood vulnerable BWSC owned outfalls. As shown in this figure, the coastal stormwater discharge concepts and tide gates substantially reduce flooding compared to shoreline protection only. This comparison illustrates the effectiveness of the concepts documented in this report, and the need to closely coordinate shoreline protection with coastal stormwater discharge adaptations and construction of tide gates on coastal flood vulnerable outfalls. Additional flooding that could result from unprotected non-Commission outfalls was not accounted for in these simulations.



Max Depth

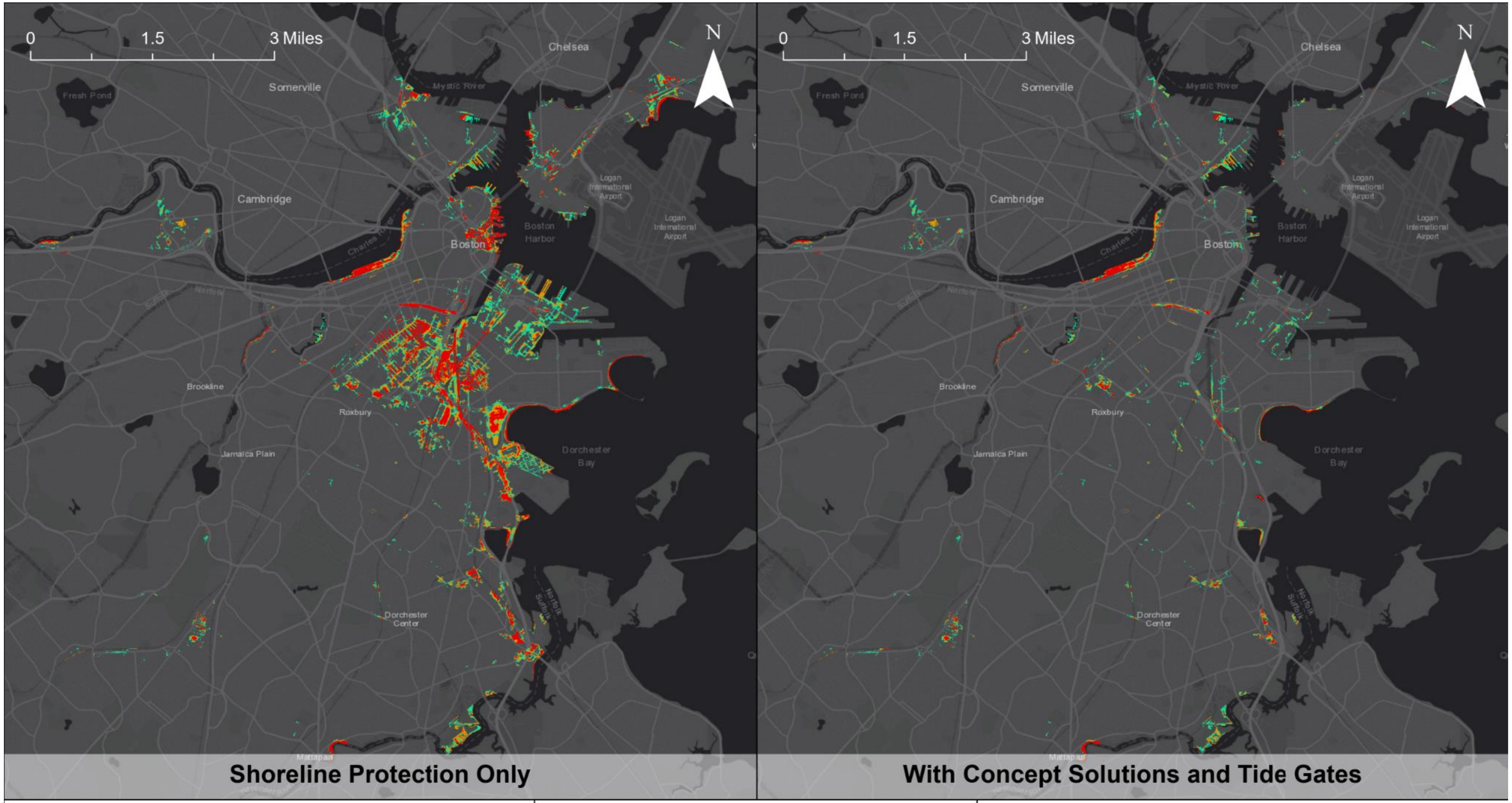
- 🟩 Flood Depth > 4 in and < 1 ft
- 🟧 Flood Depth > 1 ft and < 2 ft
- 🟥 Flood Depth > 2 ft

Boston Water and Sewer Commission

Hazen

Simulation Parameters	
Storm Type	100 yr Tropical
Rainfall Depth	9.6 inches
Peak WSE 2070 SLR + 100 yr Surge	13.8 ft NAVD88

Figure 10-2: No Action Scenario vs Shoreline Protection Only



Simulation Parameters	
Storm Type	100 yr Tropical
Rainfall Depth	9.6 inches
Peak WSE 2070 SLR + 100 yr Surge	13.8 ft NAVD88

Figure 10-3: Shoreline Protection versus Concept Solutions

It is important to note that the solutions developed in this project include the addition of tide gates on all coastal flood vulnerable BWSC outfalls. While tide gates do not facilitate stormwater discharge, they effectively prevent backflow and reduce coastal flooding. Due the nature of the outfall identification and ranking process identified in **Section 3** of this report, most of BWSC's most important outfalls (that discharge the greatest volume of water) were included in the conceptual design process. As such, these concepts have the potential to facilitate stormwater discharge for more than 70% of Boston's coastal flood vulnerable outfalls. Regardless, the addition of tide gates on the remaining coastal flood vulnerable outfalls is an important action to achieve the flood reduction benefits shown in the flood modeling in this report. Additionally, the addition of tide gates on large outfalls owned by other agencies and private entities may also be required to effectively reduce coastal flooding under some flood conditions.