MEMORANDUM

TO: Patricia Bowie, Kathryn Glenn; Office of Coastal Zone Management

FROM: Frank Ricciardi and Robert Almy, Weston & Sampson;
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DATE: April 1, 2016

SUBJECT: **Lynn Coastal Resiliency Assessment: Task 4 Technical Memorandum Vulnerability Assessment Literature Synthesis and Study Scenarios**

CC: Jim Cowdell, Bill Bochnak, Mary Jane Smalley; Lynn EDIC

The City of Lynn Economic Development and Industrial Corporation (EDIC) is completing a community-based process to assess vulnerability and plan for adaptation to future climatic conditions, specifically along the Lynn shoreline and Saugus River areas (refer to Figure 1). The project is funded through a grant provided by the Coastal Community Resilience Grant Program (CCRGP) of the Massachusetts Office of Coastal Zone Management (CZM). The overall goal of the CCRGP is to improve coastal resiliency, which refers to the capacity of shoreline areas to protect and preserve infrastructure and other socioeconomic resources in response to predicted sea level rise and increased frequency and intensity of coastal storms.

This technical memorandum summarizes the second of three tasks for the Lynn Coastal Resiliency Assessment. The Task 1 Technical Memorandum included synthesis of available relevant technical analyses and reports, compilation of data into a geographic information system (GIS), development of study scenarios, and preliminary review of relevant regulations. This Task 2 technical memorandum summarizes progress made during the second task of the project, which includes the following:

- Section 1: Estimates of inundation under future climate change scenarios; and
- Section 2: Vulnerability and risk assessment of critical infrastructure and natural areas

SECTION 1: ESTIMATES OF INUNDATION UNDER FUTURE CLIMATE CHANGE SCENARIOS

The science of forecasting weather, and specifically the intensity of storm events and associated flooding, is complex. Consideration of climate change effects, in terms of sea level rise and increasing precipitation/storm patterns, results in a higher level of uncertainty in estimating future coastal conditions. Consistent with CZM guidance (CZM 2013), the approach used to estimate inundation under future climate change scenarios for Lynn was developed to provide a reasonable range of expectations based on a range of time horizons and rates of climate change effects. The results of this study are intended to provide a basis for planning that is informed by the potential future changes that the Lynn coastal zone could undergo, with the overall goal of increasing the resiliency of Lynn waterfront areas.

The Task 1 Technical Memorandum defined the future climate change scenarios to be evaluated. In Task 2, the following factors were modeled/evaluated to map estimated inundation of land areas under future sea level rise and storm scenarios:

- Current tidal datum
- Estimates of storm surge
- Estimates of water levels under future climate change scenarios

The approach to evaluating each of these factors is described in the sections below, and maps are presented to illustrate the results.

Inundation maps illustrate the elevation of the estimated water level over the land surface, but do not account for the effects of sea walls and other coastal protection structures located along the Lynn coastline. In general, coastal protection structures will offer some protection against wave action but inundation from sea level rise and/or a storm can flow around the structures. Also, the estimated water levels are “still water levels” and do not account for wave action. Overall, the purpose of the mapping exercise is to provide estimates of inundation for planning purposes, and to determine where vulnerabilities require additional technical analyses or modeling.

Current Tidal Datum

To establish the current extent of tidal inundation in Lynn, current tidal datum, shown on the table below and illustrated on Figure 1, were defined based on National Oceanic and Atmospheric Administration (NOAA) online databases. Elevations are referenced to the standard vertical datum: the North American Vertical Datum of 1988 (NAVD88). Because low and high tide extents vary over the year based on lunar cycles, tidal datum are defined to represent the elevations of the full range of tides from the mean higher high water (MHHW), which represents the mean elevation of the highest of high tide elevations over a year, to the mean lower low water (MLLW), which represents the mean of the lowest of low tide elevations over a year.

Tidal Datum for Lynn, MA

Tidal Datum – Lynn, MA	Feet NAVD88
Mean higher high water (MHHW)	4.79
Mean high water (MHW)	4.35
Mean sea level (MSL)	-0.15
Mean low water (MLW)	-4.81

Mean lower low water (MLLW)	-5.15

* Tidal datum taken from NOAA Lynn Harbor gage (Station #443187) (NOAA 2016a)
NAVD88 = North American Vertical Datum of 1988

Estimates of Storm Surge

During storms, surges and wave action result in increased inundation beyond the range of tidal datum presented in the previous section. Impacts to shoreline communities can be devastating, as the Northeast United States has recently experienced. The increase in the water level beyond the normal tidal range associated with a storm (i.e., storm surge) is one of the most influential factors in storm damage and flooding and is therefore a primary focus of this evaluation. Lynn is particularly vulnerable to storm flooding, and much of the city is within the 100-year flood elevation established by the Federal Emergency Management Agency (FEMA).

The effects of a storm depend on many factors including the intensity of the storm, the direction of the storm trajectory relative to the coastline, the tide level when the storm hits, and wind direction. Many approaches to forecasting weather are in use, but there is always uncertainty associated with any forecast, especially given the increasing intensity of storms expected under future changing climatic conditions.

Several lines of evidence were considered in combination to estimate storm surge water elevations, including the results of forecasting models and historic storms experienced by the Boston area. In general, the evaluation focuses on storms that could produce storm surges with a 1% probability of occurring in any given year (100-year storm surge elevation) and 10% probability of occurring (10-year storm surge elevation).

Flood elevations for historic storms that have occurred near Lynn, including both hurricanes and nor'easters, are summarized in Table 1. Nor'easters have occurred more frequently in New England than hurricanes, particularly over the past several decades. Although not associated with a storm, the extreme high tide (sometimes referred to as a "perigean spring tide" or "King Tide") that occurred in November 2015 is also included for reference. King tides occur once or twice a year when the orbits of the Sun, Moon, and Earth align (EPA 2015). The November 2015 King Tide resulted in a tidal elevation of 7.2 feet, which was 2.4 feet higher than the current MHHW tidal datum. The extents of inundation associated with the Blizzard of 1978, Hurricane Bob, and the November 2015 King Tide are illustrated in Figure 1.

Model-based Approaches

Two model-based approaches to estimating storm surges were used for this evaluation: Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model and FEMA flood elevations. Both of these flooding estimates are based on the evaluation of large databases of historic storms.

FEMA still water flood elevations are determined based on statistical evaluation of historic tide gage and water level data. In addition, wave heights and wave crest heights higher than the still water flood elevation are estimated along the shoreline and immediately overland using models. Results are included on the FEMA Flood Insurance Rate Maps (FIRMS).

The SLOSH model was developed by the National Weather Service (NWS) and is the National Hurricane Center's primary model to forecast storm surge (NOAA 2016b). The model estimates storm surge heights resulting from historical, hypothetical, or predicted hurricanes and accounts for atmospheric pressure, size, forward speed, and track data. These parameters are used to create a model of the wind field that drives the storm surge. The model is computationally efficient and provides a full database of storms of varying intensities (Category 1, 2, 3, and 4 storms). The model does not account for wave impacts in addition to the storm surge (including wave setup), nor'easters (only hurricanes are included in the database), normal river flow, rain flooding, or tidal interaction. Although the SLOSH model provides an estimate of still level elevations, it is important to consider wave action and height above the still water level to complete the vulnerability assessment. Our approach will be to select specific areas of vulnerability for additional analysis of potential wave action and erosion.

The SLOSH model includes predictions for the maximum storm surge for a specific location based on running the model several thousand times with hypothetical hurricanes under varying storm conditions. Storm Surge Maximums of the Maximum are referred to as the "MOMs," which are the Maximum of the Maximum Envelopes of Water (MEOWs). MOMs are generated for specified tidal condition and storm intensity (category) (NOAA 2016c, 2016d). A comparison of the MOMs generated for Lynn to the FEMA 100-year (1% probability) and 10-year (10% probability) flood levels is presented below:

Estimated Storm Surge Water Levels

FEMA 10-year Return-interval Still Water Level (feet NAVD88)	FEMA 100-year Return-interval Still Water Level (feet NAVD88)	SLOSH MOMs Water Level (feet NAVD88)		
		High Tide (2 feet)		
		Category 1	Category 2	Category 3
8.4	10	7.1[1]	11.1[2]	15.2

Notes
1. Estimate of a 10% probability storm (10-year return) to be used for assessment
2. Estimate of a 1% probability storm (100-year return) to be used for assessment

For purposes of this evaluation, the SLOSH Category 2 storm under 2-foot-high tide conditions (mid-high tide) is considered to represent a 100-year storm, and the SLOSH Category 1 storm for the same tidal conditions will be used to roughly represent a 10-year storm. The SLOSH 100-year storm water level estimate of 11.1 feet is higher than the 9.5-foot elevation reported for the Blizzard of 1978. This higher SLOSH estimate will account for increasing storm intensity forecasted for future climate change conditions.

High water levels do not happen only during storms. A “King Tide” may raise water level well above the MHHW level. For example, the predicted 10-year storm elevation estimate is comparable to the measured November 2015 King Tide and therefore water elevation at that level should be considered a greater than 10% probability occurrence under existing sea level conditions.

Estimates of Water Elevations under Future Climate Change Scenarios

As outlined in the Task 1 Technical Memorandum, changes in the MHHW level under future climate change scenarios were calculated based on:

- Global sea level rise projections developed by NOAA (Parris et al. 2012); and
- Local sea level change based on local historic tide records.

The NOAA sea level rise projections are based on extensive modeling of climate change scenarios and associated sea level rise, and are standardly used to predict the range of potential general increases in future sea levels. Additional details on approach used for the Lynn assessment, discussion of the sea level rise projections, and calculations of local sea level changes are provided in the Task 1 Technical Memorandum.

The estimated changes in MHHW levels due to climate change for the 25-year time horizon (2041) and 50-year time horizon (2066) are listed in the table below:

Estimates of Sea Level Rise under Future Climate Change Scenarios for Lynn, MA

Year	Estimated Sea Level Rise including Local Effects Relative to 2016[1] (feet)		
	NOAA Low	NOAA Intermediate High	NOAA High
2041	0.23	0.75	1.16
2066	0.46	1.86	2.97

Notes
1. Estimates include local sea level changes from subsidence calculated from historic record plus global SLR estimates

These were calculated by adding the projected global sea level rise for each time horizon described by NOAA (Parris et al 2012), plus the current local sea level change of 1.1 mm/yr (0.043 inches), calculated based on historic tide records from Boston Harbor (See Task 1 Technical Memorandum). The 25-year time horizon was selected to support short-term planning, and the 50-year time horizon was selected to support longer term planning of municipal projects and multi-use development. The NOAA-Low projection assumes that sea level will rise at the current rate, while the Intermediate-High and High projections assume more rapid sea level rise rates.

The estimated level of MHHW under future sea level rise scenarios plus the estimated storm surges for 10- and 100-year storms at Lynn are summarized in the table below.

Estimated Water Surface Elevations including Projected Sea Level Rise and Storm Effects

		2041			2066		
Scenario	**2016**	**NOAA Low**	**NOAA Intermediate High**	**NOAA High**	**NOAA Low**	**NOAA Intermediate High**	**NOAA High**
Mean higher high water (MHHW) (based on Lynn Datum)	4.8	5.0	5.5	6.0	5.3	6.7	7.8
Category 1 Storm Results from SLOSH (approximately 10% exceedance probability)	7.1	7.3	7.8	8.2	7.5	8.9	10.0
Category 2 Storm Results from SLOSH (approximately 1% exceedance probability)	11.1	11.3	11.8	12.2	11.5	12.9	14.0

Notes
All elevations in North American Vertical Datum 1988 (NAVD88)

SECTION 2: VULNERABILITY AND RISK ASSESSMENT

The vulnerability/risk assessment focuses on facilities and other resources essential to public safety and health and the economic viability of the City of Lynn. Federal and State owned facilities that are not critical to protecting public health and safety were not included in the assessment. Assets within the areas subject to inundation were identified from the City's Hazard Mitigation Plan, analysis of available GIS information and discussions with City and state officials. The results of the vulnerability assessment will support planning to further define and implement adaptation measures to reduce hazards and increase resiliency. The process used to assess risk/vulnerability for this study follows the following steps:

1. Identify areas subject to inundation for each scenario using the estimated future water elevations described above;
2. Identify/list critical assets subject to inundation (both natural and built assets);
3. Identify threshold water elevation that would result in impacts for each asset;
4. Identify the probability associated with the threshold elevation for each impact;
5. Identify the consequences and calculate the total consequence score for each asset; and
6. Calculate Risk for each Time Horizon and List Critical Assets by Weighted Risk Score.

The final list of critical assets will then be carried forward to the next step in the process, which will include identification of potential adaptation strategies that may make each asset more resilient to sea level rise/storm surge.

Each step of the risk assessment process is described in further detail below.

Step 1: Identify areas subject to inundation for project scenarios

Based on the estimates of water levels under project scenarios described in Section 1 areas subject to inundation are delineated on the following figures:

- Figure 1: Inundation Based on Historic Storm Water Elevations with Current Tidal Datums
- Figure 2: 2041 Preliminary Estimated Inundation under Future Sea Level Rise Scenarios
- Figure 3: 2066 Preliminary Estimated Inundation under Future Sea Level Rise Scenarios
- Figure 4: 2041 - Preliminary Estimated Inundation under Future Sea Level Rise Scenarios 1% -Probability Storm
- Figure 5: 2066 - Preliminary Estimated Inundation under Future Sea Level Rise Scenarios - 1% Probability Storm

The scenarios represented in these maps represent a range of storm surge and sea level rise scenarios, including a reasonable worst case for both 2041 and 2066. For reference, Figure 1 includes a map illustrating water levels under historic storms. Estimated inundation for MHHW for the three sea level rise projections (NOAA-Low, NOAA-Intermediate High, and NOAA-High) for the years 2041 and 2061 are illustrated on Figures 2 and 3. Estimated inundation considering both sea level rise and the storm surge for a 1% probability (100-year) storm is illustrated on Figures 4 and 5.

Depth and duration of inundation are considered in the evaluation of consequence. For each scenario, water depth at any location may be calculated by comparing the difference between water elevation and land surface elevation. Duration is considered to be short term (on the order of hours) for storm surge, or long term for base sea level rise. These factors are considered in steps 3 and 4 discussed below.

Step 2: List all critical assets subject to inundation

The City's Hazard Mitigation Plan, available GIS information and discussions with City and State officials were used to identify critical assets/facilities located within the worst-case inundation scenario (2066 SLR estimate and 1% probability storm; Figure 5). These assets/facilities include transportation and utility infrastructure, emergency response facilities, hazardous waste sites/landfills, recreational facilities and historic structures. Natural resource areas (e.g. wetlands, critical habitat, riverfront area, etc.) and coastal protection structures identified by the state[1] were also considered. Coastal protection structures were included for identification only.

1 RPS ASA, 2013, Mapping and Analysis of Privately-Owned Coastal Structures along the Massachusetts Shoreline. Prepared for: Massachusetts Office of Coastal Zone Management

The performance of these structures relative to sea level rise and storm surge was not evaluated. This analysis could be done as a subsequent study, which would evaluate wave action, geotechnical and structural considerations, and effectiveness in protecting critical assets/facilities for each study scenario.

A full list of the critical assets/facilities subject to inundation is provided in Appendix A. A qualitative analysis of natural resources areas in the study area is provided in Appendix B.

Step 3: Identify threshold elevation for impact(s) for each asset in each scenario

The threshold elevation is the level of inundation that would cause damage/impact to functionality of each critical facility. These elevations have been calculated for each asset/critical facility that would be inundated due to sea level rise or storm surge. For each facility the threshold elevation was obtained from one or more sources including onsite observation, estimates from aerial photography and contour data, owner supplied information and published data[2]. The threshold elevation for each asset is provided in Appendix A.

Step 4: Identify the probability associated with the threshold elevation for each impact

For each of the project scenarios, the probability that water levels would reach a given level was assigned as follows:

- 100% for the predicted MHHW level
- 10% for the predicted 10-year storm water level
- 1% for the predicted 100-year storm water level

Probabilities are expressed as percent probability that water level will reach the threshold elevation in a given year. In this approach, predicted SLR is assigned 100% probability because inundation in areas at or below MHHW elevation would be a recurring and frequent event. For the purpose of our analysis, we will look at sea level rise (100% probability) as the basis for long term inundation and 10% and 1% probability storms in terms of short term inundation.

Step 4 Example

A representative example of the calculation of the probability of exceeding the critical flood depth for a specific site is described below for the Reed Street Pump Station (see location on Figure 5). For this facility, the threshold elevation is 8.35 ft. NAVD88, the site elevation, because the emergency shutoff is in a below ground vault which is subject to flooding. Water

2 BCE, 2009, Massachusetts Coastal Infrastructure Inventory and Assessment Project. Prepared for Massachusetts Department of Conservation and Recreation.

level above ground surface would enter and fill the below ground vault forcing the facility to shut down. The following observations are made from the modeled inundation data:

- For the present year time frame, the pumping station site would not be inundated by MWWH (100% probability) or a 10 year storm (10% probability), but would be inundated by a 100 year storm (1% probability) because the elevation of the storm surge would be elevation 11.0 ft., which equates to a water depth of approximately 2.7 ft above ground surface elevation. Since the threshold elevation is the ground surface elevation, the 100 year storm would cause 2.7 ft. of inundation above the threshold elevation.
- For the 2041 scenario, the pumping station site would not be inundated by high tide or a 10 year storm, but would be inundated by a 100 year storm because the elevation of the storm surge would be elevation 12.2 ft. The storm surge would result in a water depth of approximately 3.9 ft. which would be 3.9 ft. above the threshold elevation.
- For the 2066 scenario, the pumping station site would not be inundated by high tide, but would be inundated by either a 10 year or a 100 year storm. The storm surge from a 10 year storm would be at elevation 10.0 ft. and result in a water depth of approximately 1.7 ft. which would be 1.7 ft. above the threshold elevation. The storm surge from a 100 year storm would be at 14.0 ft. elevation and result in a water depth of approximately 5.7 ft., which would be 5.7 ft. above the threshold elevation.

Inundation Scenarios at the Reed Street Pump Station

	Present		2041		2066	
% Probability	Inundation Elevation	Depth Above Threshold Elevation	Inundation Elevation	Depth Above Threshold Elevation	Inundation Elevation	Depth Above Threshold Elevation
1%	11.0	2.7	12.2	3.9	14.0	5.7
10%	7.1	N/A	8.2	N/A	10.0	1.7
100%	4.8	N/A	6.0	N/A	7.8	N/A

Notes: 2041 and 2066 inundation based on NOAA highest estimate for Sea Level Rise
All elevations show are in feet, NAVD 88
Site elevation equals the threshold elevation of 8.35.

Step 5: Identify the consequences and calculate the total consequence score for each asset/resource

Risk was determined based on the probability of water reaching the threshold elevation multiplied by the consequence of the failure of the specific asset. The following matrix illustrates risk based upon severity of consequence and probability[2]:

Risk Severity Matrix

Probability/Frequency					
	High (10% per year)				
	Medium (1% to 10% per year);				
	Low (0.1% to 1% per year)				
	Very Low (less than 0.1% per year)				
		Minor	Serious	Extensive	Catastrophic
		Severity of Consequence			

Increasing Risk

In order to address the range of potential consequences from the various facilities at risk, more detailed criteria were developed in matrix form. Using these criteria the individual consequences of failure at each facility were given a severity score on a scale of 1 to 5. The

2 Definitions used in the Commonwealth of Massachusetts State Hazard Mitigation Plan

severity scores for each critical asset/facility were used to calculate a composite consequence score as discussed below. .

		Criteria Describing Consequence				
Score		Public Safety, Emergency Services	Public Health, Environment	Repair cost	Reduced Economic Activity	Public Services; Duration
Severity	5	Regional Emergency	Regional Emergency	>$20MM	Regional Emergency	>1 Month
	4	City Emergency	City Emergency	$2MM - $20MM	City Emergency	15-30 Days
	3	High	High	$200K - $2MM	High	7-14 days
	2	Moderate	Moderate	$20K - $200K	Moderate	1-6 days
	1	Low	Low	<$20K	Low	< 1 day

The severity scores for each criteria were added together and a composite consequence score was "normalized" using the following formula:

$$((Sum\ all\ criteria\ severity\ number)/25)x100 = \textbf{Consequence Score}$$

The composite scores for each facility are shown in Table 2. The calculations showing the individual severity scoring, probabilities and total consequence score for each critical asset/facility are provided in Appendix C.

Example Step 5

The consequence score for the Reed Street Pump Station developed by the project team is shown below.

Consequence of Failure for the Reed Street Pump Station (2041, 100 year storm)

	Public Safety, Emergency Services	Public Health, Environment	Repair cost	Reduced Economic Activity	Public Services; Duration	Consequence Score
Rating	4	4	3	2	3	64

It is important to note that the consequence score of facility failure does not change if the depth of water above the threshold elevation were to be higher in a different scenario. That is, if the pump station failure has a consequence score or 64 due to a failure under 2014 1% storm conditions, the consequence score would be the same due to a failure under 2066 10% storm conditions even if the depth of water above the threshold elevation were different.

Roads and Intersections

Inundation of roads is treated differently than inundation of other infrastructure facilities. Roads are lineal facilities and impacts may occur only in limited sections. Inundation of a critical intersection may affect an entire road network, while flooded neighborhood roads may affect a more limited area.

For the purposes of this evaluation, inundation of 1.0 ft. was considered the level at which the road segment or intersection would be impassable to general traffic and emergency vehicles. Therefore the threshold elevation of arterials and intersections was 1.0 ft. above their roadway elevation. Roadways in residential neighborhoods that are subject to inundation are listed in Appendix D, but the detailed impact assessment was focused on major intersections. Five major intersections would be inundated to a depth of 1.0 ft. or more as a result of a 100 year storm in 2041:

- Lynnway and Commercial Street
- Lynnway and Broad Street
- Nahant Circle
- Summer and River Street (Camden)
- Lynnway and Blossom Street

These intersections would also be inundated by a 10 year storm in 2066, with the exception of the intersection at Lynnway and Broad Street. The roadway sections that would be impassible under future conditions are summarized in Appendix D. The consequences of inundation of major intersections are included in Table 2 and Appendix C.

Step 6: Calculate Risk for each Time Horizon and List Critical Assets by Weighted Risk Score

To calculate the risk score, the probability of water level exceeding the threshold elevation for each facility (from each time horizon in Step 4) was multiplied by the composite consequence score calculated for failure (in step 5). A “0” value was assigned for scenarios which the threshold elevation was not exceeded. Since the consequence of failure for a particular facility was considered to be the same in any failure, the difference in probability of reaching the threshold elevation for each facility was the variable in the risk calculation.

Once the risk was calculated for each time horizon a composite risk score was developed. The composite risk score was weighted for each time horizon, with risk under present conditions being weighted more heavily than the risk in 2041 or 2066. This resulted in some facilities that are not at risk for decades receiving a lower risk score than facilities with more immediate vulnerability. Despite some facilities being given a lower weighted risk score due to their failure being predicted only in a future scenario, consideration should be given to mitigate risk at these facilities if they are renovated or otherwise modified in the future.

Step 6 Example

For the Reed Street Pump Station the probability of failure for each time horizon (calculated in Step 4) was multiplied by the consequence score calculated in Step 5 (composite score 64). This resulted in risk scores of 0.64 under present conditions, 6.4 under 2014 conditions and 6.4 under 2066 conditions, as shown in the table below.

A weighted risk score was then calculated based on a "weighting" factor for each time horizon (present, 2041 and 2066) to weight the score for more imminent vulnerabilities. The weighting factors used are:

- Present conditions 0.65
- 2041 conditions 0.30
- 2066 conditions 0.05

The formula for calculating the weighted risk score is therefore:

Weighted Risk = (0.65 * Present Risk Score) + (0.30 * 2041 Risk Score) + (0.05 * 2066 Risk Score)

Applying the formula to the Reed Street Pump Station, as follows:

Weighted Risk = 0.65(.64) + 0.30 (6.4) + 0.05(6.4) = 2.7

Based on this calculation the Reed Street Pump Station is given a weighted risk score or 2.7. This is a comparative score and is shown along with the other critical facilities in Table 2. The probability, consequence and risk scores are shown in more detail in Appendix C.

Weighted Risk Score, Reed Street Sewer Pump Station

	Probability	Risk Score	Weight	Weighted Risk Score
Present	0.01	0.64	0.65	0.93
2041	0.01	0.64	0.30	
2066	0.1	6.4	0.05	

Note: Reed Street Pump Station is vulnerable to a 100 year storm under present sea level conditions and predicted sea level rise in 2041, and a 10 year storm under predicted sea level rise in 2066.

Due to the function of the Reed Street Pump station, the consequences of failure remain constant throughout the life of the facility. If the function of the facility was to change, or there was a change in the area the pump station serves, the consequences of inundation may change.

The final list of critical assets, including roadways, showing the score and weighted risk is provided on Table 2. The consequence scores, probabilities and risk scores are provided in Appendix B.

Finally, a significant number of private residences and businesses are located within the inundation zone of each scenario. Although risk scores were not calculated for each property, the vulnerable residential and commercial areas are illustrated on the inundation maps in Figures 1-5.

REFERENCES

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TABLES

Table 1 – Summary of Historic Storm Flood Elevations

Storm Name	Date[1]	Flood Elevation (feet NAVD88[4])
Storm Not Named	4/14/1905	8.0
Storm Not Named	4/21/1940	7.8
Storm Not Named	11/30/1944	7.9
Storm Not Named	12/29/1959	8.3
The Kennedy Inaugural Snowstorm	1/20/1961	7.9
Storm Not Named	5/26/1967	8.1
1972 Nor'easter	2/19/1972	8.2
Blizzard of 1978	2/7/1978	9.5
Storm Not Named	1/25/1979	8.4
Storm Not Named	1/2/1987	8.5
Hurricane Bob [2,3]	8/19/1991	3.9
The No Name Storm (also known as The Perfect Storm)	10/30/1991	8.7
December 1992 Nor'easter	12/12/1992	8.5
Hurricane (Superstorm) Sandy[3]	10/29/2012	7.4
November 2015 King Tide[3]	10/29/2015	7.2

Notes

1. Dates from National Oceanic and Atmospheric Administration (NOAA) for high water extremes exceeding the 10% annual exceedance probability levels (NOAA 2016a)
2. Storm caused extensive damage but not as a result of coastal flooding
3. Storms not in NOAA maximum event lists but included for name recognition
4. NAVD88 – North American Vertical Datum of 1988

Table 2 – Weighted Risk Scores, Critical Infrastructure and Intersections

Facility	Location	Type	Consequence Score	Weighted Risk Score
Critical facilities				
C.L. Hauthaway	638 Summer St	Hazardous Materials	64	5.54
National Grid Power Station	Marine Blvd	Power Station	88	2.9
Camden Street Sewer Lift Station	Camden Street	Sewer Pumping Station	68	2.8
Lynn EDIC Pier	Riley Way	Transportation Facility	56	2.3
MBTA Bus Terminal	Western Ave	Transportation Facility	44	1.6
General Electric Aircraft Engines	1000 Western Ave	Hazardous Materials	76	1.1
Garelick Farms - Lynn	626 Lynnway	Hazardous Materials	68	0.99
National Grid Gas	255 Blossom St	Hazardous Materials	68	0.99
Blossom Street Sewer Lift Station	Blossom Street	Sewer Pumping Station	64	0.93
Reed Street Sewer Lift Station	Reed Street	Sewer Pumping Station	64	0.93
Hanson Street Sewer Lift Station	Hanson Street	Sewer Pumping Station	64	0.93
Gear Plant Heliport	1000 Western	Heliport	48	0.70
Price Rite of Lynn	395 Lynnway	Grocery	44	0.64
Ford Annex	100 Bennet St.	Special Needs	40	0.58
Volunteer Yacht Club	68 Lynn Way	Recreation	36	0.52
St Michaels House	Elmwood	Place of Assembly	36	0.52
Barry Park	Waterford Street	Recreation/	32	0.46
DCR Skating Rink	Shepherd St	Emergency Mortuary	36	0.36
Bridge No. 6 Substation	Bridge Street	Power Substation	52	0.18
Habit Management Center	11 Circle Avenue	Medical Facility	40	0.14
Harbor Loft 2	680 Washington St	Large Residential Facility	32	0.11
Lynn WWTP	2 Circle Ave.	Maint Bldg.	64	0.03
North Shore Community College	300 Broad St	School	64	0.03
All Welding Supplies Inc	101 Harbor St	Hazardous Materials	52	0.03
Ocean Shores	50 Lynnway	Large Residential Facility	32	0.02
Critical Intersections				
Lynnway and Commercial	Lynnway and Commercial	Intersection	52	0.75
Nahant Circle	Nahant Circle	Intersection	52	0.75
Lynnway and Blossom	Lynnway and Blossom	Intersection	52	0.75
Lynnway and Broad	Lynnway and Broad	Intersection	52	0.75
Summer and River (Camden)	Summer and River (Camden)	Intersection	44	0.44

APPENDIX A

LIST OF CRITICAL ASSETS/FACILITIES AT RISK

LIST OF CRITICAL ASSETS/FACILITIES AT RISK

				Potentially Protective Structure	
NAME	**ADDRESS**	**TYPE**	**Site Elevation**	**Structure ID**	**Top Elevation**
C.L. Hauthaway	638 Summer St	Hazardous Materials	8.12		
Garelick Farms - Lynn	626 Lynnway	Hazardous Materials	9.87		
National Grid Gas	255 Blossom St	Hazardous Materials	8.63	038-050-752-073-100	14.2
General Electric Aircraft Engines	1000 Western Avenue	Hazardous Materials	9.72		
DCR Skating Rink	Shepherd St	Emergency Mortuary	10.12		
Barry Park	Waterford Street	Recreation	9.15		
Ford Annex	100 Bennet St.	Special Needs	8.29		
Reed Street Sewer Lift Station	Reed Street	Sewer Pumping Station	8.35		
Camden Street Sewer Lift Station	Camden Street	Sewer Pumping Station	8.02		
Hanson Street Pump Sewer Lift Station	Hanson Street	Sewer Pumping Station	8.97		
Blossom Street Sewer Lift Station	Blossom Street	Sewer Pumping Station	7.92	038-066-751-015-100	14.2
Lynn WWTP	2 Circle Ave.	Maint Bldg. Ground Floor	9.91		
MBTA Bus Terminal	Western Ave	Transportation Facility	6.92		
Lynn Yacht Club	86 Lynn Way	Recreation	7.66	163-066-749-105-001	9.5
Volunteer Yacht Club	68 Lynn Way	Recreation	9.25	163-066-749-105-001	9.5
Ocean Shores	50 Lynnway	Large Residential Facility	12.70	163-066-749-105-001	9.5
Lynn EDIC Pier	Riley Way	Recreation	8.01	038-050-752-073-100	14.2
National Grid Power Station	Marine Blvd	Power Station	9.26	163-050-752-067-002	6.9
Gear Plant Heliport	1000 Western	Helliport	9.13		
Habit Management Treatment Center	11 Circle Avenue	Medical Facility	11.73		
All Welding Supplies Inc	101 Harbor St	Hazardous Materials	11.52		
Harbor Loft 2	672-680 Washington St	Large Residential Facility	11.22		
North Shore Community College	300 Broad St	School	13.44	163-066-749-105-001 038-067-749-110-100 163-067-749-124-001 038-067-749-110-200	9.5
Price Rite of Lynn	395 Lynnway	Grocery	9.67		
St Michaels House	Elmwood	Place of Assembly	9.06		
Bridge No. 6 Substation	Bridge Street	Power Substation	12.12		
Elevations in Feet (NAVD88)					

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APPENDIX B

NATURAL RESOURCE AREA EVALUATION

Qualitative Analysis of Natural Resource Area Vulnerability

Natural resources in Lynn that are vulnerable to sea level rise include intertidal areas along the waterfront (tidal mudflats) as well as estuarine mudflats and marsh along the lower Saugus River (Figures B-1 and B-2). The National Wetlands Inventory[3] (NWI) indicates wetlands immediately adjacent to the Lynn waterfront comprise 16.2 acres of marine mudflats. This Inventory also indicates wetland areas along the Lynn side of the Saugus River comprising approximately 18.8 acres of estuarine marsh fringed at lower elevation by approximately 37 acres of estuarine mudflats. Under predicted sea level rise scenarios, the nature of these marshes would likely be altered with some areas of marsh converted to mudflats and some areas of mudflats converted to open water. Because no space is available for retreat, little new estuarine marsh could become established.

Table B-1 Summary of National Wetlands Inventory Wetlands, Lynn Massachusetts

Location	Wetlands Type	Description	Area (Acres)
Saugus River	E2EM1P	Estuarine Marsh	18.78
Saugus River	E2USN	Estuarine Mudflats	37.39
Lynn Waterfront	M2USN	Marine Mudflats	16.16

Source: US Fish and Wildlife Service National Wetlands Inventory Wetlands Mapper

NWI Explanation of Lynn Area Wetlands Types Shown on Figures B-1 and B-2

<u>Saugus River Wetlands</u>

Description for code **E2USN** :

E System **ESTUARINE**: The Estuarine System describes deepwater tidal habitats and adjacent tidal wetlands that are influenced by water runoff from and often semi-enclosed by land. They are located along low-energy coastlines and they have variable salinity.

2 Subsystem **INTERTIDAL**: This is defined as the area from extreme low water to extreme high water and associated splash zone.

US Class **UNCONSOLIDATED SHORE**: Includes all wetland habitats having two characteristics: (1) unconsolidated substrates with less than 75 percent areal cover of stones, boulders or bedrock and; (2) less than 30 percent areal cover of vegetation. Landforms such as beaches, bars, and flats are included in the Unconsolidated Shore class.

Subclass :

N WATER REGIME **Regularly Flooded**: Tidal water alternately floods and exposes land surface at least once daily.

Description for code **E2EM1P** :

E System **ESTUARINE**: The Estuarine System describes deepwater tidal habitats and adjacent tidal wetlands that are influenced by water runoff from and often semi-enclosed by land. They are located along low-energy coastlines and they have variable salinity.

2 Subsystem **INTERTIDAL**: This is defined as the area from extreme low water to extreme high water and associated splash zone.

EM Class **EMERGENT**: Characterized by erect, rooted, herbaceous hydrophytes, excluding mosses and lichens. This vegetation is present for most of the growing season in most years. These wetlands are usually dominated by perennial plants.

1 Subclass **Persistent**: Dominated by species that normally remain standing at least until the beginning of the next growing season. This subclass is found only in the Estuarine and Palustrine systems.

P WATER REGIME **Irregularly Flooded**: Tidal water floods the land surface less often than daily.

3 http://www.fws.gov/wetlands/Data/Mapper.html

Lynn Waterfront Wetlands

Description for code **M2USN** :

M System **MARINE**: The Marine System describes open ocean and high energy coast lines with salinities exceeding 30 parts per thousand (ppt) and little or no dilution except outside the mouths of estuaries.

2 Subsystem **INTERTIDAL**: This is defined as the area from extreme low water to extreme high water and associated splash zone.

US Class **UNCONSOLIDATED SHORE**: Includes all wetland habitats having two characteristics: (1) unconsolidated substrates with less than 75 percent areal cover of stones, boulders or bedrock and; (2) less than 30 percent areal cover of vegetation. Landforms such as beaches, bars, and flats are included in the Unconsolidated Shore class.

Subclass :

N WATER REGIME **Regularly Flooded**: Tidal water alternately floods and exposes land surface at least once daily.

APPENDIX C

CONSEQUENCE SCORING SPREADSHEET

Risk Calculation for Critical Facilities and Intersections Subject to Inundation above Critical Depth

			Consequence Criteria1					Step 5 [2]		Step 4 [3]			Risk by Time Horizon-Step 6 [4]			Step 6 [5]
Facility	Location	Type	Public Safety, Emergency Services	Public Health, Environment	Repair Cost	Reduced Economic Activity	Public Services; Duration	Consequence Sum	Consequence Score	Probability 2016	Probability 2041	Probability 2066	Risk Score 2016	Risk Score 2041	Risk Score 2066	Weighted Risk Score
Critical facilities																
C.L. Hauthaway	638 Summer St	Hazardous Materials	5	5	2	2	2	16	64	0.01	0.10	1.00	0.64	6.4	64	5.54
National Grid Power Station	Marine Blvd	Power Station	5	5	4	5	3	22	88	0.01	0.01	0.10	0.88	0.88	8.8	2.9
Camden Street Sewer Lift Station	Camden Street	Sewer Pumping Station	4	5	3	2	3	17	68	0.01	0.10	0.10	0.68	6.8	6.8	2.8
Lynn EDIC Pier	Riley Way	Transportation Facility	3	2	3	3	3	14	56	0.01	0.10	0.10	0.56	5.6	5.6	2.3
MBTA Bus Terminal	Western Ave	Transportation Facility	2	2	2	3	2	11	44	0.01	0.10	0.01	0.44	4.4	0.44	1.6
General Electric Aircraft Engines	1000 Western Ave	Hazardous Materials	5	5	3	3	3	19	76	0.01	0.01	0.10	0.76	0.76	7.6	1.1
Garelick Farms - Lynn	626 Lynnway	Hazardous Materials	5	5	3	3	1	17	68	0.01	0.01	0.10	0.68	0.68	6.8	0.99
National Grid Gas	255 Blossom St	Hazardous Materials	5	5	2	3	2	17	68	0.01	0.01	0.10	0.68	0.68	6.8	0.99
Blossom Street Sewer Lift Station	Blossom Street	Sewer Pumping Station	4	4	3	2	3	16	64	0.01	0.01	0.10	0.64	0.64	6.4	0.93
Reed Street Sewer Lift Station	Reed Street	Sewer Pumping Station	4	4	3	2	3	16	64	0.01	0.01	0.10	0.64	0.64	6.4	0.93
Hanson Street Sewer Lift Station	Hanson Street	Sewer Pumping Station	4	4	3	2	3	16	64	0.01	0.01	0.10	0.64	0.64	6.4	0.93
Gear Plant Heliport	1000 Western	Heliport	3	3	2	3	1	12	48	0.01	0.01	0.10	0.48	0.48	4.8	0.70
Price Rite of Lynn	395 Lynnway	Grocery	2	2	3	2	2	11	44	0.01	0.01	0.10	0.44	0.44	4.4	0.64
Ford Annex	100 Bennet St.	Special Needs	2	2	2	1	3	10	40	0.01	0.01	0.10	0.4	0.4	4	0.58
Volunteer Yacht Club	68 Lynn Way	Recreation	1	1	3	1	3	9	36	0.01	0.01	0.10	0.36	0.36	3.6	0.52
St Michaels House	Elmwood	Place of Assembly	2	2	2	1	2	9	36	0.01	0.01	0.10	0.36	0.36	3.6	0.52
Barry Park	Waterford Street	Recreation/	1	1	2	1	3	8	32	0.01	0.01	0.10	0.32	0.32	3.2	0.46
DCR Skating Rink	Shepherd St	Emergency Mortuary	1	2	2	1	3	9	36	0.01	0.01	0.01	0.36	0.36	0.36	0.36
Bridge No. 6 Substation	Bridge Street	Power Substation	4	3	2	2	2	13	52	0.00	0.01	0.01	0	0.52	0.52	0.18
Habit Management Center	11 Circle Avenue	Medical Facility	2	3	2	1	2	10	40	0.00	0.01	0.01	0	0.4	0.4	0.14
Harbor Loft 2	680 Washington St	Large Residential Facility	2	2	2	1	1	8	32	0.00	0.01	0.01	0	0.32	0.32	0.11
Lynn WWTP	2 Circle Ave.	Maint Bldg.	4	5	2	3	2	16	64	0.00	0.00	0.01	0	0	0.64	0.03
North Shore Community College	300 Broad St	School	2	3	3	4	4	16	64	0.00	0.00	0.01	0	0	0.64	0.03
All Welding Supplies Inc	101 Harbor St	Hazardous Materials	3	3	2	3	2	13	52	0.00	0.00	0.01	0	0	0.52	0.03
Ocean Shores	50 Lynnway	Large Residential Facility	2	2	2	1	1	8	32	0.00	0.00	0.01	0	0	0.32	0.02
Critical Intersections																
Lynnway and Commercial	Lynnway and Commercial	Intersection	3	2	2	4	2	13	52	0.01	0.01	0.10	0.52	0.52	5.2	0.75
Nahant Circle	Nahant Circle	Intersection	3	2	2	4	2	13	52	0.01	0.01	0.10	0.52	0.52	5.2	0.75
Lynnway and Blossom	Lynnway and Blossom	Intersection	3	2	2	4	2	13	52	0.01	0.01	0.10	0.52	0.52	5.2	0.75
Lynnway and Broad	Lynnway and Broad	Intersection	3	2	2	4	2	13	52	0.01	0.01	0.10	0.52	0.52	5.2	0.75
Summer and River (Camden)	Summer and River (Camden)	Intersection	2	1	2	4	2	11	44	0.01	0.01	0.01	0.44	0.44	0.44	0.44

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APPENDIX D

Arterial roadways and intersections vulnerable to flooding

Arterial roadways and intersections vulnerable to flooding

Arterials

Roadway	Roadway Segment Subject to Greater than 1ft. Inundation			
	2041 MHHW (100%)	2041 (1%)	2066 MHHW (100%)	2066 (1%)
Lynnway (Rt. 1A)		Bridge Approach to Pleasant Street		Pleasant Street to Washington St.
Western Avenue (SR 107)		SW of Burns St.	Route 107 Bridge approach	SW of Minot St
Summer Street		Ashland to Albion	1. Summer St at GEAA Field culvert 2. Summer at Linden (intersection)	Ames to Ashland
Commercial St		Neptune Park to 225 Commercial	Railroad underpass	Neptune Blvd. to Circle St.
Bennett St.	Railroad Underpass	Elmwood to Commercial	Orchard to South Street	Elmwood to Commercial
Lynnshore Drive		Nahant Circle to Beach Road		Nahant St to Beach Road
Washington St (lower)		Farr St. to Lynnway rt. turn lane		1. Washington St at Lynnway 2. Washington St. at Farr

Intersections

Intersection	Elevation of Intersection (LiDAR NAVD88 Ft)	Depth of Inundation (Ft)		Depth of Inundation (Ft)	
		NOAA 2041 Scenario		NOAA 2066 Scenario	
		10% Storm (8.2')	1% Storm (12.2')	10% Storm (10.0')	1% Storm (14.0')
Lynnway and Commercial	8.46	0.00	3.74	1.54	5.54
Lynnway and Broad	9.81	0.00	2.39	0.19	4.19
Nahant Circle	8.32	0.00	3.88	1.68	5.68
Summer and River (Camden)	8.39	0.00	3.81	1.61	5.61
Broad and Market	13.78	0.00	0.00	0.00	0.22
Lynnway and Blossom	8.41	0.00	3.79	1.59	5.59

Note: Critical Depth of intersection is 1.0 FT

Shading indicates conditions that exceed 1.0 ft. depth in intersection

ACRONYM LIST

Acronyms

CZM	Massachusetts Office of Coastal Zone Management
EDIC	City of Lynn Economic Development and Industrial Corporation
EPA	US Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FIRMS	FEMA Flood Insurance Rate Maps
GIS	Geographic Information System
LLC	Limited Liability Company
MEOWS	Maximum of the Maximum Envelopes of Water
MHHW	Mean Higher High Water
MLLW	Mean Lower Low Water
MOMs	Storm Surge Maximums of the Maximum
NAVD88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SLR	Sea Level Rise

FIGURES

The following revised figures can be found in the Final Lynn Coastal Resiliency Assessment

U.S. Fish and Wildlife Service

National Wetlands Inventory

Lynn Saugus River wetlands

Mar 14, 2016

Wetlands

- Freshwater Emergent
- Freshwater Forested/Shrub
- Estuarine and Marine Deepwater
- Estuarine and Marine
- Freshwater Pond
- Lake
- Riverine
- Other

This map is for general reference only. The US Fish and Wildlife Service is not responsible for the accuracy or currentness of the base data shown on this map. All wetlands related data should be used in accordance with the layer metadata found on the Wetlands Mapper web site.

User Remarks:

U.S. Fish and Wildlife Service

National Wetlands Inventory

Lynn MA Lynnway Bridge Area

Mar 14, 2016

Wetlands

- Freshwater Emergent
- Freshwater Forested/Shrub
- Estuarine and Marine Deepwater
- Estuarine and Marine
- Freshwater Pond
- Lake
- Riverine
- Other

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User Remarks: