Boston Coastal Storm Risk Management Study

Draft Integrated Feasibility Report and Programmatic Environmental Assessment

APPENDIX J

HYDRAULICS & HYDROLOGY: INTERIOR DRAINAGE ANALYSIS

July 2026

Contents

Tables

Figures

Attachments:

1.0 Introduction

1.1 Objective

The purpose of this appendix is to document the preliminary (i.e., initial and limited) hydrologic and hydraulic (H&H) analyses of the interior drainage areas associated with the proposed structures in the Boston Coastal Storm Risk Management (CSRM) project (the Project).

1.2 Background

The construction of the Boston CSRM project has the potential to result in increases in depth, duration and extent of rainfall-induced flooding because of structural measures implemented. The increases may result if the alignment of the floodwalls/levees prevent overland flow that would have otherwise occurred and/or tide-gates restrict the discharge of stormwater flows, diminishing the performance of the stormwater system.

Due to time constraints, a simplified approach was taken by performing initial limited macro-scale analyses prior to the Decision Point 2 meeting (DP-2). The macro-scale level analysis was used to understand the high-level flooding impacts such as the necessity of storage and/or pumping. However, at the macro-scale, there is a gap in understanding the more minor nuances of hydraulics in areas that are not well depicted in the stormwater model. The PDT had discussions with NAD and concluded that this macro-scale analysis is appropriate to the Decision Point 2 milestone, but additional interior drainage analysis is needed to bring the concepts to the required 35% design by performing the interior drainage analysis at a local-scale to capture the details of the drainage system.

1.3 Study Area

The study area focuses on the five neighborhoods aligning the 47 miles of coastline within the city of Boston, Massachusetts. These are: East Boston, Charlestown, Downtown/North End, South Boston, and Dorchester.

1.4 BWSC and Hazen On-Going Analysis

The Boston Water and Sewer Commission (BWSC) and its consultant, Hazen and Sawyer (Hazen), are currently executing a project that includes inundation modeling and development of conceptual designs to mitigate the impacts of extreme storms, sea level rise and storm surge on drainage system performance. This project builds on prior work that included development of BWSC's original 2D inundation model, which predicts the extent, duration and magnitude of surface flooding in the City of Boston, and also the Coastal Stormwater Discharge Analysis (CSDA) project, which developed stormwater management solutions to mitigate the model-predicted flooding. The analysis is documented in the 2023 report entitled "Coastal Stormwater Discharge Analysis" (BWSC, 2023), which had 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.

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.

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.

Note that BWSC and Hazen were consulted during the scoping phase of this interior drainage analysis that is documented in this report. The USACE requested BWSC and Hazen's input on the conditions that were most likely to produce flooding due to the proposed barriers. The USACE relied heavily on BWSC and Hazen' system knowledge. After discussions with BWSC, the USACE understood that BWSC had a vested interest in simulating runs that would result in induced flooding and consequentially would support USACE construction of drainage facilities like storage and pump stations. Therefore, the USACE understands that this interior drainage analysis performed is considered acceptable to serve as a preliminary flooding assessment while not every scenario (e.g., 0.02 AEP) was analyzed, an effort was made to identify the conditions that are most critical for incorporation in an induced flooding analysis.

2.0 Basis of Interior Drainage Analysis

The H&H analyses of the interior drainage areas associated with the proposed line-of-protection of the Boston CSRM presented herein are based on the concepts and guidelines contained in the USACE Engineering Manual (EM) No. 1110-2-1413 *Hydrologic Analysis of Interior Drainage Areas* (USACE, 2018), and the DPM-CW Memo, *Guidance for Induced Flooding* (USACE, 2025).

2.1 EM 1110-2-1413 Hydrologic Analysis of Interior Drainage Areas

The H&H analyses for the interior drainage addressed two main requirements discussed in EM 1110-2-1413 (USACE, 2018) including the coincident nature of the coastal and rainfall events, and the “Minimum Facilities” requirements, which are explain in the sub-sections below.

2.1.1 Coincident Nature of Coastal and Rainfall Events

EM 1110-2-1413 states the following requirement for interior drainage analysis:

> *“Hydrologic analyses of interior areas must address the coincident nature of flooding at the line-of-protection for existing and future with-project and without-project conditions.”*

A correlation analysis was performed to validate the assumption of independence between the coastal storms and the interior drainage rainfall events. The correlation analysis is described in Section 3.1.

2.1.2 Minimum Facilities

The following is the definition of “Minimum Facilities” taken from EM 1110-2-1413:

> *“The minimum facility should provide interior flood relief such that during low exterior stages (gravity conditions) the local storm drainage system functions essentially as it did without a levee in place for floods up to that of the storm sewer design. If a local storm drainage system is in existence, then the minimum facility should pass the local system design event with essentially no increase in interior flooding.”*

A summary of the “Minimum Facilities” key points taken from EM 1110-2-1413 is presented below:

The “Minimum Facilities” are considered integral to the proposed line-of-protection of the recommended plan, and they are intended to be the starting point from which additional interior facilities planning will begin. If a levee is being proposed (planned), the minimum facility must be formulated and the evaluation of the line-of-protection benefits performed with the facility in place. The residual interior flooding problem is the target of the interior facility planning efforts and benefits attributable to the increased interior facilities will be the reduction in the residual damage.

Hydrologic analyses of existing without-project conditions will be performed to develop the basis for which the interior facilities will be planned. The analyses provide flood hazard information (frequency, magnitude, elevations, and velocities) which are integrated into assessments of other study elements (e.g., flood damage, cost, social factors, and environmental factors). Hydrologic analyses include the development of information for estimating elevation-frequency functions (discharge or storage-based) at desired locations throughout the system.

The performance of the interior facilities over the full range of anticipated interior events, including those that exceed the system capacity, are particularly important to understand what happens when the system capacity is exceeded.

2.1.3 Interior Drainage Flooding Beyond Storm Sewer Design

Beyond the Minimum Facilities evaluation, DPM-CW Memo, Guidance for Induced Flooding (USACE, 2025) provides clarification of processes to identify and evaluate induced flooding that may be caused by a proposed project.

> *"For feasibility studies, a preliminary takings analysis should be completed no later than the tentatively selected plan (TSP) milestone. At the TSP stage, the preliminary takings analysis should be based on model results and information available at this stage in the planning process. The preliminary takings analysis should be considered tentative and subject to change as project plans are developed, models are refined, or other additional information is produced. The analysis will be updated as additional information is available. See ER 405-1-12, Paragraph 12-17 which addresses preparation of preliminary Attorney's Opinion of Compensability and recognizes the concept that project impacts may not be fully understood during a feasibility level of study and a lesser degree of certainty and formality is required for study purposes, similar to preparing the preliminary physical takings analysis."*

3.0 Methodology and Results

This section documents the methodology and results for the interior and exterior stages correlation analysis, and the two flooding analyses for interior areas including "Minimum Facilities" and the flooding beyond the storm sewer design analyses.

3.1 Rainfall and Storm Surge Correlation Analysis

The construction of the structural measures (e.g., floodwall) of the Boston CSRM project creates coastal interior areas that have risk of rainfall-induced flooding. According to USACE EM 1110-2-1413 (USACE, 2018), it is required to study the relationship between the interior areas flooding caused by rainfall with the exterior coastal stages. The results of the correlation analysis dictate the approach that should be used in selecting the exterior costal conditions to be used in the interior areas flooding analysis.

3.1.1 Introduction

While the primary focus of the CSRM is preventing damage from coastal storm surge water levels during tropical storms or nor'easters, the occurrence of water level fluctuations in the interior areas attributed to rainfall events associated with the same storms must be evaluated for coincidence and correlation. The runoff in the interior drainage created by the construction of structural measures often relies on gravity to flow into a larger body of water (e.g., ocean), but this system can fail if the external water level rises too high, effectively trapping the runoff. Therefore, it's crucial to study the relationships between interior drainage and exterior water levels to select the appropriate methodology to estimate the frequencies of the interior drainage flooding.

The purpose of this analysis is to examine and determine correlations between rainfall and coastal water levels, and dependence of coastal water levels on rainfall. Fundamentally, this analysis specifically investigates the relationship between precipitation events and tidal water levels in Boston. A single analysis has been performed for all interior areas of the Boston CSRM. This analysis was performed in accordance with Engineering Manual 1110-2-1413- *Hydrologic Analysis of Interior Areas* (USACE, 2018).

The analysis and conclusions presented within are limited to observed/ historic rain and surge events. Development and analysis of synthetic datasets have the potential to identify a greater dependence for tropical events. Dependence for tropical events is difficult to identify and quantify within historic datasets because of the infrequent occurrence within the limited period of record. Such analysis is beyond the scope of what can be accomplished in this study.

3.1.2 Methodology

The method for this correlation analysis for interior drainage is to use statistics to answer key questions regarding the relation between levels of precipitation (which create the need for interior drainage) and the tidal/downstream water levels (which can impede interior drainage. These key questions are as follows:

- Do high precipitation events occur at the same time as high water level or subtidal events?

- Does precipitation increase with increasing water level or subtidal signal?
- Do high subtidal events have associated high precipitation levels during the same event?
- Do high precipitation events have an associated high subtidal level during the same event?

3.1.2.1 Data

Tidal data was sourced from the Boston NOAA Tide Gauge, located in Downtown Boston adjacent to where the Evelyn Moakley Bridge crosses the Fort Point Channel. Data availability for the station is listed in **Table 1**.

Table 1: NOAA Tide Station 8443970 Data Availability

Measurement	Availability*
Observed	
High-Low	1979-Present
Hourly	1921-Present
6-min	1995-Present
Predicted	
6-min	1921-Present

*Analysis completed in Fall of 2024, data downloaded up to 10-21-24

Precipitation data was sourced from Boston Logan Airport. Hourly precipitation data was available from 1948 to 2023 with some gaps in the late 1960s, late 1970s, and late 80s. Location of these data sources is shown below in **Figure 1**.

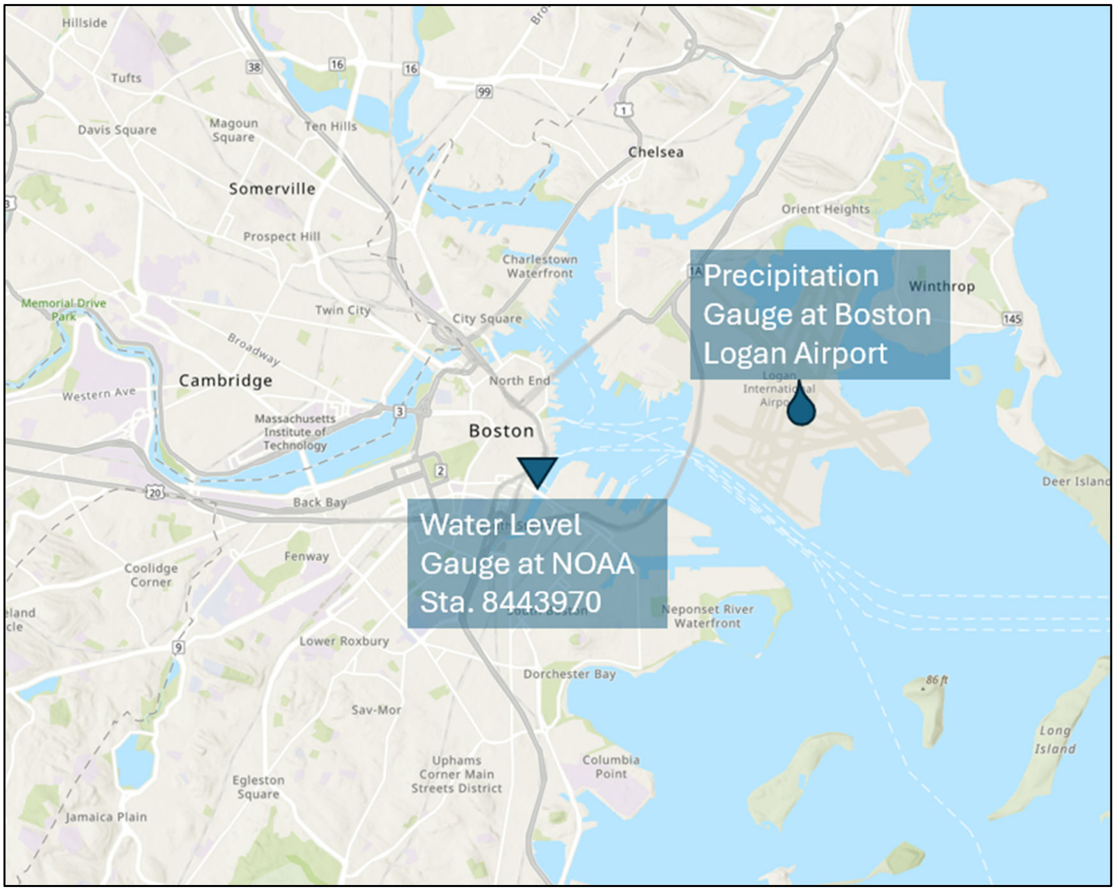


Figure 1: Boston Tidal and Precipitation Data Source Locations

3.1.2.2 Annual exceedance probability (AEP)

Annual exceedance probability (AEP) values (partial duration) were sourced to add perspective to precipitation and water level statistics. AEP precipitation values were sourced from the NOAA Atlas 14 (NOAA, 2025). AEP subtidal and water levels were sources from output of the USACE North Atlantic Coastal Comprehensive Study (NACCS; USACE, 2015). NACCS expected value confidence limit values were used for subtidal and water level AEPs. The precipitation and subtidal AEPs are shown in **Table 2**.Table 3

Table 2: AEP Values for Precipitation, Subtidal Signal, and Water Level

AEP	Precipitation (in)				Subtidal Signal (ft)	Water Level (ft NAVD88)
	1-Hour	3-Hour	6-Hour	24-Hour		
1.0	-	-	-	-	2.44	6.35
0.5	1.02	1.56	2.03	3.14	3.30	7.04
0.2	1.34	2.08	2.69	4.14	4.25	7.82
0.1	1.60	2.51	3.24	4.98	4.83	8.39
0.04	1.97	3.11	3.99	6.12	5.33	8.93
0.02	2.24	3.54	4.54	6.96	5.90	9.58
0.01	2.53	4.02	5.15	7.88	6.30	10.04
0.005	2.88	4.62	5.90	9.04	6.81	10.50
0.002	3.42	5.55	7.08	10.90	8.11	11.16
0.001	3.87	6.36	8.10	12.40	9.19	11.84
					MLLW	-5.51
					MHHW	4.77

3.1.2.3 Data Pre-Processing

Limited data preprocessing was necessary to perform the correlation analysis. Given the data availability, focus was given to the hourly tidal datasets. Predicted and observed hourly tide data was verified for time-step congruency. Following this, subtidal signal was computed by subtracting the predicted tide values from the observed values. While astronomical tides are driven by the gravitational pull of the moon and sun, the subtidal component represents the influence of meteorological forces. This includes the "inverse barometer effect" (where low atmospheric pressure allows the sea surface to rise) and wind-driven "setup" (onshore winds physically pushing water against the coast), two phenomena that encompass storm surge.

Precipitation and tidal data were interpolated onto the same dataset for ease in plotting and analysis. The tidal data includes surge, tide, wind setup, but does not include waves record. Coverage of tidal and precipitation data are shown in **Figure 2** and **Figure 3**.

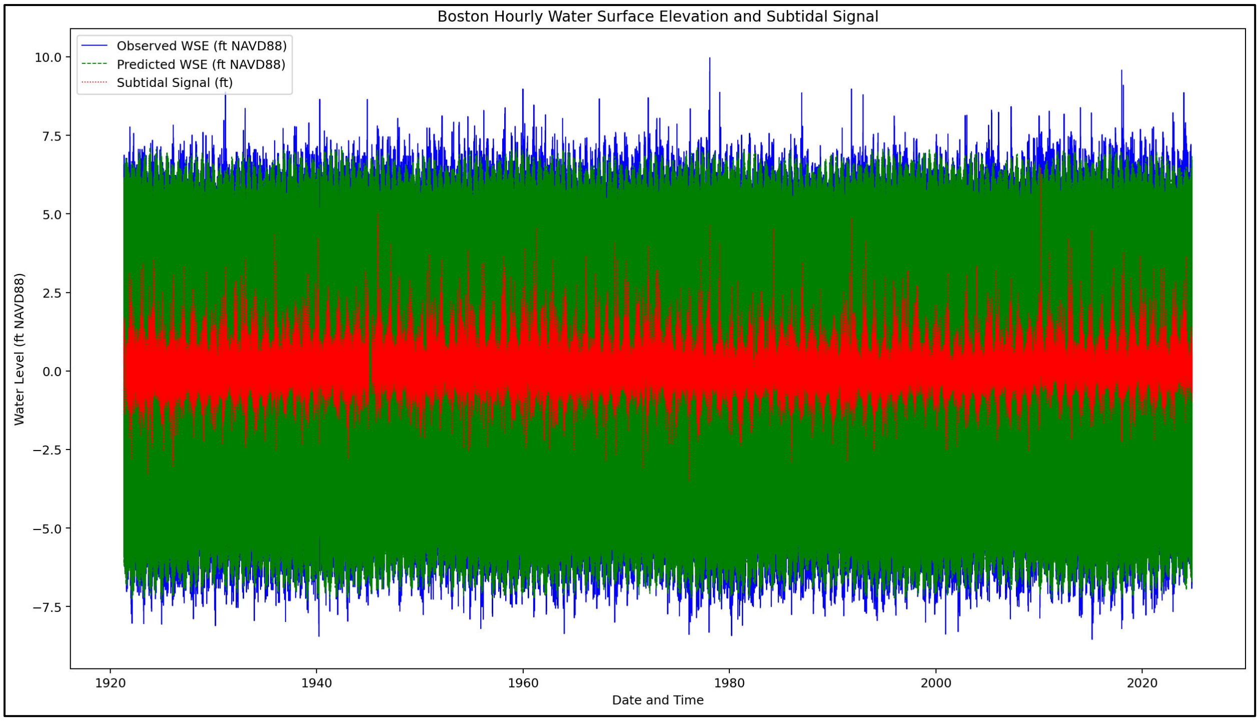


Figure 2: Hourly Tidal Data and Subtidal Signal Coverage (1923-Present)

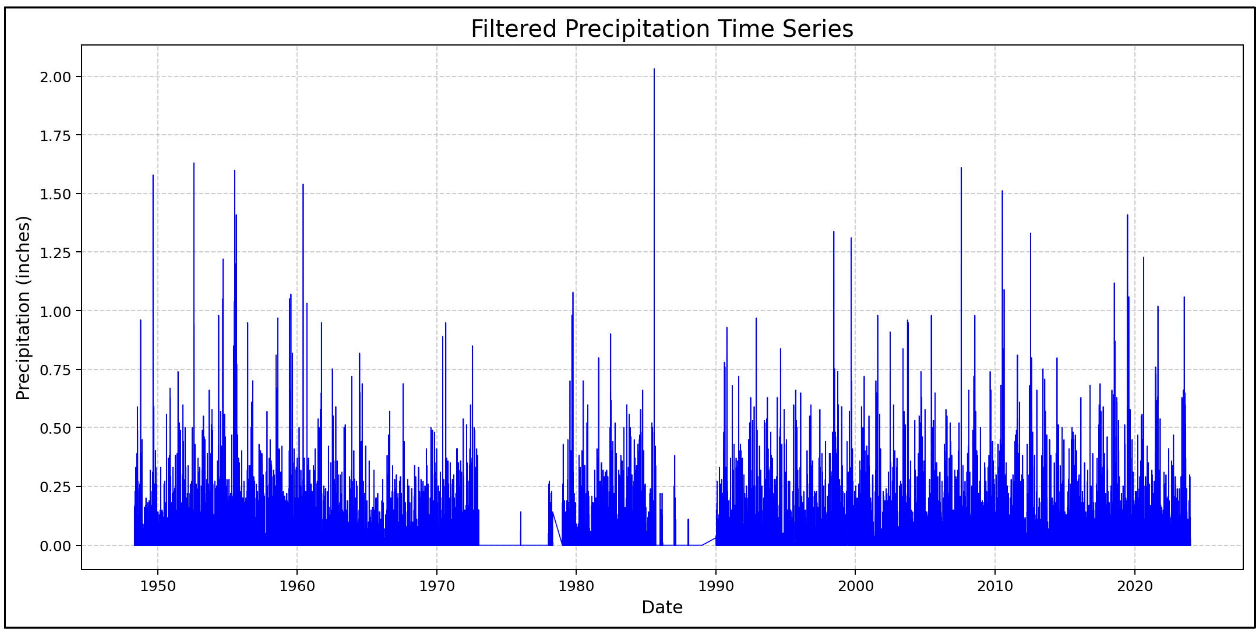


Figure 3: Hourly Precipitation Coverage (1948 to Present)

3.1.2.4 Correlation Statistics

Three statistical parameters were utilized to determine correlation and coincidence between tidal and precipitation values. See **Table 3** below for these parameters and numerical ranges.

Table 3: Statistical Parameter Information

Statistic	Numerical Range	Core Measurement
Pearson's **r**	-1.0 to +1.0	Measures how closely data points cluster around a straight linear line.
Spearman's $\boldsymbol{\rho}$	-1.0 to +1.0	Measures the consistency of the rank order (whether variables increase together, regardless of the rate).
Kendall's $\boldsymbol{\tau}$	-1.0 to +1.0	Measures the probability of two variables moving in the same direction across all possible pairs of data.

All three coefficients, Pearson's **r**, Spearman's $\boldsymbol{\rho}$, and Kendall's $\boldsymbol{\tau}$, operate on a standardized numerical scale ranging from -1.0 to +1.0. A value of +1.0 represents a perfect positive correlation, where both variables increase in unison, while -1.0 indicates a perfect negative correlation, where one variable increases as the other decreases. A result of 0 implies no statistical relationship between the precipitation and water level data.

An evaluation of the degree of correlation based on the Pearson's **r** correlation coefficient is provided in Table 4, which is an excerpt from EM 1110-2-1413 (USACE, 2018) and indicates that r less than 0.4 is a weak correlation.

*Table 4: Degree of Correlation for Ranges of Pearson's Coefficient **r** (USACE, 2018)*

Table 4-4. Degree of correlation for ranges of R.

Range of Correlation Coefficient, *R*	Degree of Correlation
$0.7 \le R \le 1.0$	Strong
$0.4 \le R < 0.7$	Moderate
$0.0 \le R < 0.4$	Weak

For Spearman $\boldsymbol{\rho}$ and Kendall $\boldsymbol{\tau}$ the correlation is considered weak if below 0.4, moderate if between 0.4 and 0.6 and strong above 0.6.

The p-value (probability value) measures the probability that the observed correlation between variables occurred by random chance. The threshold used to determine if a p-value is statistically significant is 0.05; therefore, if $p \le 0.05$ it is considered statistically significant.

3.1.3 Correlation

Correlation refers to the degree to which coincident interior and exterior events tend to be consistent in magnitude in a predictable manner. If the exterior and interior occurrences are such that a consistent relationship exists one to the other (to some degree, one can be predicted from the other), the interior and exterior events are said to be correlated.

For this study, correlation was evaluated by examining rainfall and tides that occur together. Initially, 1-hour duration precipitation was plotted against subtidal signal and still water level. A weak correlation (i.e., **r** < 0.4) was seen in this analysis for subtidal correlation, as Pearson **r**, spearman $\boldsymbol{\rho}$, and Kendall $\boldsymbol{\tau}$ were reported as 0.17, 0.21 and 0.17, respectively (see **Figure 4**). Negligible correlation was observed for still water levels (SWL) and precipitation with statistical parameters of 0.02, 0.03, and 0.03 observed respectively (see **Figure 5**). Notably, of all events with a subtidal level above a 1-yr AEP, only one event had a precipitation AEP level above 2-yrs, and in all events with a still water level above a 1-yr AEP, no precipitation level was above a 2-yr AEP.

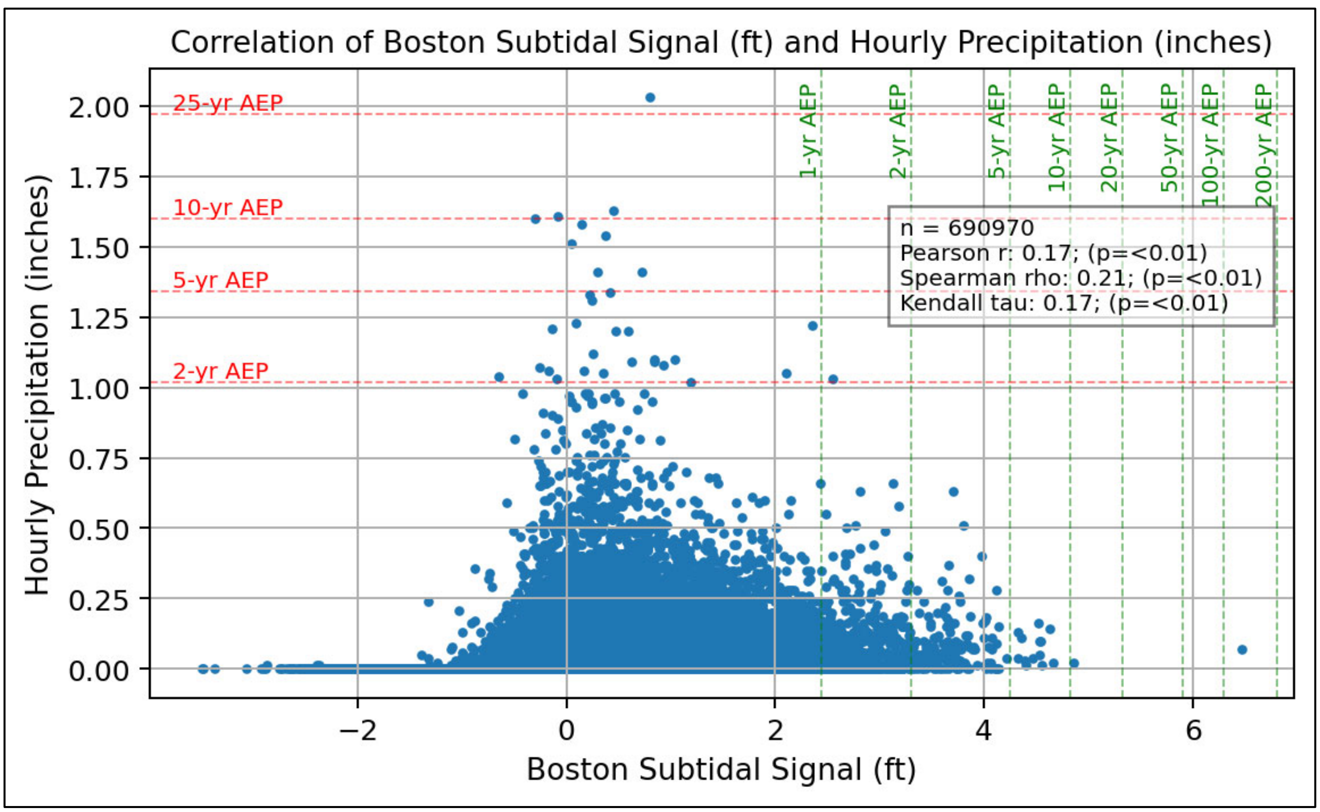


Figure 4: Subtidal Correlation of Entire Dataset

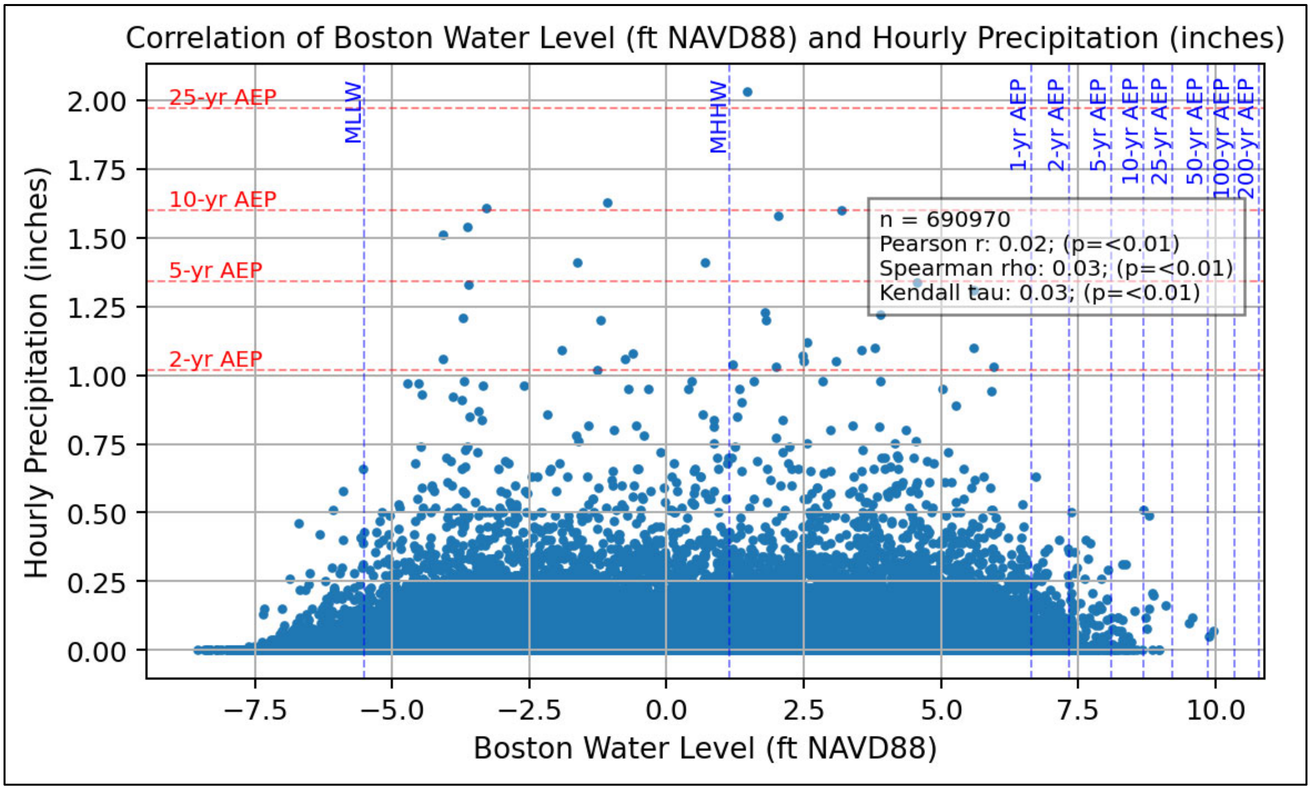
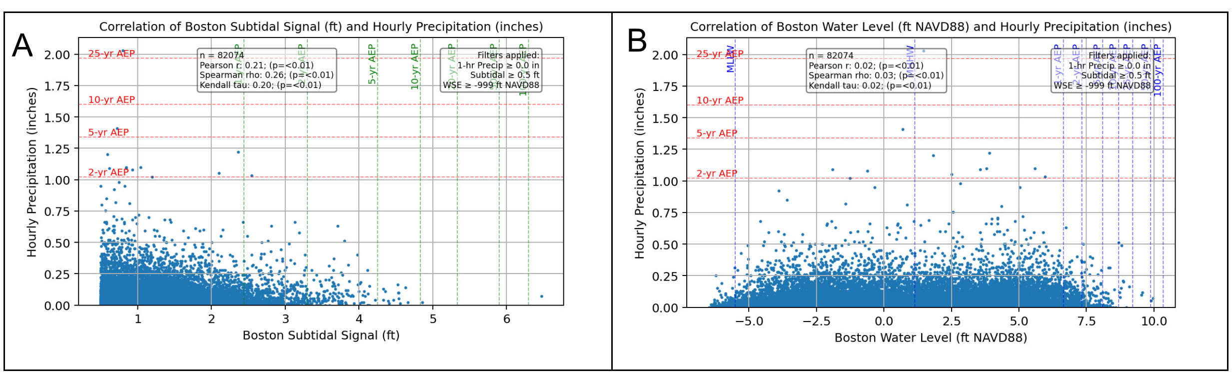


Figure 5: Water Level Correlation of Entire Dataset

Correlation was also examined by filtering for large subtidal events and by filtering for large precipitation events. When filtering only for subtidal events (above 0.5 ft), correlation increased slightly, as statistical parameters were in the range of 0.20 to 0.26 (See **Figure 6A**). Correlation of SWL for this filter was still negligible (**Figure 6B**). When filtering for larger subtidal events (greater than 1 foot) and significant precipitation (above 0.5 inches), negative weak correlation was reported for subtidal events (**Figure 6C**), and the SWL correlation (**Figure 6D**) was similarly weak.



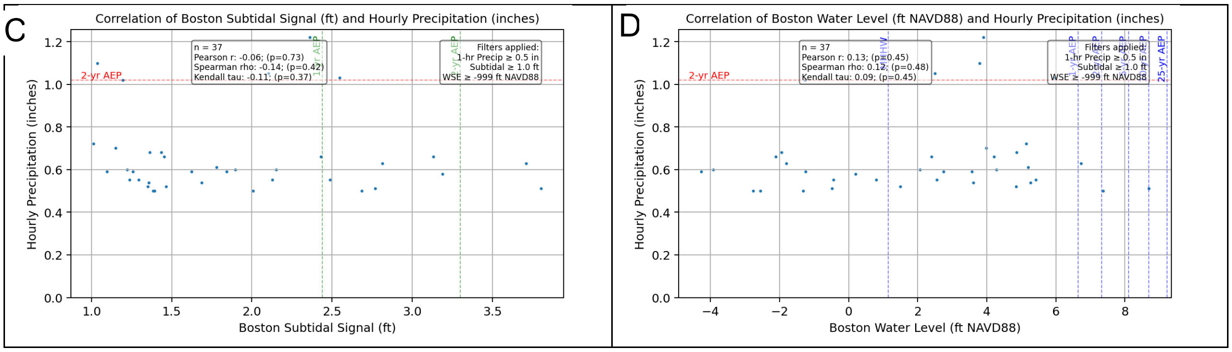


Figure 6: Filtered Correlation Plots for Subtidal Signal and Water Level

A summary of correlation statistics is reported in **Table 5**. When looking at the full dataset correlation and filtered correlations, there is at best weak correlation between rainfall and exterior stage.

Table 5: Statistical Parameter Summary for 24-Hour Subtidal and SWL Correlation Precipitation

Correlation Metric (SWL vs Subtidal)	Subtidal Filter	Precipitation Filter	N, samples	Pearson R	Spearman Rho	Kendal Tau
Subtidal	None	None	690970	0.17	0.21	0.17
SWL	None	None	690970	0.02	0.03	0.03
Subtidal	None	>0.5 in	286	-0.09	-0.08	-0.05
SWL	None	>0.5 in	286	-0.01	0.03	0.02
Subtidal	>0.5 ft	None	82074	0.21	0.26	0.20
SWL	>0.5 ft	None	82074	0.02	0.03	0.02
Subtidal	>1.0 ft	>0.5 in	37	-0.06	-0.14	-0.11
SWL	>1.0 ft	>0.5 in	37	0.13	0.12	0.09

3.1.4 Dependence

If the physical and meteorologic processes of the interior and exterior events are related to one another, the occurrences are said to be dependent.

It is understood that the storms that typically produce tidal surges, i.e., Nor'easters and hurricanes, can also produce somewhat significant rainfall. Likewise, many of the high rainfall events are accompanied by at least some storm surge. If this were not true, the high surge events would not likely have any rainfall, and the paired data in **Figure 4** would fall much closer to each axis. As expected, there exists a minor dependence between the interior and exterior conditions. The fact that the main cluster of points that include some rainfall in **Figure 4** (1-2 inches) also includes a subtidal level greater than 0 is evidence of this. However, when the randomness of the tide is considered in the

SWL, no dependence was identified between the interior and exterior conditions as shown in **Figure 5.**

3.1.5 Coincidence

The coincidence between the interior and exterior conditions involves the timing of the peak discharge from the interior drainage analysis and the timing of the peak exterior stage from the exterior storm surge analysis. In the exterior condition, the timing of the peak exterior stage is unpredictable because of the impacts of tidal fluctuation to the overall storm surge elevation. Therefore, predicting the coincidence of the peak exterior event and the peak interior flows is uncertain. If the interior and exterior events occur at the same time, this would be considered the worst-case scenario and a conservative approach for modeling coincidence. To examine if there is any coincidence between rainfall and storm surge, individual events were analyzed by taking the maximum 1-hour rainfall and maximum subtidal signal and SWL across 48-hour windows in the data domain. If correlation values were to increase using this method, it could be concluded that while instantaneous correlation is not observed, that event coincidence has been occurring.

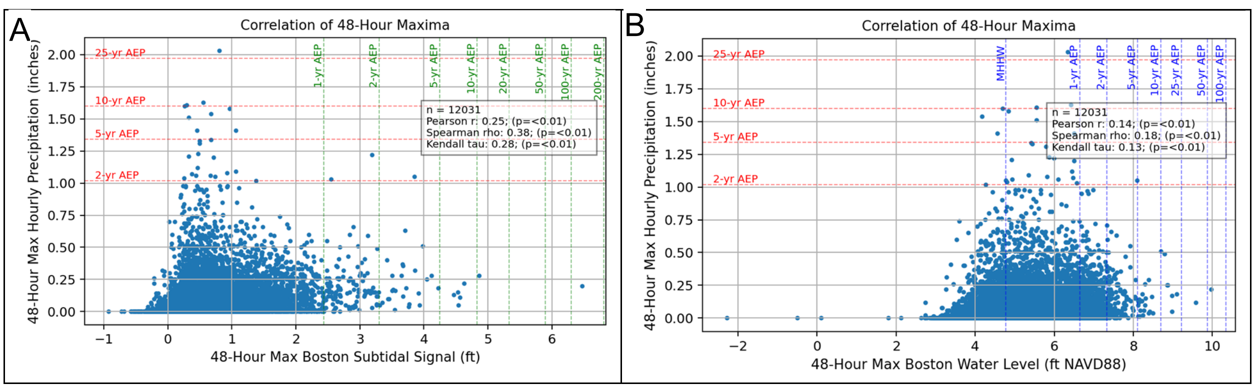


Figure 7: Subtidal and SWL to Precipitation Correlation of 48-Hour Maxima

When examining the entire dataset in 48-hour duration windows, correlation parameters increased slightly for both subtidal to rainfall and SWL to rainfall correlation, however these statistical parameter values still fell below 0.4, indicating weak correlation.

Table 6: Statistical Parameter Summary for 48-Hour Subtidal and SWL Correlation Precipitation

Correlation Metric (SWL vs Subtidal)	Subtidal Filter	Precipitation Filter	N, samples	Pearson R	Spearman Rho	Kendal Tau
Subtidal	None	None	12031	0.25	0.38	0.28
SWL	None	None	12031	0.14	0.18	0.13
Subtidal	None	>0.5 in	232	-0.09	-0.12	-0.08
SWL	None	>0.5 in	232	0.00	-0.03	-0.02

Subtidal	>0.5 ft	None	6399	0.20	0.29	0.21
SWL	>0.5 ft	None	6399	0.11	0.14	0.10

We can lend evidence to this lack of coincidence by examining historical events with high subtidal levels or high rainfall. The top 3 subtidal events in Boston occurred in February 2010 (Snowmageddon), October 1991 (The Perfect Storm), and February of 1978 (Blizzard of ’78). These events were all nor’easters. The blizzard of 78 was characterized by an increased subtidal signal across nearly two days. During this time, hourly precipitation in water equivalent (in this case, snowfall) never exceeded 0.25 inches per hour.

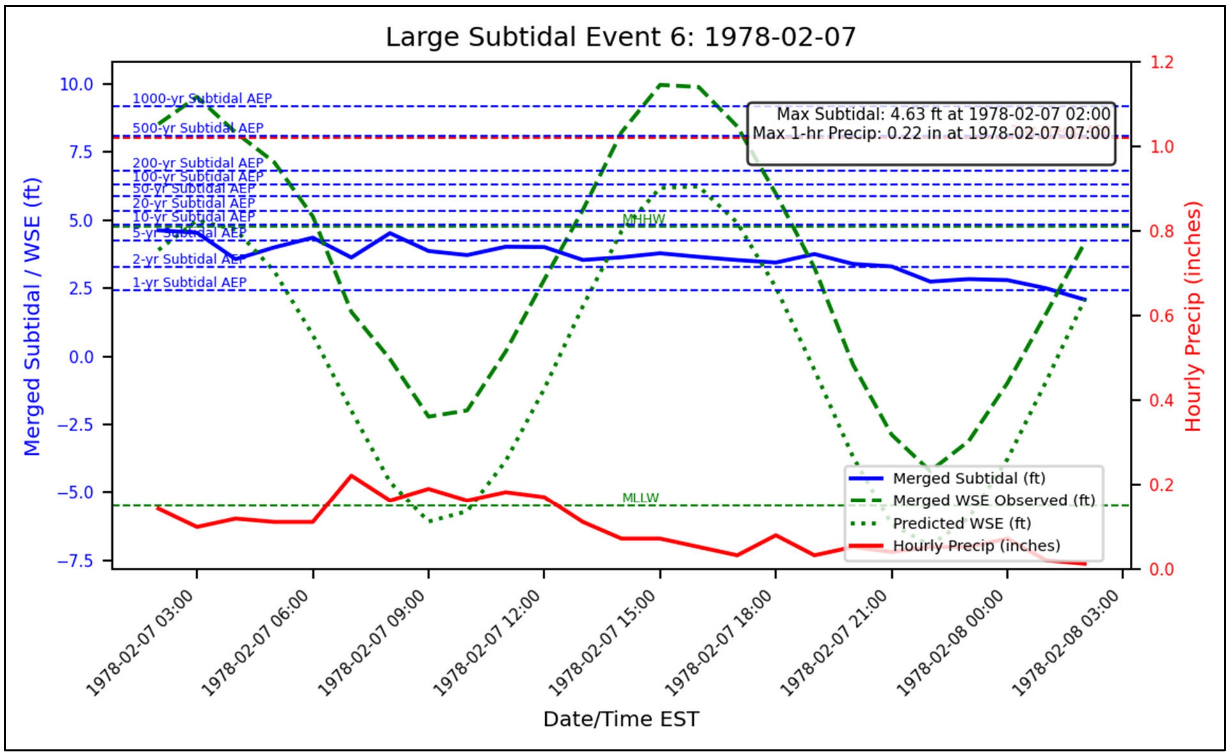


Figure 8: Blizzard of '78 Tidal and Precipitation Time Series

In the Perfect Storm, subtidal levels similarly remained high for a 2-day period, and much like the Blizzard of ’78, precipitation never reached a level over 0.25 inches of rain per hour.

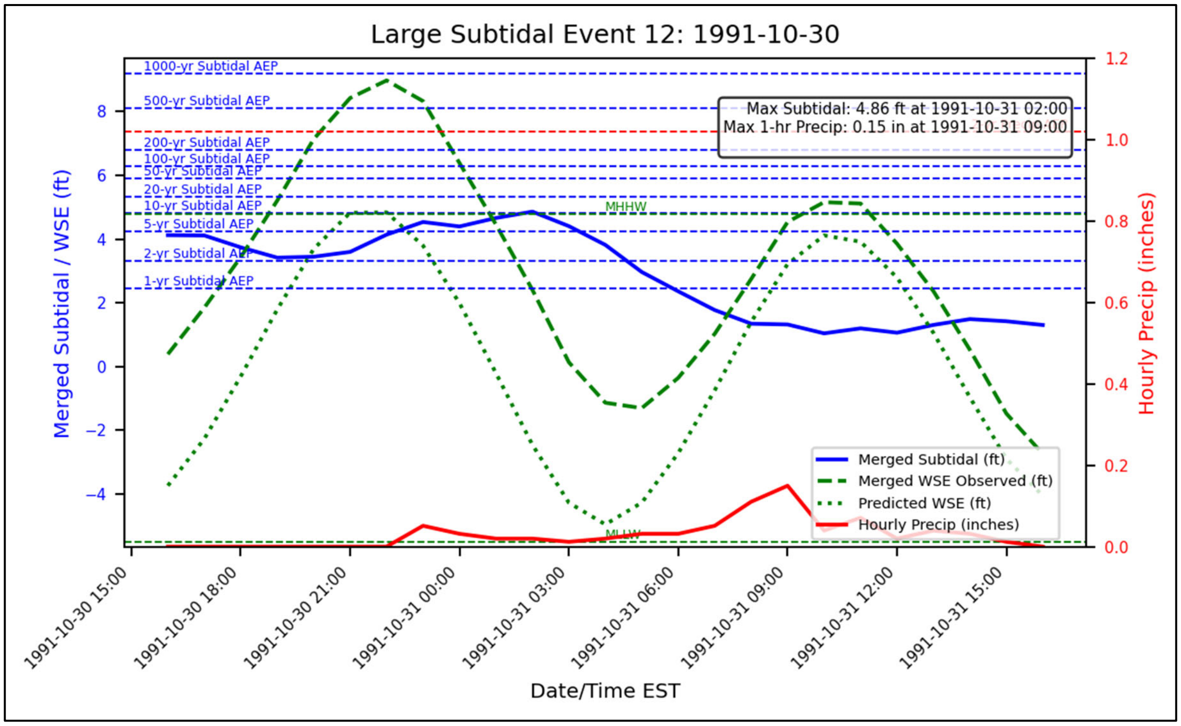


Figure 9: The Perfect Storm Tidal and Precipitation Time Series

Snowmaggedon similarly had elevated subtidal levels over a 2-day period, with a large peak occurring. During this peak, there was small precipitation peak, however this did not exceed 0.3 inches of rain per hour.

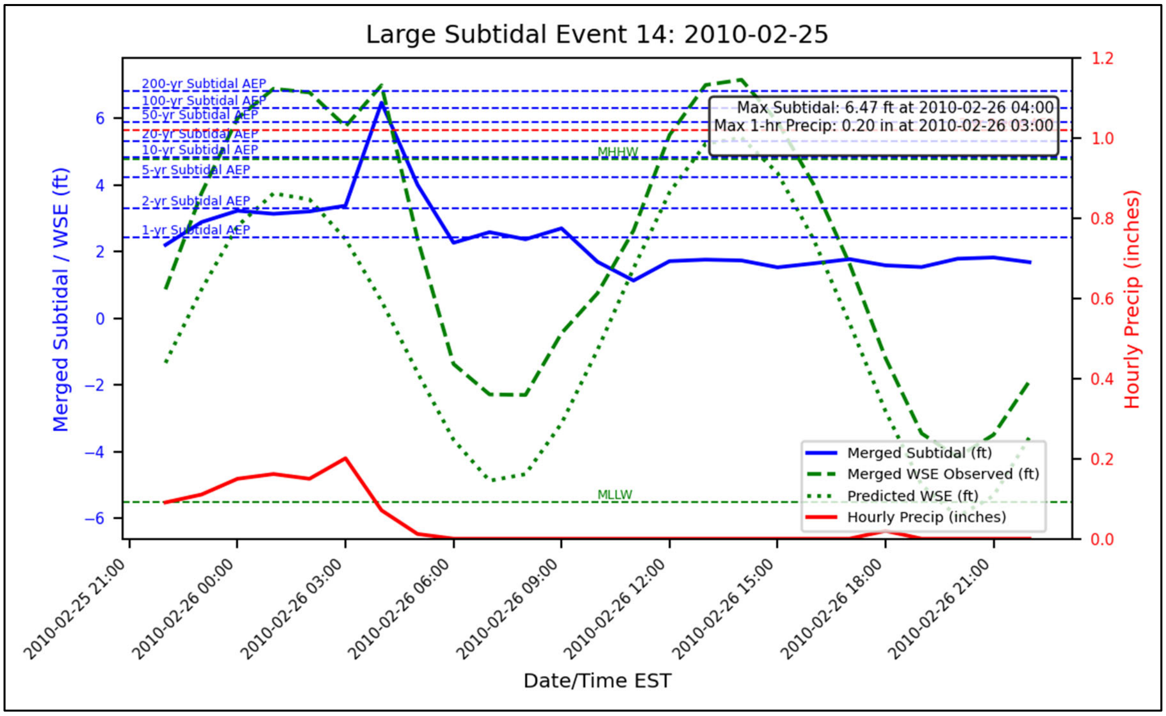


Figure 10: Snowmaggedon Tidal and Precipitation Time Series

When examining the highest precipitation events in Boston's history, they nearly all occur in summer months and are generally characterized by a short but intense rainfall peak. For the top 3 precipitation events, the subtidal level never exceeded 1 foot (far below a 1-year AEP event)

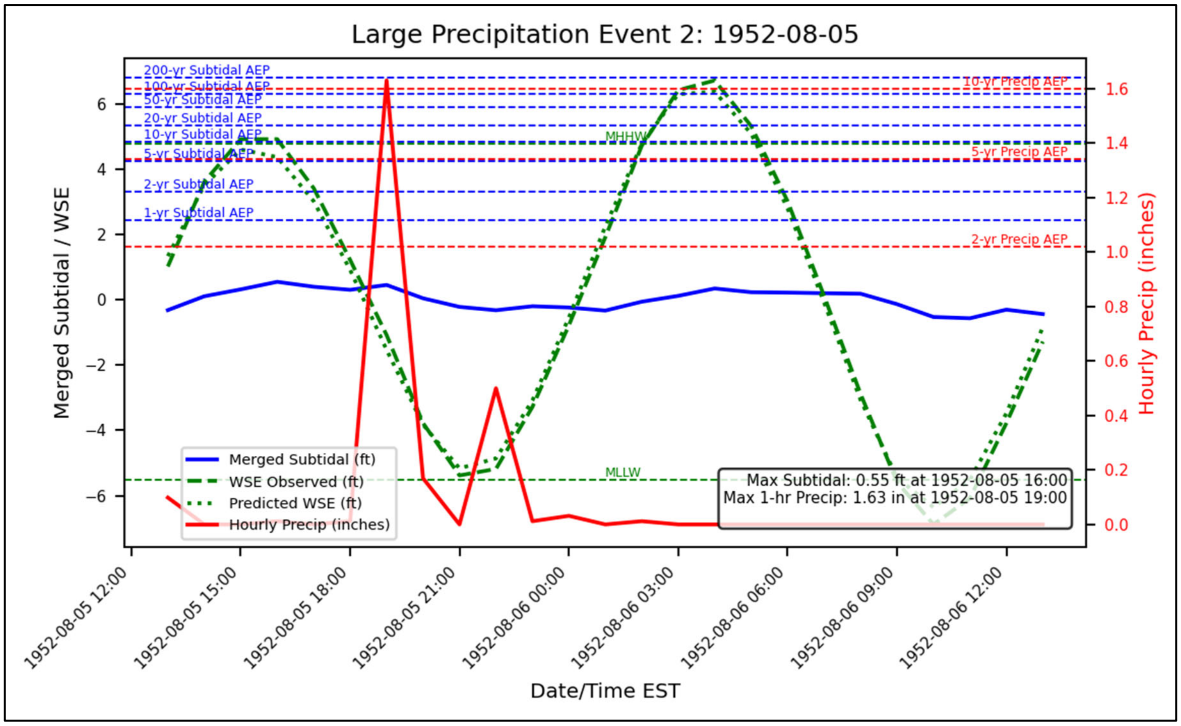


Figure 11: August 1952 Tidal and Precipitation Time Series

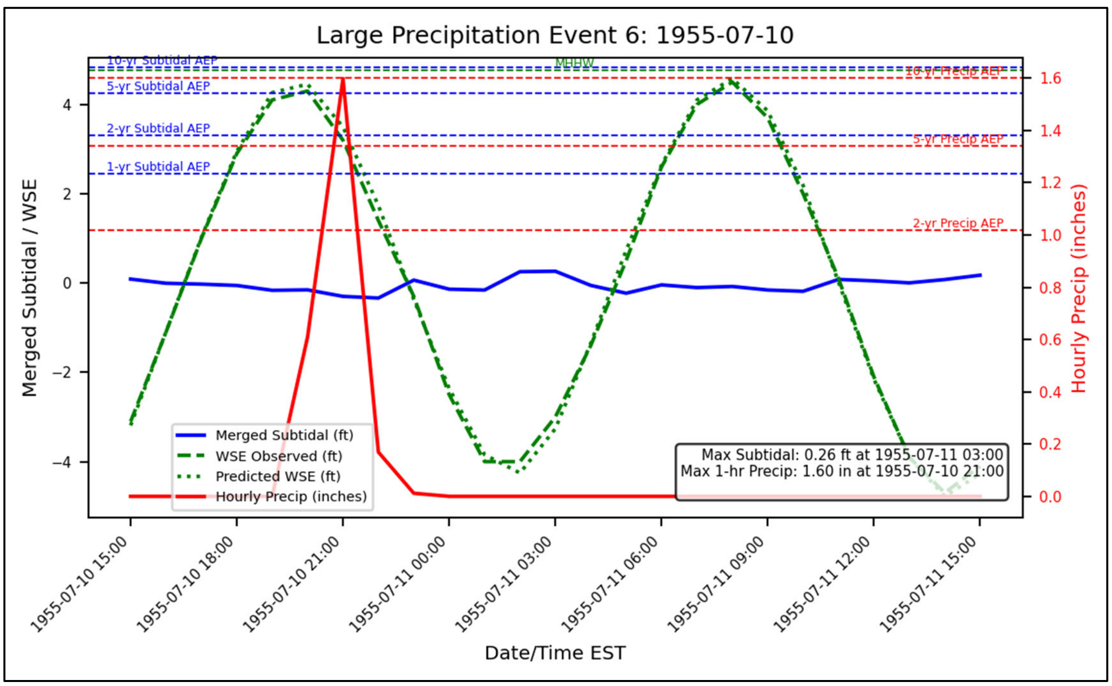


Figure 12: July 1955 Tidal and Precipitation Time Series

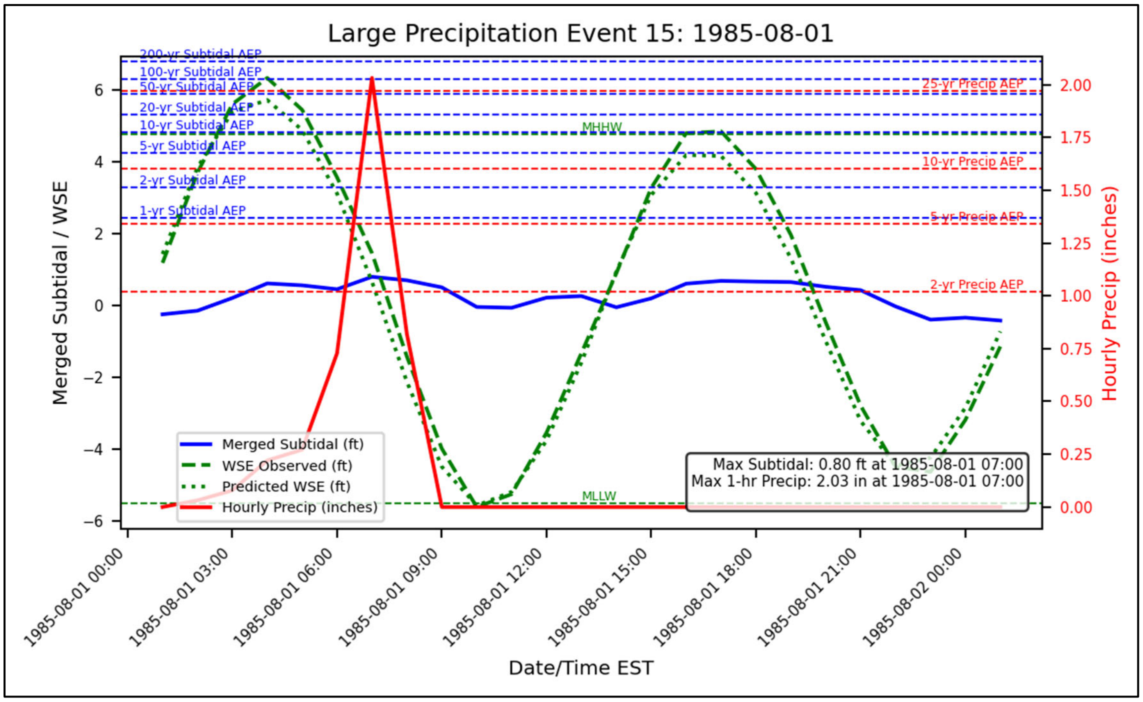


Figure 13: August 1985 Tidal and Precipitation Time Series

3.1.6 Summary

Boston's historical record-breaking subtidal water levels (surges) are almost exclusively dominated by Nor'easters. In general, Nor’easters are characterized by long durations, where elevated subtidal water level can last over several high tides. While Nor'easters can produce significant precipitation (often as heavy wet snow or steady rain), their overall precipitation intensity per hour is typically lower. In contrast, hurricanes in New England are notoriously fast transit events. A hurricane's surge might last only 2 to 6 hours. If that peak surge occurs during low tide, the impact is minimized.

In this analysis of historical data, it has been concluded that there is minimal and weak correlation and coincidence between rainfall (interior stage) and subtidal/water level (exterior stage) in Boston.

3.2 BWSC Inundation Model Description

The information in this section describing the Boston Water and Sewer Commission (BWSC) inundation model is based on the 2020 Inundation Model Final Report developed by Hazen and Sawyer (Hazen) for BWSC (BWSC, 2020) and the 2017 *Draft Collection System Model Update and Calibration Report* prepared by AECOM (BWSC, 2017).

The BWSC developed a two-dimensional (2D) hydrologic/hydraulic model, using Personal Computer Storm Water Management Model (PCSWMM) software, designed to predict the extent and duration of flood inundation within the City of Boston for a variety of wet weather events.

The model utilizes precipitation data with high spatial (speed and direction) and temporal (distribution of rainfall over time) resolution for dynamic synthetic storms of various intensities, durations, and depths. The City's collection system infrastructure is composed of a sewer system (partially combined) and a storm drain system, each of which has outfalls that are subject to tidal fluctuations and vulnerable to storm surge. In the sewer and drain systems, the model has the ability to dynamically simulate flows that surcharge the systems and cause flooding. The inundation model utilizes the existing 1D models of the BWSC sewer and storm drain systems (last updated in 2012) as a starting point. The 2D model was developed using these models as a basis, with advancement to include detailed topographic data and the ability to predict the movement of water on the ground surface and around buildings. The 1D model network and 2D model zones are shown in **Figure 18**. The modeling software package PCSWMM was selected to develop this coupled 1D- 2D sewer and drain model. PCSWMM utilizes the US EPA SWMM5 computational engine for fully dynamic routing of pipe and open channel flows. SWMM5 is a free and open source software package developed and distributed by the US EPA. The simulations were performed using SWMM engine version 5.2.4 and PCSWMM version 7.7.3920.

It is important to note that the entire City extent (~48 square miles) was not simulated in 2-dimensional modeling format, due to computational limitations. The parts of the City, which were simulated in 2D were determined to be most vulnerable to flooding based on previous BWSC studies, testing using the combined 1D model, and discussions with BWSC. The Inundation Model also does not account for the impact of non-Commission infrastructure. For example, pumps owned and operated by the MBTA, MassDOT, MassPort, the MWRA, and others are not accounted for in the model (for example, pumps in the Mass Pike Tunnel are not accounted for). Therefore, in some locations, flooding may be overpredicted by the model.

3.2.1 Terrain

The digital elevation model (DEM) developed for the Inundation Model is based on the "2021 USGS 3DEP Central Eastern Massachusetts Lidar" that was acquired in Spring of 2021. **Figure 14** includes resolution information of the dataset published in the Mass Gis website.

Hazen stated the following modifications on the DEM:

"Some slight modifications based on field survey were made in critical locations, especially near the Mass Pike, to accurately capture thin walls which may have an impact on water movement across the surface."

Item	Description
Vertical accuracy $RMSE_z$:	10 cm
Nominal pulse spacing:	Less than or equal to 0.35 meter/Greater than or equal to 8 points per sq. meter
DEM cell size:	0.5 meter
Horizontal Projection:	NAD83(2011)/UTM zone 19N
Horizontal Datum:	NAD83 (NSRS 2011)
Horizontal Units:	meters
Vertical Datum:	NAVD88 – Geoid18 (m)
Vertical Units:	meters

Figure 14: 2021 Lidar Technical Information

3.2.2 Description of "Sewershed" (BWSC, 2017)

BWSC owns and operates the collection system serving the City of Boston. The collection system conveys both wastewater and stormwater and is comprised of sanitary sewers, storm drains, combined sewers and combined sewer overflows. The BWSC' sewer model covers the sanitary sewers, combined sewers and combined sewer overflows. The storm drain system is covered in a separate storm drain model. However, the sewer model includes storm drains where the systems are interconnected. The sewer model encompasses the portions of the MWRA North System that are tributary to the Ward Street, Columbus Park, and Chelsea Creek Headworks, Caruso Pump Station, and the portion of the MWRA South System that drains south to Milton. The model includes the following features:

- BWSC sanitary sewers with diameters greater than or equal to 24 inches.
- BWSC combined sewers greater than or equal to 36-inches.
- BWSC combined sewer regulators, overflow conduits and CSO outfalls.
- MWRA North System pipes downstream of a Boston public connection extending to each MWRA headworks.
- Simplified representations of key components of the MWRA North System upstream of Boston.
- MWRA South System pipes downstream of a Boston public connection and upstream of the Boston- Milton boundary.

The catchments in the model are classified as sanitary flow only, combined, or storm water.

3.2.3 Hydrology (BWSC, 2017)

The hydrologic component of the model refers to the processes that generate runoff in combined sewer and stormwater areas, and rainfall dependent infiltration / inflow (RDII) in separated areas. To accomplish this, the watershed and sewershed are divided into subareas that receive precipitation and generate runoff and RDII; see **Figure 15** for an example of delineation. The quantity of runoff and RDII produced by each subcatchment depends on the parameters specified in the model. This section describes the delineation of the watershed and sewersheds and the initial estimates of the model parameters. The model parameters were further refined as part of the model calibration.

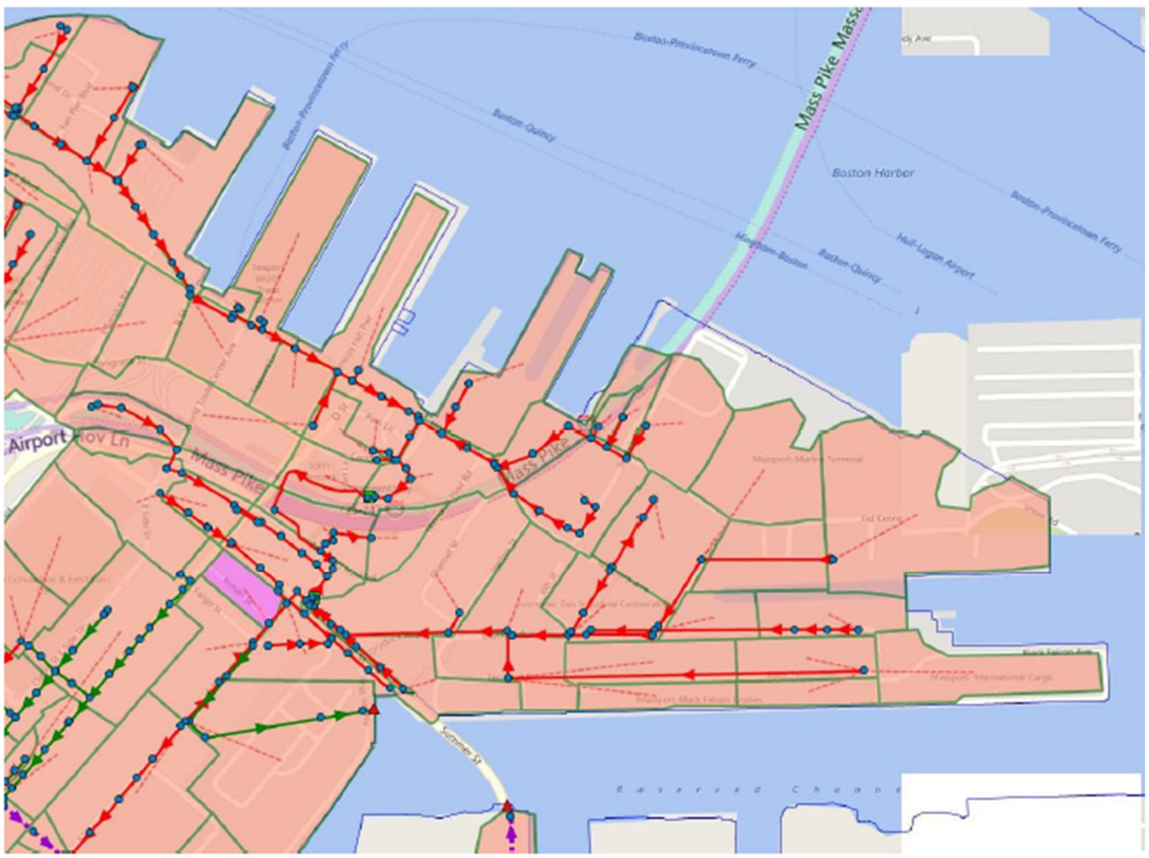


Figure 15: Example of Subcatchments Delineation in Seaport Area (BWSC, 2017)

Figure 16 illustrates the delineation of the sewershed. The delineation covers 100% of the service area with either a combined sewer or separated subcatchment. If an area has no wastewater service, such as a park, then it was not included.

If the stormwater in a separated area entered the wastewater collection system further downstream or potentially had an impact on the hydraulics of a CSO outfall pipe, then it was included in the sewer model delineation. An exception to this rule was the Seaport

District, which included a delineation of the stormwater system even though it is not connected to the wastewater system. In general, the stormwater delineation was based on the sanitary sewer delineation and then adjusted if necessary. **Figure 17** illustrates the combined sewer and stormwater watershed areas that were included in the collection system model.

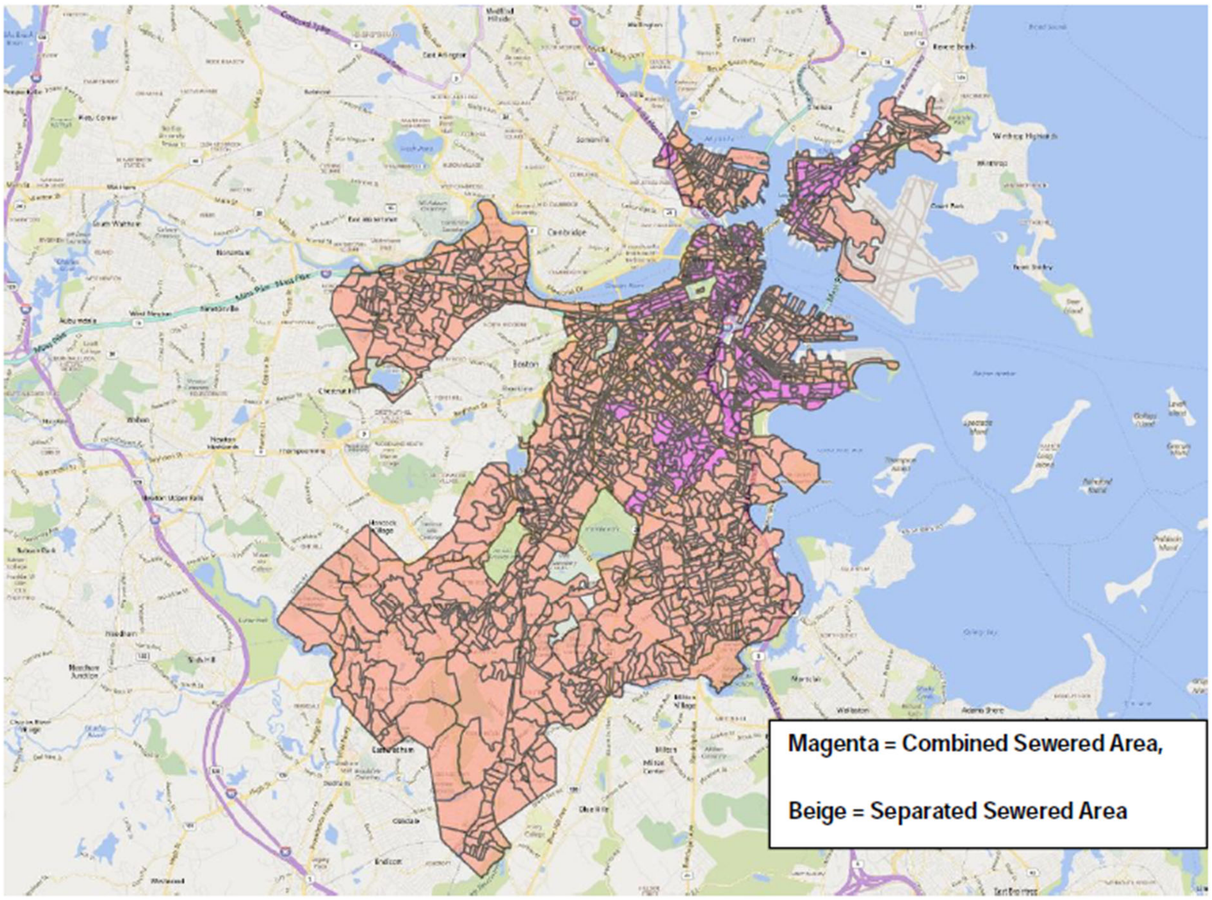


Figure 16: Sewershed Delineation (BWSC, 2017)

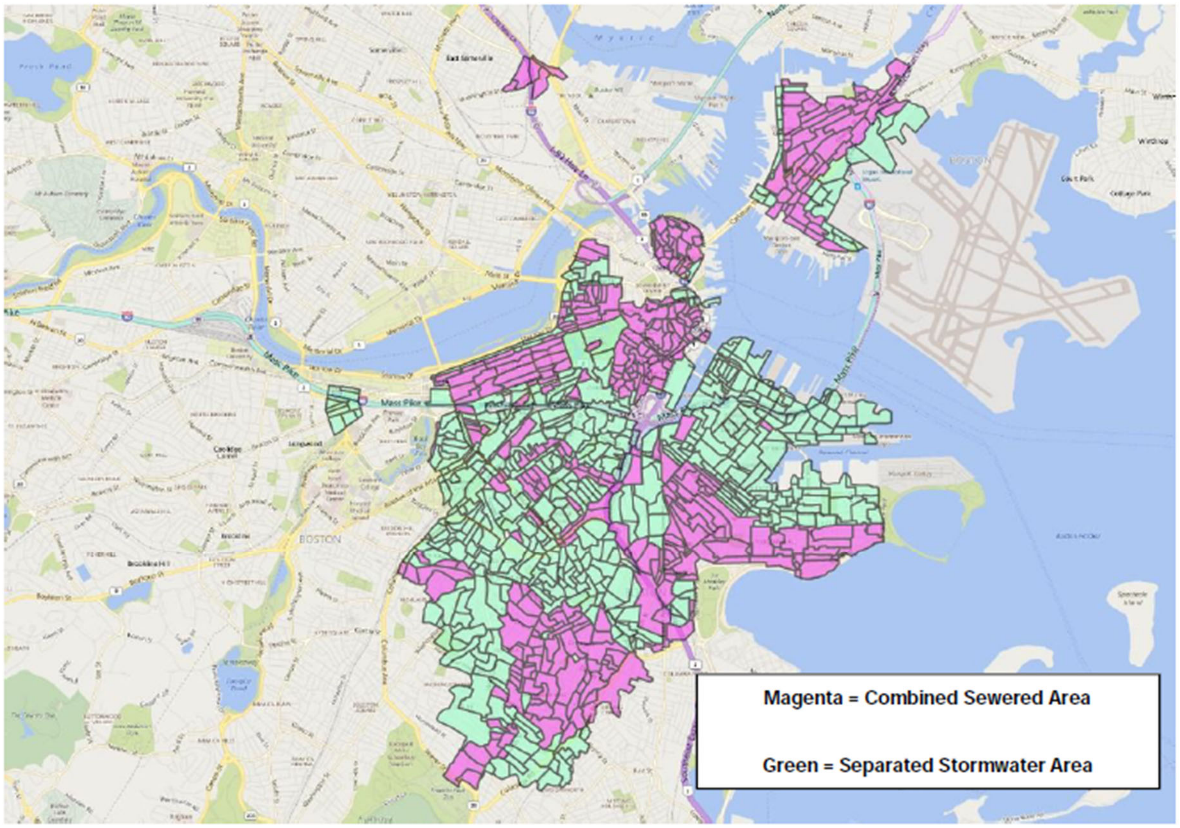


Figure 17: Combined Sewer and Stormwater Watersheds Delineation (BWSC, 2017)

3.2.3.1 Estimation of Parameters

The hydrology model is used to generate storm water runoff in combined sewer / stormwater areas, and RDII in separated areas. The model parameters for simulating runoff are different from the parameters used to simulate RDII. The parameters for each of these categories are summarized below.

Runoff: Several parameters must be specified to simulate runoff, including:

- Impervious %
- Roughness
- Depression Storage
- Slope
- Soil Infiltration
- Catchment Width

Impervious Area. For combined and stormwater areas, the total impervious area for each subcatchment was estimated from the BWSC's impervious GIS coverage using the PCSWMM area weighting tool. The total impervious area (TIA) calculated from the impervious coverage is specified in the model. However, the runoff that enters the collection system is driven by the directly connected impervious area (DCIA). The

SWMM model allows the DCIA to be modeled using the routing feature. The subcatchment impervious area is routed to the pervious area, with the initial routing set at a typical value of 65%. The interpretation of this is that 65% of the impervious area is routed to pervious surfaces, and 35% directly to the sewer system. Thus, the DCIA is equal to the TIA x (100 - routing percent). The routing percentage was adjusted as part of the model calibration.

The ground infiltration routine was used to simulate RDII from the service area, and total tributary area is required using this methodology. Therefore, the actual area was used for separated sanitary sewer subcatchments with the parameters adjusted to produce the correct flow. The percent impervious was reduced to reflect only direct inflow into the system, which was determined through model calibration.

Roughness. Manning's roughness coefficients are assigned to impervious and pervious surfaces. To provide consistency with the Commission's stormwater model, these values were set at 0.02 for impervious surfaces and 0.08 for pervious surfaces.

Depression Storage. Depression storage values of 0.05 inches were specified for impervious surfaces and 0.08 inches for pervious surfaces.

Slope. The catchment slope for each subcatchment was calculated using the National Elevation Dataset (NED) https://lta.cr.usgs.gov/NED maintained by the USGS, and the USEPA Basins tool.

Soil Infiltration Parameters. The Green-Ampt soil infiltration routine was used for the soil infiltration. All of the catchments used a suction of 5.8 inches, a saturated hydraulic conductivity of 1.2 in/hr, and an initial moisture deficit of 33 percent.

Catchment Width. The catchment width controls how fast the rainfall reaches the drainage inlet, and it is the primary calibration parameter for peak flow. The initial width was specified as the equivalent diameter assuming the catchment was a circle, which was subsequently adjusted during model calibration.

Rainfall Dependent Infiltration / Inflow (RDII). RDII can consist of two components: a fixed component that occurs throughout the year and a groundwater component that may only occur during high groundwater conditions, such as during the spring or during a specific storm. The fixed component may be due to I/I sources such as roofs or cross-connected drainage, and this was simulated using the RUNOFF routine in SWMM. If groundwater inflow was observed, then the impact of groundwater was simulated using the SWMM groundwater routines.

3.2.4 BWSC Sewer and Drain Models

The sewer model includes 7,458 catchments (4,606 are within Boston), 5,640 nodes, and 5,714 conduits/links. The drain model includes 3,657 catchments (3,501 within

Boston), 4,336 nodes, and 4,389 conduits/ links. These models form the basis of the 1D component of the 2D model. **Figure 19** depicts the sewer system model and **Figure 20** depicts the drain model. Note that the storm drain model contains the Charles River and the Neponset Rivers watersheds.

BWSC's existing sewer and drain models do not explicitly account for each individual catch basin and drain inlet. The hydrologic component of the model uses calibrated subcatchments to "load" rainfall runoff into specific nodes (i.e., manholes) in the model where flows are introduced to the system. Flow may only leave the 2D model network by discharging through a 2D outfall or entering the 1D model network through a linked node. Considering this, and the fact that explicit surface drainage features are not included in the 1D model, predicted surface flooding may persist for a longer period of time in the model than in reality. Low points in the 2D mesh will not drain if they are not connected to a 1D node. Lack of explicit surface drainage features in the 1D model network will not impact the accuracy of model predictions regarding the extent and depth of inundation but may lead to overstated predictions regarding the length of inundation in some areas.

The existing sewer and drain models provide the "backbone" of 2D models by predicting in-pipe flows and levels. The existing sewer and drain models also contain the hydrologic parameters that determine how much rainfall becomes runoff that enters into the sewer or drain system. Rainfall is not applied directly to the 2D surface.

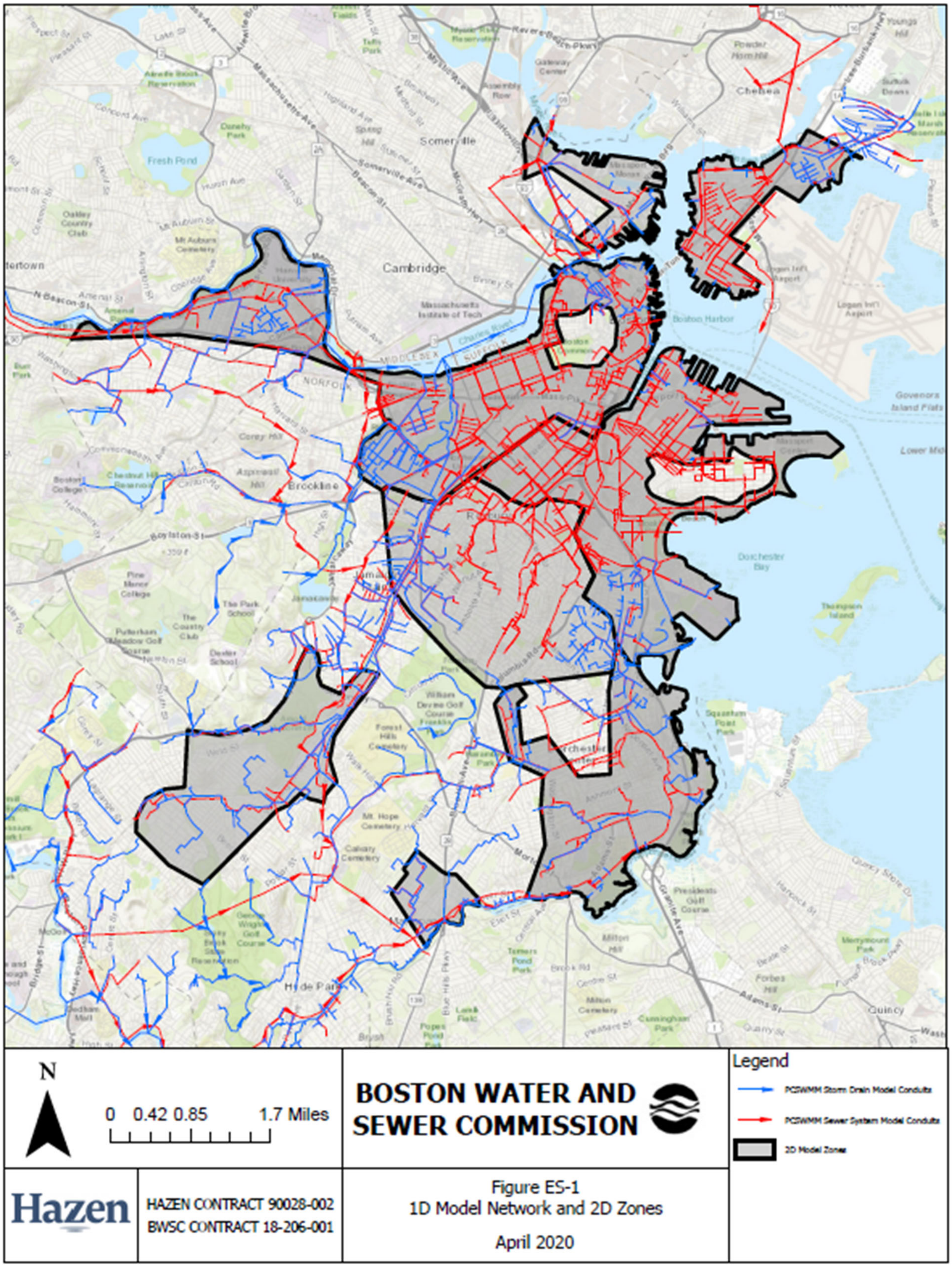


Figure 18: 1D Model Network and 2D Zones (BWSC, 2020)

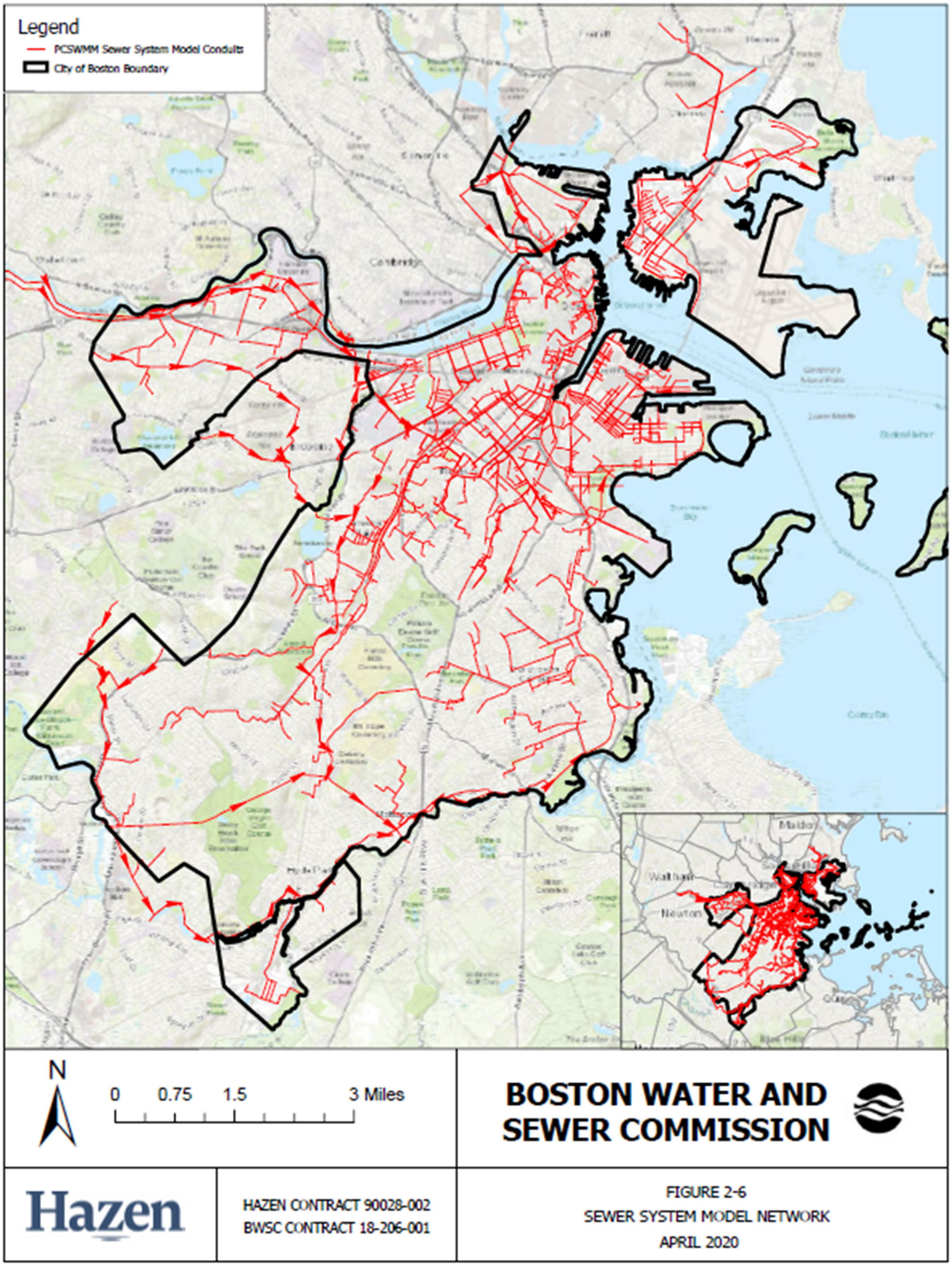


Figure 19: 1D Sewer System Model Network (BWSC, 2020)

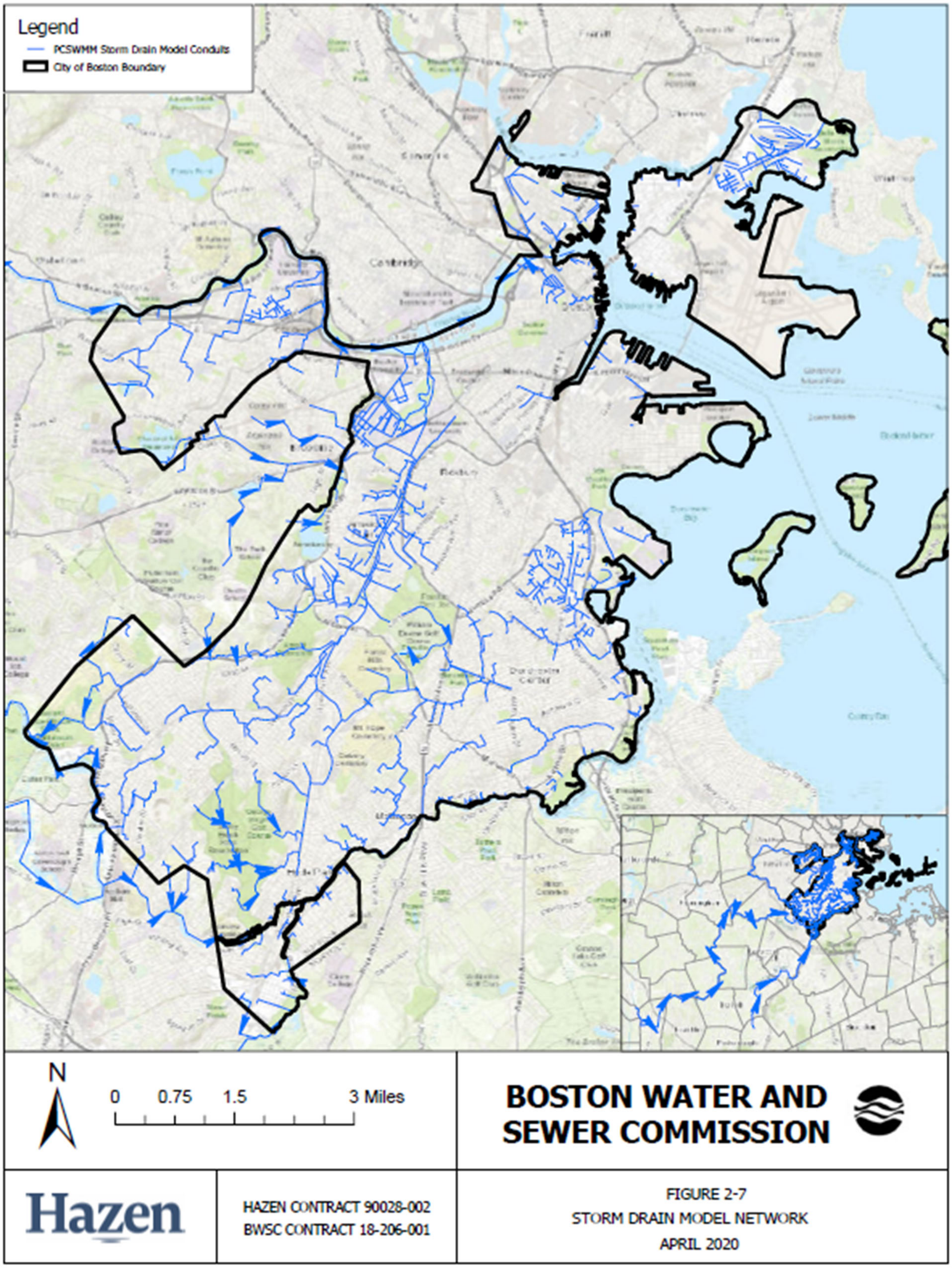


Figure 20: 1D Storm Drain Model Network (BWSC, 2020)

3.2.5 Development of 2D Model Zones

PCSWMM provides an integrated approach to 2D modeling. The user may select specific overland areas to be modeled using the augmented 1D-2D functionality, while the remainder of the sewer and drain network is modeled in 1D. PCSWMM simulates the movement of flood water over a defined surface, which represents ground topography and uses a hydraulic link-node network to create a 2D mesh. Water depth is computed at nodes and free surface flow between nodes is conveyed by links. Each 2D node is connected to adjacent 2D nodes with open channels to form a hexagonal pattern referred to as a 2D cell. The spacing between nodes in the hexagonal mesh is user defined. The developer of PCSWMM, Computational Hydraulics Institute, provides guidance stating that the recommended maximum number of 2D nodes in a 2D domain should be approximately 100,000. As such, it was necessary to determine a reasonable spacing between nodes and limit the extent of 2D mesh to preserve model stability and usability. Therefore, the 2D model network was divided into eight distinct 2D “zones”, in order to provide adequate coverage across the City and maintain stable simulations.

Each 2D zone represents a distinct 2D model that is coupled with the Citywide sewer and drain model. As such, it is not possible for overland flow (2D) to move between model zones, and each numbered zone is hydraulically isolated from all other zones. The 2D model zones are shown in **Figure 21.** Note that among the eight distinct 2D model zones, only five 2D model zones were used to simulate the effects of the Project barrier alignments including:

- Zone 1: Charlestown (Part of the USACE “Downtown” and all of “Charlestown” barrier alignments)
- Zone 2: East Boston (All of USACE “East Boston” barrier alignments)
- Zone 3: Back Bay/Downtown (Part of USACE “Downtown” barrier alignments)
- Zone 5: Dorchester Bay (Part of USACE “Dorchester” and all of “South Boston” barrier alignments)
- Zone 6: Neponset (Part of the USACE “Dorchester” barrier alignments)

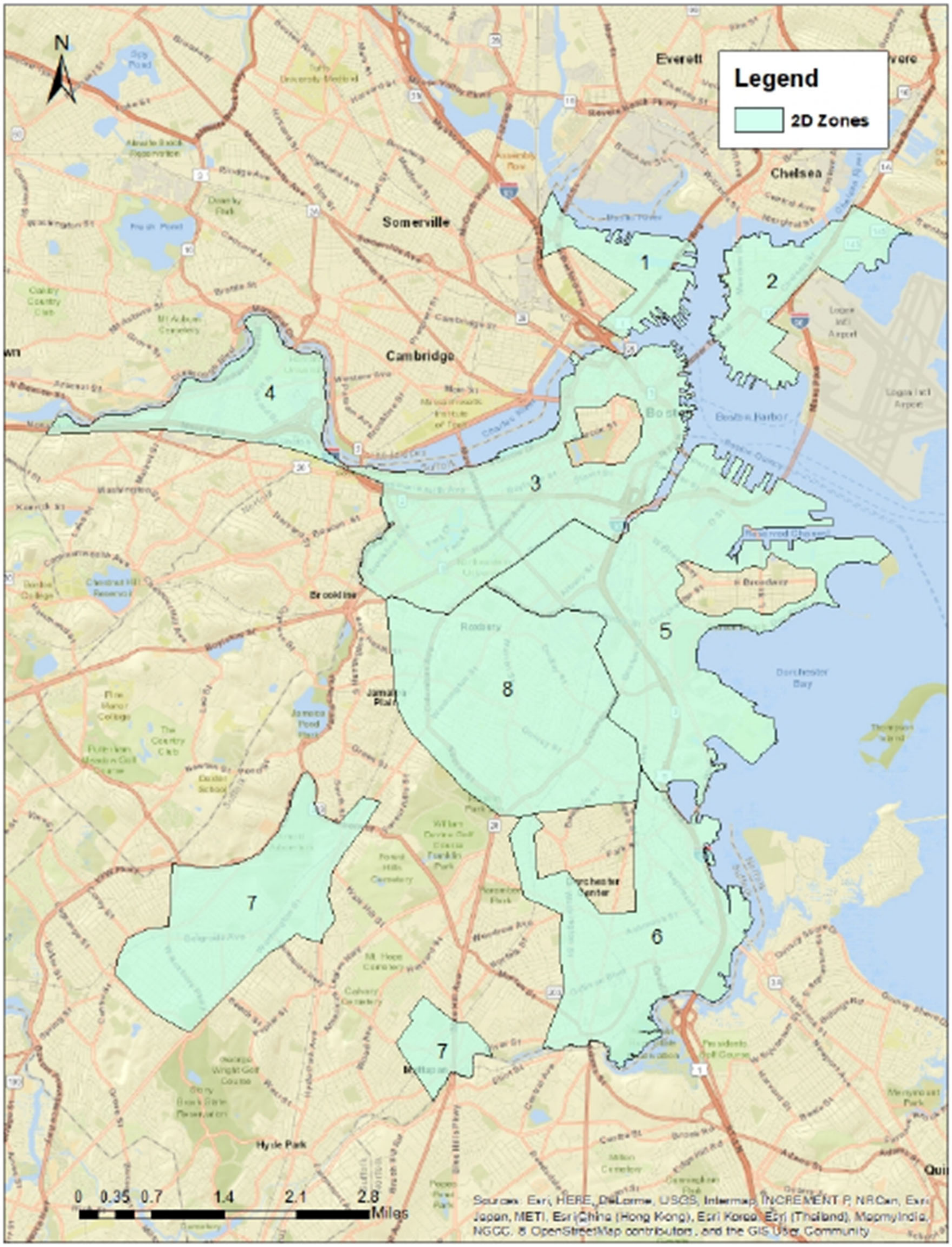


Figure 21: 2D Model Zones (BWSC, 2020)

3.2.6 Model Calibration

The effort to calibrate the sewer and drain models were extensive and it is documented in Section 4 *Model Calibration* in the 2017 *Draft Collection System Model Update and Calibration Report* prepared by AECOM (BWSC, 2017).

3.2.7 Model Limitations

The entire land area of the City of Boston is not simulated explicitly in 2D due to software and computational (practical) limitations. The developer of the modeling software used for this study, Computational Hydraulics Institute (CHI), recommends that 2D models do not exceed 100,000 elements. As such, it was not possible to simulate the entire City using a single 2D model that contained sufficient detail and resolution to evaluate flooding impacts. The Inundation Model strikes a reasonable balance between the number of model elements in each simulation and the size of each element. An extensive pilot testing effort was undertaken at the outset of the inundation model development to determine the City's most flood vulnerable areas and to determine the appropriate extent and resolution of the 2D mesh. The 2D models developed utilize a 30-foot hexagonal mesh, which means average depths are predicted for 30- foot wide areas. Given this, the following limitations should be considered when interpreting model results and the findings of this study:

1. The Inundation Model accuracy was estimated to be four inches for the estimated water surface elevations and depths. Therefore, the inundation maps are based on a flood depth threshold of four inches to display flooding areas.
2. The Inundation Model does not include all catch basins or pipes less than 24-inch in diameter.
3. Since the size of the 2D mesh was 30 feet, it is not possible to interpret results at a finer resolution (e.g., 15 feet). In reality, the amount of flooding may vary over any given 30-foot area. As such, predicted flood depths should not be interpreted as definitive amounts of water, but as general probable depths that could result from a given storm scenario.
4. Flood duration is calculated based on the depth predicted for individual 30-foot 2D cells in the mesh. It is possible that the duration of flooding may differ within each 2D cell due to localized differences in depth within each 30-foot area.
5. Non-BWSC infrastructure (e.g., private outfalls) is not accounted for in the model. As such, any flood protection equipment and structures that MassDOT, the MBTA, MassPort, and other agencies may own and operate are not accounted for explicitly in the model. For example, pumps that evacuate water from the Mass Pike tunnel and other infrastructure are not accounted for. As a result, the amount of flooding predicted may be overstated in some areas.
6. The Commission's existing 1D sewer and drain models do not explicitly include some features that could impact the depth and duration of flooding, such as individual catch basins. Since the sewer and drain models are the basis for the Inundation Model, the accuracy of model predictions is limited by the accuracy and resolution of the existing sewer and drain models. Due to the lack of catch

basins, it is possible the duration of flooding may be overestimated in some low-lying areas. It is not expected that lack of catch basins significantly impacts model predictions related to flood magnitude or extent due to the large size of the events simulated.

7. The Inundation Model included existing tide gates, but the model did not include proposed tide gates. Therefore, the scenarios with the barriers in place do not account for the effects of the proposed tide gates.

3.3 Minimum Facilities Analysis

A "Minimum Facilities" analysis was performed according to requirements described in EM 1110-2-1413 Section 3-3c.

*"The minimum facility should provide interior flood relief such that during **low exterior stages (gravity conditions)** the local storm drainage system functions essentially as it did without a levee in place for floods up to that of the storm sewer design. If a local storm drainage system is in existence, then the minimum facility should pass the local system design event with essentially no increase in interior flooding."*

For each coastal neighborhood in the City (i.e., 2D zone) where there is a proposed structural solution such as a levee or floodwall, the following two scenarios were modeled to assess the effects of the proposed USACE barriers on the interior drainage associated with the proposed barriers:

Scenario 1: Future Without Project (FWOP)

FWOP is an existing conditions model scenario, where BWSC infrastructure is modeled as-is, with no changes or additions of USACE-proposed barriers or interior drainage projects. This scenario uses the future condition mean sea level tidal cycle that incorporates relative-sea-level-change (RSLC) in absence of storm surge.

Scenario 2: Future With Barriers (FWB)

FWB uses the existing BWSC infrastructure model with the addition of USACE-proposed barriers (floodwalls/levees) without proposed interior drainage projects. This scenario uses the future condition mean sea level tidal cycle that incorporates relative-sea-level-change (RSLC) in absence of storm surge.

3.3.1 Coastal Boundary Condition

The coastal boundary condition applied to both scenarios was the mean tidal cycle with MSL at 4.67 ft NAVD based off USACE High Sea Level Change projection for the year 2090. The peak tide elevation is approximately 9.9 feet NAVD88 as displayed in **Figure 22**.

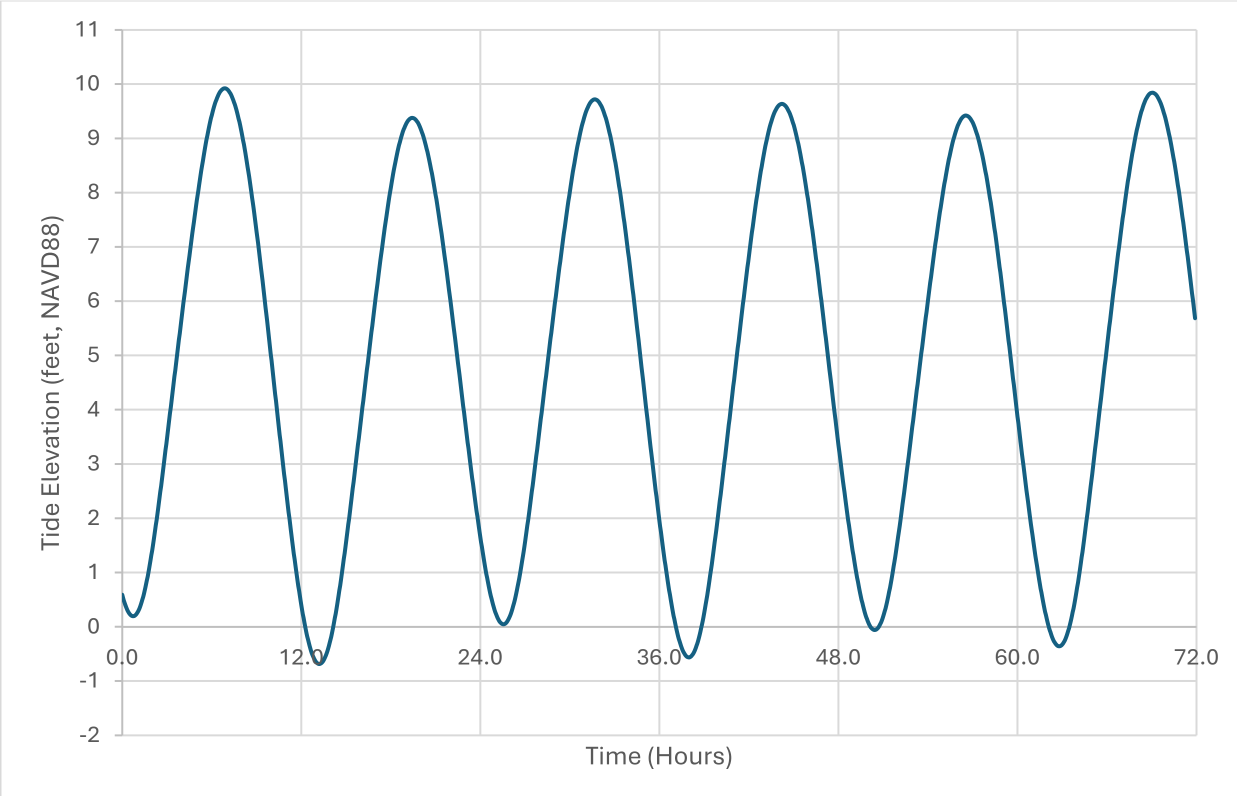


Figure 22: Tidal Signal at Boston for USACE High SLC in 2090

3.3.2 Rainfall Hyetograph

According to the BWSC Coastal Stormwater Discharge Analysis report (BWSC, 2023), the storm sewer design event for BWSC sewer infrastructure is the 24-hour duration 0.1 AEP (10-year) event that has total depth of 5.15 inches. BWSC adopted the SCS Type III distribution. It is not clear what the source is for the 5.15 inches of total depth. For comparison purposes, NOAA Atlas 14 (NOAA, 2025) outputs 4.91 inches at Logan Airport for the 24-hour duration 0.1 AEP, and TP-40 (NWS, 1961) shows a value of approximately 4.7 inches. Note that the adopted SCS Type III distribution is more intense than the Atlas 14 distribution, which compensates for the lower total depth of 4.7 inches. For purposes of this analysis, the model using the 5.15 inches is considered sufficiently similar to adopt.

3.3.3 Interior and Exterior Coincidence

Based on the correlation analysis described above, predicting the coincidence of the peak exterior event and the peak interior flows is uncertain, and if the interior and exterior events occur at the same time, this would be considered the worst-case scenario and a conservative approach for modeling coincidence. The USACE discussed with BWSC and Hazen and concluded that assuming that the peak discharge of the interior drainage and the peak of the coastal tidal signal was coincident it would be the scenario most likely to demonstrate the need for minimum facilities based on Hazen's knowledge and experience with system function and operation of the Inundation Model.

3.3.4 Results and Conclusion

Inundation maps for both scenarios (FWOP and FWP) were developed and compared visually for each of the five neighborhoods, which are included in **Attachment 1** (BWSC, 2025). The model predictions did not show increased flooding in the FWP scenario due to the proposed barriers. Therefore, this macro-scale analysis that assessed high level flooding impacts concluded that minimum facilities are not required. However, additional interior drainage analysis is required for the measures carried forward to the 35% design to incorporate localized piping, final proposed barriers alignment, and associated grading once they are determined after DP-2. The results of this future analysis may require local conveyance and outlets, which need to be captured in the project cost.

3.4 Interior Drainage Flooding Beyond Storm Sewer Design

Beyond the Minimum Facilities evaluation, DPM-CW Memo, Guidance for Induced Flooding (USACE, 2025) provides clarification of processes to identify and evaluate induced flooding that may be caused by a proposed project; see Section 2.1.3. Therefore, an assessment of increased flooding was performed as described below and the results were shared with the Office of Counsel and Real Estate PDT members to inform their assessment of induced flooding.

A preliminary analysis was performed to assess the effects of the proposed barriers by simulating a larger rainfall than the BWSC storm sewer design event (0.1 AEP, 10-year). Due to time constraints, only the 100-year (0.01 AEP) rainfall was used as a representative rainfall scenario to assess if the Project's proposed barriers (e.g., levees, floodwalls) were increasing flooding in a more extreme rainfall event. If increasing flooding was predicted, the stormwater management solutions developed by BWSC and Hazen and documented in the 2023 Coastal Stormwater Discharge Analysis (BWSC, 2023) were evaluated whether they were sufficiently sized to manage the potential increases in flooding caused by the construction of the Project levees/ floodwalls and/or tide gates. The solutions developed by BWSC and Hazen were designed to a conceptual level with design conditions that differed from those proposed by the USACE for this analysis. Refer to Section 1.4 for a summary of the design conditions used by BWSC and Hazen.

Three modeling scenarios were requested and performed as needed including:

(1) Without Project, which means not including the Project or proposed BWSC interior drainage features;

(2) With barriers (e.g., floodwalls/levees) only, which means not including the proposed BWSC interior drainage features; and,

(3) With Project, which means modeling the Project and the BWSC interior drainage features.

The results of the scenarios (1) and (2) were compared, and for the locations where there was an increase in flooding in scenario (2), in either depth or footprint, scenario (3) was simulated to understand if, the rainfall-induced flooding in the FWP (scenario 3) is less than in the FWOP (scenario 1).

3.4.1 Coastal Boundary Condition

Two coastal boundary conditions were modeled. Initially, the same future condition that includes sea level change used with the "Minimum Facilities" simulations was modeled; see Figure 23. It was decided to also simulate a lower coastal water level (present MHW = El. 4.3 feet NAVD88, present MSL = El. -0.3 feet NAVD88) that could potentially result in more rainfall-driven flooding in low-lying areas. When the coastal water level is higher, the floodwall keeps the water out, improving conditions, even if it traps runoff and causes flooding. When the water level is lower, routine tides do not reach the floodwall, so any flooding caused by the floodwall blocking runoff is isolated and can be identified.

Also, simulating the two different coastal boundaries provides insights into a coincident frequency analysis that was not performed as part of this preliminary analysis due to time and resource constraints. Based on the results of the correlation analysis that showed a weak correlation between precipitation events that represent interior drainage flood and the exterior coastal levels, EM 1110-2-1413 states that a coincident frequency analysis between the interior drainage flood elevations and the exterior coastal levels is required. In general, the analysis shows similar interior flooding depths associated with exterior runoff for the two future coastal conditions assessed inferring that the coastal level is not a driver for the analysis. As noted earlier in this document, the interior drainage analysis performed so far is considered macro-scale, and additional interior drainage analysis is anticipated for the measures carried forward to the 35% design to incorporate localized piping, final proposed barriers alignment, and associated grading once they are determined after DP-2.

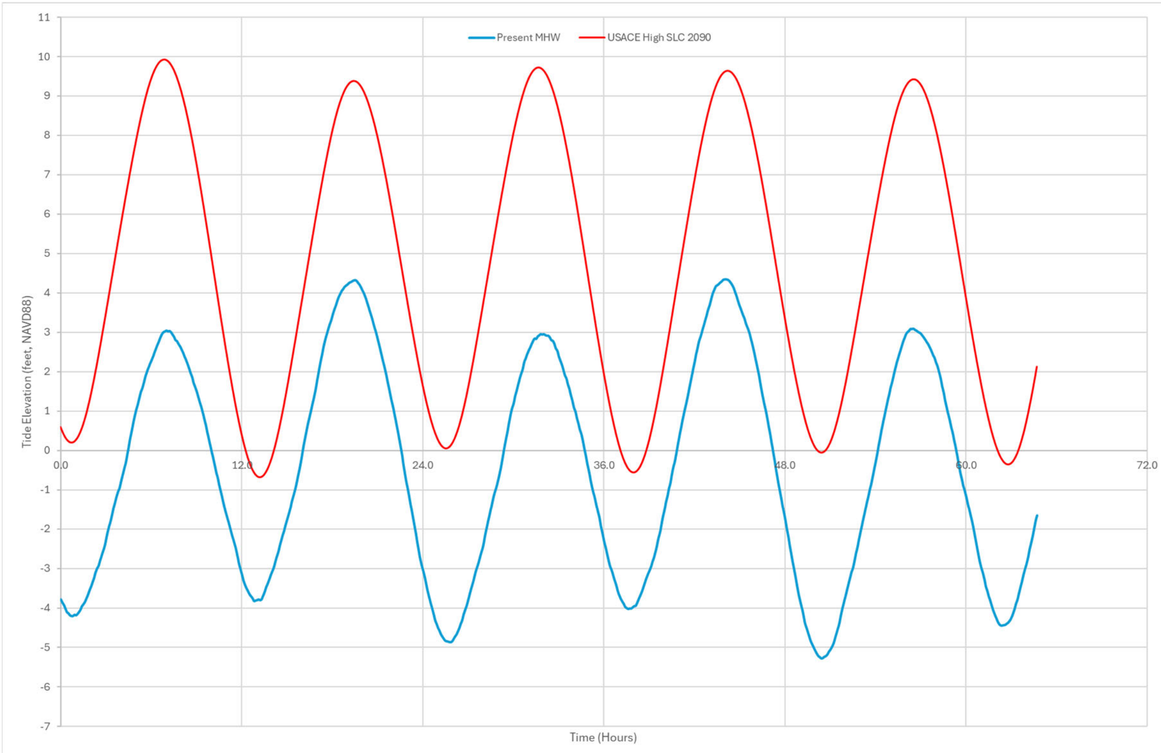


Figure 23: Modeled Tidal Signals at Boston: Present MHW (blue) and USACE High SLC in 2090 (red)

3.4.2 Rainfall Hyetograph

The adopted frequency storm that exceeds the storm sewer design is the 0.01 AEP (100-year) based on Atlas 14 (NOAA, 2025) at Logan Airport. The storm duration is 24 hours, and the time increment is five minutes. The total precipitation depth is 7.89 inches. The temporal distribution was obtained by using the frequency storm routing within HEC-HMS that maintains the frequency depths for the lower durations (e.g., 6-hour). The cumulative precipitation hyetograph is shown in **Figure 24**.

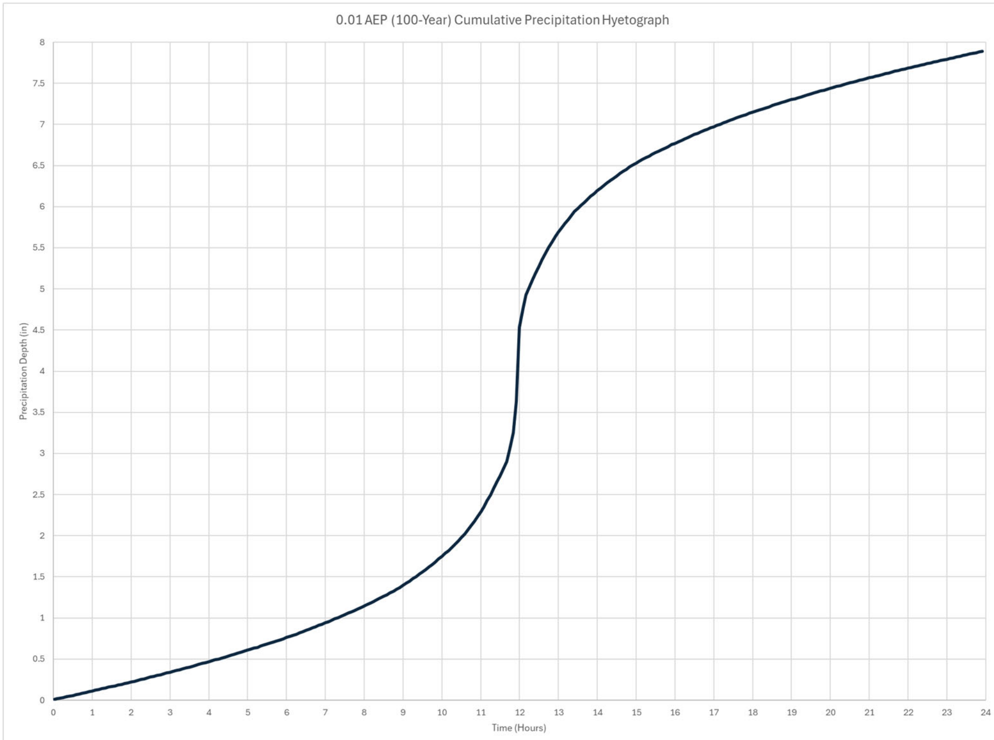


Figure 24: Cumulative Precipitation Hyetograph – 0.01 AEP (100-year)

3.4.3 Interior and Exterior Coincidence

Based on the correlation analysis in Section 3.1, interior rainfall and exterior coastal events are statistically independent. Because a rainfall event could occur at any point during the tidal cycle, this preliminary analysis adopts a conservative approach by evaluating the upper bound of potential tailwater conditions. The modeling assumes the peak discharge of the interior drainage coincides with the peak of the coastal tidal signal, representing the worst-case scenario where gravity drainage is maximally restricted.

3.4.4 Results and Conclusions

The maps showing the resultant inundation extents and depths for each modeled scenario for both coastal water levels (4.3 feet and 9.9 feet NAVD88) are included in a technical memorandum (BWSC, 2026b) that summarizes the analysis; see **Attachment 2**. Also, a comparison map that shows the difference between scenario 1 and scenario 2 is provided for each of the two coastal boundaries. In addition to the inundation maps in Attachment 2, this appendix provides inundation maps with imagery background and zoomed in view (smaller scale compared with Attachment 2 maps).

In general, the depth and extent of the flood increases were greater for the simulations that used the present condition coastal water level (4.3 feet NAVD88) that is approximately 6.6 feet lower than the future. This result can be explained by the lower coastal level that isolate the rainfall-driven flooding in low-lying areas from the high coastal flooding prevented by the proposed barriers. When the coastal water level is higher, the floodwall keeps the water out, improving conditions, even if it traps runoff and causes flooding. When the water level is lower, routine tides do not reach the floodwall, so any flooding caused by the floodwall blocking runoff is isolated and can be identified.

Some of the neighborhoods do not show inundation in the difference map (with barriers minus without barriers scenario) because the depths differences were lower than the threshold adopted of 4 inches.

Note that the results maps included in the attachments reference the Boston City Base (BCB) datum for the coastal elevations. The datum conversion from BCB to NAVD88 is -6.5 feet (0 NAVD88 = BCB – 6.5 feet).

For each neighborhood, model predictions for Scenarios 1 and 2 were compared, and if Scenario 2 exhibited an increase in flooding, Scenario 3 was also simulated. Charlestown was the only neighborhood whose results demonstrated that under the conditions modeled, the USACE-proposed barriers increased flooding. Scenario 3 results demonstrated that for the specific rainfall and coastal scenarios modeled, BWSC's proposed stormwater improvements have limited benefit in reducing the model-predicted induced flooding caused by USACE's proposed barriers.

Note that the neighborhood boundaries and terminology adopted by BWSC diverge from the regions and nomenclature used in the Boston CSRM; Figure 25 shows the adopted regions and nomenclature by BSWC for the study areas.

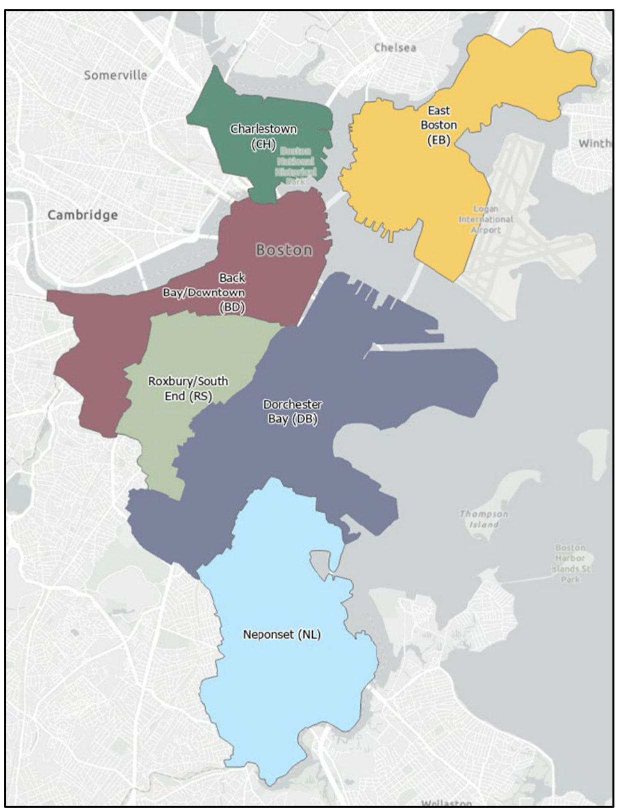


Figure 25: BWSC Adopted Nomenclature for Study Areas (Neighborhoods)

3.4.4.1 East Boston

The results map showing the difference in flood depths and extent between the with barriers only (scenario 2) and without Project (scenario 1) for East Boston based on the present condition coastal water level (4.3 feet NAVD88) is shown in Figure 26 (corresponds to Figure EB-3 in Technical Memorandum). The increased flooding consists of a few small areas mostly with depths differences up to one foot except for a localized area with depths differences up to two feet. Results therefore indicate that the proposed barriers within this neighborhood will not significantly increase flooding in the region. Thus, Scenario 3 was not modeled.

Figure 26: East Boston Model-Predicted Increased Flooding (Present Day Tide Cycle)

3.4.4.2 South Boston

The results map showing the difference in flood depths and extent between the with barriers only (scenario 2) and without Project (scenario 1) for South Boston based on the present condition coastal water level (4.3 feet NAVD88) is shown in Figure 27 (corresponds to Figure DB-3 in Technical Memorandum). The increased flooding consists of one small area on the Interstate-90 (Mass Pike) with depths up to two feet. Note that as stated in Section 3.2, the Inundation Model does not account for the impact of non-Commission infrastructure such as pumps that may exist for mitigating flood along the Interstate-90.

The small area of increased flooding at Dorchester Ave with depths up to one foot is not considered to be caused by the proposed barriers; instead, it appears to be model inaccuracy due to its significant distance from the proposed barriers.

Figure 27: South Boston Model-Predicted Increased Flooding (Present Day Tide Cycle)

3.4.4.3 Dorchester

The results map showing the difference in flood depths and extent between the with barriers only (scenario 2) and without Project (scenario 1) for the center and south regions of Dorchester based on the present condition coastal water level (4.3 feet NAVD88) is shown in Figure 28 (corresponds to Figure NP-3 in Technical Memorandum). The increased flooding consists of two small areas next to Conley Street with depths up to one foot.

Figure 28: Dorchester Model-Predicted Increased Flooding (Present Day Tide Cycle)

3.4.4.4 Downtown

The results map showing the difference in flood depths and extent between the with barriers only (scenario 2) and without Project (scenario 1) for Downtown based on the present condition coastal water level (4.3 feet NAVD88) is shown in Figure 29 (corresponds to Figure BD-3 in Technical Memorandum). The increased flooding consists of one small area north of Battery Street with depths exceeding two feet, a large area on Sargent's Wharf Lot (Pilgrim Parking) with flood depths up to two feet, a small area at Old Atlantic Ave with flood depths up to one foot, and the Long Warf area between Christopher Columbus Park and the New England Aquarium with flood depths up to one foot.

Figure 29: Downtown Model-Predicted Increased Flooding (Present Day Tide Cycle)

3.4.4.5 Charlestown Initial Modeling

This section summarizes the results of the initial modeling for Charlestown using the methods common to all neighborhoods. Based on the results described below that shows increasing flooding, a more refined an updated model was used to further investigate, which is described in the next Section 3.4.4.6 below.

The results map showing the difference in flood depths and extent between the with barriers only (scenario 2) and without Project (scenario 1) for Charlestown based on the present condition coastal water level (4.3 feet NAVD88) is shown in Figure 30 (corresponds to Figure CH-3 in Technical Memorandum). The increased flooding areas included a small area with depths up to one foot next to the Schrafft's Center, a large area with flood depths up to one foot east of the barrier alignment at Schrafft's Center (outside of the protected area), large areas with flood depths exceeding two feet along the Little Mystic Channel, and a large area with floods up to one foot at the Charlestown Naval Shipyard.

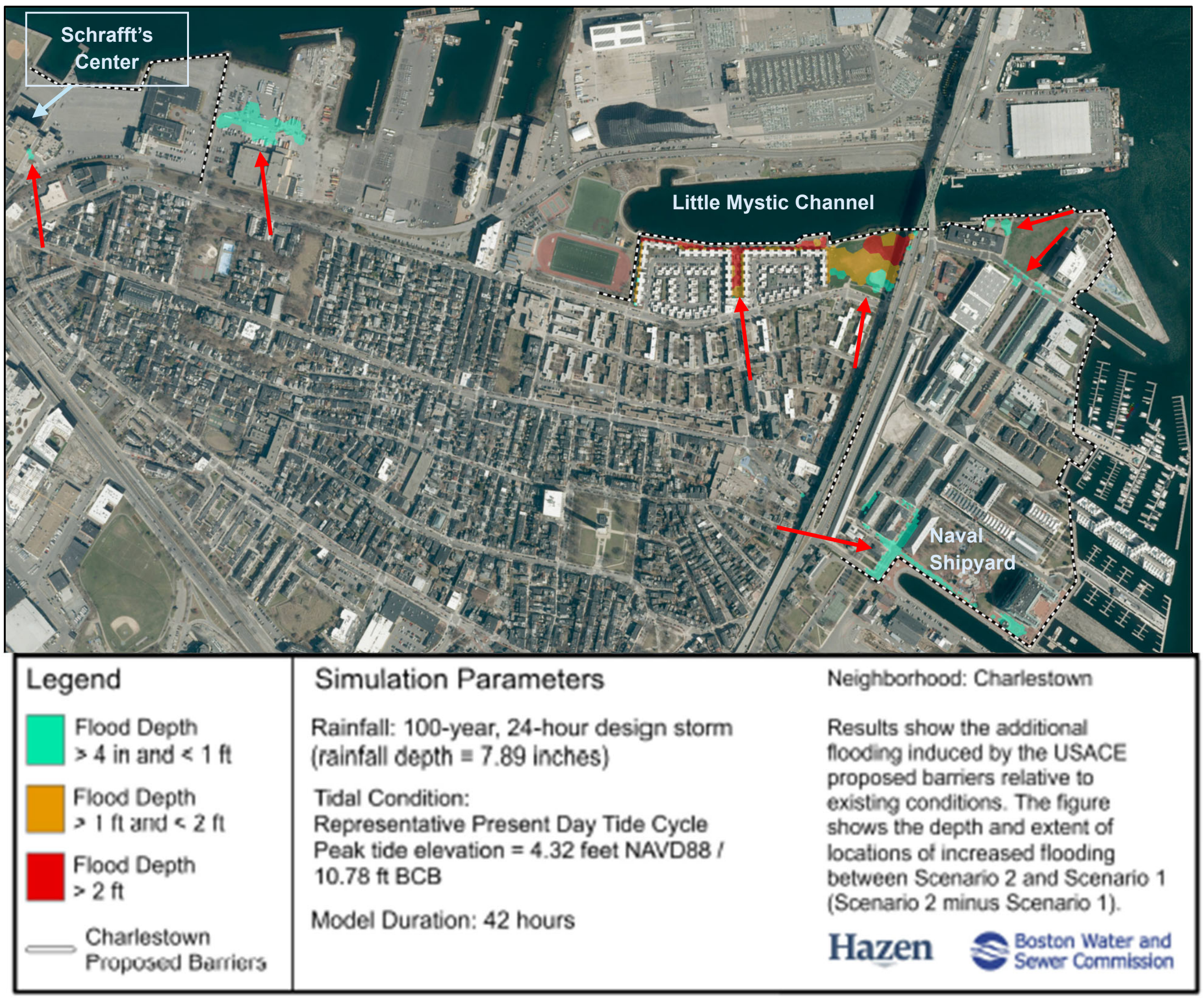


Figure 30: CH-3 – Model-Predicted Increased Flooding (Present Day Tide Cycle)

Scenario (3) was simulated for the Charlestown area that included the BWSC storage and pump stations solutions for the Schrafft's Center, but there were no drainage structures for the Little Mystic Channel or Charlestown Naval Shipyard included in the simulation because these solutions had not yet been developed when the simulations were performed. Results (Figure CH-4 in Attachment 2) demonstrated that for the specific rainfall and coastal scenarios modeled. As expected, BWSC's proposed stormwater improvements at Schrafft's Center have limited benefit in reducing the model-predicted increased flooding caused by USACE's proposed barriers because the storage and pump station solutions developed by BWSC for the Schrafft's Center area mitigate flooding within the protected area of the proposed barriers, but the large extent of increase flooding is outside (i.e., wet side) of the barrier.

3.4.4.5 Charlestown Additional Simulations with Updated Model

In parallel to this CSRM Project, BWSC and its consultant, Hazen, have been updating the PCSWMM inundation model as part of other ongoing projects. The modifications were described by Hazen as minor tweaks such as catchments adjustments to improve the model in specific areas.

Due to time constraint, only the Charlestown area was simulated with the updated model. Charlestown was selected based on the results that showed the largest increased flooding among the five neighborhoods. BWSC provided results maps for the updated simulations included in a presentation file that is in **Attachment 3** (BWSC, 2026a).

The results map showing the difference in flood depths and extent between the with barriers only (scenario 2) and without Project (scenario 1) for Charlestown based on the present condition coastal water level (4.3 feet NAVD88) is shown in Figure 31. The results based on the updated model do not show increased flooding along the Little Mystic Channel west of U.S. Route 1 where the previous model show large areas with flood depths exceeding two feet and the small area next to the Schrafft's Center with flood depths up to one foot. However, the other increased flooding area identified with the previous model on the east side of the proposed barrier (a large area with flood depths up to one foot east of the barrier alignment at Schrafft's Center and outside of the protected area) was similar to the increased flooding area predicted by the updated model.

The increased flooding results based on the updated model were adopted for the Charlestown area because the updated model is an improvement to the previous model.

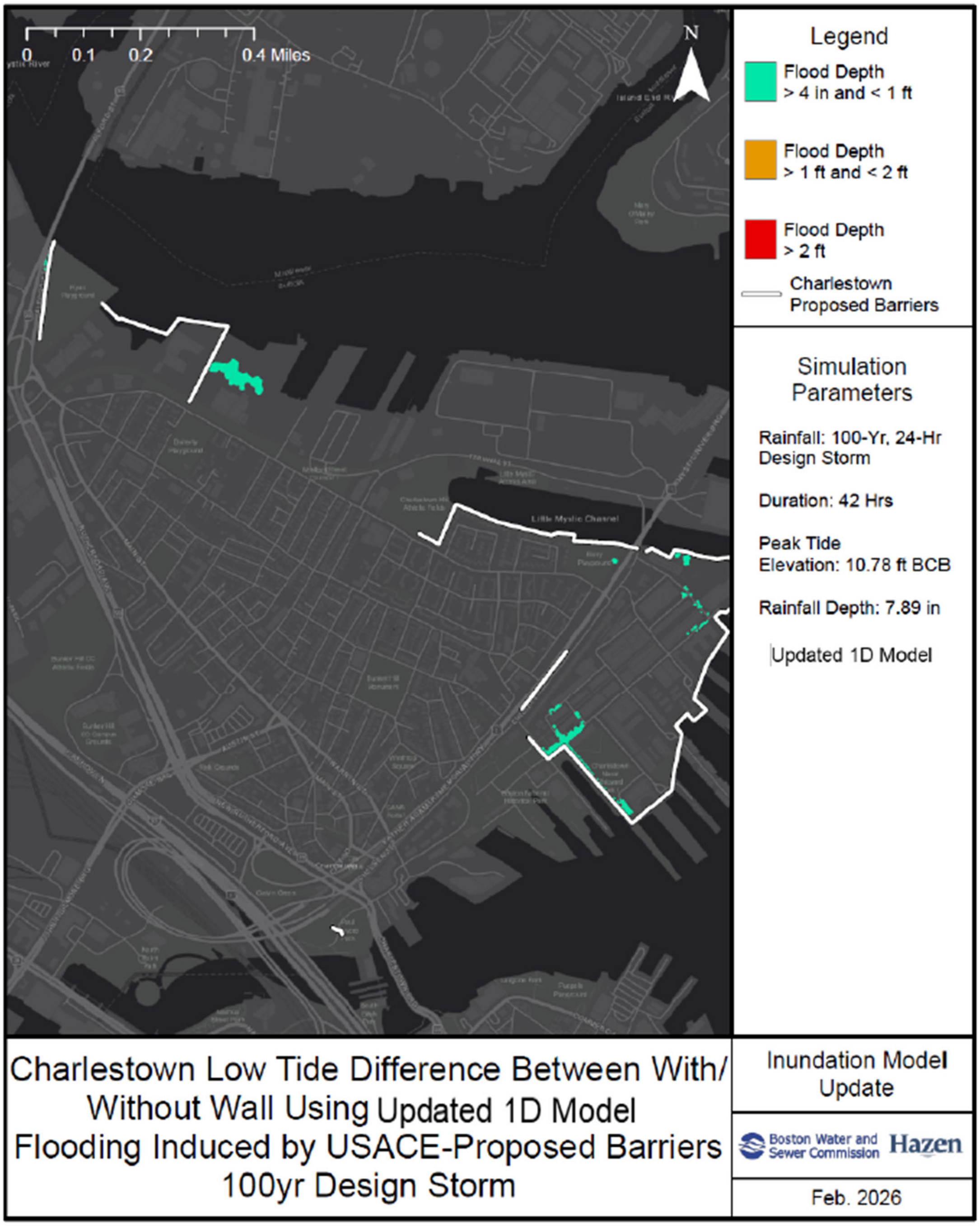


Figure 31: Updated Model – Scenario 1 minus Scenario 2 (Present Day Tide Cycle)

4.0 Uncertainty Analysis

The hydrologic and hydraulic analyses presented in this report are based on engineering methodologies, input data, and a set of informed assumptions. While the modeling approach was suitable for this feasibility study, it is important to acknowledge the inherent uncertainties that could influence the calculated results. This section outlines the primary sources of uncertainty in the interior drainage analysis.

Although the sections below identified sources of uncertainty on the interior drainage flood parameters, the objective of the interior drainage analysis is to estimate whether there is an increase in flooding caused by the proposed barriers. This is important because the costs to address the flooding need to be captured and considered in the selection of the TSP. Therefore, the uncertainties that can lead to miscalculations of flood estimates affect all scenarios simulated in the analysis including with and without the proposed structures resulting in less influence in the incremental flood estimates.

4.1 Hydrologic Model Uncertainties

4.1.1 Precipitation Data

The analysis utilized synthetic 24-hour storms based on precipitation depths from a single NOAA Atlas 14 location. Actual storm events can have different durations, intensities, and spatial distributions, which could lead to different runoff responses than those modeled.

4.1.2 Soil Infiltration Parameters

The Green-Ampt soil infiltration routine was used for the soil infiltration computations in PCSWMM. There is high uncertainty in estimating soil properties for Green-Ampt (suction, conductivity, initial deficit) model across highly heterogeneous urban soils, which can lead to miscalculated infiltration capacities during long-term or high-intensity design storms. Also, the inundation model assumes an initial moisture deficit of 33 percent that can diverge from actual antecedent soil moisture conditions.

4.1.3 Time of Concentration

The catchment width controls how fast the rainfall reaches the drainage inlet, and it is the primary calibration parameter for peak flow. Although the catchment width parameter was calibrated, idealizing irregular, complex urban subcatchments into simplified uniform overland flow paths with a single "width" and average slope can lead to significant uncertainty in peak flow estimation.

4.2 Hydraulic Model Uncertainties

4.2.1 Sewer Infrastructure Data

The existing 1D sewer and drain models do not explicitly include some features that could impact the depth and duration of flooding, such as individual catch basins, pipe less than 24-inches in diameter, and proposed tide gates. Due to the lack of catch basins and local drainage pipes smaller than 24-inches in diameter, it is possible the duration of flooding may be overestimated in some low-lying areas. BWSC and Hazen did not include tide gates on all the structures that we will need to include gates on, and BWSC and Hazen indicated that the head losses were not significant and would not influence the results.

Non-BWSC infrastructure is not accounted for in the model such as MassDOT, the MBTA, MassPort, and other agencies equipment are not accounted for explicitly in the model (e.g., pumps in Mass Pike tunnel). As a result, the amount of flooding predicted may be overstated in some areas. Also, private outfalls are not included in the inundation model.

Inaccurate invert elevations, pipe diameters, and structure shapes can lead to miscalculations of flood depths.

4.2.2 Conduit Roughness

Estimating Manning's roughness for older, sedimented, corroded, or partially blocked pipe networks is a significant source of uncertainty. The Manning's roughness is a sensitive parameter in hydraulic capacity calculations; therefore, minor variations can trigger incorrect flooding predictions.

4.2.3 Model Accuracy

Hazen estimated the accuracy for the Inundation Model to be four inches for the estimated water surface elevations and depths. Therefore, the resultant inundation maps are based on a flood depth threshold of four inches to display flooding areas. Note that the depth difference inundation maps consisted of subtracting all the flood depths from both scenarios, which included depths less than the threshold of four inches.

5.0 Conclusions

The main conclusions of this preliminary (i.e., initial and limited) interior drainage analysis are as follows.

5.1 Assessment of Minimum Facilities

For the “Minimum Facilities” analysis, inundation maps for both scenarios (FWOP and FWP) were developed and compared visually for each of the five neighborhoods (**Attachment 1)**. The macro-scale model predictions did not show increased flooding in the FWP scenario due to the proposed barriers. Therefore, it is concluded that the minimum facilities needs are limited and will likely not include storage or pumping. However, additional interior drainage analysis is required for the measures carried forward to the 35% design to incorporate localized piping, final proposed barriers alignment, and associated grading once they are determined after DP-2. The results of this future analysis may require the addition of structures such as trunk lines, outlets, and tide gates, which will need to be captured in the project cost.

5.1 Assessment for Interior Flooding Beyond Storm Sewer Design

For the 0.01 AEP (100-year) storm simulations, two coastal boundary conditions were modeled including: 1) present conditions (El. 4.3 feet NAVD88), and 2) future conditions with SLC (9.9 feet NAVD88). In general, the flood increases due to the proposed barriers were greater for the simulations that used the present condition coastal water level (4.3 feet NAVD88). This result can be explained by the lower coastal level that isolate the rainfall-driven flooding in low-lying areas from the high coastal flooding prevented by the proposed barriers.

Based on the results map showing the difference in flood depths and extent between the with barriers only (scenario 2) and without Project (scenario 1), it is concluded the following for each neighborhood:

- East Boston: The increased flooding consists of a few small areas mostly with depths differences up to one foot except for a localized area with depths differences up to two feet. Results therefore indicate that the proposed barriers within this neighborhood will not significantly increase flooding in the region.
- South Boston: The increased flooding consists of one small area on the Interstate-90 (Mass Pike) with depths up to two feet. Note that the Inundation Model does not account for the impact of non-Commission infrastructure such as pumps that may exist for mitigating flood along the Interstate-90.
- Dorchester: The increased flooding consists of two small areas next to Conley Street with depths up to one foot and one small area immediately upgradient of the barrier.
- Downtown: The increased flooding consists of one small area north of Battery Street with depths exceeding two feet, a large area on Sargent's Wharf Lot (Pilgrim Parking) with flood depths up to two feet, a small area at Old Atlantic Ave with flood depths up to one foot, and the Long Warf area between Christopher Columbus Park and the New England Aquarium with flood depths up to one foot.
- Charlestown: The increased flooding areas included a large area with flood depths up to one foot east of the barrier alignment at Schrafft's Center (outside of the protected area), and a large area with floods up to one foot at the Charlestown Naval Shipyard.

This interior drainage analysis is considered preliminary and limited due to the macro-scale level of detail of the Inundation Model, which does not include all catch basins and pipes smaller than 24-inches in diameter. This macro-scale level analysis was used to understand the high-level flooding impacts such as the necessity of storage and/or pumping. However, at the macro-scale, there is a gap in understanding the more minor nuances of hydraulics in areas that are not well depicted in the stormwater model. The PDT had discussions with NAD and concluded that this macro-scale analysis is appropriate to the Decision Point 2 milestone, but additional interior drainage analysis is needed to bring the concepts to the required 35% design by performing the interior drainage analysis at a local-scale to capture the details of the drainage system.

6.0 Future Work

The interior drainage analysis documented in this report is considered preliminary and limited due to the macro-scale level of detail of the Inundation Model that did not include local structures such as pipes smaller than 24-inches in diameter, all catch basins, and all proposed tide gates. The PDT had discussions with NAD and concluded that this macro-scale analysis is appropriate to the Decision Point 2 milestone, but additional interior drainage analysis is needed to bring the concepts to the required 35% design at the end of the feasibility study and during the Preconstruction, Engineering, and Design (PED) phase.

6.1 End of Feasibility Study – Early Actionable Increment

As part of the Early Action Implementation strategy of this feasibility study, Moakley Park in Dorchester is the only Early Actionable Increment currently being proposed. The description of the proposed improvements to Moakley Park consists of an upland vertical wall behind Day Boulevard transitioning to a shallow foundation levee feature through the contours of Moakley Park tying into the existing stadium (Moakley Park and Northern Connector). These improvements are based on a design that the City of Boston has already developed and is being adopted in the feasibility study. Based on reviewing the draft drawings (City of Boston, 2025) and stormwater memorandum (Nitsch Engineering, 2025) for the city of Boston's proposed design, the following are the key information related to interior drainage analysis.

Moakley Park is being significantly redeveloped around the proposed barrier alignment that includes grading and drainage modifications. The stormwater modifications include new catch basins, sewer lines, and underground detention chambers (i.e., storage) to control peak flows. A site-specific stormwater model has been developed (Nitsch Engineering, 2025) with the computer program HydroCAD that can likely be adapted for the purpose of this study. A direct flood depth comparison with and without project could be challenging due to the extensive grading changes being proposed. Therefore, it is likely that a more generic comparison of the flood depths will be accomplished. It is expected that no major modifications will be required to the proposed drainage system design to address minimum facilities or induced flooding, but this will need to be confirmed.

Refer to Section 6.2 below for general evaluation considerations in Moakley Park.

6.2 End of Feasibility Study - Chief's Report – Full System

The current requirement for feasibility studies is to develop a Level 3 Cost for the recommended measures, which requires a 35% level design for the proposed structures. Minimum facilities and increased flooding analyses will need to be reassessed in more detail using a micro-scale model.

6.1.1 Minimum Facilities

Minimum facilities analyses will need to be performed for the recommended measures included in the Chief's report by the end of the feasibility study for each element. The analysis will consist of the following:

- Develop/use a micro-scale (i.e., local level) model that incorporates all catch basins, pipes, underground storage system (e.g., StormTech), tide gates and any structure that affects the stormwater drainage system of the interior area.
- Include any changes to the barrier's alignments and associated grading modifications to the micro-scale model.
- Simulate the stormwater design storm to assess the need for minimum facilities.
- Perform sensitivity analysis on key features of the drainage system such as blocked gates to assess the effects on the interior flood depths.

6.1.2 Interior Flooding Beyond Storm Sewer Design

Analysis of interior flooding beyond storm sewer design will need to be performed for the recommended measures included in the Chief's report by the end of the feasibility study. The analysis will consist of the following:

- Use the micro-scale model described in the minimum facilities Section 6.1.1.
- Simulate the frequency storms (e.g., 0.02 AEP) requested by the Office of Counsel and Real State and provide the results to inform their induced flooding analysis.
- Simulate engineering solutions alternatives to offset the increased flooding depths (if warranted due to amount of flooding).
- Perform sensitivity analysis on feasible engineering solutions that minimize takings. (if warranted due to amount of flooding).

6.2 Preconstruction, Engineering, and Design (PED) Phase

During the PED phase, it is anticipated that the micro-scale model be updated and refined based on changes performed to the proposed structures (e.g., levees) and associated gradings during the design process. As a result of these modifications, the minimum facilities and interior flooding beyond storm sewer design will need to be reassessed according to the requirements described in Sections 6.1.1 and 6.1.2.

References

BWSC, 2017: Draft Collection System Model Update and Calibration Report, prepared by AECOM for BWSC, June 8, 2017.

USACE, 2018: Engineering Manual No. 1110-2-1413, Hydrologic Analysis of Interior Areas, USACE, 24 August, 2018.

BWSC, 2020: Inundation Model Final Report, prepared by Hazen for BWSC, December 30, 2020.

BWSC, 2023: Coastal Stormwater Discharge Analysis, prepared by Hazen for BWSC, January 20, 2023.

BWSC, 2025: Inundation Model Update Draft USACE Model Runs, prepared by Hazen for BWSC, November 24, 2025. See Attachment 1.

BWSC, 2026a: USACE Present Day Tidal Model Simulations - Charlestown, prepared by Hazen for BWSC, March 6, 2026. See Attachment 3.

BWSC, 2026b: Technical Memorandum Induced Flooding Analysis, prepared by Hazen for BWSC, May 15, 2026. See Attachment 2.

City of Boston, 2025a: Resilient Moakley Park Improvements Project set of 87 drawings for permitting only, prepared by Weston & Sampson for the City of Boston Park and Recreation Department, November 17, 2025.

Nitsch Engineering, 2025: Stormwater Report Moakley Park, prepared by Nitsch Engineering for Weston & Sampson for the city of Boston, November 2025.

NOAA, 2025: *Atlas 14 - Precipitation Frequency Atlas of the United States*. Hydrometeorological Design Studies Center, NOAA National Weather Service. Precipitation frequency estimates obtained in 2025 using the Precipitation Frequency Data Server (PFDS) https://hdsc.nws.noaa.gov/pfds/

NWS, 1961: Technical Paper No. 40 – Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years, U.S. Department of Commerce Weather Bureau, May 1961.

USACE, 2015: *North Atlantic Coast Comprehensive Study (NACCS), USACE, 2015 https://www.nad.usace.army.mil/CompStudy.aspx.*

USACE, 2018: Engineering Manual (EM) No. 1110-2-1413 - Hydrologic Analysis of Interior Drainage Areas, USACE, 24 August, 2018.

USACE, 2025: Memorandum for Headquarters and Major Subordinate Commands, Districts, and Field Operating Units, Guidance for Induced Flooding, USACE, 28 July, 2025.

USACE, 2025: Work Statement for Interior Drainage Analysis for TSP, USACE, 31 July, 2025.

USACE, 2025: Work Statement for Interior Drainage Induced Flooding Analysis for TSP, USACE, 25 October 2025.

Attachment 1:
Minimum Facilities Results
(BWSC, 2025)

Attachment 2:

Interior Drainage Flooding Beyond Storm Sewer Design

(BWSC, 2026b)

Attachment 3:
Charlestown Updated Modeling
Interior Drainage Flooding Beyond Storm Sewer Design
(BWSC, 2026a)