Town of West Newbury
Select Board
Friday, September 8, 2023 @ 4:00pm
381 Main Street, Town Office Building
www.wnewbury.org

AGENDA
(Amended to in-person/hybrid meeting)

Open Session: *4:00pm, by in-person attendance, First Floor Hearing Room, or remote participation (instructions below)*

Announcements:

- This meeting is accessible by remote participation; instructions below.
- Reminder to subscribe for emailed Town news/announcements at https://www.wnewbury.org/subscribe

Regular Business

A. Discussion of draft Weston & Sampson report regarding potential water testing at 31 Dole Place

Addendum to Meeting Notice regarding Remote Participation

Public participation in this meeting of the West Newbury Select Board will be available via remote participation. For this meeting, members of the public who wish to listen to the meeting may do so in the following manner:

Zoom Meeting
Phone: (646) 558 8656
Meeting ID: 819 0510 6882
Passcode: 230105
Join at: https://us06web.zoom.us/j/81905106882?pwd=blZseEV1K25lYUVNN3ovQnA4Vk5hZz09

Every effort will be made to ensure that the public can adequately access the proceedings in real time, via technological means. In the event that we are unable to do so, despite best efforts, we will post on the West Newbury website an audio or video recording of proceedings as soon as practicable after the meeting.

55 Walkers Brook Drive, Suite 100, Reading, MA 01867
Tel: 978.532.1900

MEMORANDUM

TO:	Angus Jennings, Town Manager and Mark Marlowe, Water Superintendent; Town of West Newbury
FROM:	Kevin MacKinnon, PG, CG, PH-GW and Sarah Ridyard, PE; Weston & Sampson
DATE:	8/31/2023
SUBJECT:	Dole Place Wellfield Peer Review

1. Background

For the past several years, the Town of West Newbury (The Town) has been evaluating the public acquisition of a privately-owned parcel at Dole Place for the purpose of use as a public water source through the development of new drinking water well(s) to be connected to the Town's existing water system. Presently, the Town's water system consists of one wellfield that supplies approximately 70% of the Town's water needs annually based on data provided by the Town from 2014-2022, and an interconnection to Newburyport that allows the Town to purchase the remainder of water needed at retail cost. An intermunicipal agreement dated 1980 governs the amount of water available for purchase from Newburyport and the payment terms.

The Town of West Newbury has expressed interest in achieving water independence to limit purchasing water from Newburyport. Currently, there are two interconnections to West Newbury's water system: one from Newburyport to supplement daily supply to West Newbury and a second interconnection from Groveland to supply emergency water if needed. Newburyport currently uses the Artichoke Reservoir, primarily located in West Newbury, as their primary water source.

The subject parcel proposed for a new groundwater source for the Town of West Newbury is located at 31 Dole Place, adjacent to the Merrimack River in a residential neighborhood. The current use of the property is residential with a single-family home and secondary garage structure located on the property, which is cleared of most vegetation and trees.

Previous evaluation of the parcel conducted by Tata & Howard in 2016-2017 indicated approximately 1 MGD of drinking water could be available to the Town from a potential wellfield at this site, which would meet the Town's current and projected water needs for the foreseeable future. Any excess water could potentially be sold to a neighboring municipality depending on an agreement reached between the two towns and subject to permitting through the Massachusetts Department of Environmental Protection (MassDEP) and Department of Conservation and Recreation (DCR).

Due to the proximity of the proposed Dole Place wellfield to the Merrimack River, sea level rise and resilience is of concern. Discussion with the Town indicated an assumption that future sea level rise, in the year 2100, would equal 6' above the current FEMA 100-year flood elevation used for other planning in the local area.

The purpose of this study is to provide peer review of the work completed to date in order to evaluate the potential of the parcel at 31 Dole Place to develop a drinking water source for the Town of West Newbury. A report was developed in 2021 to summarize Tata & Howard's work on the evaluation that included budgetary cost estimates for the development of the wellfield at the Dole Place parcel, and infrastructure updates necessary to provide water from the Town of West Newbury to one or more neighboring communities. The contents of this report were examined as well as other materials provided by the Town related to the site evaluation performed to date, as well as recommended next steps.

2. Water Quantity Evaluation

Dole Place Wellfield Pumping Test and Results (2016)

Weston & Sampson conducted a thorough review of the Tata & Howard Source Final Report (BRP WS 19 permit application) submitted to MassDEP on June 22, 2016, for a new groundwater source of supply located on Dole Place in West Newbury, Massachusetts. A five-day pumping test was conducted between February 4th and February 9th, 2016 by Tata & Howard in support of the new source permitting process required by MassDEP. According to the report, the pumping test was conducted using three clusters of small diameter wells to simulate a final wellfield in this location. The test wells were reportedly pumped at a combined rate of approximately 427 gpm (135 gpm in Well Cluster TW-1, 137 gpm in Well Cluster TW-4, and 155 gpm in Well Cluster TW-5) throughout the five-day pumping test.

The Source Final Report (BRP WS19) submitted to the DEP and reviewed by Weston & Sampson, unfortunately, did not include many of the required elements detailed in Chapter 4 of the Massachusetts Guidelines and Policies for Public Water Systems. Specifically, Chapter 4, Section 4.6.1 Report Contents.

The missing report contents and deficiencies include:

- Ambient (pre long term pumping test) water level / potentiometric fluctuation trends
- Surveyed site plan showing the location and elevation of all test wells
- Proof of stabilization at the conclusion of the pumping test
- Evaluation of the hydrogeology (including aquifer characteristics) based upon data generated during the prolonged pumping test and recovery
- Failure to remove the ambient aquifer trend and tidal influence from the pumping test dataset
- Zone II delineation was determined using a pumping test dataset that was not stabilized or corrected for external influences (ambient aquifer trend and tidal influence)

As a result of the missing data collection and analysis, Weston & Sampson has several concerns. Since stabilization was not reached (or proven), Weston & Sampson believes the following DEP-approved aspects of this project are uncertain:

- Water quality results may not be representative of long-term steady-state pumping conditions.
- Weston & Sampson does not agree with the approach taken to calculate the approvable yield of this site; however, Weston & Sampson does agree that the approved yield is sustainable. The concerns with the approach include:
    - Pumping wells did not meet the DEP requirements for stabilization (<0.04 ft of drawdown in 24 hours of pumping)
    - Pumping test data was not corrected for ambient aquifer trend, or filtered for tidal impacts, or precipitation event.
    - Specific capacity used in the calculation was an average based on high and low tide. If the data were corrected as stated above and filtered for tidal influence, one (1) specific capacity value should be used to represent each of the pumping wells.
- Zone II delineation was conducted using an uncorrected data set from a pumping test that had not stabilized. Mass balance calculations from the Tata & Howard delineated Zone II suggest that 60% of the water withdrawn from this source is a result of induced infiltration from the Merrimack River. No other hydraulic or water quality parameters support that assumption, which means the Zone II is either 1) incorrect or 2) the pumping test was not conducted long enough to reach stabilization.

Recommendations

Based on our review of the Dole Place Wellfield Pumping Test Report and the analysis conducted by Tata & Howard, Weston & Sampson believes the site is capable of pumping the approved withdrawal rate of 684 gpm (0.98 MGD) but offers the following recommendations for future testing to better understand the steady state water quality characteristics of the source water:

- Conduct a long-term pumping test (5 days or greater) until it can be confirmed that stabilization was achieved.
- An accurate analysis of pumping-test data requires consideration of several standard corrections of the pumping test data set to ensure the data set is representative of the hydraulic response in the aquifer to pumping from the pumping well(s). In this case, data corrections should have included ambient aquifer trends, precipitation (recharge events) and tidal influence.
- A complete survey of all monitoring points to obtain reference elevations so groundwater and surface water levels can be converted to groundwater elevations.
- Perform a basic evaluation of aquifer parameters, which includes estimations of hydraulic conductivity, transmissivity and storativity.
- Refine conceptual hydrogeologic model of the Dole Place Wellfield aquifer.

3. Water Quality Evaluation

Water Quality Results (2016)

During the February 2016 pumping test, water quality samples were collected at test wells TW1, TW4 and TW5 at 31 Dole Place by Maher Services, who subcontracted Nashoba Analytical for analysis of water quality parameters. The test well water quality results are presented in Table 1. The only parameter at the time of sample collection and analysis that failed to meet a state or federal Maximum Contaminant Level (MCL) was pH. Sodium was above the Massachusetts Office of Research and Standards Guideline (OSRG) Massachusetts Drinking Water Guideline of 20 mg/L for all three samples with an average value of 31.7 mg/L. For comparison, the 2022 Annual Water Quality Report for West Newbury indicated the current water system had a maximum value of 68.2 mg/L for sodium from the West Newbury wellfield. No total coliform, volatile organic compounds, or synthetic organic contaminants were detected in the three samples. Per- and polyfluoroalkyl substances (PFAS) were not analyzed in the 2016 analysis.

Table 1. Summary of Sampling Results from February 2016

Contaminant	TW1	TW4	TW5	MCL/SMCL
Total Coliform (per 100 mL)	0	0	0	0/Absent
E. coli (per 100 mL)	-	-	-	0/Absent
Radionuclides				
Gross Alpha (pCi/L)	2.4 +/- 1.1	0.8 +/- 0.7	0.7 +/- 0.8	15
Uranium (pCi/L)	1.1	1	ND[1]	30
Radon (pCi/L)	273	283	302	10,000**
Radium 226 (pCi/L)	0 +/- 0.08	0.1 +/- 0.1	0.2 +/- 0.1	5 combined
Radium 228 (pCi/L)	1.8 +/- 0.6	0.8 +/- 0.5	0.5 +/- 0.5	
Inorganic				
Antimony (mg/L)	ND	ND	ND	0.006
Arsenic (mg/L)	0.003	ND	0.003	0.010
Barium (mg/L)	0.006	0.008	0.004	2
Beryllium (mg/L)	ND	ND	ND	0.004
Cadmium (mg/L)	ND	ND	ND	0.005
Chromium (mg/L)	ND	ND	ND	0.1
Cyanide (mg/L)	ND	ND	ND	0.2
Fluoride (mg/L)	ND	ND	ND	4.0
Mercury (mg/L)	ND	ND	ND	0.002
Nickel (mg/L)	ND	ND	ND	0.1
Selenium (mg/L)	ND	ND	ND	0.05
Sodium (mg/L)	42.3	25.5	27.3	20*
Thallium (mg/L)	ND	ND	ND	0.002
Nitrate (mg/L)	2	1.4	1.8	10
Nitrite (mg/L)	ND	ND	ND	1
Secondary				
Aluminum (mg/L)	ND	ND	ND	0.2
Calcium (mg/L)	36.8	26.2	28.5	NS[2]
Copper (mg/L)	ND	0.004	ND	1
Iron (mg/L)	0.022	0.013	0.009	0.3

Magnesium	5.3	4.7	4.1	NS
Manganese (mg/L)	ND	ND	ND	0.05
Potassium (mg/L)	3.8	2.7	2.6	NS
Silver (mg/L)	ND	ND	ND	0.1
Zinc (mg/L)	ND	0.004	ND	5
Alkalinity (mg/L)	77	60	62	NS
Chloride (mg/L)	93.7	60.2	58.1	250
Color (C.U)	0	0	0	15
Hardness (mg/L as $CaCO_3$)	114	85	88	NS
Odor (TON)	ND	ND	ND	3
pH	7.4	6.3	6.8	6.5 – 8.5
Sulfate (mg/L)	20.8	12.5	15.7	250
TDS (mg/L)	244	178	188	500
Turbidity (NTU)	ND	ND	ND	NS
Synthetic Organic (μg/L)	ND	ND	ND	All
Volatile Organic (μg/L)	ND	ND	ND	All
Miscellaneous				
Perchlorate (μg/L)	2.0	ND	ND	2.0
Conductivity (μmhos/L)	570	400	412	NS

[1]ND: Non-detect (result was below the detection limit for the testing method)

[2]NS: Not Specified

*ORSG MassDEP guideline for sodium

**MassDEP MCL for radon, EPA proposed MCL for radon is 300 pCi/L

Recent Regulatory Updates

In the years since the water quality sampling was performed at Dole Place there have been several regulatory updates regarding drinking water on both a state and national level. Most notably for this project, updates related regulations to PFAS and the Lead and Copper Rule.

PFAS

In 2016, the EPA announced the first health advisory (non-enforceable) regarding PFAS, which advised the sum of PFOS and PFOA be no higher than 70 parts per trillion (ppt) for drinking water. On June 15, 2022, the EPA announced a second health advisory for four PFAS in drinking water. After considering the public and industry's input, the EPA released proposed MCLs for six PFAS on March 14, 2023, with anticipation of approval by the end of 2023. The proposed MCLs listed PFOS and PFOA at 4 ppt each, and a Hazard Index based on synergistic effects of no more than 1.0 for PFNA, PFHxS, PFBS, and GenX. Unlike the previous health advisories, these proposed MCLs will be enforceable, prompting each state to adapt drinking water treatment processes to meet these regulations. The proposed rule will require public water systems to monitor for these six PFAS, notify the public of the levels of these PFAS, and reduce the levels of these six PFAS in drinking water if they exceed the proposed standards (EPA 2016; 2022, and 2023).

Table 2. Federal EPA Progression on PFAS Regulations			
PFAS	**2016 Health Advisory**	**2022 Health Advisory**	**2023 Proposed MCLs**
PFOS	∑ ≤70 ppt	0.02 ppt	4 ppt
PFOA		0.004 ppt	4 ppt
PFNA	NA	NA	Hazard Index* 1.0 (unitless)
PFHxS	NA	NA	
PFBS	NA	10 ppt	
GenX	NA	1,000 ppt	

$$*Hazard\ Index = \frac{GenX}{10\ ppt} + \frac{PFBS}{2{,}000\ ppt} + \frac{PFNA}{10\ ppt} + \frac{PFHxS}{9\ ppt}$$

In October 2020, Massachusetts published MCLs on six PFAS in drinking water, stating the sum of the six must not exceed 20 ppt. The six currently regulated PFAS in Massachusetts are PFOS, PFOA, PFHxS, PFNA, PFHpA, and PFDA, which MassDEP refers to as "PFAS6" (MassDEP, 2020). There is overlap between the proposed federal MCLs and the Massachusetts's current MCLs, however, Massachusetts does not currently regulate PFBS or GenX, and the EPA does not currently intend to regulate the two perfluoro carboxylic acids (PFCAs), PFHpA (7 carbons) and PFDA (10 carbons) that Massachusetts currently regulates. Current MCLs in four New England states in drinking water are shown in Table 3.

Table 3. Current PFAS MCL Regulations in Four New England States				
PFAS	**Massachusetts**	**Maine**	**Vermont**	**New Hampshire**
PFOS	∑ ≤20 ppt	∑ ≤20 ppt	∑ ≤20 ppt	15 ppt
PFOA				12 ppt
PFHxS				18 ppt
PFNA				11 ppt
PFHpA				NA
PFDA			NA	NA
PFBS	NA	NA	NA	NA
GenX	NA	NA	NA	NA

Lead and Copper Rule

On December 16, 2021, the U.S. EPA announced final revisions to the National Primary Drinking Water Regulations for lead and copper under the authority of the Safe Drinking Water Act – called the Lead and Copper Rule Revisions (LCRR). The revisions include requirements for inventory of lead service lines and replacement plans for community systems and non-transient non community (NTNC) systems, establishment of a 90^{th} percentile system wide trigger level of 10 parts per billion (ppb) of lead (in addition to the system-wide 90^{th} percentile action level of 15 ppb), and requirements for community systems to offer testing to schools and childcare facilities. These changes highlight the emphasis on lead and copper for current and future regulatory updates.

The MassDEP will likely require West Newbury to re-establish its Optimal Water Quality Parameters (OWQP's) once the new source comes online, given the significant changes and potentially different water quality considerations. OWQP's are established by collecting water samples from the finished water line, all other entry points (for example, source water and post treatment), and from sites within the distribution system, with the number of points within the distribution system based on the population served by the system. The details of the sampling plan and number of samples are specific to the system and must be determined through discussion with MassDEP once the new source is online.

Recommendations for Sampling

It has been over seven years since water quality sampling and analysis has been done at this site. The water quality data must be updated for the New Source Approval from MassDEP. It is recommended that the Town update water quality data with a new suite of water quality sampling and analysis to both update existing data and provide additional insight for infrastructure planning. The sampling shall include all previous parameters sampled, and the additional items noted in the list below. Crucial parameters for water quality and water treatment considerations at the wellfield include:

- PFAS sampling at a minimum should include at least 18 PFAS from EPA Methods 537 or 537.1. The following eight compounds, a combination of MA's PFAS6 and EPA's proposed MCL, must be included in the analysis: PFBS, PFHxS, PFOS, PFHpA, PFOA, PFNA, PFDA, and HFPO-DA (GenX).
- UV254 to indicate aromatic organic materials, which are precursors to disinfection byproducts (DBPs). Surface waters typically have higher concentrations of natural organic matter (NOM) than groundwater. Unfavorable or high UV254 absorbance may impact disinfection methods and treatment processes.
- Total Organic Carbon (TOC), Dissolved Organic Carbon (DOC), inorganics (iron and manganese), pH, radionuclides (radium), perchlorate, and nitrogen are typical water quality parameters that contribute to a variety of health based MCLs and filtration infrastructure needs. If granular activated carbon (GAC) filtration, common for PFAS removal in drinking water, is utilized at the site, iron and manganese can foul the vessels, lessening the removal of PFAS and other contaminants of concern. If there are high radionuclide or radium concentrations, GAC filter media may be considered a radioactive hazardous waste.
- Microparticulate Analysis (MPA) is recommended for an initial indication of the potential of this source to be Groundwater Under the Direct Influence of Surface Water (GWUDI) as defined by EPA's Surface Water Treatment Rule (SWTR). The determination of whether or not the source is GWUDI will be made based on MPA samples taken twice during a twelve-month period once the source is online; once between August 15 and October 15 (fall) and again between April 1 and May 30 (spring). Depending on whether the site is GWUDI or not will determine the log removal and chlorine contact time necessary, as well as the potential need for filtration in the treatment process. Per 310-CMR 22 Drinking Water, 4-log inactivation of viruses and 3-log inactivation of giardia cysts is required for groundwater under direct influence of surface water. Pressure filters typically account for 2-log credit.
- Corrosivity is a crucial water quality parameter to conform with EPA's Lead and Copper Rule to prevent leaching. Per EPA Optimal Corrosion Control document 816-B-16-003, factors affecting corrosivity and lead and copper leaching are:
    - Alkalinity, pH, and dissolved inorganic carbon (DIC)
    - Hardness (calcium and magnesium)
    - Dissolved oxygen (DO)
    - Ammonia, chloride, and sulfate
    - Natural organic matter (NOM)

  - Iron, aluminum, and manganese
  - Temperature
- All water quality test methods should conform to most recent State and EPA Methods for drinking water analysis.

Potential Implications of Results

Depending on the results from updated water quality sampling and analysis, certain treatment processes and infrastructure may be required to meet MCLs and improve water quality for a groundwater source located at the project site. Typical treatment of certain water quality parameters is shown in Table 4.

Table 4. Water Quality Parameters, Treatment Technologies, and Concerns

Water Quality Parameter	Treatment Technology or Concerns
PFAS	Ion Exchange (IX) Resin and/or Granular Activated Carbon (GAC).
UV254	Change in disinfection methods and/or organics removal: processes to avoid DBPs formation.
TOC, DOC, inorganics (iron and manganese), radionuclides (radium)	Green sand filtration or GAC, high radionuclides may cause GAC media to be considered radioactive hazardous waste.
MPA Analysis	4-log inactivation for viruses and 3-log inactivation for giardia cysts if GWUDI (disinfection). Pressure filters typically account for 2-log credit
Corrosivity	Control of corrosivity is crucial to prevent lead and copper leaching. Corrosion control is typically accomplished through chemical addition.

4. Permitting

DEP Permits

Required Actions

Weston & Sampson consulted with Jim Persky and Duane LeVangie of MassDEP regarding the next steps required to renew the approval of the Dole Place Wellfield on behalf of the Town. The Dole Place Wellfield was officially approved on May 23, 2017 and the letter states that the approval is only valid for 5 years. Because it has been more than 5-years since the approval letter was obtained, the Town must complete another 5-day pumping test and collect water quality samples for parameters previously analyzed as well as additional parameters, such as PFAS, that were not collected in 2016. Prior to conducting another pumping test on the Dole Place Wellfield, MassDEP requires a brief pumping test proposal to be submitted that outlines the following:

- Updated Zone II land use evaluation
- Proposed pumping test sampling schedule and list of constituents to be sampled

- Proposed wellfield configuration including test well construction and location of discharge
- Proposed withdrawal rate

Recommended Actions

In addition to MassDEP requirements outlined above, Weston & Sampson recommends the following actions:

- Design and construct final pumping wellfield based on final production well standards prior to the pumping test
- Consider a long-term pumping test (more than 5 days) to confirm stabilization criteria is met
- Collect Microscopic Particulate Analysis (MPA) to confirm whether groundwater is under the direct influence of surface water
- Collect water quality field parameters from both the Merrimack River and the pumping wells (temperature, pH, Oxidation Reduction Potential, specific conductivity, dissolved Oxygen) daily for the duration of the pumping test both to meet regulatory requirements and to have an indicator of the influence of the surface water on the water quality of the groundwater.

MEPA Permitting

Weston & Sampson reviewed the available permitting documents for the Massachusetts Environmental Policy Act (MEPA) for the proposed wellfield at 31 Dole Place. In June 2016 an Environmental Notification Form (ENF) was submitted to the Executive Office of Energy and Environmental Affairs by Tata & Howard on behalf of the Town of West Newbury for the site. The ENF identified a water withdrawal of 868,000 gallons per day for the site, in exceedance of the MEPA threshold of 100,000 gallons per day, which necessitated the review of this potential project by MEPA.

The ENF Determination for the project was issued on August 19, 2016 by the Executive Office of Energy and Environmental Affairs. The project was determined to not require an Environmental Impact Report (EIR) at that time. The MEPA regulations at 301 CMR 11.10 dictate that if more than 5 years have elapsed since any work, including "non-construction related work or activity" then a new ENF shall be filed.

On August 16, 2023 Weston & Sampson met with Jennifer Hughes of the MEPA office for a virtual Teams meeting to discuss the project and next steps from the MEPA perspective. It was discussed that the Determination was issued more than five years ago, but the Town has been actively pursuing the purchase and evaluation of this property throughout the time since 2016 without a lapse of time occurring. Jennifer Hughes followed up after the meeting with additional detail. Because the subject project was determined to not require an EIR and the Town has been actively pursuing the project during the time since the Determination was issued, the Determination would still be valid from 2016 provided the project has not changed from the impacts documented in the 2016 ENF. If the proposed project has changed, for example if the building size increases due to additional treatment required, a Notice of Project Change should be filed with MEPA.

Since the 2016 ENF Determination the MEPA process has undergone several changes. Most notably, the inclusion of Environmental Justice as an area of concern for MEPA review, as well as additional review of climate change considerations. Weston & Sampson reviewed the Environmental Justice communities mapping available from the Executive Office of Energy and Environmental Affairs (https://mass-eoeea.maps.arcgis.com/apps/webappviewer/index.html?id=1d6f63e7762a48e5930de84ed4849212) and determined there are no Environmental Justice communities located within the 1 mile radius of the project, however there are several within the 5 mile radius. The proposed project is not anticipated to have significant impacts on these communities, but this should be reviewed further once the extent of the proposed project is defined.

It was noted during this meeting that priority habitat overlaps the project site. It is recommended that the National Heritage and Endangered Species Program of the MA Division of Fisheries and Wildlife be contacted to confirm that the priority habitat located on the site will not be impacted by the project.

Additional Permits During Construction

In addition to permitting actions recommended above, there are local permitting considerations during construction. Local permits applicable to this project as identified in the Town's bylaws (as of January 2023, accessed online via the Town's website) would include a Street Opening Permit, a Trench Permit, and a Building Permit.

A memorandum prepared by West Newbury's Conservation Agent in March 2023 documents actions to be taken for wetlands permitting on the local level. It was noted that there is an open Enforcement Order on the property related to tree clearing in 2013 which would need to be addressed as part of any new work on the property. It was also noted that proposed work for this project may fall within the buffer zone of wetlands located adjacent to the property and additional wetlands delineation should be performed in order to determine the necessary next steps for proceeding. In addition, the project would be subject to the Massachusetts Stormwater Standards.

5. Sea Level Rise Implications

Weston & Sampson conducted an evaluation on the potential effects of Sea Level Rise (SLR) impacts on groundwater and surface water elevations near the Dole Place Wellfield. The evaluation was conducted to assess potential impacts on both infrastructure as well as safe yield and water quality of the source of supply under normal operating conditions (mean higher high water). As requested by the Town, the evaluation was conducted using the assumption that sea level rise during a 100-year flood condition in the year 2100 would equal six (6) feet above the current (2023) FEMA 100-year flood elevation. It is important to understand the consequences of the 100-year flood condition with respect to the proposed infrastructure needed to support the withdrawal, and the Town would like to incorporate the projected sea level rise into its evaluation for this.

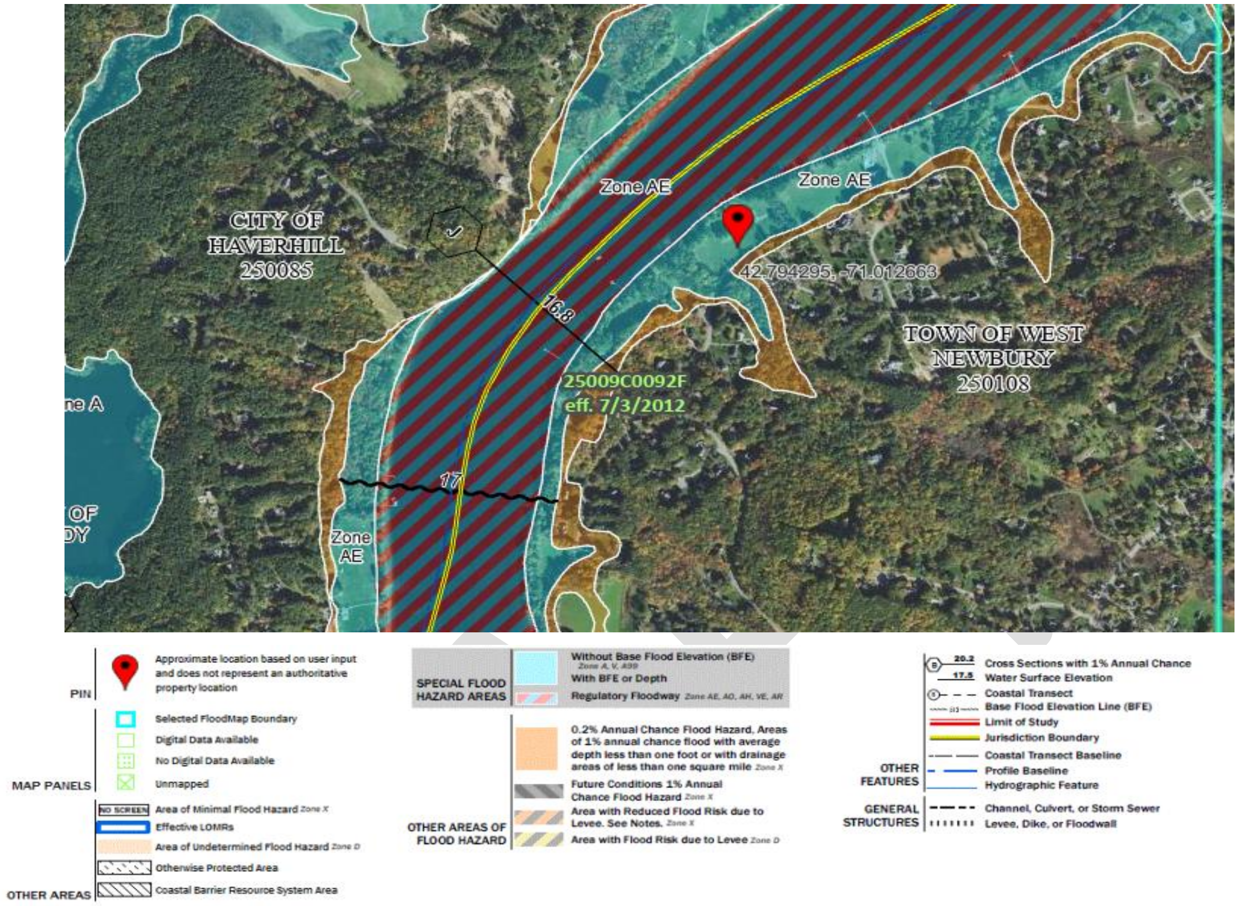
Potential Impact on Groundwater Elevations

Groundwater elevations in 2100 (town recommendation) were evaluated to understand the implications to the safe yield of the aquifer and water quality of the source water for the proposed source of supply under a 100-year flood condition and under normal operating conditions (mean higher high water).

The change (or rise) in groundwater elevations were calculated by using the relationship between the tidally influenced Merrimack River and the groundwater conditions under the 2016 observed conditions during the pumping test and applying that relationship to the predicted river elevations in both 2100 and 2070. Much of the information required for this evaluation was missing from the Tata & Howard Report because an assumed datum was used to estimate relative groundwater elevations. Weston & Sampson used the most recent LiDAR ground elevation data obtained from MassGIS to estimate elevations at the test wells based on the NAVD88 datum. The minimum and maximum observed groundwater levels provided in the report from February 2016 were used in conjunction with LiDAR surface elevations to estimate a range of groundwater elevations at the Dole Place Wellfield site throughout the pumping period. These elevations were then compared to the stage of the Merrimack River at USGS stream gage Newburyport, MA – 01100870 for the same period record as the pumping test. This evaluation showed that for every foot the Merrimack River increases due tidal changes, groundwater elevations increase by approximately 0.08 ft.

Town Recommended Approach: The current 100-year flood elevation of the site is currently 16.8 feet NAVD88 and was determined based on the FEMA Mapping Firm panel 25009C0092F as shown in Exhibit A below. The Town requested that Weston & Sampson assess the possible impacts to future elevated groundwater elevations resulting from sea level rise (SLR) by projecting the 100-year flood plain elevation with an additional 6 feet based on the 2070 sea level rise projection. Weston & Sampson's assumption is that this condition represents a 100-year flood condition in 2100.

Exhibit A: FEMA Flood Map



The current 100-year flood plain elevation with an additional 6 feet to represent the 100-year flood elevation in 2100 is equivalent to a water level elevation of 22.8 feet NAVD88. It should be noted that the Dole Place Wellfield is located within a FEMA special flood hazard area (Zone AE) as shown in Exhibit A and Figure 1. In order to illustrate our findings, a cross-section was developed representing the current groundwater conditions and projected SLR conditions (Figure 2). As a conservative approach, Weston & Sampson anticipates the land surface that parallels the Merrimack River to eventually be overtopped causing groundwater elevations to be impacted and rise at the same rate as SLR. Therefore, the projected SLR value was superimposed onto the current condition groundwater elevations. Based on the mapping of the FEMA Flood Hazard Areas (Figure 1) and projections explained above, the entire Dole Place Wellfield is expected to be overtopped by approximately 6.8 feet from rising river levels during a 100-year flood. This approach should be considered highly conservative and representative of a flood condition only.

Under the Town's recommended approach, the entire site would be underwater during a flood condition unless all surface infrastructure is raised 2 feet over the expected 100-year flood elevation in 2100. This represents raising the wellhead(s) and associated infrastructure 8.8 feet above current ground surface.

Under the Massachusetts State Hazard Mitigation and Climate Adaptation Plan, the groundwater elevations in 2070 would rise approximately 0.36 feet. The impact from the resultant SLR-induced groundwater elevation rise would be de minimums on the safe yield of the wellfield, the water quality of the source water, and the associated infrastructure.

6. Recommendations

Assuming the Town decides to pursue the parcel for the development of a groundwater source, the following are recommended next steps for the Town.

Preliminary Steps (Fall 2023-Spring 2024)

The Town can take steps in the short term to move forward with the analysis of the parcel for use as a groundwater source, including the following:

- Submit to MassDEP a brief pumping test proposal that outlines the following:
  - Updated Zone II land use evaluation
  - Proposed pumping test sampling schedule and list of constituents to be sampled
  - Proposed wellfield configuration including test well construction and location of discharge
  - Proposed withdrawal rate and length of test
- Following the pumping test proposal submission, a long-term pumping test and water quality sampling should be performed incorporating the recommendations in Sections 2 and 3 above.
- Survey of the site can be conducted to obtain topographic elevation data and update previously used values for groundwater elevation developed with an assumed datum.

Additionally, the following steps can be taken in the short term to move forward with permitting of the project:

- Additional wetlands delineation should be performed to understand the extent of wetlands and buffer zones for the property.
- National Heritage and Endangered Species Program of the MA Division of Fisheries and Wildlife should be contacted to confirm that the priority habitat located on the site will not be impacted by the project.

Once the additional pumping test and water quality sampling are completed, there will be additional clarity as to the treatment requirements for the potential drinking water source. Treatment requirements will dictate the size of the building and scope of the design which will inform the need to update MEPA permitting for the project and move towards design and construction of the infrastructure necessary for a wellfield at 31 Dole Place.

Figure 1

FIGURE 1

WEST NEWBURY, MA
DOLE WELLFIELD

FEMA MAP

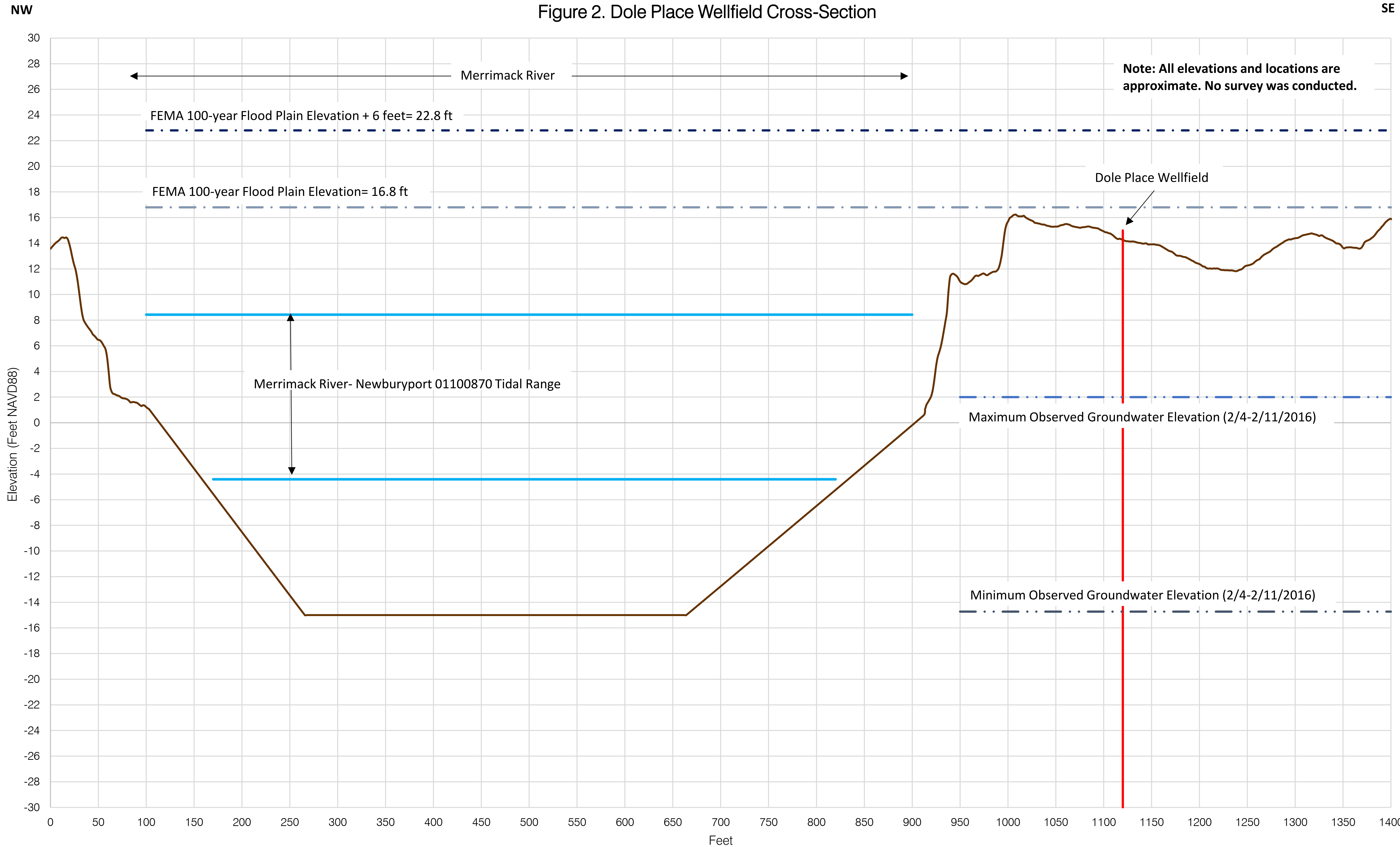
AUGUST 2023 | SCALE: NOTED

Weston & Sampson

Path: \\wse03.local\WSE\Projects\MA\West Newbury MA\Dole Wellfield\007 GIS\Mapfiles\FEMA.aprx Map: Map User: GetchellJ Saved: 8/15/2023 4:05 PM Opened: 8/15/2023 4:18 PM

Figure 2

Figure 2. Dole Place Wellfield Cross-Section



Newburyport Climate Resiliency Plan

Newburyport Resiliency Committee

Donna D. Holaday, Mayor

Barry Connell, City Councilor At-Large

David Chatfield, Co-Chair

Michael Morris, Author and Co-Chair

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Chris LeClaire, Fire Chief

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John O'Connell, Newbury Resident

Lisë Reid, Parks Director

Joe Teixeira, Conservation Commission Chair

Jon-Eric White, City Engineer

October 8, 2020

Executive Summary

During the period of 2015-2019, the city completed four studies to assess its vulnerability to the impacts of climate change. This plan summarizes resiliency planning efforts to date, climate change hazards, the city's vulnerabilities to those hazards, and identifies adaptation strategies and recommendations to minimize its risk exposure.

The identified climate hazards relevant to Newburyport are:

1. Sea Level Rise
2. Coastal Storms -Extra Tropical, Tropical, and Hybrid Cyclones
3. Heavy Precipitation Events
4. Flooding
5. Wind
6. Tornados
7. Weather Extremes –Drought, Heat Waves, Winters and Cold Snaps, Persistent Precipitation

Vulnerable high priority city owned infrastructure includes the public water supply and the Wastewater treatment facility (WWTF). The public water supply is critically vulnerable and requires urgent action to avoid being compromised by river flooding or an extreme weather event. The Lower Artichoke dam's spillway currently sits approximately 3 feet lower than FEMA's 100-year flood elevation. Thus, a lesser storm could overtop the spillway with CSO tainted Merrimack river waters thereby cutting off access to

75% of the city's water supply. The WWTF lies within FEMA's 100-year flood zone and so is also vulnerable to service interruption.

As the National Grid substation is located adjacent to the WWTF, it too is located within FEMA's 100-year flood zone and is currently vulnerable to storm and flooding impacts. However, the facility's impact upon Newburyport, should it be compromised, has not yet been evaluated by the city, and a review with National Grid is required to ascertain the risk and impacts.

Many parts of the city are vulnerable to flooding due to river influences, sea level rise, and storm surge or a combination of the three. Areas within the city differ enough from one another such that the three variables contributing to flooding will not contribute equally within each neighborhood. The Plan has identified five neighborhoods with differing flooding vulnerabilities, these include Plum Island, the riverfront from Bartlett Spring Pond east through Joppa and the Little River Basin which includes the Business Park and nearby residential neighborhoods.

Identified strategies to mitigate risk exposure include a mixture of protection, adaptation and retreat with suggested timelines of immediate, short term (current day to 2030), and long term (2030 -2070). The strategies fall into four main strategic areas:

- Infrastructure Installations/Improvements
- Regulatory and Administrative Approaches
- Community Communication and Education
- Mitigation through Carbon Footprint Reductions

Resiliency Plan Summary Recommendations:

<u>Infrastructure installations/improvements</u>

- Immediately deploy methods to protect vulnerable Critical Assets from inundation.
    - Water Supply
    - Wastewater Treatment Facility
    - National Grid Substation
- Develop, evaluate and implement plans for permanent protection of the water supply
- Develop and evaluate plans for protecting low lying sanitary sewer lift stations and in the long-term the future relocation of the WWTF and National Grid facilities.
- For the areas surrounding and including Cashman Park and Waterfront Park, perform a design, cost and feasibility analysis that considers elevating or protecting these properties to preserve their amenities vs. adapting and transitioning the assets to alternate uses in a rising sea and surge scenario.
- Strengthen the electrical grid by reducing conflicts with trees, burying utilities and evaluating micro grids.

<u>Regulatory and Administrative Approaches</u>

- As some shoreline areas will become uninhabitable sooner than others, use sea level rise (SLR) and inundation projections to prepare an inundation timeline for neighborhoods along the river and Plum Island.
- Review, evaluate, and revise zoning and building regulations to improve resilience, water conservation, energy efficiency and discourage development in the FEMA high hazard flood zones.
    - Develop and adopt a design flood elevation for all new and proposed renovations of

    - properties in the FEMA high hazard flood zones.
    - Continue to enforce existing Wetlands Protection act regulations.
- Develop and Implement a task force to develop with Newbury and implement a long-term, sustainable, science-based plan to address the multifaceted challenges facing Plum Island. Continue to work with the Merrimack River Beach Alliance, the Plum Island Foundation, the U.S. Army Corp of Engineers, Legislators and State Agencies in this process.
- Evaluate alternative access options to Plum Island.
- Develop and implement an automated water quality monitoring and warning system to protect residents from the health risks associated with combined sewer overflows (CSO's). Continue to work with legislators to support efforts to upgrade upriver wastewater treatment facilities to reduce CSO's.
- Implement a storm water/impervious surfaces management program in compliance with EPA MS4 permit. Impervious surfaces contribute to flooding, raise summer temperatures citywide through heat island effects, and increase the cost of snow removal.
- Develop alternative revenue streams to fund the city's budget and pay for resiliency and emergency response activities. As future sea level rise and inundations begin to claim shoreline properties, resiliency costs will increase, and current sources of real estate tax revenues would decline.
    - Design and implement a storm water utility
    - Evaluate a differential tax rate for properties located within the FEMA high hazard flood zones.
    - Evaluate additional use tax strategies

<u>Community Communication and Education</u>

- Develop recommendations for personal resilience to assist and educate residents to make their households resilient to climate hazards.
- Develop a property owner's flood resiliency guide and educate property owners of acceptable methods to flood proof their properties.
- Engage with the community to determine under what circumstances and resources, that a managed retreat from shoreline areas would be acceptable.
- Educate and alert residents to emerging public health impacts related to heat, air and water quality, insect disease vectors, public safety, and emergency response, access and shelter. Educate residents of the need to evaluate and strengthen their own personal resilience to climate hazards.
- Develop a public outreach and education program to educate residents about this resiliency plan. Specifically: promote personal preparedness, community resiliency, natural hazard mitigation, public health impacts, CPR, First Aid training and managing carbon footprints. Create school-based programs to educate future generations about climate change impacts and resiliency.

<u>Mitigation through Carbon Footprint Reductions</u>

- To mitigate climate change and temper hazards for future generations, Newburyport and each of its residents must do their part to achieve communitywide net-zero emissions by 2050. To that end, track the current municipal carbon footprint and implement a program to quantify and track the impact of residential households. Implement an annual program of residential carbon footprint reporting.

- Increase the use of renewable energy versus fossil fuel energy citywide.

"Newburyport's Climate Resiliency Plan supports the current and future social, economic, and environmental policies and practices as outlined in the city's 2016 Master Plan. These values serve to strengthen the city and make it more resilient, ensuring that its residents, neighborhoods, and businesses have the capacity to thrive as the community navigates a changing climate and an evolving economy.

This Climate Resiliency Plan represents the culmination of past studies, identified climate hazards, at risk assets and vulnerabilities in Newburyport. The process engaged key stakeholders, partners and community members who contributed to debate, deliberation and creation of the plan. Newburyport has been at the forefront of green and sustainable initiatives, and it is our vision that everyone within the community join us to reduce energy use, promote energy independence, improve public health, strengthen our economy, and build a more livable and resilient community."

Mayor Donna Holaday

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Introduction

Overview

Throughout our short history on this planet humanity has been able to adapt, innovate, manipulate and exploit the earth's resources and systems to its benefit. As a species, we've been able to traverse those growth limiting hurdles that sustain balance within the earth's ecosystems. We've been able to overcome disease, dominate our predators, ensure a stable food supply, and even avoid the self-destruction of nuclear war. Our immense growth in population and our ability to inhabit every corner of this planet bears testament to our command of this world.

When viewed in light of the characteristic biological population growth curve (*Figure 1. Biological Population Growth Cycle*), humanity's population is still strongly set in a phase of exponential growth (*Figure 2. World Population, Last 12,000 Years*), which interestingly, parallels our development of technology and a capitalist economy that was ignited by the burning of the fossil fuels which powered our industrial age. However, like colonies of bacteria in a confined Petri dish, the waste products of life are beginning to accumulate to the detriment of the environment we inhabit. Bacteria in a Petri dish can't comprehend what's happening, and as they can't respond, their population dies off. As humans we understand what's happening and we have the opportunity and ability to change a predictable outcome. A formidable challenge is rapidly emerging on our evolutionary horizon. Will manmade climate change apply the brakes to human population growth and usher in a decline, or, will we be resourceful and diligent enough to overcome our largest hurdle?

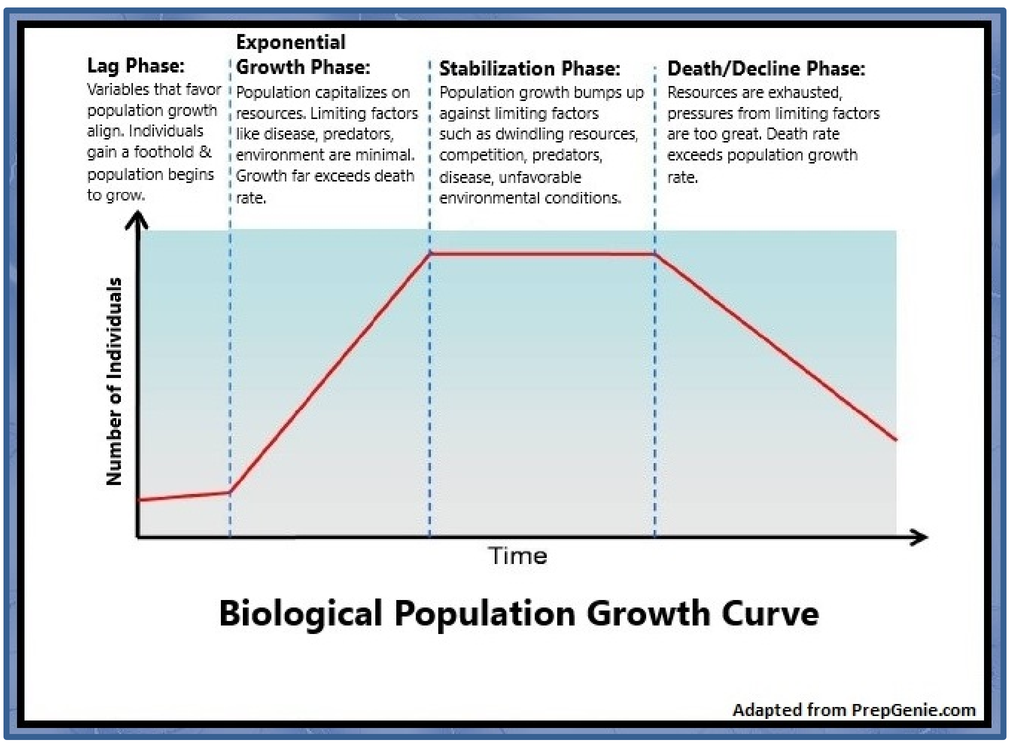

Figure 1. Biological Population Growth Cycle

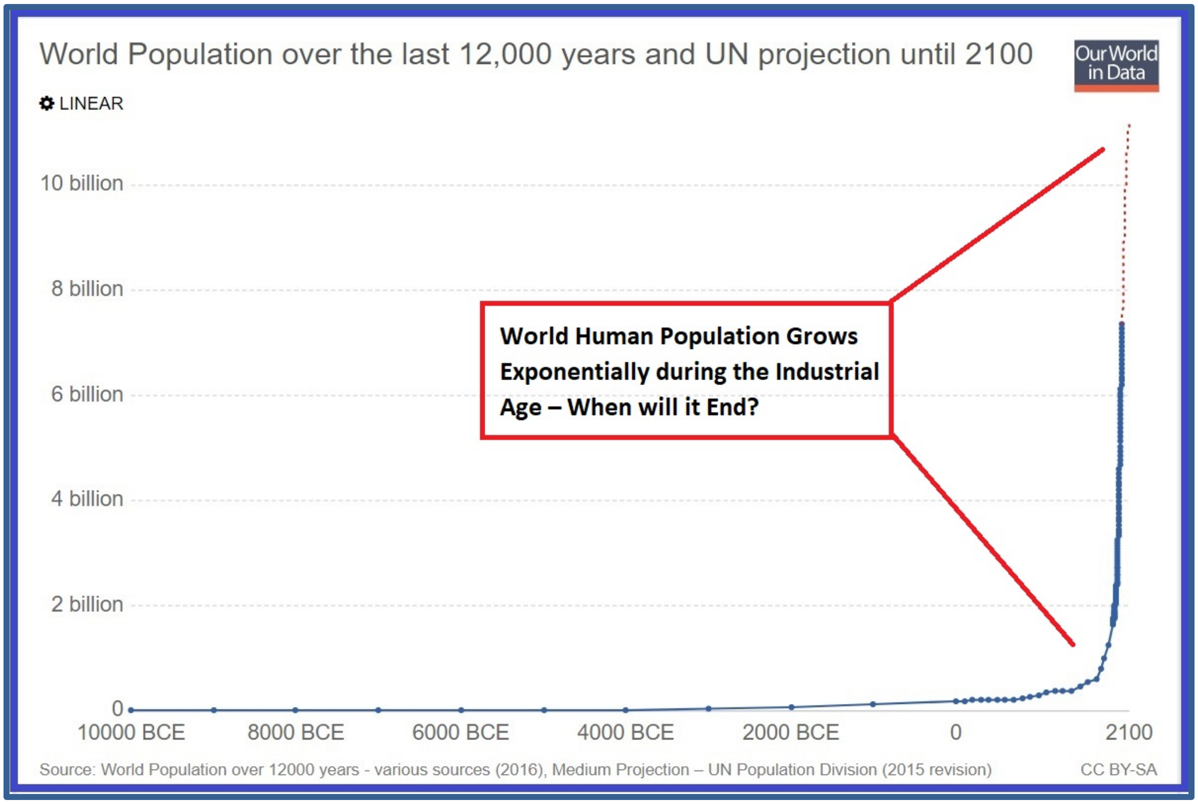

Figure 2. World Population, Last 12,000 Years

The effects of climate change are already, and will continue to be, far reaching; touching our lives, communities, economies and every ecosystem on this planet. While globally and locally, great strides will need to be made to apply the brakes to the factors driving climate change, we will also need to prepare for, and ensure our survivability of the hazards that it will usher in. That is the goal and purpose of Newburyport's Climate Resiliency Plan.

Newburyport - General Characteristics and Lay of the Land

Physical Location

The Historic Seaport City of Newburyport is located on the Northeast coast of Massachusetts, along the southern bank of the Merrimack River. The city's easterly extent touches the Atlantic Ocean along the northern shores of Plum Island. There, Newburyport shares the Merrimack River inlet with the town of Salisbury located across the river to the north. In addition to Salisbury, three other towns share Newburyport's border: West Newbury along the river to the west, Amesbury across the river to the northwest, and Newbury (including much of populated Plum Island), to the south.

PHOTO: Alex Maclean, alexmaclean.com

Elevation

Areas along Newburyport's riverfront (to the north of Merrimac and Water Streets) extending all the way to Plum Island are relatively low lying. Immediately back from the river's edge, Newburyport's elevation climbs a gentle to at times moderate hill towards High St., after which it crests and slopes back down toward Low St. and the Business Park. It is on either side of this hill, and continuing northwest towards Storey Ave, that most of Newburyport's homes and businesses are located.

Rivers and Streams

Newburyport and Salisbury together are the most downstream communities within the Merrimack River's Watershed. They are the last municipalities through which the river flows before it empties into the Atlantic Ocean. The watershed is the fourth largest in New England and extends north into central New Hampshire some 150 miles and drains, in total, 5,010 square miles of territory to the Massachusetts coastline. www.mass.gov/service-details/merrimack-river-watershed. Where this watershed meets the Atlantic, the river's delta is bordered by two densely populated barrier beaches (Salisbury and Plum Island). In the distant past the river's delta was in a natural state. It occupied two or more inlets and had access to an expansive salt marsh to the north and south, into which it could disperse the flows of heavy rain and storm surges. Today the Merrimack River Delta is "hemmed in" by two beach access causeways and a single engineered inlet (which was constructed to aid in navigation). The causeways, acting as dams, restrict the dispersion of flood waters to the salt marshes. The river's single engineered inlet (Merrimack River jetty system) while intended to guide and narrow the river's flow, may contribute to the backing of flood waters upstream during extreme precipitation events.

Within the Merrimack River Watershed Nearly 600,000 people rely on the river for their drinking water, including the environmental justice communities of Lowell and Lawrence, Methuen, Tewksbury, and other towns (http://www.merrimack.org/web/improve-water-quality-and-quantity/). (Environmental justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.) Additionally, according to the Merrimack River Watershed Council, some 45 wastewater treatment facilities are releasing treated, and during heavy rain events, sometimes untreated wastewater either directly into the Merrimack or one of its tributaries. These waters flow past Newburyport on their way to the Atlantic Ocean.

In addition to the Merrimack, headwaters of the Little River begin west of I-95 near the intersection of Storey Avenue and Turkey Hill Road and meanders along the abandoned I-95 roadway. Its main eastern tributary begins near the shopping centers behind Storey Avenue. The Little River then flows along the southwestern and then southern edge of the business park, ultimately emptying into the Parker River. The Parker flows through the Great Marsh and into Plum Island Sound with the waters ultimately emptying into the Atlantic Ocean in Ipswich Bay. The Little River drains the area along I-95, Storey Ave, and much of Newburyport that slopes toward Low St.

Finally, overflow from Newburyport's Artichoke drinking water Reservoir passes over the Lower Artichoke dam located along State Road 113 into a small tributary called the Artichoke River which borders West Newbury. This sometimes tidally influenced tributary slowly meanders for ¾ of a mile and empties directly into the Merrimack River (*Figure 3. Lower Artichoke Reservoir and Artichoke River*).

Figure 3. Lower Artichoke Reservoir and Artichoke River

The Atlantic Ocean and Gulf of Maine

Newburyport is located on the Northeast Coastline of Massachusetts and is exposed to the Atlantic Ocean. While the bulk of Newburyport's population and infrastructure sit inland to the west and are protected by the barrier beaches of Plum Island and Salisbury, it is still heavily under the influence of the Atlantic's weather, waves and storm surge. The northern and subtropical jet streams often direct weather off the east coast in the northeastern United States. Hence the region can be under the influence of extreme heat, cold, dry and wet weather during any season. Positioned between the highly contrasting cold and dry air masses over Canada, and the relatively warm and moist marine layer of the Atlantic and nearby Gulf Stream, New England sits in a unique position where the interaction of these air masses has historically spawned significant ocean storms, with major impacts.

Regarding exposure, Newburyport is offered some significant nearshore protection from wind and wind driven waves by Nova Scotia located some 265 miles to the Northeast, and by Cape Ann located some 13 miles to the Southeast. Cape Cod also provides protection from swell energy originating from due south. However, Newburyport's wind and wave window is quite open to the great expanse of the Atlantic Ocean between ENE and ESE; essentially an area extending to the west of the British Isles and south to Antarctica. It is from this area extending sometimes more than 700 miles out into the Atlantic that large and destructive wave energies are formed.

It is also important to note, that while Nova Scotia and Cape Cod offer some protection by limiting the window of exposure to wind and wave fetch, they are also a liability. Coupled with the mainland, Cape Cod and Nova Scotia, form an area known as the Gulf of Maine which has a relatively shallow continental shelf that extends some 200 miles out to sea. (*Figure 4. Gulf of Maine Bathymetry*) In the presence of a storm driven surge coming in from the east or southeast, the Gulf behaves as a giant catcher's mitt capturing the surge; with the shallow sea floor driving it higher, thereby enhancing coastal flooding. Storm surges during the Blizzard of 1978 and the Perfect Storm (Halloween Gale of 1991) capitalized on this feature. Had Hurricane Sandy traveled four hours further north and then made land fall near eastern Long Island, she would have devastated the Gulf of Maine coastline with her storm surge and waves.

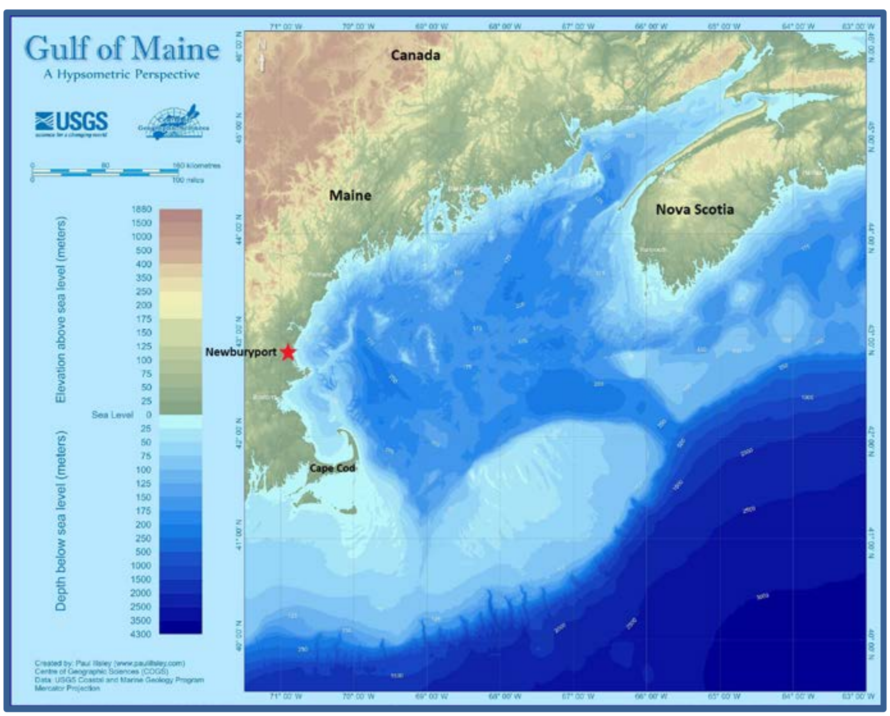

Figure 4. Gulf of Maine Bathymetry

Open Space, Parks and Recreation

Newburyport possesses approximately 2,913 acres of open space. It is home to 37 municipal and private parks, 6 public and private cemeteries, and an array of non-profit land and private open spaces protected by conservation restrictions. Together this mix of open space helps to define the character of Newburyport, playing a vital role in fostering civic pride, public health and wellbeing, biodiversity and economic development.

Recreation

The city offers a broad array of recreational opportunities within its parks, playgrounds and playing fields, tennis and basketball courts, skate park, boat ramps, walking trails, rail trail, gardens and water features. In addition to providing venues for community building programs that foster civic pride, these areas promote a network of connections throughout the city for bikes and pedestrian travel that connect with the downtown and the MBTA station. Newburyport's park and recreational facilities allow youth and adults alike to engage in a variety of sports whether organized or informal, including baseball, softball, lacrosse, soccer, skateboarding, Frisbee, football, hockey and pickup sports, and provide for places to walk dogs, learn to swim, fish, launch boats and small watercraft.

Heritage Landscapes

Historic, scenic places and spaces have helped to define the character of the city which make it a desirable community for people to live and visit. Newburyport's Heritage landscapes evolved from human interaction with the area's natural resources. In Newburyport, such landscapes include beaches, marshes, farm fields and pastures, views of Merrimack River, a historic grist mill and its woodland surroundings, and other historic settings. Recreational heritage landscapes include Bartlett Mall, Brown Square, and Joppa Park. Many significant privately-owned open spaces add to the character of Newburyport. Extensive and historic gardens and backyards along the High Street ridge represent an important heritage landscape that reflects a significant period in Newburyport's history. Preserving landscape character has been important to developing the community's character.

Habitat and Green Infrastructure

Newburyport's open space areas including Plum Island, the Great Marsh, Maudslay State Park, the City Forest, Common Pasture and the Artichoke watershed to name a few, feature rivers, waterways and wetlands that provide habitat for endangered, rare, and threatened species. They also contribute to the regional coastal fisheries economy and to the community's growing ecotourism economy. Newburyport's protection of its environmental resources and open spaces has served residents by providing clean air, clean water, flood protection, stormwater dispersal, and noise reduction.

Economic and Public Well being

The city's parks and open spaces have enhanced the community's economic wellbeing by boosting, home values and property tax revenues, and by attracting residents, tourists and businesses to the city. Economics aside, Newburyport's parks and open spaces are positively enhancing human health and wellbeing through encouraging exercise, stress reduction while also reducing air pollution. The mix of open space makes Newburyport an attractive place to live, visit and conduct business. Appendix 1 provides an inventory of Newburyport's parks and open spaces by acreage.

Population Characteristics

The city Clerk reported in 2019 that Newburyport is home to 18,207 residents that occupy some 7622 households. The city's population is one of the densest in the Merrimack Valley, with 2124 residents per square mile. Households within the city are relatively affluent when compared to the State and county. With a median income of $83,149 Newburyport's median income is significantly higher than the state ($70,628) and Essex County ($68,776). Residents are also well educated with 58% of the city's population (over age 25) earning a bachelor's degree or Higher, vs 37% for Essex County. Source: Merrimack Valley Planning Commission US Census Bureau, American Fact Finder, 2010-2014 American Community Survey 5-Year Estimates.

http://mvmb.biz/wp-content/uploads/newburyport-acs-social-characteristics.pdf

Regarding age, 16% of the population is over the age of 65 (which is slightly higher than Essex County at 14%). Like Essex County, 63% are of working age (18-64), but fewer (21%) of Newburyport's population is age 18 or younger when compared to Essex County (23%). 96% of the population categorize themselves as Caucasian. (MVPC, US Census, 2010-2014 American Community Survey 5-Year Estimates)

Through 2030 Newburyport's total population size is expected to remain steady, but within it significant age-related shifts will occur. As Newburyport's baby boom population continues to age, forecasts predict that by 2030, the population of residents age 65+ *will swell to 32%,* with a commensurate decrease in proportion of residents of working age (50%) and those ages 18 or younger (14%).

http://www.housing.ma/newburyport/profile

Infrastructure

Access

Newburyport is accessible by land, sea and air. By land the city can be accessed from the north and south via I-95 and US Route 1, both passing through the city. Access from the west is possible via state road 113. MBTA Commuter Rail service and a Bus line are also available offering a convenient transit commuter connection between the city and downtown Boston. Access via air is possible via Plum Island Airport (seasonally), located just over the border in Newbury. The airport is a privately owned, public-use airport owned by Historic New England and operated by Plum Island Aerodrome, Inc., a non-profit corporation. It has two runways, one asphalt at 2105 feet in length, and the other grass with a length of 2300 feet. The airport averages 54 flights a week and has approximately 8 based aircraft. Access by air year-round is also possible via the Helipad Located at Anna Jaques Hospital, though its intended use is for emergency medical evacuations. Access by water is possible from the west and east via the Merrimack River and Atlantic Ocean. As there are no ferry services, marine access is via pleasure and charter craft.

Water Supply

Newburyport's drinking water comes from both surface water and groundwater supplies. Four surface water reservoirs, which represent 80% of the city's drinking water supply, include the Indian Hill Reservoir in West Newbury, the Upper and Lower Artichoke Reservoirs in both West Newbury and Newburyport, and the Bartlett Spring Pond in Newburyport. These surface reservoirs supply 780 million gallons of water primarily to Newburyport and some also to the towns of Newbury and West Newbury. The watersheds for our reservoirs are primarily a mixture of residential, agricultural, recreational and forestland. Most of the land abutting the surface reservoirs lies in West Newbury and is privately owned. Groundwater, which accounts for 20% of the drinking water, is supplied by two gravel-packed wells located on Old Ferry Road (Well #1) and Ferry Road (Well#2). A drinking water treatment plant (WTP) located on Spring Lane near Well #1 treats the surface water supplies and the water from Well #1. Groundwater from Well #2 is minimally treated at the well and is directly connected to the city's water distribution system. The Plant is permitted to treat and deliver 2.5 million gallons per day (MG/D), but on average treats 1.6 MG/D. A chlorine booster station is located next to the Plum Island drawbridge to inject chlorine into the water distribution system.

Wastewater Treatment

Wastewater is channeled to the city's recently updated Wastewater treatment facility (WWTF) located along the waterfront. The WWTF is designed to handle 3.4 million gallons per day (MG/D) of wastewater, and on average processes 1.7 MG/D. Unit operations include: four aeration basins, eight mechanical mixers, two primary clarifiers, two gravity thickeners, two aerobic digesters, two secondary clarifiers, and two chlorine contact chambers with chlorination and de-chlorination. Sludge dewatering is performed with two, two-meter belt filter presses. The facility was recently updated to improve water quality treatment and emissions/odor control but was not updated to handle more flow. The city owns and operates 16 sanitary sewer pumping stations and many are located in or near flood zones.

Power and Utilities

National Grid is the electrical utility provider with a substation located downtown along the waterfront between the Merrimack River Coast Guard Station and Newburyport's Wastewater treatment facility. National Grid is also the supplier of natural gas within Newburyport. In total, five gasoline refueling stations are located within the city. Three clustered along Storey Ave, one on High St. in the city's north end, and another along Merrimac St. near Cashman Park just north of US Route 1. Two Electric vehicle charging stations are located downtown on State St., four more in the recently completed municipal parking garage with additional charging stations in development.

Public Safety

The city has a well-equipped Public Safety infrastructure comprised of a Police Force, Fire Department (2 stations), Department of Public Services, Harbor Master, Private Ambulance Service, and US Coast Guard Station located along the waterfront. In addition, these public safety departments are organized under the Newburyport Emergency Management Agency (NEMA) to coordinate responses to natural disasters, power outages and other community wide emergencies. Newburyport, together with the municipalities of Amesbury, Boxford, Georgetown, Ipswich, Merrimac, Newbury, Rowley, Salisbury and West Newbury comprise the Northern Essex Regional Emergency Planning Committee (REPC). Emergency Planning Committees are responsible for protecting their communities from incidents involving hazardous materials. This includes developing emergency response plans and educating the community about chemical facilities and the actions that could be taken if there is a chemical accident. Massachusetts has six hazardous material response teams that can respond to a release of hazardous materials anywhere in the state within one hour. When needed, the city provides access to three emergency shelters: one located at the Rupert A. Nock/Molin School on Low Street, another at the Newburyport Senior and Community Center on High St. and the third downtown at the Salvation Army.

Healthcare

Newburyport has within its borders a full-service community hospital (Anna Jaques Hospital) with a 24-hour emergency room and ICU, and nearby doctor's office buildings. A helipad is available on the hospital campus for med-flight evacuations to Boston Trauma Centers. Pentucket Medical with some onsite lab testing is located back from the River on Merrimac St., along the western border of Cashman Park. Also, within Newburyport's borders are three nursing homes, and two assisted living centers.

Economic Characteristics

The city's proposed Fiscal Year 2020 operating budget is estimated to be $70,450,776 with 84% of revenues originating from property taxes. Of all property taxes collected in 2019, 88.5% originated from residential properties, while 11.5% originated from Commercial and Industrial properties.

Chief Economic drivers within the community include the Historic Downtown Waterfront, the Business Park, Plum Island Beach, Smart Growth District (Route 1 Traffic Circle/MBTA Station) and the Storey Ave business district near the I-95/Route 113 interchange.

The bustling downtown hosts a variety of shops, restaurants, banks, city buildings, a newly constructed parking garage, and other attractions that draw both residents and visitors year-round - though the summer months are the busiest. The downtown economy is intricately tied to the Merrimack River with many restaurants and shops located close by. Year round, visitors and residents alike frequently use the 1.6-mile scenic river walk that extends east to Hale Park and runs west through Waterfront and Cashman Parks to the North End Boat Club.

Plum Island is roughly an 8-mile-long barrier beach, most of which falls outside the city's boundary to the south. However, the far northern extent of the island (the last ½ to ¾ of a mile) that extends into the Merrimack River inlet, falls within Newburyport's jurisdiction. Aside from seasonal Charter Fishing enterprises, the area has few commercial businesses, but is densely populated with increasingly larger vacation and year-round residences. A large city owned parking lot promotes Public access to the beach and river shorelines there.

The Business Park located roughly between Hale Street, Low Street, Route 1 and the Newbury border, is home to approximately 60 large-scale industrial businesses. Several manufacturing businesses are located outside of the business park and *Figure 5. Business Park Hazardous Materials* illustrates the facilities within the Business Park that store hazardous materials. A stated goal of the of Newburyport's 2017 Master Plan is to "enable new and expanded commercial and industrial use at the Business Park to generate at least 15% of the city's property tax revenues."

The busy Storey Ave area located near the intersection of I-95 and Route 113 is home to several banks, three gasoline pumping stations, two major supermarkets with adjoining strip mall businesses, fast food franchises, office buildings and apartment/condo complexes along with their associated impermeable parking lots.

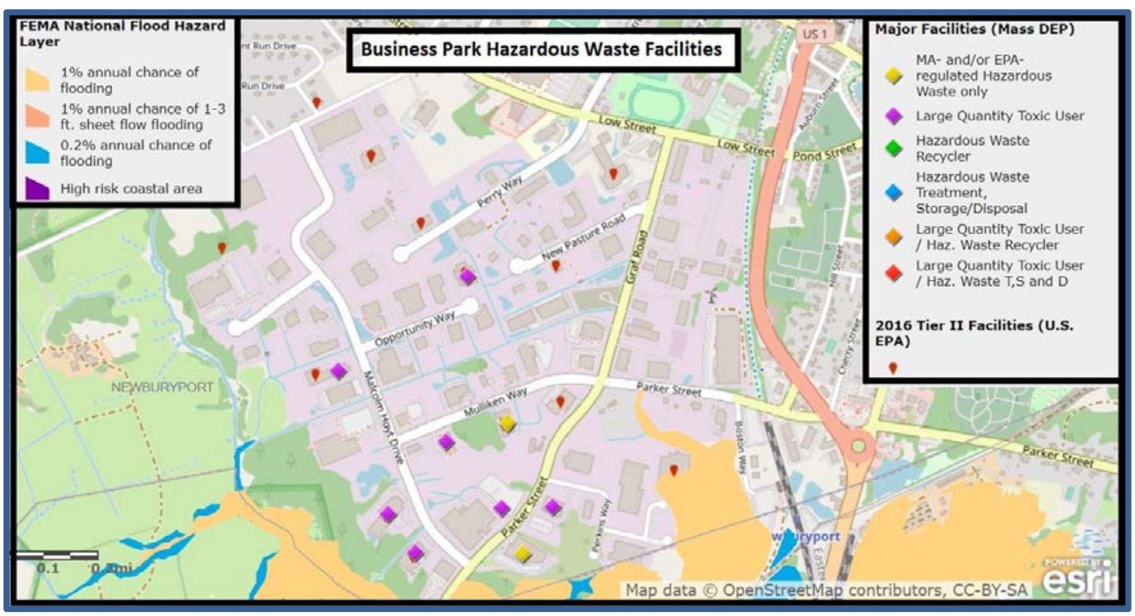

Figure 5. Business Park Hazardous Materials

Resiliency Planning Efforts to Date

Following the turn of the millennium, impacts of challenging weather events began to become more frequent in Newburyport. Flooding from the 2006 Mother's Day Storm along with impacts on Plum Island increasingly drew attention. Following Hurricane Sandy and the traumatic winter storm season of 2012-13 that resulted in the loss and damage of many homes on Plum Island, the non-Profit Community Group *Storm Surge* began to educate the community about the urgent need to prepare for, and mitigate, the impacts of climate change and sea level rise. Concurrently, Newburyport participated in the Hurricane Sandy Coastal Resiliency Competitive Grants Program administered by the National Fish and Wildlife Federation.

Under the direction of Newburyport's Mayor Donna Holaday and Sustainability Coordinator, Molly Ettenborough, Newburyport had already made significant strides towards sustainability and energy efficiency. Newburyport has been a leader in the region in energy and waste reduction. In 2005 former Mayor John Moak signed the US Mayors Climate Protection Agreement, and in 2006 the city established an Energy Advisory Committee. In 2008 it installed, what at that time was the largest municipal building solar array in Massachusetts. In 2010 it was designated a Green Community and in 2011 it signed a 20-year 2.4 MW agreement for net metered solar. The city has also committed to Net Zero Energy and significant waste reduction goals by 2050, amongst many other achievements.

However, Mayor Holaday also realized that her city had immediate risk exposure to critical infrastructure and needed to start the process of addressing those vulnerabilities. To that end on December 9, 2015 she convened the Newburyport Resiliency Committee (NRC) to take on the responsibility of evaluating Newburyport's risks to climate change and sea level rise, and to develop and help execute a plan to mitigate those risks.

Prior to convening the NRC, city officials were already engaged in assessing hazards as part of the City's Multi-Hazard Mitigation Plan Update. In addition, the City has completed five risk assessment studies, with the most recent going beyond just assessing storm and flood impacts, but also considering other impacts from climate change on Newburyport:

Merrimack Valley Region Multi-Hazard Mitigation Plan *– prepared with assistance from the Merrimack Valley Planning Commission (MVPC), Report Update April 2016*

To minimize the financial burden on the National Flood Insurance Program and costs to FEMA associated with disaster response and rebuilding, the Federal Government has made grant monies available to communities to mitigate potential natural disasters. To qualify, the Federal Government requires that natural hazards common to the communities of the Merrimack Valley region be identified along with their respective impacts to locations, populations, and facilities. It further requires Communities to formulate mitigation goals, strategies, and actions to reduce associated risks and impacts. By developing and implementing a hazard mitigation plan prior to an anticipated disaster, communities could prevent, or minimize, loss of life, property, and break the cycle of repetitive losses. Federal regulations further require that regional and local jurisdictions review and revise their plan every 5 years, to reflect changes in priorities and *demonstrate progress* relative to the previous plan. To be eligible for mitigation grants, the updated plan must be resubmitted to MEMA and FEMA for review and approval.

Plan update was prepared with the guidance and assistance of local and regional hazard mitigation planning team representatives and representatives from Newburyport's Emergency Management team, City Engineering and Conservation/Planning Departments.

The Multi-Hazard Mitigation Plan identified the following natural hazards and their relative risk of occurrence. It is worth noting that 6 of the 7 hazards listed are weather related, not mutually exclusive, and are affected by climate change:

- Flood-related hazards
- Wind-related hazards
- Winter-related hazards
- Fire-related hazards
- Geologic hazards (Earthquakes and Landslides)

- Heat waves/extreme heat
- Climate change /sea level rise

The Multi-Hazard Mitigation Plan identified the following non-natural hazards. Again, even our non-natural hazards can be realized and exacerbated through weather and climate events, and are not mutually exclusive

- Public Health Emergencies and Hazards (Disease -communicable – infectious - waterborne, mass heat mortality,
- Transportation Accidents
- Nuclear Event
- Infrastructure Failure (Water/Sewer, Power Grid/Energy, Communication, Transportation, Manufacturing, Pollution Control Systems)
- Commodity Shortages (Energy; Petroleum, Natural Gas, Electricity)
- Food Contamination/Food-borne Illnesses
- Water Contamination/Water-borne Illnesses
- Chemical/Hazardous Materials Spills and Releases
- Terrorism

The complete Multi-Hazard Mitigation Plan can be found here: https://mvpc.org/wp-content/uploads/April-2016-MV-Multi-Hazard-Mitigation-Plan-Update.pdf

Flood Resilience for Riverine and Coastal Communities – EPA, Final Report Issued January 2016

To protect human health and the environment, the EPA's Office of Sustainable Communities awarded Newburyport a grant to help it determine whether its current strategies fostered flood resilience and to consider additional strategies to reduce long-term risk from flooding. The program helped the city to identify potential challenges and opportunities to make progress. It included a series of pre-and post-workshop conference calls, a self-assessment, and an on-site convening of the public and stakeholders to discuss issues, next steps, and actions related to advancing the community's specific goals. The program was primarily focused on sea level rise and flooding and didn't encompass all the potential impacts of climate change.

The complete Flood Resilience for Riverine and Coastal Communities – EPA, Final Report can be found here: https://www.cityofnewburyport.com/recycling-energy-resiliency-sustainability/resiliency-sustainability

***Great Marsh Coastal Adaptation Plan* –** *National Wildlife Federation (NWF), Final Report issued December 2017*

Following the devastation inflicted by Hurricane Sandy, the Federal Government made funds available to improve the resilience of coastal communities. In 2014, NWF was awarded $2.9 million dollars for the project titled "Community Risk Reduction through Comprehensive Coastal Resiliency Enhancement for the Great Marsh." This project offered a holistic and integrated approach to reducing the growing vulnerability of communities within the Great Marsh to coastal hazards by strengthening the resiliency of the ecological systems upon which those communities depend. Upon receipt of the award, this investment was leveraged by project partners to provide an additional $1.3 million dollars in research and conservation efforts in this priority coastal area.

Within the larger scope of this project, The NWF and Ipswich River Watershed Association led a community-driven process to assess community vulnerability and develop ecosystem-oriented adaptation strategies for the municipalities of Essex, Ipswich, Rowley, Salisbury, Newbury and *Newburyport.* The planning process resulted in the development and engagement of cross-sector municipal resiliency task forces, six town-specific summary vulnerability assessments, community engagement workshops focused on community vulnerability and resiliency strategy planning and development, task force prioritization of near-term and long-term risk-reduction strategies, and ultimately the development of the Great Marsh Coastal Adaptation Plan.

This effort, along with what had been completed via the EPA grant set the stage for the NRC to start formulating Newburyport's own Climate Change Resiliency Plan.

The complete *Great Marsh Coastal Adaptation Plan* can be found here:
https://www.nwf.org/Home/Educational-Resources/Reports/2017/12-01-2017-Great-Marsh-Adaptation-Plan

Newburyport Municipal Vulnerability Preparedness Workshop **-** *Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA), Final Report Issued May 2018*

The Commonwealth of Massachusetts observed that while some coastal communities were attempting to develop risk assessments and resiliency plans, their focus narrowly considered only sea level rise and coastal flooding impacts. Furthermore, the processes being employed were not uniform. Climate change was having far reaching effects and would be affecting all municipalities, both coastal and non-coastal. Hence the Massachusetts Executive Office of Energy and Environmental Affairs developed a standardized process called the Municipal Vulnerability Preparedness (MVP) program as a means for Communities to consider all the potential climate change impacts, and not just sea level rise and coastal storms. The process served to level the field, allowing communities to become MVP certified and apply for grants to mitigate the risks identified via the MVP program. In early 2017, Newburyport sought, and was awarded, a grant from EOEEA to become an MVP certified community. The goal of the program was to not only identify community vulnerability imposed by climate change, but to also involve community residents, business owners and other stakeholders in the process.

On April 7, 2018, Newburyport held a Municipal Vulnerabilities Preparedness (MVP) workshop. The workshop's goal was to identify hazards Newburyport faced that were being exacerbated by climate change, and to prioritize actions the city could take to prepare for identified hazards. This workshop, planned by a core team of the NRC and the Horsley Witten Group, Inc. was a step towards MVP certification, which allowed certified communities access to additional state grants for projects related to climate change resiliency. Thirty-eight community members attended the workshop, representing a wide cross section of city officials, response partners, and other interested parties.

During discussion, participants concluded that the most relevant hazards to Newburyport were storms including nor'easters, winter storms, and hurricanes; bipolar weather including extreme cold, extreme heat, and drought; inland flooding; and sea level rise. In four small groups, participants listed features of Newburyport that may be impacted by climate change or may help the community cope with climate related hazards. Small groups then listed actions that could be taken to protect or utilize features to mitigate the impact of prioritized hazards. Following small and large group discussion and voting, participants prioritized seven action items. *Figure 6. MVP Prioritized Action Items* details the action items developed from the MVP process.

Newburyport Municipal Vulnerability Preparedness Workshop *Summary of Findings (May 31, 2018)*

On April 7, 2018, Newburyport held a Municipal Vulnerabilities Preparedness (MVP) workshop. The workshop's goal was to identify hazards Newburyport faces that are being exacerbated by climate change, and to prioritize actions the city can take to prepare for identified hazards. This workshop, planned by a core team of organizers and the Horsley Witten Group, Inc. was a step towards MVP certification, which allows certified communities access to additional state grants for projects related to climate change resiliency. Thirty-eight community members attended the workshop, representing a wide cross section of city officials, response partners, and other interested parties.

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- Enhance the resilience of the Wastewater treatment facility. Specifically, in the short term, protect and flood proof the Wastewater treatment facility, and in the long term (estimated 40-50 years, at the close of the useful lifespan of the current facility), relocate the wastewater treatment facility.
- Create a short term and long-term plan for the city's management of Plum Island, including discussion of access via the Plum Island turnpike, dune and floodplain management and potential retreat from current residential areas.
- Enhance emergency preparedness and response procedures. Specifically, improve participation in and use of the community's Code Red system, and enact an educational program to help residents improve their family's emergency preparedness.
- Develop a resiliency study of the Lower Artichoke Reservoir Dam to improve protection of the public water supply.
- Improve flood protection of utilities (water, sewer, electric, and gas). Specifically, require an annual accountability report from all utilities in the community.
- Create an inventory of coastal infrastructure (e.g., seawalls, boat ramps, bulkheads, and jetty) and conduct an assessment evaluating the efficacy of each component.
- Evaluate and plan for raising roadways and modifying culverts in areas of the city where it may be needed due to current or potential inundation risks (e.g., Water Street, Business Park, and Malcolm Hoyt Drive).

Figure 6. MVP Prioritized Action Items

The complete Newburyport Municipal Vulnerability Preparedness Workshop Report can be found here: https://www.cityofnewburyport.com/recycling-energy-resiliency-sustainability/resiliency-sustainability

Wastewater treatment facility Climate Change Resiliency, Climate Change Vulnerability Report

As a result of participation in the Massachusetts EOEEA MVP Program (discussed above), the city was awarded an MVP Action Grant in fiscal year 2018 to develop a Resiliency Plan for the WWTF. The Plan was completed in June 2019 and assessed the vulnerabilities of the facility and provided measures and strategies to make the plant resilient to climate change impacts. The assessments, strategies, and conclusion of that Plan are provided in the applicable sections of this Resiliency Plan.

Newburyport's Office of Emergency Management

Newburyport's Office of Emergency Management (NEMA) is responsible for the development and implementation of a comprehensive emergency program for Newburyport Massachusetts. The agency is also responsible for the coordination of the municipality's efforts to respond to, severe emergency and disaster situations affecting the community, whether natural or man-made.

More information and resources are available at NEMA's website: https://newburyportema.org/about-nema/. Additional resources are available through the Massachusetts Emergency Management Agency (MEMA) website: https://www.mass.gov/safety-tips-for-specific-threats-hazards

Newburyport Climate Resiliency Plan

This Resiliency plan's focus is on Newburyport's short and long-term vulnerability to climate change. While it incorporates some of the risks identified in the Hazard Mitigation plan, it doesn't consider non-climate related risks such as terrorism and earthquakes, for example. This plan also does not replace current emergency response and evacuation plans, although information developed in this plan may contribute to both of those plans. This plan does consider and combine elements of previous risk and vulnerability studies and examines in greater detail the impacts of climate hazards on areas within the city in order to chart a course to meet Newburyport's climate related challenges.

Future Climatology Data considered was derived from the National Climate Assessment https://nca2018.globalchange.gov/, EPA, NOAA, the Boston Research Advisory Group (BRAG), the Massachusetts Executive Office of Energy and Environmental Affairs website www.resilientma.org *the Climate Change Clearinghouse for the Commonwealth,* and other sources as noted.

Chapter 1. Climate Change Hazards Assessment

Greenhouse gases emitted through the burning of fossil fuels since the beginning of the industrial age have accumulated and trapped heat in our atmosphere, much like placing a blanket on a bed. This added heat energy has been absorbed by our land and atmosphere, and to a greater extent by our oceans. It has altered the jet stream that guides our weather and storm tracks, has infused more water vapor and energy into storm systems, and is contributing to sea level rise through thermal expansion of our oceans, the slowing of nearby ocean currents and the melting of our polar ice caps. While a certain amount of sea level rise has been prescribed by global emissions thus far, continued greenhouse gas emissions will further drive sea level rise well into the future and will cause all sorts of weather conditions to persist – be it hot, cold, wet or dry – any of which can become extreme.

Hazards from our changing climate will arise from changes in our weather and sea level rise. Fluctuations in the jet stream will result in more severe, extreme, and fluctuating weather events, including periods of storminess and calm, heavy precipitation and drought, cold and heat, and wind and lack thereof. In the longer term, sea level rise will continue to creep upwards, exacerbating any storm and heavy precipitation effects and leading to increased flooding and erosion. Though sea level rise will generally be a longer-term impact, pulsations in the Gulf Stream's speed can lead to sudden short-term changes in sea level. To assess our risk and vulnerability we need to examine the hazards created by our rising sea and changing weather.

The following identified Climate Hazards are discussed in greater detail:

1. Sea Level Rise
2. Coastal Storms - Extra Tropical, Tropical, and Hybrid Cyclones
3. Heavy Precipitation Events
4. Flooding
5. Wind
6. Tornados
7. Weather Extremes – Drought, Heat Waves, Winters and Cold Snaps, Persistent Precipitation
8. Insect Disease Vectors - Tick and Mosquito related illness
9. Combined Sewer Overflows (CSOs)

More information about how climate change affects our weather and oceans to give rise to identified Climate Hazards can be found Appendix 2 - Climate Change Summary. For additional climate change information specific to the U.S. and Massachusetts, please consult:

- The 2018 National Climate Assessment (https://nca2018.globalchange.gov/)
- The Climate Change Clearinghouse for the Commonwealth (http://www.resilientma.org/)

1.1 Sea Level Rise

During the period 1963-2012 sea level in Boston rose 6 inches (Figure 7. East Coast Sea Level Rise).

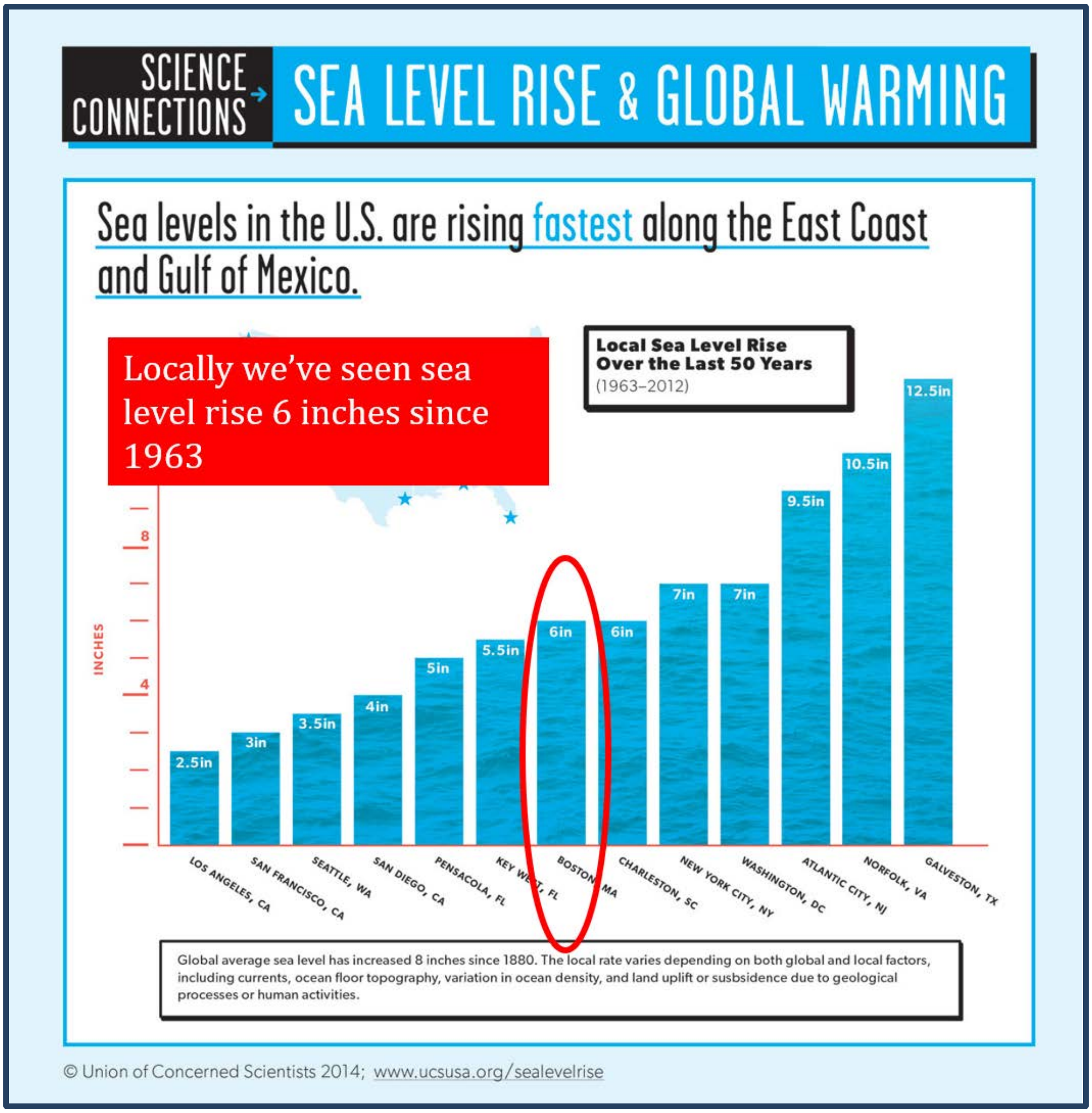

Figure 7. East Coast Sea Level Rise

As presented in *Figure 8. Sea Level Rise Causes*, ninety percent (90%) of current sea level rise is resulting from:

- The thermal expansion of water as the oceans absorb heat (38%), and
- The melting of land-based ice sheets and glaciers (52%).

In addition to thermal expansion and ice sheet melt, sea level is rising more quickly along the east coast than elsewhere due to the additional influence of land subsidence in response to land-based ice sheets melting at the poles and fluctuations in the speed of the nearby Gulf Stream.

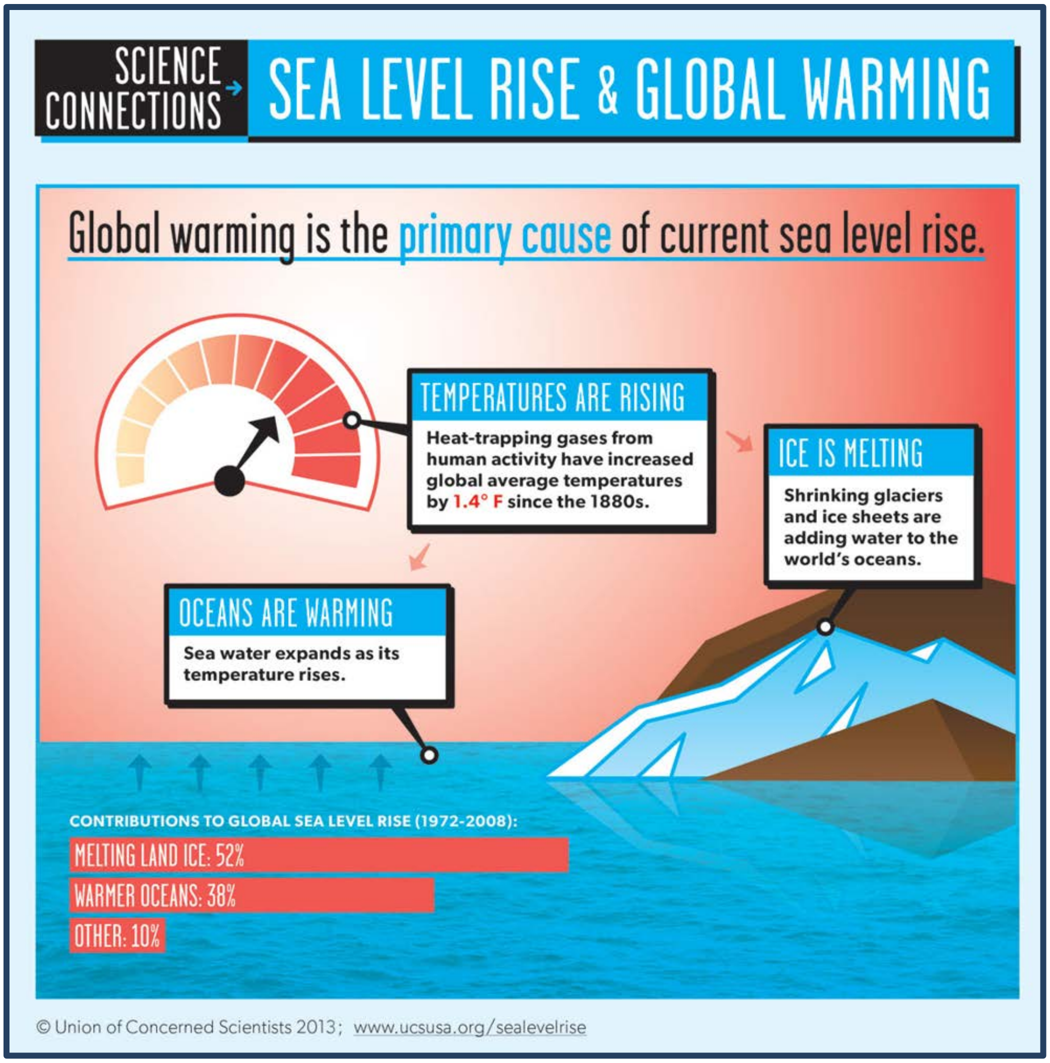

Figure 8. Sea Level Rise Causes

In general, sea level rise (SLR) projections are all based on those developed by NOAA through the U.S. Interagency Sea Level Rise Task Force which was charged with developing Global Sea Level Rise scenarios for the 2018 National Climate Assessment[1]. Differences among sea level rise scenarios are based upon emissions assumptions and local factors. Output from the Interagency SLR report was used by the Boston Research Advisory Group (BRAG) to develop regional sea level rise scenarios for Boston[2]. Due to the influence of regional-scale processes such as land subsidence, variations in the speed of the Gulf Stream, and the gravitational effect of melting ice sheets, Regional Sea Level Rise (RSLR) in Boston will likely exceed the global average throughout the 21st century, regardless of which emissions trajectory is followed. BRAG's RSLR projections for Boston are applicable to Newburyport not only because of geographic proximity (Boston lies only some 30 miles to the south), but also because an extensive panel of experts incorporated a suite of regional and global scale processes into the Global Sea Level Rise data used by the 2018 National Climate Assessment to develop RSLR projections for Boston.

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[1] Global and Regional Sea Level Rise Scenarios for the United States. Sweet, W. V., R. E. Kopp, C. P. Weaver, J. Obeysekera, R. M. Horton, E. R. Thieler, and C. Zervas, 2017. NOAA, National Ocean Service.

[2] Climate Change and Sea Level Rise Projections for Boston. The BRAG Report June 1, 2016.

Subcommittee members of the Resiliency Committee evaluated data from these two sources to conclude that (relative to year 2000) sea level rise of 6 feet was possible locally by the year 2100. Figure 9. Sea Level Rise Progression for Newburyport, depicts sea level rise projections for Newburyport during the period 2000-2100.

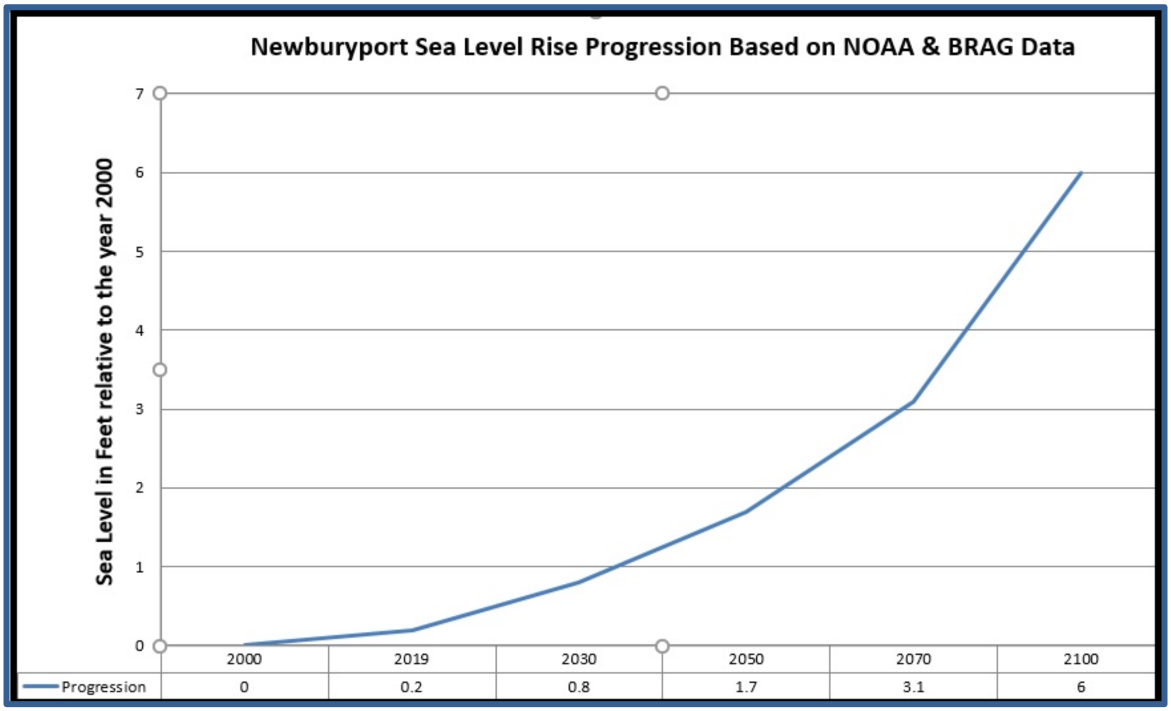

Figure 9. Sea Level Rise Progression for Newburyport

Figure 10. Global Mean and Boston Regional Sea Level Rise Projections displays the NOAA U.S. Interagency Sea Level Rise Task Force (in meters) and BRAG sea level rise tables (in feet) used to develop Newburyport's sea level rise progression. More information regarding sea level rise in Newburyport, including the methodology used to develop the progression in *Figure 9. Sea Level Rise Progression for Newburyport*, can be found in Appendix 3 – Future Local Sea Level Rise**.** Appendix 4 contains the Subcommittee of the Newburyport Resiliency Committee's Final Report of Sea Level Rise for Newburyport's Waterfront West.

Sea Level Rise in Meters (NOAA Interagency Sea Level Rise Task Force)

Table 5. GMSL rise scenario heights in meters for 19-year averages centered on decade through 2200 (showing only a subset after 2100) initiating in year 2000. Only median values are shown.

GMSL Scenario (meters)	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2120	2150	2200
Low	0.03	0.06	0.09	0.13	0.16	0.19	0.22	0.25	0.28	0.30	0.34	0.37	0.39
Intermediate-Low	0.04	0.08	0.13	0.18	0.24	0.29	0.35	0.4	0.45	0.50	0.60	0.73	0.95
Intermediate	0.04	0.10	0.16	0.25	0.34	0.45	0.57	0.71	0.85	1.0	1.3	1.8	2.8
Intermediate-High	0.05	0.10	0.19	0.30	0.44	0.60	0.79	1.0	1.2	1.5	2.0	3.1	5.1
High	0.05	0.11	0.21	0.36	0.54	0.77	1.0	1.3	1.7	2.0	2.8	4.3	7.5
Extreme	0.04	0.11	0.24	0.41	0.63	0.90	1.2	1.6	2.0	2.5	3.6	5.5	9.7

Source: NOAA Technical Report NOS CO-OPS 083: Global and Regional Sea Level Rise Scenarios for the United States, Silver Spring, Maryland, January 2017.

Note: Global Mean Sea Level (GMSL) is an average of sea level heights across all the world's oceans.

Sea Level Rise in Feet (Boston Research Advisory Group)

Regional Sea Level Rise Projections for Boston (in feet. rel. to yr. 2000) by Emission Pathway, Categorized by Exceedance Probability

Emissions Pathway	Exceedance Probability		Likely Range					Maximum
	0.99	0.95	0.833	0.5	0.167	0.05	0.01	0.001
RCP8.5								
2030	-0.1	0.1	0.3	0.5	0.7	0.9	1.0	1.2
2050	0.1	0.4	0.7	1.1	1.5	1.8	2.1	2.4
2070	0.6	1.0	1.5	2.2	3.1	3.7	4.3	4.8
2100	1.6	2.4	3.2	4.9	7.4	8.6	9.5	10.5
2200	18.9	19.9	21.4	26.1	32.8	34.1	35.3	36.9
RCP4.5								
2030	-0.1	0.1	0.3	0.5	0.7	0.9	1.0	1.2
2050	0.1	0.4	0.7	1.0	1.4	1.7	2.0	2.3
2070	0.4	0.9	1.3	1.9	2.6	3.1	3.6	4.1
2100	0.9	1.7	2.4	3.6	5.1	6.1	7.0	8.0
2200	5.5	6.2	7.2	10.9	16.5	18.0	19.3	20.9
RCP2.6								
2030	-0.1	0.1	0.3	0.5	0.7	0.9	1.0	1.2
2050	0.1	0.4	0.6	1.0	1.4	1.7	2.0	2.3
2070	0.3	0.7	1.1	1.7	2.3	2.7	3.1	3.6
2100	0.4	1.2	1.8	2.8	3.8	4.6	5.3	6.2
2200	3.6	4.4	5.2	6.4	7.7	8.8	9.9	11.8

SOURCE: *Climate Change and Sea Level Rise Projections for Boston.* The BRAG Report June 1, 2016.

Note: RCPs (Representative Concentration Pathways) are scenarios that describe greenhouse gas concentration trajectories and the resulting atmospheric concentration from 2000 to 2100. The *Extreme Scenario* presented in the NOAA table is comparable to *RCP 8.5* in the BRAG Table.

Figure 10. Global Mean and Boston Regional Sea Level Rise Projections

1.2 Coastal Storms - Extra Tropical, Tropical, and Hybrid Cyclones

The accumulation of heat in our oceans and atmosphere represents a reservoir of energy for storms to capitalize upon. A warmer ocean produces more water vapor and convection, and a warmer atmosphere can hold more water and thus deliver more rain and snow. Changes to our jet stream favor extra-tropical (northeasters) and tropical storm development, as well as the creation of slow-moving storms such as Hurricanes Harvey in August 2017 and Florence in September 2018. Moreover, in response to the polar jet stream weakening and retreating during the summer months, the tropical storm track is expected to shift northward to include New England.

While there is debate as to the absolute change in number of tropical storms during any given year, it is clear that once the meteorological variables align, development of these tropical storms is rapid and intense. This was observed with Hurricanes Humberto (2007), Mathew (2016), Harvey (2017), Maria (2017), and Florence (2018), for example.

Newburyport is located in the mid-latitudes of the northern hemisphere. As presented *in Figure 11. High and Mid Latitude Storms - More Intense and Frequent*, the frequency and intensity of mid-latitude storms (extra-tropical or northeasters for example) has been on the rise since at least 1950.

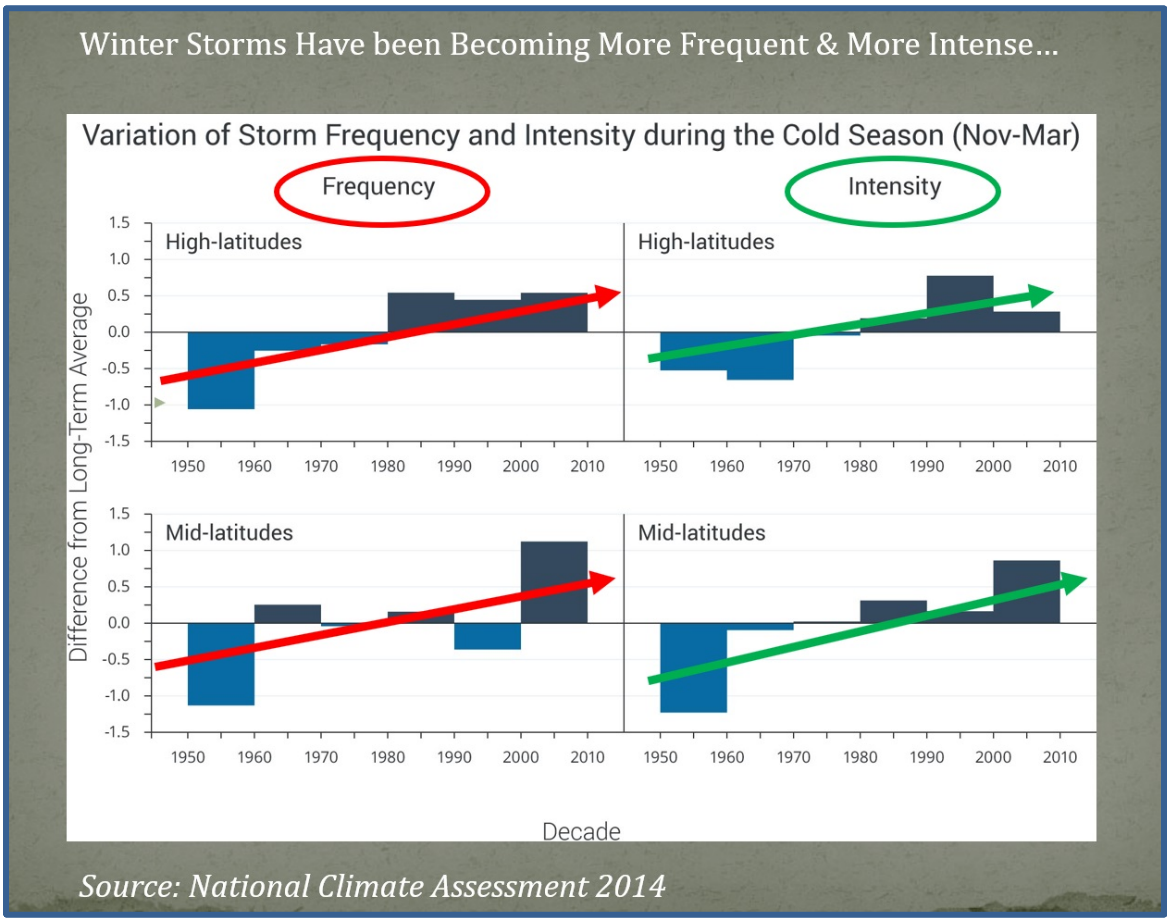

Figure 11. High and Mid Latitude Storms - More Intense and Frequent

1.3 Heavy Precipitation Events

A warmer atmosphere holds more water and therefore can deliver more precipitation during a single rain or snow event. A weak or stalled jet stream can further drive up the volume of precipitation affecting a given location during a single storm event simply by failing to move a weather system along. Extreme precipitation does not need to come from a big, stalled, organized storm such as a Hurricane or Northeaster; rather, a slow-moving train of thunderstorms ahead of a cold front can deliver copious amounts of rain and flooding. The trend towards heavier precipitation events is already underway. During the period 1958-2012, the northeast experienced a 71% increase in heavy precipitation (defined as the heaviest 1% of all daily events). (*Figure 12. National Changes in Heavy Precipitation*).

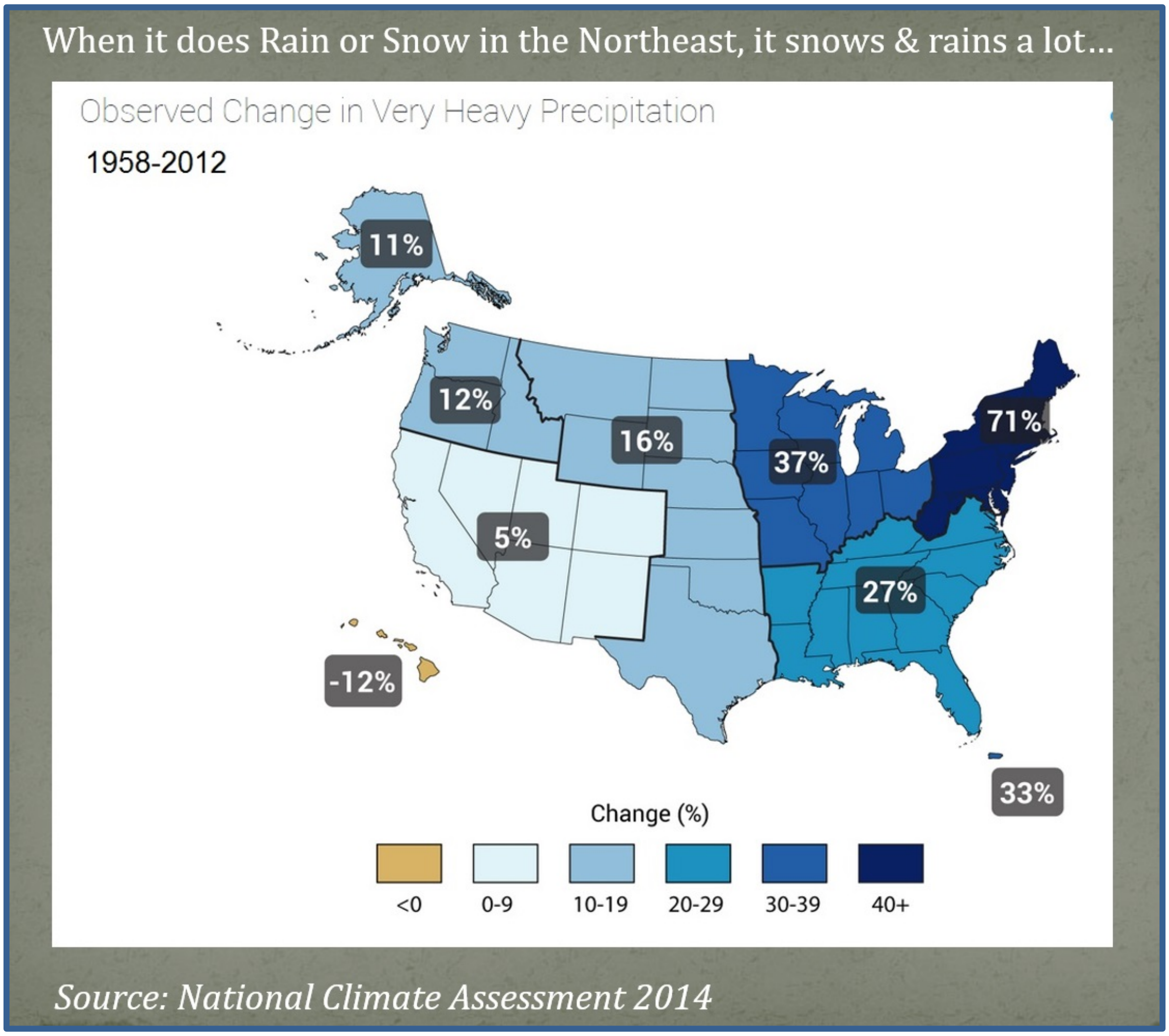

Figure 12. National Changes in Heavy Precipitation

1.4 Flooding

When one considers Newburyport's geography, one might conclude that flooding is a real possibility. Newburyport is located at the mouth of the Merrimack River, where it discharges into the Atlantic Ocean. Newburyport also includes a portion of the barrier island, Plum Island, and the back marsh system that has formed just south of the mouth of the Merrimack, as well as a portion of the Little River watershed, which discharges behind Plum Island. Considering this geography together with sea level rise, climate enhanced storm activity, and more frequent heavy precipitation events, it is clear that flooding is very much a short and long-term hazard for Newburyport. Flooding in Newburyport is influenced by three primary factors:

1. precipitation and the resulting runoff
2. sea level rise
3. storm surge

Independently, each variable can cause flooding. When combined, flooding can be extreme.

1.5 Wind

Located on the coastal plain, Newburyport is exposed to the open Atlantic and can be susceptible to high wind events associated with coastal storms, storm systems traversing the Ohio River Valley to our West (such as the Mother's Day Storm of 2006), as well as passing frontal systems. As climate enhanced storm activity increases, so will damage from wind. Wind coupled with heavy precipitation, especially in the form of snow and ice, is most damaging. Newburyport's tree lined streets are interlaced with power lines and are particularly susceptible. In addition, many of Newburyport's buildings, especially its historic homes, are not built to withstand Hurricane force winds.

The hill, atop of which is High Street, faces into the northeast, a common wind direction for coastal storms. Homes, powerlines and trees along that northeast-facing slope are susceptible to wind gusts riding in from the Atlantic. As coastal storms pass away to the northeast, winds wrapping in around the storm center back in from the northwest and gust. Any accumulated snow or ice on Newburyport's tree lined streets and exposed powerlines are susceptible to these damaging winds. Additionally, blowing and drifting snow across exposed roadways such as the Plum Island Turnpike, U.S. Route 1, Interstate 95 and Scotland Rd./Parker St./Graf Rd. makes passage impossible at times.

1.6 Tornados

While tornados in Massachusetts are a possibility and do happen, historically they currently do not appear to be increasing in frequency. On average the state sees about 2-3 per year, and most events are relegated to Worcester County westward. However, recently, in July of 2019, several tornados touched down along Cape Cod causing widespread damage. It is uncertain at this time whether tornados will become a hazard to Newburyport in the future.

1.7 Public Health Impacts of Weather Extremes

As a function of a meandering Jet Stream, any type of weather pattern can become stuck and persist. If the Jet Stream is lifted far to the north and we happen to be in a ridge on the warm side of the Jet Stream, weather can be hot, and drought could set in. Conversely, if the Jet Stream undulates, digging far to the south, we could be in for a very cold spell. As the Jet Stream wiggles and waves, we can also fluctuate from cold to warm and then back to cold again in a short period of time. We experienced such a bout of "bi-polar" weather in late February of 2017 when two days of 80-degree warmth were followed by a succession of intense winter storms that resulted in flooding and power outages.

A Jet Stream stuck overhead can usher in extended periods of precipitation in the form of rain, ice, snow or some combination. The extreme variability, its possibility of persisting, and its effects on the public health, vulnerable populations and our local environment are hazards.

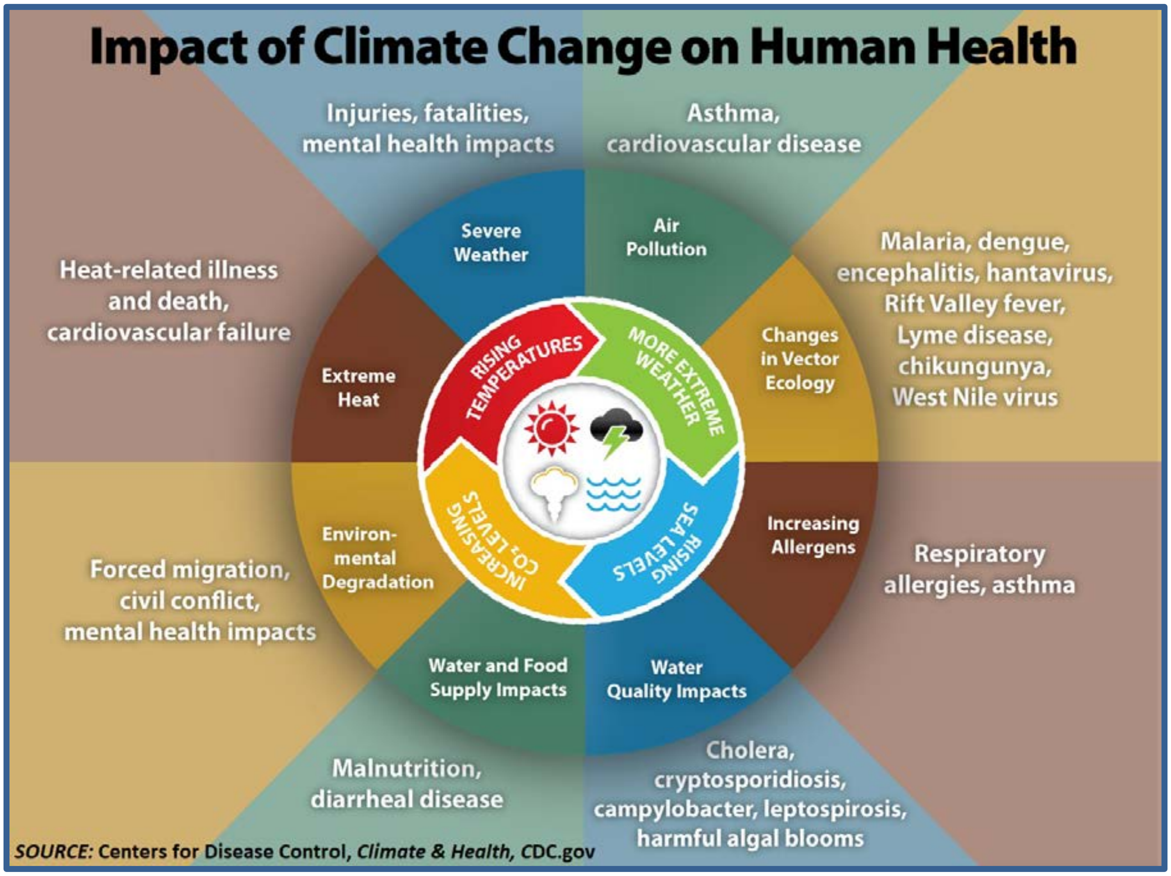

Figure 13. Impact of Climate Change on Human Health

Stagnated weather systems will increase public health vulnerabilities (*Figure 13. Impact of Climate Change on Human Health*). The Centers for Disease Control report that heat waves deteriorate air quality, lead to drought, wildfires, reduced water quality, heat stress and heat related mortality. Persistent rainfall engenders waterborne disease outbreaks, mold and indoor air quality problems that spike asthma, pneumonias and other upper respiratory tract symptoms, especially when combined with heat and humidity. Vulnerability to winter weather depends upon factors including housing, age, and baseline health. Excessive snow will pose problems for emergency access and transportation safety. While deaths and injuries related to extreme cold events are projected to decline due to climate change, these reductions are not expected to compensate for the increase in heat-related deaths. Finally, persistently extreme weather degrades mental health promoting irritability, anxiety and stress related disorders.

1.8 Insect Disease Vectors - Tick and Mosquito related illness

Climate change is motivating ecosystem shifts and relocation of animals and plants to find favorable living conditions. Creatures of all sorts are seeking out conditions that favor their own survival, or they are extending their range to capitalize on new, more hospitable frontiers. Such is the case with our mosquito and tick populations and their disease vectors. Nationally, since 2004, insect borne diseases from mosquitoes, ticks and fleas have been on the rise (*Figure 14. Mosquito Tick and Flea Disease Cases USA 2004-2016*).

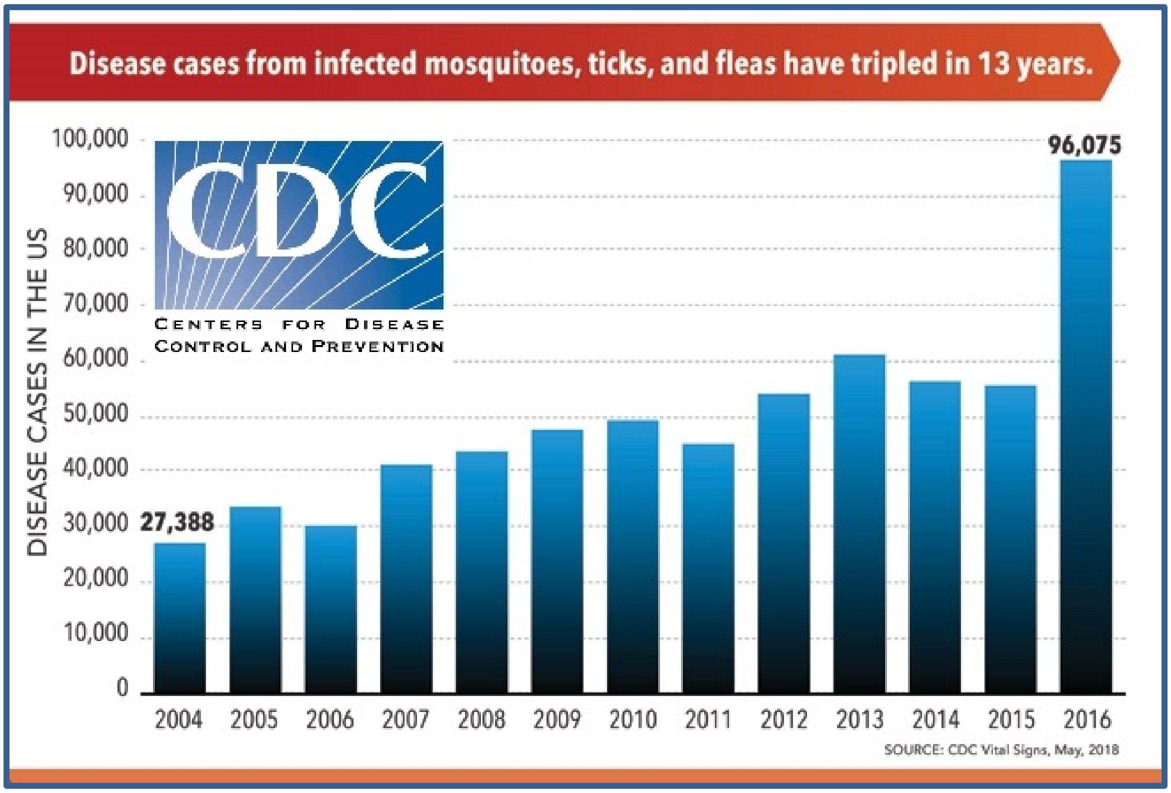

Figure 14. Mosquito Tick and Flea Disease Cases USA 2004-2016

Lyme disease has steadily spread northward towards Canada from 1996-2016. While Canada was once too cold for tick nymphs to survive, it is expected to provide new habitat for Lyme Ticks as the climate warms and they spread northward. Insect borne disease vectors are of concern due to their rapid growth motivated by a warmer climate, and because of the difficulty in treating these diseases (*Figure 15. Lyme Disease Cases 1996 and 2016*. *Figure 16. Lyme Tick Distribution North America 2020, 2050 and 2080. Figure 17. Massachusetts Lyme Disease Trend*.)

Additional detail regarding insect disease vectors and susceptible populations can be found in Appendix 5 – Insect Disease Vectors, Tick and Mosquito Related Illnesses.

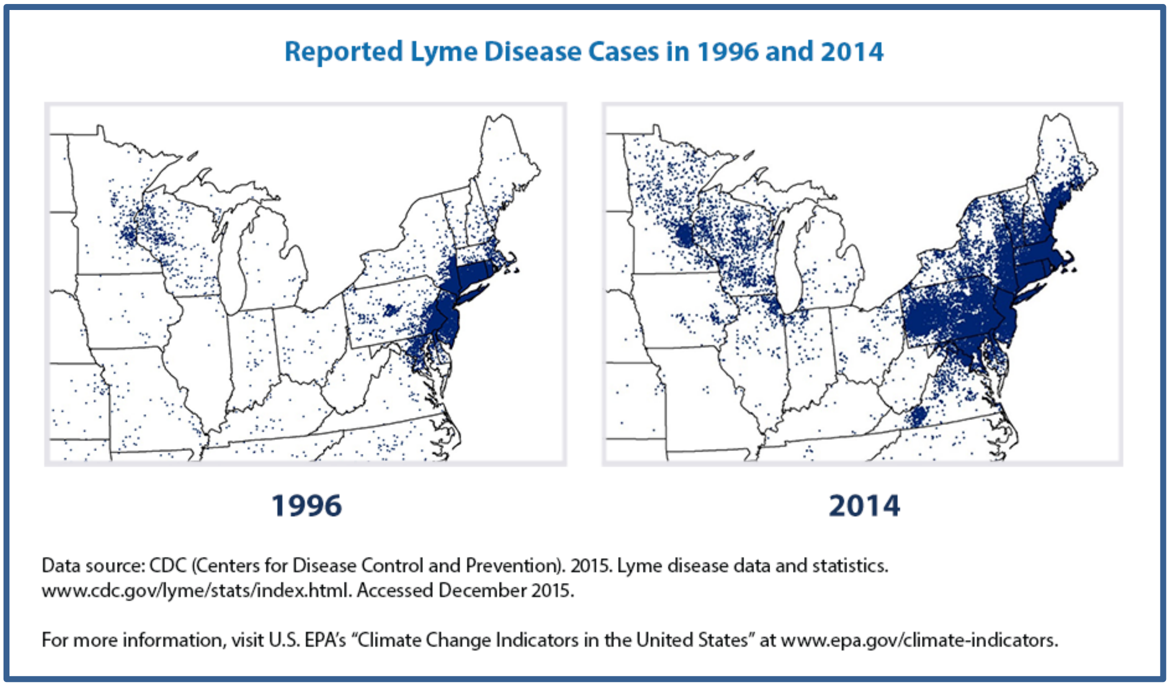

Figure 15. Lyme Disease Cases 1996 and 2016

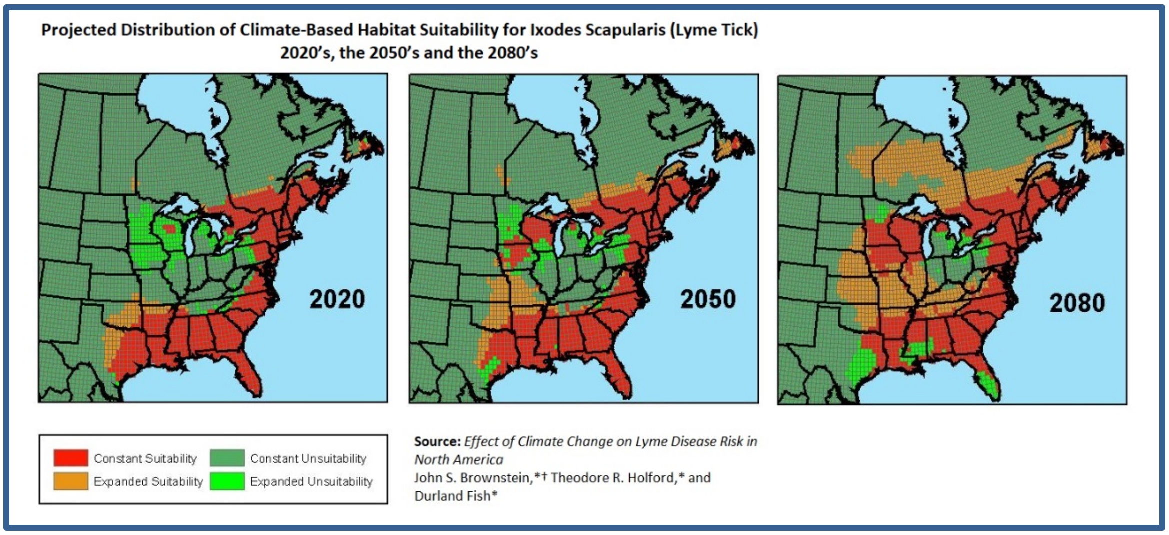

Figure 16. Lyme Tick Distribution North America 2020, 2050 and 2080

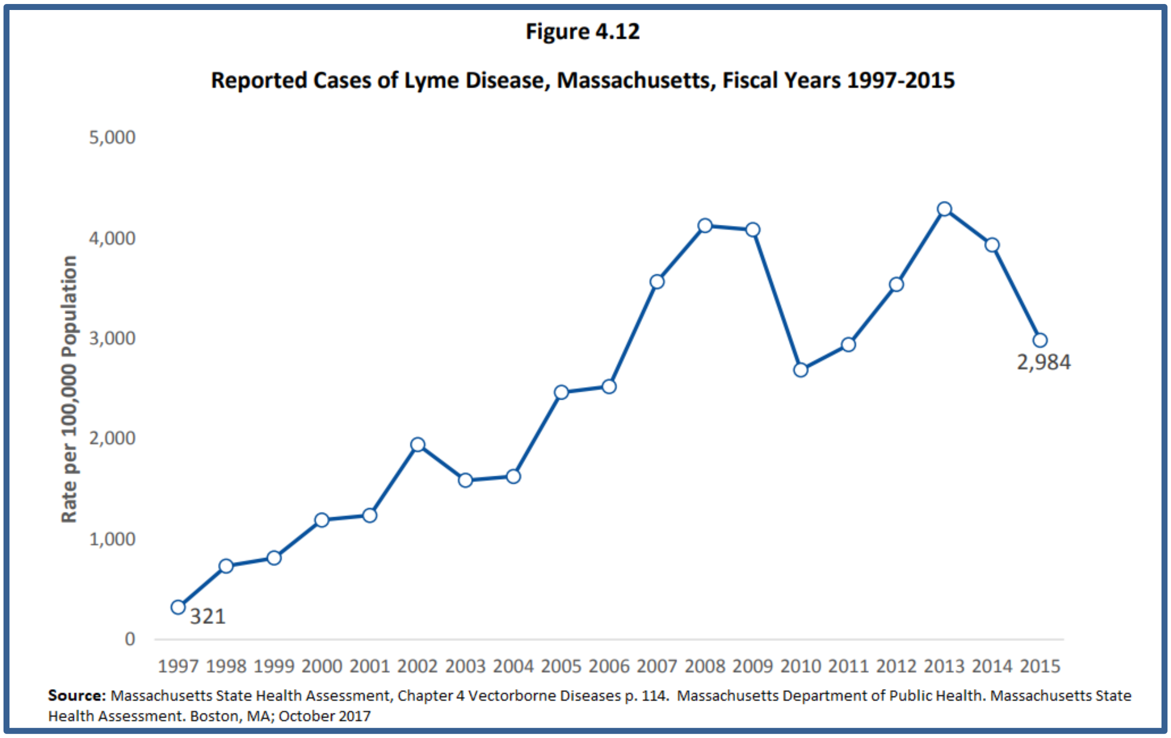

Figure 17. Massachusetts Lyme Disease Trend

1.9 Combined Sewer Overflows (CSOs)

Climate change has been the driving force behind increasing episodes of heavy precipitation, which in turn have led to an increase in the frequency and volume of combined sewer overflows (CSOs) into the Merrimack River. When rainfall is excessive, sewer systems that treat both sanitary waste water and storm water can be overwhelmed. In this instance the combined sewer system will discharge its excess volume to avoid sewer backups. The term CSO is used to refer to both the outfall location as well as the discharge from that location. Because these CSO event and CSO volumes are increasing with increasing extreme precipitation events, CSOs have been classified as a climate hazard for this report. CSOs contain untreated or partially treated human and industrial waste, toxic materials, and debris as well as stormwater. According to the US EPA, they are a priority water pollution concern for the nearly 860 municipalities across the U.S. that have combined sewer systems. There are six combined sewer systems upriver from Newburyport that frequently have CSOs:

1. Manchester, NH
2. Nashua, NH
3. Lowell, MA
4. The Greater Lawrence Sanitary District
5. Haverhill, MA
6. Fitchburg, MA (on the Nashua River, a Merrimack tributary)

Newburyport's Wastewater treatment facility has been updated and is not a CSO contributor. Appendix 6 – Combined Sewer Overflows provides more information on the CSO problem.

Chapter 2 – Vulnerability Assessment

The previous chapter described in detail the following list of escalating Climate Hazards that Newburyport is, and will continue to be, subject to:

- Sea Level Rise
- Coastal Storms - Extra Tropical, Tropical, and Hybrid Cyclones
- Heavy Precipitation Events (Rain and Frozen – Snow/Ice)
- Flooding - Coastal, River and Run-off
- Wind
- Weather Extremes - Drought and Heat Waves, Winters and Cold Snaps, Persistent Precipitation
- Insect Disease Vectors - Tick and Mosquito related illness
- Combined Sewer Overflows (CSOs)

Hazards within the list are not mutually exclusive and they likely won't occur alone. Rather, some are interrelated, and their impacts will escalate as their effects synergistically combine. As an example, while heavy rain events alone will certainly raise the likelihood of flooding, when coupled with sea level rise, coastal storms and storm surge, flooding can become extreme. During the winter, a severe coastal blizzard that drives surge related flooding and powerline damaging winds and then wraps in a persistent period of bitter cold as it departs, will make recovery efforts slow and painful. In the summer, frequent heavy rainfall interspersed with consistent periods of warm weather would favor a bloom of insect growth and the spread of the diseases they carry. Or, a persistent summer drought followed by a period of heavy rainfall from slow moving thunderstorms or a tropical depression would increase flooding potential as the run-off from these sudden and heavy precipitation events is initially poorly absorbed by dead vegetation and a dry, hard soil. A bad case scenario might be for a tropical depression to deposit 15-20 inches of rain into a parched Merrimack River watershed, multiple wastewater treatment facilities would experience a record CSO event with flood waters downstream backing over the Lower Artichoke dam, filling an already low reservoir with contaminated flood waters.

This Chapter's assessment of vulnerability examines:

- Critical Assets
- Neighborhoods Vulnerable to Flooding
- Community-wide Vulnerabilities

2.1 Evaluating Current and Future Flood Risks

This Resiliency plan discusses current and future inundation risk by examining:

- The current FEMA 100-year floodplain
- Current Worst-Case Hurricane Storm Surge Inundations
- Today's Mean High Water + Future Sea Level Rise
- Today's FEMA 100-Year Floodplain + Future Sea Level Rise

The FEMA 100-year floodplain illustrates properties and assets subject to a 1% or greater chance of flooding in a given year. The risk of experiencing 1% inundation depths is 26% over the term of a 30-year mortgage, however properties may still be flooded to a shallower depth by lesser events. FEMA Flood Zones A and V are high risk areas. FEMA A zones may experience moving water, over-wash, storm surge and breaking waves. The FEMA V Zone is subject to the same impacts, but with greater wave heights and wave run-up depths.

The Worst-Case Hurricane Surge Inundation water levels are derived from the Sea, Lake, and Overland Surge from Hurricanes (SLOSH) computerized weather model. SLOSH was developed by the National Weather Service (NWS) to estimate storm surge (the rise of water generated by a storm, over and above the predicted astronomical tides) resulting from historical, hypothetical, and predicted hurricanes. The SLOSH model computes storm surge heights from tropical cyclones using pressure, size, forward speed, and track data to create a model of the wind field which pushes the water around thereby calculating a potential "worst-case" surge based on the results from thousands of combinations of hurricane category, forward speed, pressure, pre-landfall location, direction, and local topography. The SLOSH model does not include rainfall amounts, river flow, or wind-driven waves riding in atop of a storm surge.

To update their Massachusetts Hurricane Evacuation Study, the US Army Corp of Engineers updated SLOSH hurricane inundation data for coastal Massachusetts. An important caveat is that the model depicts inundation from *every* possible storm within an intensity category all on the same map. Therefore, any *single* storm may likely *not* deliver the level of surge depicted across all areas of the map *at the same time*. For any location on the map, the depicted inundation is the worst it could possibly be for that location should all variables perfectly align. As an example, a Category 1 storm delivering hurricane force NE winds would drive a surge well into Joppa, but leave Salisbury across the river unscathed – however the Worst Case Map shows equal inundations as the map is based on many storm scenarios including one where winds might be from the S/SE which would spare Joppa, but inundate Salisbury.

Today's Mean High Water + Future Sea Level Rise (SLR) as depicted in this chapter illustrates mean high water in the future. It simply depicts which areas will become wet twice daily with the tide and does not consider the effects of wind, storms, river influences or king tides. Sea level rise projections developed by the Resiliency Committee's Sea Level Rise Technical Subcommittee (Appendices 3 and 4) were used to develop the future sea level rise maps used in this plan. Future sea levels depicted are added to today's mean high water.

Today's FEMA 100-Year Floodplain + Future Sea Level Rise illustrates approximately where the 100-year floodplain might be in the future. The maps simply show Future SLR (calculated in Appendix 3) atop of the current FEMA 100-year floodplain.

It is important to understand the implications with this simple equation. This equation utilizes current FEMA flood elevations knowing that future FEMA flood elevations will be much higher as FEMA recalculates flood elevations. Refer to Appendices 3 and 4. Future flood zones will be higher in elevation and will extend further into our city.

DISCLAIMER: The FEMA flood zone areas depicted in the graphics that follow are approximate as they coincide with the topographic datalayers retrieved from the MassGIS website in 2011. (Updates of these datalayers are not available.) Therefore, the FEMA flood zones shown herein may not reflect the same horizontal areas as the zones that are shown on FEMA's FIRMs. The flood inundation maps provided herein are for resiliency planning and illustrative purposes only. **For official flood zone locations please consult FEMA flood insurance rate maps**.

The North American Vertical Datum of 1988 (NAVD 88) – explained…

NAVD 88 is a reference system used by surveyors, engineers, and mapping professionals to measure and relate elevations to the Earth's surface. Using a fixed reference point as a baseline (i.e., a zero-elevation point), elevation values can be consistently measured and compared among various maps and surveys. The North American Vertical Datum of 1988 (NAVD 88) is the official vertical datum of the United States and FEMA, as well as Newburyport, and it supersedes the older National Geodetic Vertical Datum of 1929 (NGVD 29). Documents created prior to 1988 reference the NGVD 29 Datum. The difference in elevation between NAVD 88 and the older NGVD 29 in our geographic area is approximately 0.78 feet. To convert from NGVD 29 to NAVD 88, subtract 0.78' from the NGVD 29 elevation being converted.

A tidal datum is a standard elevation framework used to track local water levels as measured by a tide gauge station. Some examples of tidal datums include Mean Lower Low Water (used for NOAA nautical charts and tide charts), Mean Low Water (MLW), Mean Sea Level (MSL), Mean High Water (MHW), and Mean Higher High Water (MHHW).

Elevation values from maps that use different vertical datums (NGVD 29, NAVD 88, MLLW, MHHW etc.) are not directly comparable, as they employ different zero points. Tools found on the following websites can be used to convert elevation values between datums.

- NOAA National Geodetic Survey *(https://www.ngs.noaa.gov/)*
- The Office of Coast Survey *(https://www.nauticalcharts.noaa.gov/)*

SOURCE: https://www.mass.gov/service-details/north-american-vertical-datum-of-1988-navd-88

Within the Newburyport area the starting point of NAVD 88 is 0.07 feet, or 0.84 inches, lower than mean sea level (mid-tide). For the reader, it might therefore be useful consider NAVD 88's starting point of zero to be mean sea level (mid-tide).

Furthermore, readers may be interested to know how much above high tide that a stated elevation might be. So, let's visualize for example, what a NAVD 88 elevation of 12 feet is relative to mean high water (MHW). Referencing GRAPHIC 18: Newburyport Tidal Elevations (NAVD 88) reveals that MHW is 4.12 feet higher than the NAVD 88 reference point of zero. To understand how high elevation 12 (for example) is above MHW, simply subtract 4.12 feet (the elevation of MHW above NAVD 88).

Elevation 12 feet – 4.12 feet MHW = 7.88 feet above mean high water.

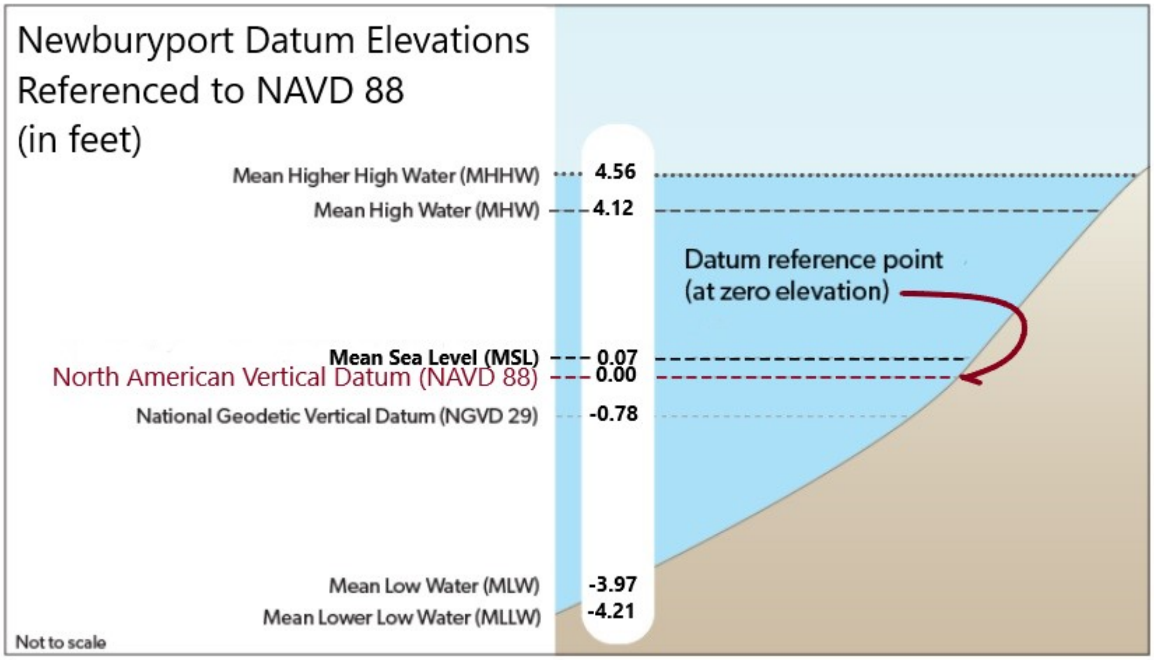

Figure 1. A comparison of common datums relative to the NAVD 88 datum at the NOAA tide gauge station, Newburyport (Station ID 8440466). The different datums have different relative zero elevation points (the starting points from which elevations are measured).

In Summary:

- Elevations today are based on the NAVD 88 Datum, which provides for a consistent baseline of measurement.
- MHW from the Rt. 1 bridge to Plum Island is approximately Elevation 4.1
- MLW is approximately Elevation -4.0
- Therefore, Newburyport's tidal range is approximately 8.1 feet
- SLR can be added to any of the common tidal reference points (MHW, MLW, MSL, etc.) to visualize what the increased-sea elevation will be.

For this report, future sea level rise was added to Mean High Water (MHW) to visualize where the daily tide would be twice daily.

2.2 Critical Assets

While many of the climate hazards detailed in Chapter 1 (Hazard Assessment) will have community-wide impacts, some areas of the city and its infrastructure are particularly vulnerable. These assets are critically vulnerable today; and will be even more so in the future.

Newburyport's FEMA Multi-Hazard Mitigation Plan identified critical infrastructure located in existing flood-hazard areas or in areas at risk from future storms and sea level rise. The report assigned Newburyport a "high" risk rating for floods, winter storms, Northeasters, and hurricanes. Merrimack Valley Region, Multi-Hazard Mitigation Plan Update, prepared with assistance of MVPC, April 2016

Those Critical Assets at High risk include:

1. Public Water Supply, Treatment and Distribution
2. Wastewater treatment facility (WWTF)
3. The National Grid substation at 95 Water Street

To underscore the current risk of these assets, the local non-profit group Storm Surge together with the National Weather Service in Taunton, MA developed a realistic storm scenario based on current day extratropical systems occurring in the North Atlantic. "Rolling the Dice with Big Storms" illustrated how a slow-moving system similar in strength to the Blizzard of '78, the Perfect Storm of 1991, or Super Storm Sandy could flood and contaminate the city's water supply while concurrently rendering the WWTF and National grid power substations inoperable. Damages to downed powerlines, private property and Plum Island aside, the contamination of the municipal water supply, loss of wastewater processing and electrical power to the community would grind the city to a halt. Using Super Storm Sandy as an approximation for the speed of recovery, one could conclude that substantial parts of the region, and not only the city, might be without power for 2-6 weeks, with repairs to wastewater and drinking water infrastructure likely taking much longer. Should such an event occur during the colder fall, winter or early spring months, additional damage to freezing pipes would occur; and so even residents unaffected by flooding would be displaced from their homes. While it could be argued that a storm of this caliber could be regarded as a 100 or 500-year storm, and hence not likely to occur, the fact that such storms do occur annually in the North Atlantic with some impacting Europe and others missing us by only a hundred miles should raise our level of concern, especially since Climate Change is expected to increase the likelihood of such an event.

2.2.1 Public Water Supply, Treatment and Distribution System

Three of Newburyport's four surface water reservoirs are linked together in a chain. These include the Indian Hill Reservoir, the Upper Artichoke and Lower Artichoke reservoirs. Bartlett Spring Pond, while part of the surface water supply is not linked to the other three. Water flows via a stream from the Indian Hill reservoir down to the Upper Artichoke and then over a spillway into the Lower Artichoke where a pumping station transfers water to the city's Drinking Water Treatment Plant (WTP) on Spring Lane. Currently, overflow from these three surface water reservoirs passes over the Lower Artichoke dam spillway, located along State Road 113, into the Artichoke River which borders West Newbury. A well field for West Newbury's drinking water supply lies a little over 1/10th of mile SW of the dam, roughly 50 feet from the Lower Artichoke's shore (*Figure 18. Newburyport's Surface Water Reservoirs* and *Figure 19. Newburyport's Linked Chain of Surface Water Reservoirs*).

The WTP is located more than 20 feet higher than the river – well out of any FEMA flood zones. So, impacts from flooding are not a concern for the physical plant. However, a detailed vulnerability assessment is needed for other non-flooding related climate change impacts – such as wind, excess heat, and more intense storms that result in power outages.

From a power outage standpoint, the WTP has fuel storage tanks which will allow for several days of backup power and, provided that fuel-supply vehicles are able to make deliveries, weeks. Extended power outages, such as those experienced from major hurricanes or cyberattacks to the power grid, are beyond this general Resiliency Plan. Nonetheless, extended backup power and more advanced renewable energy-type power supply systems currently exist and should be considered.

The water distribution system begins at the Artichoke Pump Station which pumps the untreated water up to the WTP. From there, the distribution system runs from the plant's pumps into over 100 miles of distribution piping throughout the city as well as the two aboveground storage tanks. The storage tanks are on high ground and not prone to flooding. However, some areas of the city will be subject to permanent flooding conditions and those areas that have water mains will be especially vulnerable.

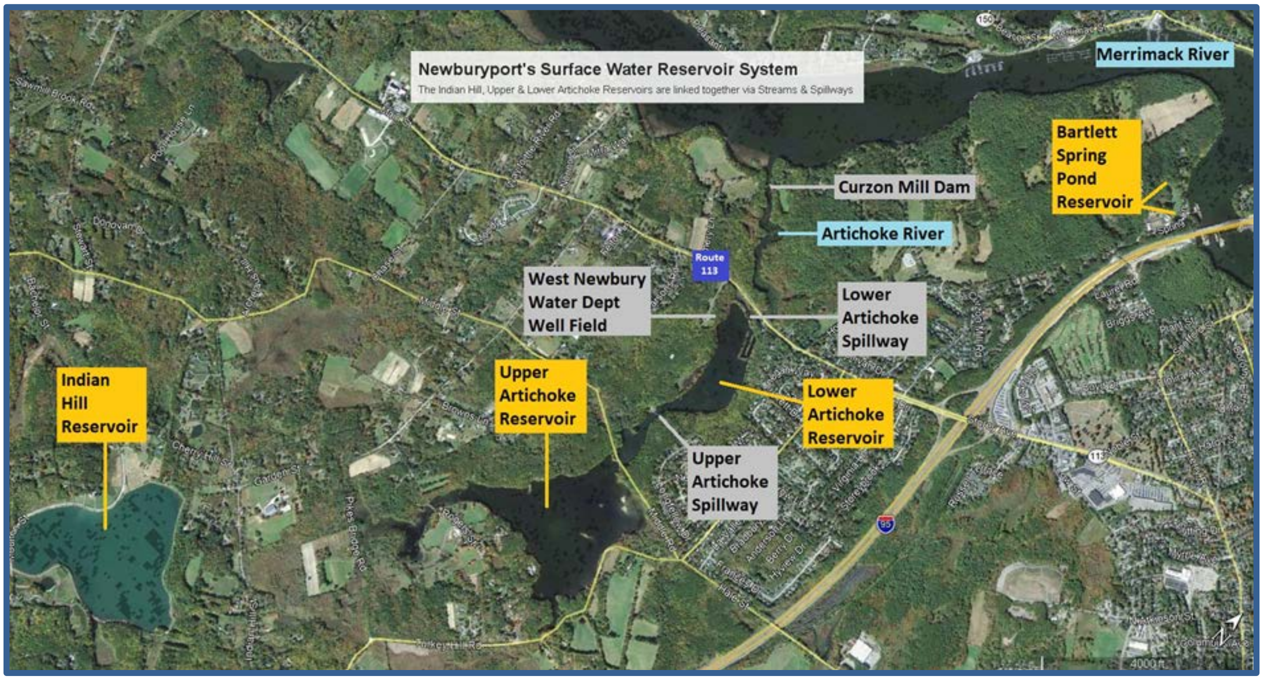

Figure 18. Newburyport's Surface Water Reservoirs

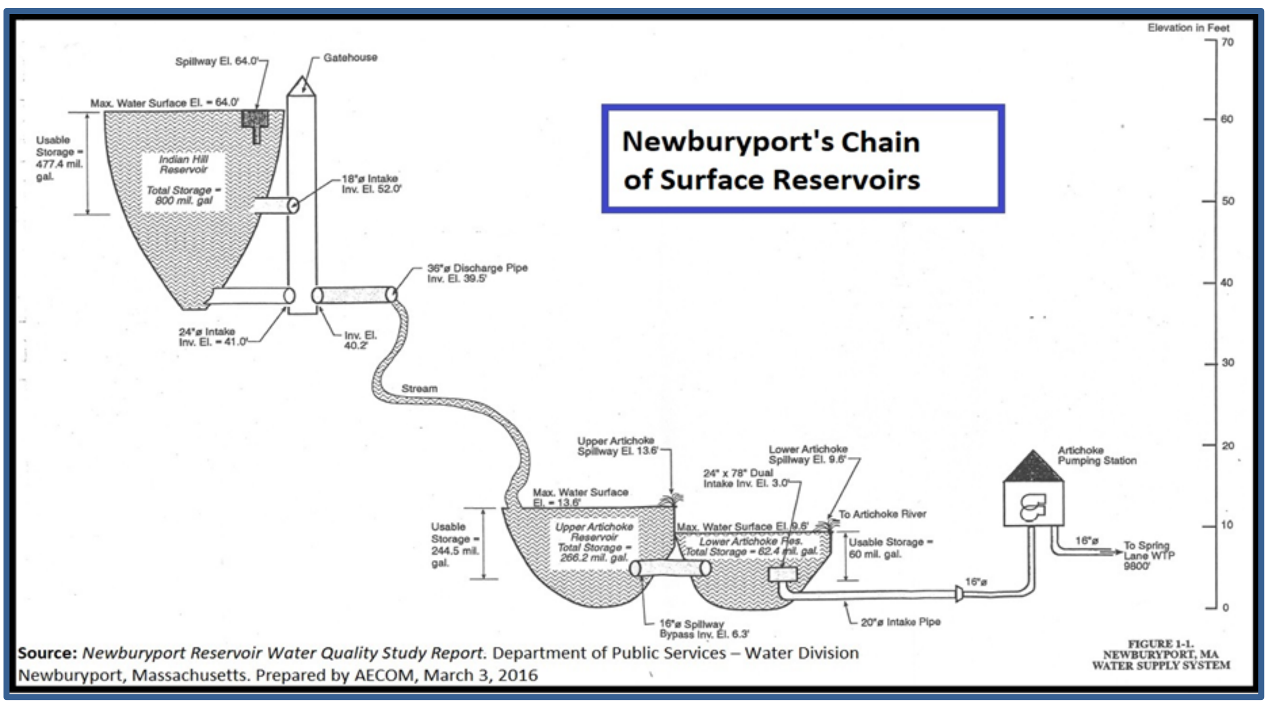

Figure 19. Newburyport's Linked Chain of Surface Water Reservoirs

The Artichoke River meanders for ¾ of a mile and spills into the Merrimack River over a dam (NID#MA01600) located at the end of Curzon Mill Road adjacent to Maudslay State Park. The purpose of the dam is for tide control. The top of the dam (approximately Elevation 5.7 feet) lies approximately 0.5

feet above mean high water (which is estimated at Elevation 5.2 feet at this location along the Merrimack). While most daily tides remain downstream of this dam, the area above the dam frequently floods with waters from the Merrimack during unusual, yet increasingly more common, high tides (*Figure 20. Curzon Mill Dam*).

Figure 20. Curzon Mill Dam

As the Merrimack rises in response to higher tides, surge and run off, its waters back up along the Artichoke River towards the Lower Artichoke dam and spillway (NID#MA00264) the crest of which, at times, sits only several inches above the backing river waters (*Figure 22* and *Figure 23: Lower Artichoke Spillway*). In fact, the spillway elevation of the Lower Artichoke dam (approximate Elevation 8.6 feet) sits approximately 3.4 feet below FEMA's 100-year flood elevation (Flood Zone AE Elevation 12), which therefore, makes it vulnerable to current day storm and river flooding.

The Upper Artichoke Spillway (*Figure 24. Upper Artichoke Spillway*) sits at approximate elevation 12.3 feet (or about 0.3 feet above the FEMA 12-foot inundation), and so is also vulnerable to the FEMA 100-year flood.

Referencing MassDEP *310CMR22.04(2) Construction, Operation, and Maintenance of Public Water Systems*, public water supplies and other critical assets are recommended to be protected to 3 feet above the FEMA 1% annual base flood elevation - a recommended elevation of 15.0 feet for the Upper Artichoke spillway, and 15.0 feet for the Lower Artichoke. This places the existing upper Artichoke spillway approximately 2.7 feet below the recommended elevation for adequate protection (15.0 feet rec – 12.3 feet, actual elevation = 2.7 feet). More frighteningly, the lower Artichoke spillway, sits approximately 6.4 feet below the recommended elevation (15 feet rec. elevation - 8.6 feet actual = 6.4 feet).

Figure 21 shows excerpts from FEMA FIRMs dated July 3, 2012 covering the Artichoke Reservoir area.

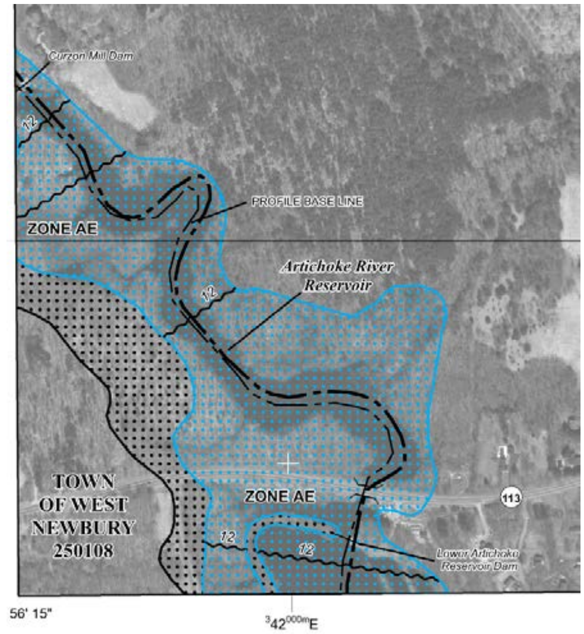

Figure 21. Excerpts from FEMA FIRMs, dated July 3, 2012, showing Artichoke Reservoir area

Figure 22. Lower Artichoke Spillway

Figure 23. Lower Artichoke Spillway

The NRC recommends that further assessment be made to these assets.

Figure 24. Upper Artichoke Spillway

It is important to underscore the city's vulnerability here. These linked surface water reservoirs account for roughly 75% of the city's total drinking water supply. The lower and Upper Artichoke Reservoirs alone represent roughly 24%.

However, due to the intake pump's location near the Lower Artichoke Dam and spillway, the intrusion of CSO contaminated Merrimack River waters into the Lower Artichoke alone would compromise the integrity of, and therefore access to, the entire linked surface water network which, again, represents at least 75% of the city's water supply.

It is important to stress that it would not take a 100-year event to compromise the city's water supply. *Figure 25. Low Water Level Vulnerability - Rear of Lower Artichoke Spillway September 5, 2019* shows a very low reservoir behind the spillway on September 5, 2019. A combined very high tide and elevated river would only need to minimally top the spillway to compromise access to 75% of the city's drinking water supply.

This would represent a major public health crisis.

Figure 25. Low Water Level Vulnerability - Rear of Lower Artichoke Spillway September 5, 2019

An examination of recent and sometimes forgotten history illustrates the length of time this asset has been exposed to risk, *with no action employed* to minimize risk exposure.

Those events include:

- The Mother's Day Storm in May of 2006
- The Great March Flood of 1936
- Hurricane Florence in 2018

Fourteen years ago, in 2006, the Mother's Day Storm delivered nearly 15 inches of rain which represented only half of the water volume of the Great March Flood of 1936 (30 inches of combined rain and melt water). Recent extreme tropical rainfall events such as Hurricane Harvey (2017) that left 61 inches of rain in Houston, and Florence (2018) that recently delivered 36 inches to North Carolina are harbingers of the new normal, and examples of the heavy precipitation events climate scientists had predicted.

A discussion of these events which follows will further underscore the water supply's ***urgent vulnerability*** which becomes increasingly worse as our climate warms, storms become more intense, and sea levels rise.

Mother's Day Storm of 2006

During the Mother's Day Storm of 2006, an unusually strong low-pressure system stalled over the central United States and drew in copious amounts of moisture from the Atlantic Ocean, depositing some 6-15 inches of rain across the Merrimack River Watershed from May 12-14th (*Figure 26. 2006 Mother's Day Storm Rainfall*)

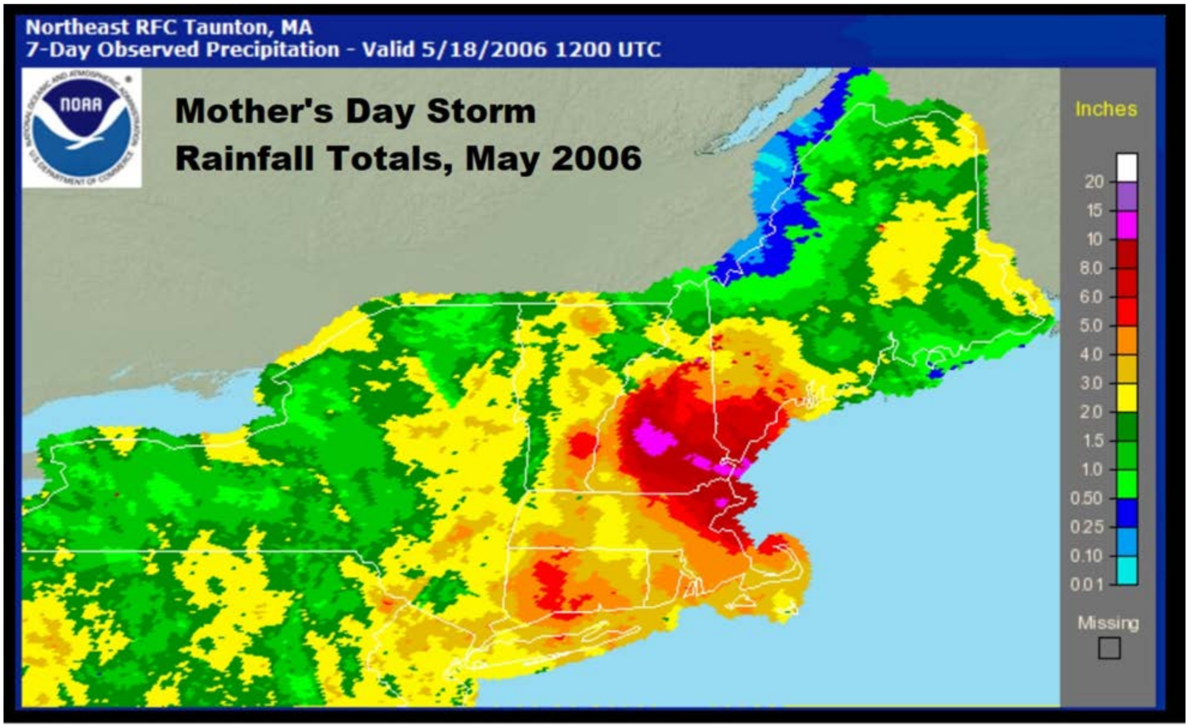

Figure 26. 2006 Mother's Day Storm Rainfall

The Merrimack River in Lowell was at its highest flood stage since the Hurricane of '38 and the third highest ever measured. Wastewater treatment facilities along the Merrimack were compromised and could not handle the additional infiltration of rainfall. The Haverhill facility alone released some 35 million gallons of untreated wastewater and unscreened solids per day into the Merrimack. All this water eventually found its way to Newburyport causing widespread flooding here and almost contaminated the city's water supply at the Lower Artichoke.

When viewing recorded water levels and considering dam elevations, it appears likely that as the Merrimack backed its way into the Artichoke River it nearly overtopped the Lower Artichoke spillway with its polluted flood waters. This event, some 14 years ago, was "a shot across the bow", and clearly demonstrated the present-day vulnerability of our water supply to flooding by polluted river waters.

The Great March Flood of 1936

In March of 1936 New England experienced a "Great Flood" where a procession of 4 storm systems passed to the west of New England, driving in sudden warmth and copious amounts of tropical moisture from the south. The heavy precipitation fell atop a frozen ground, and thick snowpack. The heaviest precipitation in New England fell between March 11th and 12th (storms 1 and 2) and March 17th and 18th (storms 3 and 4). Rainfall varied across the watershed with 6-10 inches of rain falling across the western flank, while areas on the eastern flank received between 10-22 inches of precipitation. Extreme flooding resulted from the combination of rainfall and snowmelt whose water totals varied across the watershed from 13-19 inches, with a peak estimate of nearly 30 inches observed. https://www.weather.gov/nerfc/hf_march_1936 This nearly 200-year event resulted in a high watermark of 16.9 feet NAVD88 at the mouth of the Artichoke river.

The winter leading up to this March event had been very cold, with significant amounts of snow that caused the Merrimack and its tributaries to fill with ice. The sudden thaw combined with heavy precipitation over a frozen ground ensured that virtually all this water content would simply run-off, quickly overwhelming rivers and streams. Incredible amounts of destruction and flooding occurred upstream of Newburyport, with untold volumes of debris flowing to the city, which was littered across the Great Marsh and back side of Plum Island. During the flood's crest, the Merrimack River backed into the lower and upper Artichoke reservoirs; likely flowed or at least made a connection to the Little River across what is now I-95, ultimately flowing into the Great Marsh. Flood Water levels were 6-7 feet over the river's bank along river road in Merrimac. Grover, Nathan C. The Floods of March 1936, Part 1. New England Rivers. U.S. Dept of the Interior. Geological Water Supply Paper 798, p 7-12.

Hurricane Florence (2018)

While 13-30 inches of water represents an extreme event, recent tropical storms and Hurricanes have deposited as much in a short amount of time. Recently, in September 2018, Hurricane Florence delivered 35.9 inches of rain to areas of North Carolina (Roth, David; Hydrometeorological Prediction Center; Camp Springs, MD). It should be noted that 10 days prior to landfall, multiple major weather models predicted a major Hurricane making landfall and then stalling on the US east coast somewhere between Maine and North Carolina. While this forecast ultimately became a reality for North Carolina, the storm had initially been traveling on a northwesterly course towards New England. At one time models were clinging to a New England impact. What shunted the storm to the south was the timing and development of a high-pressure ridge over the Canadian Maritimes that was larger than initially forecast. Had this feature not developed to its extent, Florence and her nearly 36 inches of rain could have impacted New England.

Following the 1936 Flood, the U.S. Army Corp of Engineers constructed a series of flood control dams upstream along the Merrimack which have reduced subsequent flood peaks in Newburyport. However, these dams have not been tested by a 30+ inch precipitation event. The Mother's Day Storm which delivered only ½ that volume proved challenging and nearly contaminated the Lower Artichoke Reservoir. Future events with higher amounts of precipitation, like Hurricane Florence, along with sea level rise and surge, will weigh in with a heavy hand and are unlikely to spare this asset.

2.2.1.a Increased Storm Water Run-off, Algal Blooms, and Drinking Water Quality

Algal blooms are a critical concern for surface water reservoirs. Of relevance to Newburyport 's reservoirs are the prevalence of nuisance blue-green algal species that can alter taste, color, turbidity, odor and in the case of cyanobacteria, could result in the water being unsuitable for consumption. There are currently enough nutrients in the system (particularly in the Artichoke Reservoir and Bartlett Pond portions) to fuel substantial nuisance algal blooms. Algae can also have significant impacts on water treatment plants by clogging intakes, filters, and screens. In addition, they can alter the water's pH balance and can cause the depletion of dissolved oxygen as their cells die off.

The driver of algal blooms is phosphorous run-off from the watershed. While primarily forested, most of Newburyport's surface water watershed is privately owned and subject to private agricultural and residential activities. Run-off from tilled soil, livestock pastures, and impervious surfaces capture and transport fertilizers, herbicides, pet and livestock waste and other pollutants to the reservoirs, encouraging algal blooms. The accumulation of nutrient rich sediments in the reservoirs also fuels the growth of rooted aquatic plants that hastens the transition of a surface water body to that of a wetland. As plants reduce water flow, capture sediments, and then die, they add to the sediment layer, thereby decreasing the reservoir's usable volume. (*Figure 27. Phosphorus Budget of Lakes*)

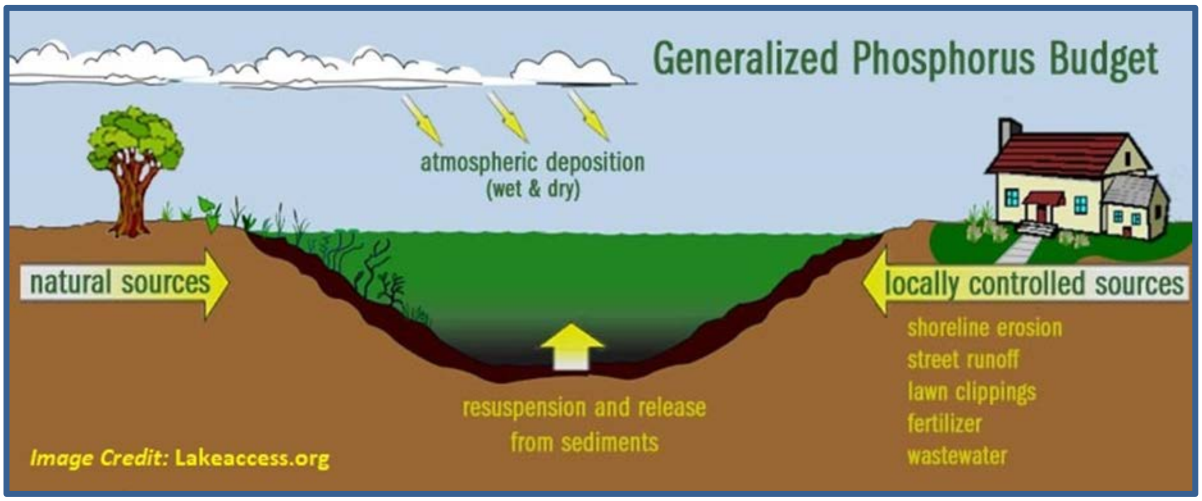

Figure 27. Phosphorus Budget of Lakes

The latest water quality study was completed in 2016 by the Water Department's engineering consultant AECOM. The study identified some concerns that the city needs to address, and the City must continue its ongoing efforts to maintain quality water. However, as climate change ushers in heavier precipitation events, we can expect higher rates of runoff, increased sedimentation and shallowing of the reservoirs. Unless watershed activities are better managed, more pollutants will enter the reservoirs and when runoff events are followed by warmer temperatures and sunshine, will foster rooted plant growth and algal blooms, decreasing the quality and quantity of the city's water supply.

As of February 2019, the Department of Public Services (DPS) has proposed to continue funding a Water Supply Resiliency Plan as part of the city's Capital Improvement Project. This plan was originally funded for FY19, but additional monies are being sought to expand its scope. The NRC will continue to assist the Water Department with the latest Climate Change forecasts as will the city's consultant. Additionally, a Capital Improvement Project has been proposed to update the Artichoke Watershed Protection Plan originally prepared by Weston and Sampson in January of 2005. The city's surface water supply is largely unprotected as the reservoirs lie outside of Newburyport in West Newbury, and they are largely bordered by private property. The Department of Environmental Protection (DEP) has designated buffer zones around these public water supplies, and abutting properties must comply with the regulations for these zones. However, concerns about future drought and additional heavy precipitation runoff have prompted the city to update its watershed protection plan.

2.2.1.b Artichoke Reservoirs Flood Risks

The following graphics illustrate Newburyport's Surface Water Reservoir risk to current and future flooding.

Current Flooding Risk

Figure 28. Upper and Lower Artichoke – Current FEMA 100 Year Inundation reveals that a 100-year event today would have the Merrimack River back over the lower Artichoke spillway and into both the Lower and Upper Artichoke Reservoirs. A 0.2% event would have flood waters push through the culverts under U.S. Interstate I-95 and into the Common Pasture along Scotland Rd.

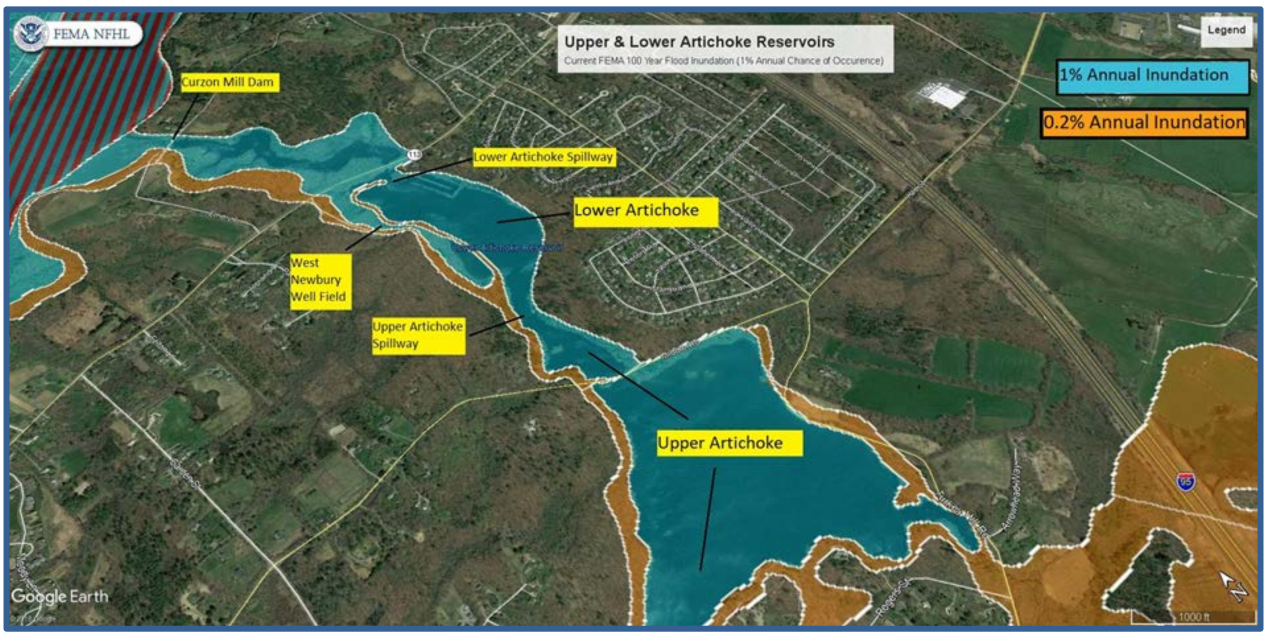

Figure 28. Upper and Lower Artichoke – Current FEMA 100 Year Inundation

When employing the National Hurricane Center PV2 basin SLOSH Model data to illustrate hurricane storm surge inundation, we see that during a worst-case scenario, the Lower Artichoke is at risk for being inundated by every category type of storm, with a Category 3 system even pushing flood waters over the Upper Artichoke spillway. It would, however, only take the surge of a worst-case Category 1 storm to top the Lower Artichoke spillway (where the intake pipe to the city's water purification plant lies) to compromise the integrity of, and therefore access to, 75% of the city's drinking water supply (*Figure 29. Hurricane Storm Surge Inundation - Lower and Upper Artichoke* and *Figure 30. Close-Up of Lower Artichoke Spillway Hurricane Storm Surge Inundation*).

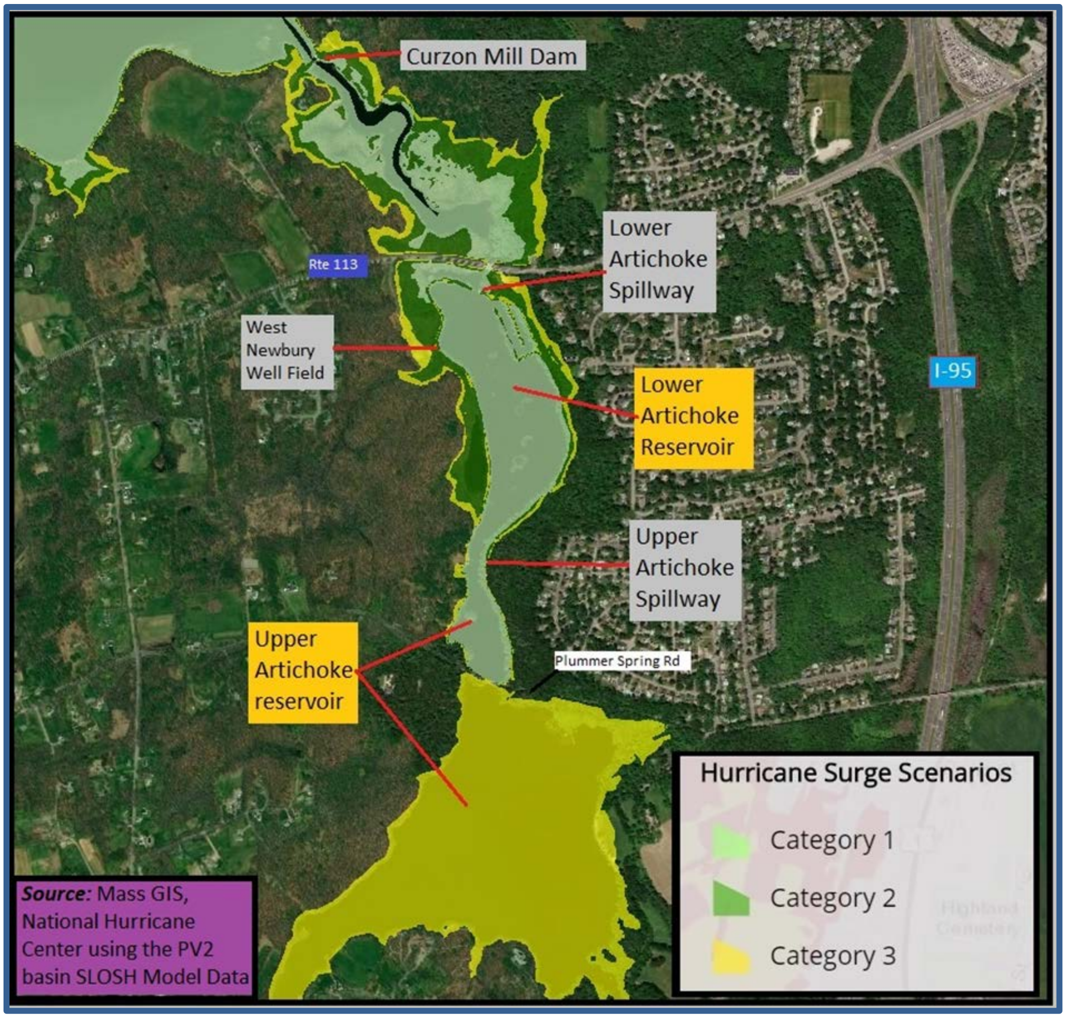

Figure 29. Hurricane Storm Surge Inundation - Lower and Upper Artichoke

Figure 30. Close-Up of Lower Artichoke Spillway Hurricane Storm Surge Inundation

Future Sea Level Rise

Figure 31. Future Sea Level Rise – Lower Artichoke Reservoir reveals that with an additional 2 feet of sea level rise expected around 2050, the daily tide would back up to the lower Artichoke spillway twice daily. Between 2070 and 2100 it is expected that the daily tide would occupy the Lower Artichoke Reservoir. However, it is important to note that increased sea level rise alone by 2050 simply coupled with current day storm activity might likely compromise this asset.

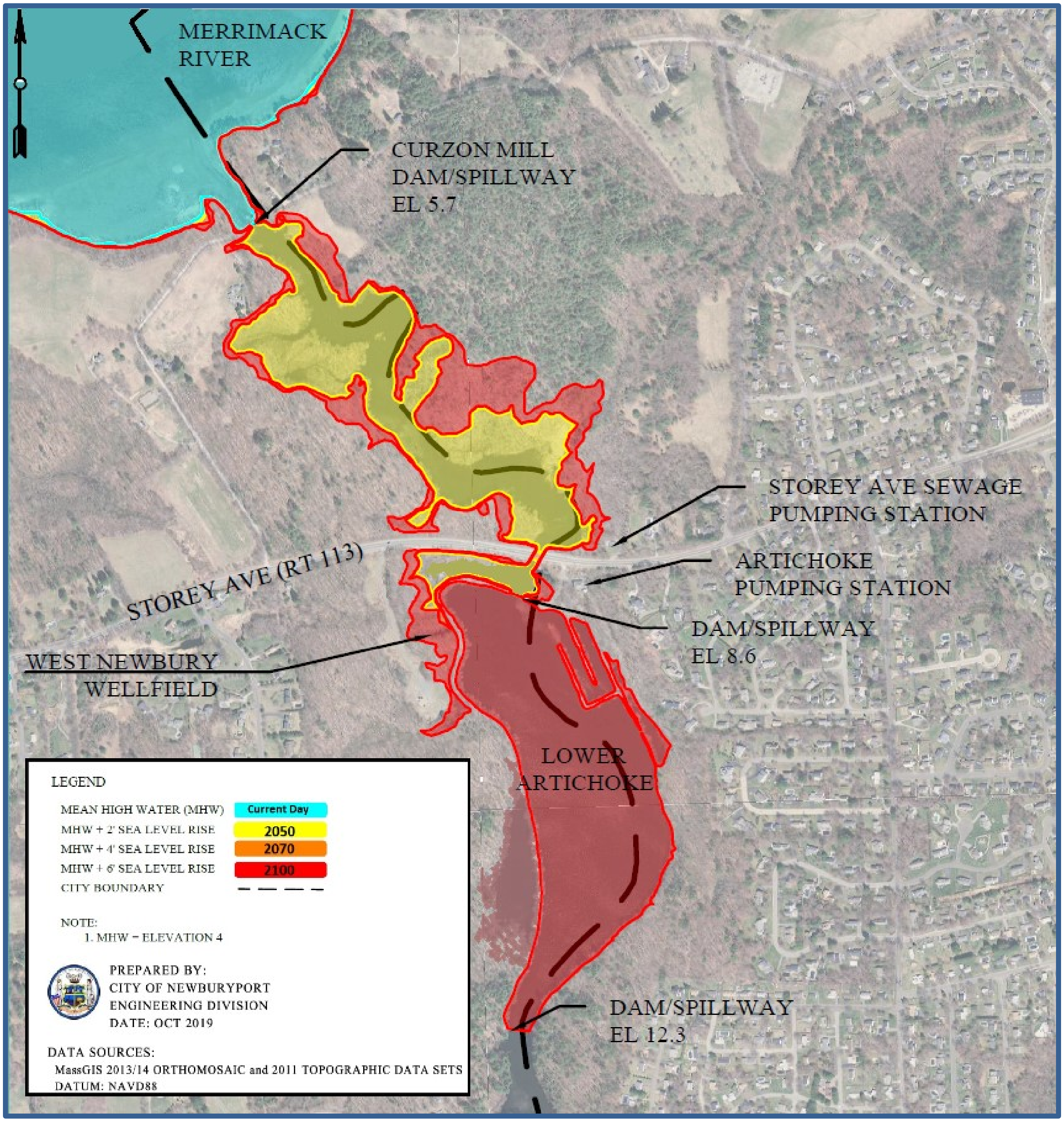

Figure 31. Future Sea Level Rise – Lower Artichoke Reservoir

Future Sea Level Rise Plus Inundation - (Current FEMA)

As the Lower and Upper Artichoke Reservoirs are currently vulnerable to FEMA's 100-year flood, without intervention, the reservoirs would continue to remain vulnerable to future SLR + FEMA 100-year events. (*Figure 32. Flood Inundation and Future Sea Level Rise – Lower and Upper Artichoke Reservoirs*).

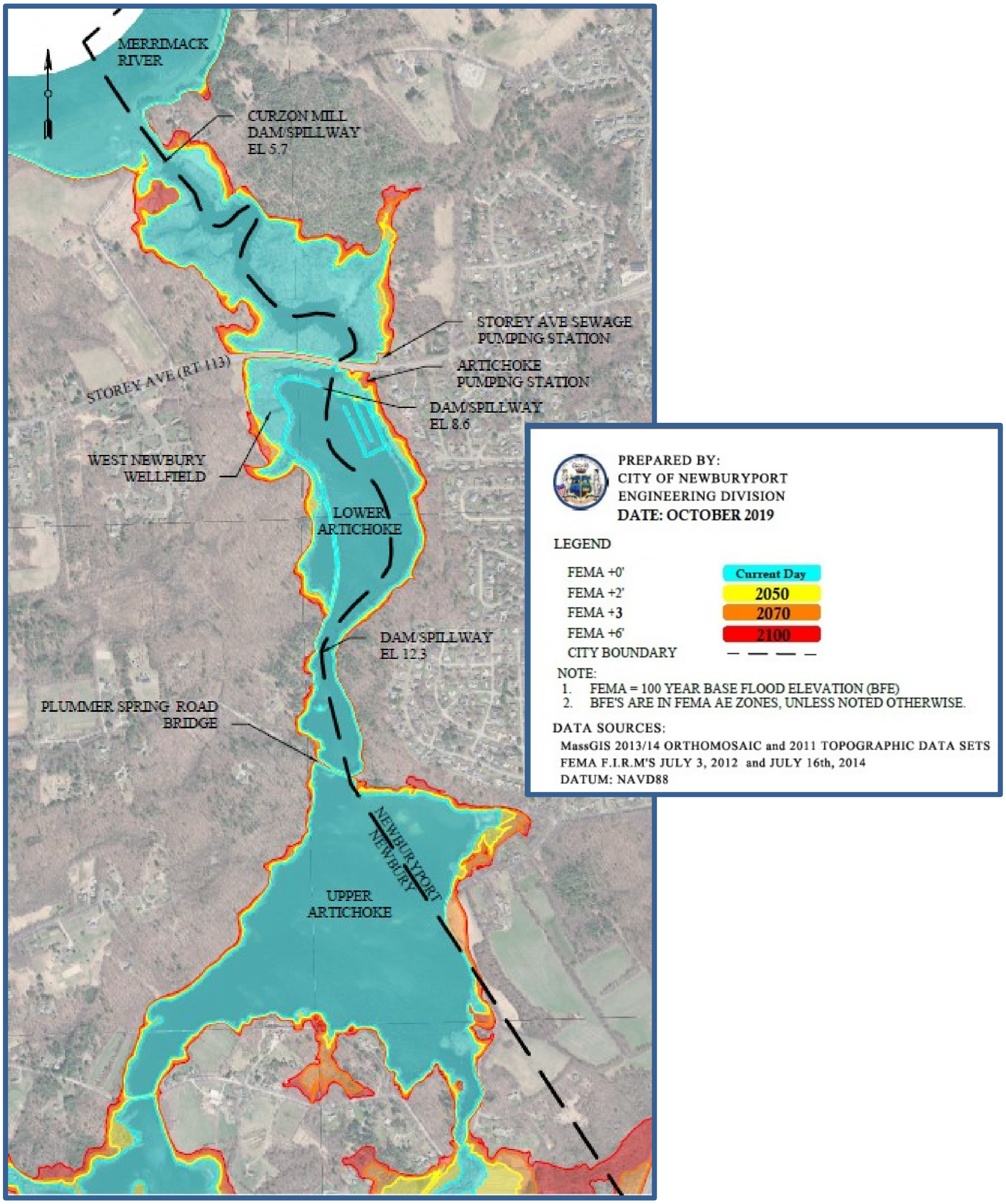

Figure 32. Flood Inundation and Future Sea Level Rise – Lower and Upper Artichoke Reservoirs

2.2.1.c Bartlett Spring Pond Flood Risks

Current Flooding Risk

Bartlett Spring pond is a small spring-fed surface reservoir located adjacent to the Merrimack River on the Water Treatment Facility property at the end of Spring lane. It represents about 5% of the city's total water supply. The pond is separated from the Merrimack by a berm atop of which runs a small road. The berm was originally constructed during the March 1936 Flood to protect the city's water supply (*Figure 33. March 1936 Flood, volunteers build a berm to protect Bartlett Spring Pond*). The pond is situated outside the FEMA flood zone, which is approximately elevation 10, or roughly 6 feet above mean high water. The roadway and berm offering protection to the pond lies at approximately elevation 14, or roughly 10 feet above mean high water. Therefore, the asset is currently at less risk from compromise when compared to Newburyport's other 2 surface reservoirs. Referencing *Figure 34. Hurricane Storm Surge Inundation - Bartlett Spring Pond*, reveals that the pond is safe from the surge of a worst-case Category 1 or 2 storm, but is over topped by a worst-case Category 3, at which point the facility is at risk. While this asset is currently protected from current day storms and water levels, it will still be subject to risks imposed by future sea level rise, storms and surge, and like the other reservoirs, is vulnerable to algal blooms.

Figure 33. March 1936 Flood, volunteers build a berm to protect Bartlett Spring Pond

Future Sea Level Rise

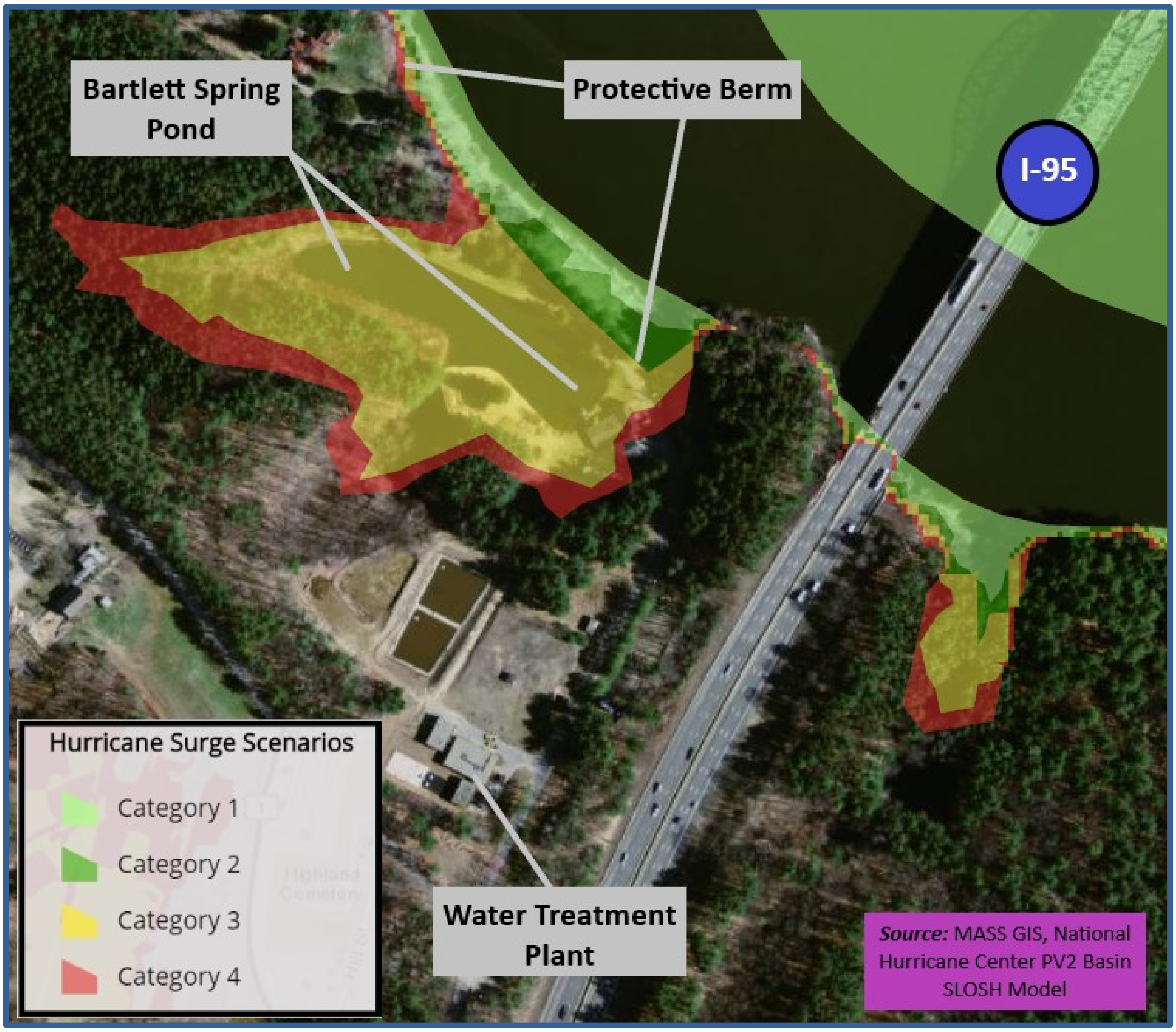

Figure 34. Hurricane Storm Surge Inundation - Bartlett Spring Pond

Bartlett Spring Pond is theoretically protected by its berm for up to 6 ***or more*** feet of sea level rise (*Figure 35. Future Sea Level Rise – Bartlett Spring Pond*). However, as we'll see in the next section, sea level rise coupled with the FEMA 1% inundation might challenge the pond's berm around the year 2070, and possibly overtop it by the close of the century (2100).

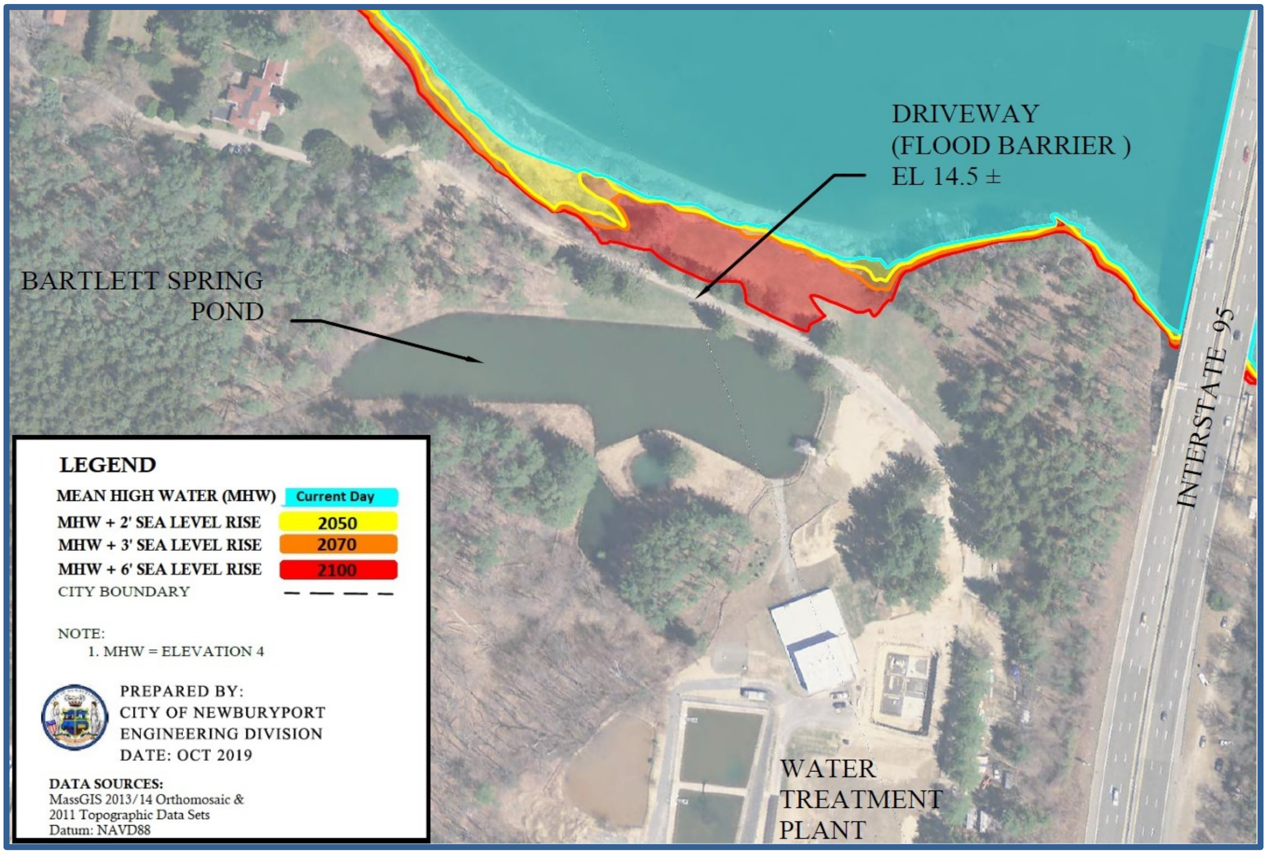

Figure 35. Future Sea Level Rise – Bartlett Spring Pond

Future SLR plus Inundation - (Current FEMA)

While the pond itself lies at an elevation that is not vulnerable to flooding today, it is the protective berm that offers the pond protection from SLR + Flooding until about 2070. The city's water Treatment (purification) plant sits at an elevation safe from current and future flooding (*Figure 36. Flood Inundation and Future Sea Level Rise – Bartlett Spring Pond*)

Unlike the Lower and Upper Artichoke reservoirs, this reservoir is not at immediate risk largely due to the efforts of volunteers who sought to protect the pond during and following the Great Flood of 1936. **Their efforts bear testament to the value of investing in resiliency today for the benefit of generations tomorrow.**

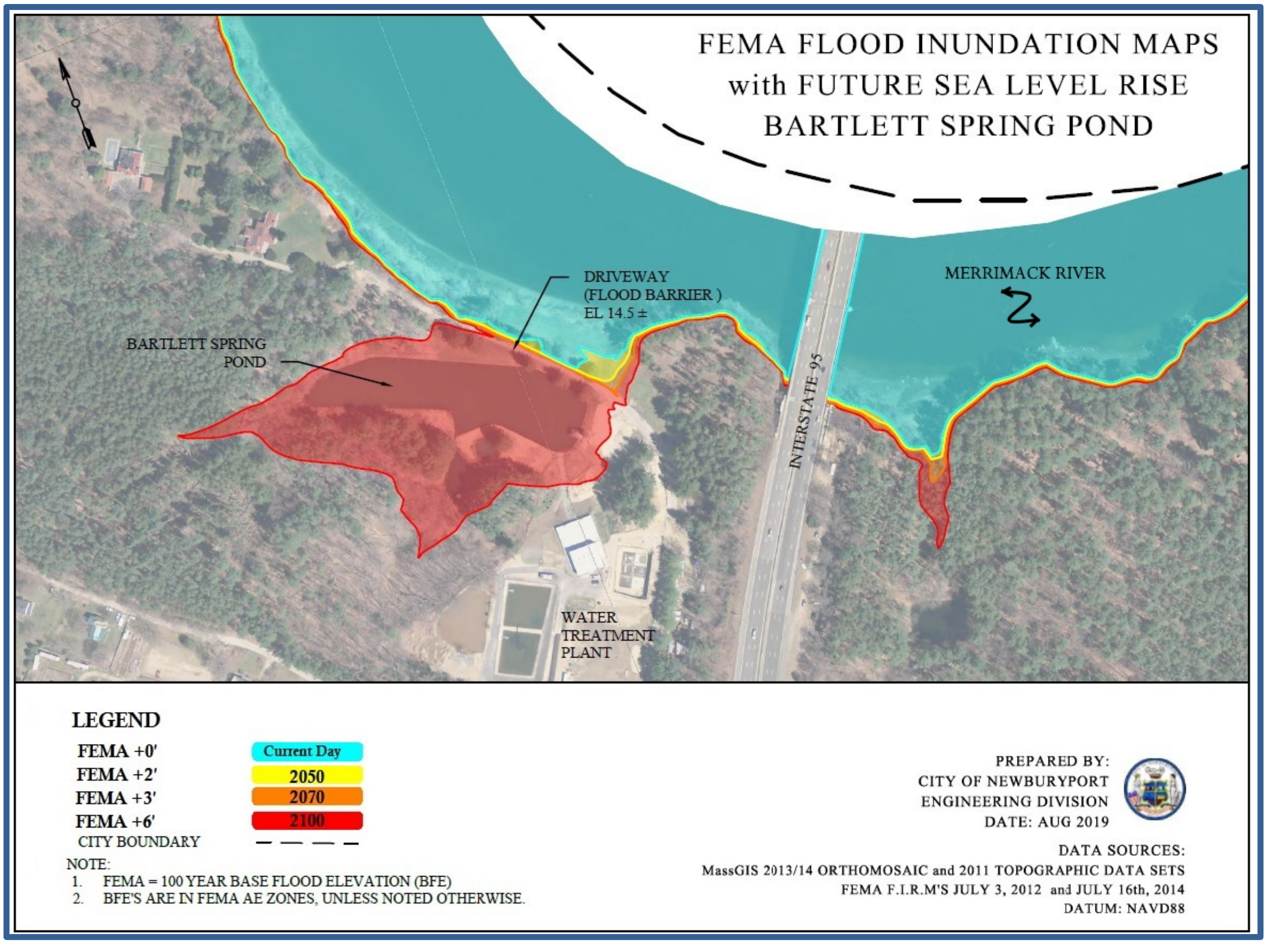

Figure 36. Flood Inundation and Future Sea Level Rise – Bartlett Spring Pond

2.2.2 Wastewater Treatment Facility Flood Risks

Wastewater is channeled to Newburyport's recently updated WWTF located along the waterfront. The WWTF is designed to handle 3.4 million gallons of wastewater per day (MG/D), and on average processes 1.7 MG/D. During rain events the WWTF also *unintentionally* processes substantial amounts of stormwater run-off. While the WWTF was recently upgraded, its aging network of pipes leading to the facility has not, and so storm water infiltrates the system via cracks in underground pipes and through manhole covers. It is therefore expected that the WWTF will process more stormwater as climate change ushers in more frequent episodes of heavy precipitation.

The elevation of the protective berm surrounding the plant is only as effective as the lowest elevation at which water can enter the sewer system from outside of the plant – and these vulnerable manholes and pump stations, have not yet been determined. The WWTF would be rendered inoperable, should floodwaters associated with heavy rains, river flooding or ocean surge enter the sewer system via low lying manholes or pump stations. These high volumes of water would overburden the plant, resulting in sewage backup into basements and via manholes onto city streets, with an eventual discharge of untreated sewage into the river. In this instance, there would be a significant public health crisis.

A harbinger of such a calamity occurred during the Mother's Day Storm in 2006, which caused the Merrimack River to rise substantially. Both the volume of rainfall entering the sewer system and the high flood elevation of the river combined with a loss of power to run the system's pumps resulted in sewage backup into basements and onto Water Street via manholes at low-lying locations. In this instance, homes otherwise unscathed by storm damage became uninhabitable.

Significant but isolated wastewater system failures, unrelated to flooding, on Plum Island during the winter of 2015-16 provided another view into the hardships imposed by wastewater system failures. Due to cold weather, valve failures and human error, some homes experienced sewage backups rendering them uninhabitable. Families were displaced and had to be housed in hotels and recovery was slow and difficult as this occurred during the cold and snowy winter months. Imagine this sort of problem on a grander scale with no electrical power to even begin recovery.

Current Flooding Risk

The Wastewater treatment facility borders FEMA's high risk VE zone (subject to wave height and run up depth of 3 feet or more) and is situated in zone AE, flood elevation 12 (NAVD88). Currently the plant is located 4.2 feet above mean high water, and some portions of the property are almost 10 feet above that level. However, the property sits 2 to 4 feet lower than FEMA's 100-year flood elevation, which therefore makes it vulnerable to current day storm and river flooding.

As stated in the WWTF Resiliency Plan prepared in June 2019, there are a number of components that were identified as vulnerable to flooding (*Figure 37. Flood vulnerability of critical assets of the Newburyport (WWTF Resiliency Plan, 2019*).

The majority of the vulnerable assets are below the current FEMA flood zone elevations but as SLR increases and storms become more common and intense, future FEMA flood zone elevations will rise. Therefore, a number of additional assets and treatment plant components will become quite vulnerable.

For more information on the WWTF's vulnerability assessment, refer to *FY 18 EEA Municipality Vulnerability Preparedness (MVP) Program Action Grant – Wastewater treatment facility Climate Change Resiliency, Climate Change Vulnerability Report,* prepared by Dewberry Engineers, Inc., Issued June 15, 2019.

Order of Criticality	Description	Critical Operation	P.O.E. EL. (ft.)	Criticality of Assets		
				High – 1	Mod. – 2	Low - 3
1	Bldg.#8 - Influent Pumping/Operations Building	Essential MCC 1 Influent Pumps and Controls	12.50	✓		
2	Bldg.#7- Secondary Sludge Building	MCC 4 – Secondary Systems	10.98	✓		
3	Bldg.#6 - Effluent Pump Building	Effluent pumps Necessary for High Tide	12.84	✓		
4	Bldg.#2 – Switchgear	Essential Main Power	12.90	✓		
5	Bldg.#3 - Emergency Generator	Essential Back Up Main Power	12.69	✓		
6	Secondary Clarifiers	There is Redundancy but Vulnerable due to P.O.E.	12.42	✓		
7	Bldg.#4 - Aeration Blower Building	Necessary for Quick Recovery	12.41	✓		
8	Chlorine Contact Tanks	There is Redundancy but Vulnerable due to P.O.E.	11.97	✓		
9	Bldg.#5 - Disinfection Building	MCC 2	12.83	✓		
10	Bldg.#9 – Headworks	Due to Low P.O.E. if Headworks Floods then the Influent Wet	12.50	✓		
11	Bldg.#11 - Primary Sludge Pumping Building	MCC 3	14.16	✓		
12	Aeration Basin Flow Splitter	Essential and no Redundancy	14.33		✓	
13	Aeration Basins	There is Redundancy	14.33		✓	
14	Primary Clarifiers	Essential but there is Redundancy	16.50		✓	
15	Aerobic Digesters	Not Essential and there is Redundancy	17.33			✓
16	Bldg.#10 - Gravity Thickener Building	Not Essential	12.50			✓
17	Bio Filters	Not Essential	15.68			✓
18	Bldg.#12 – Odor Control Building	Not Essential	12.60			✓
19	Bldg.#13 - Ferric Chloride Containment	Not Essential	12.44			✓

Figure 37. Flood vulnerability of critical assets of the Newburyport (WWTF Resiliency Plan, 2019)

Referencing *Figure 38. Hurricane Storm Surge Inundation - WWTF and National Grid Substation*, we see that the SLOSH Model predicts that the facility is currently challenged by a worst-case Category 1 Storm and inundated by a worst-case scenario Category 2 or stronger system.

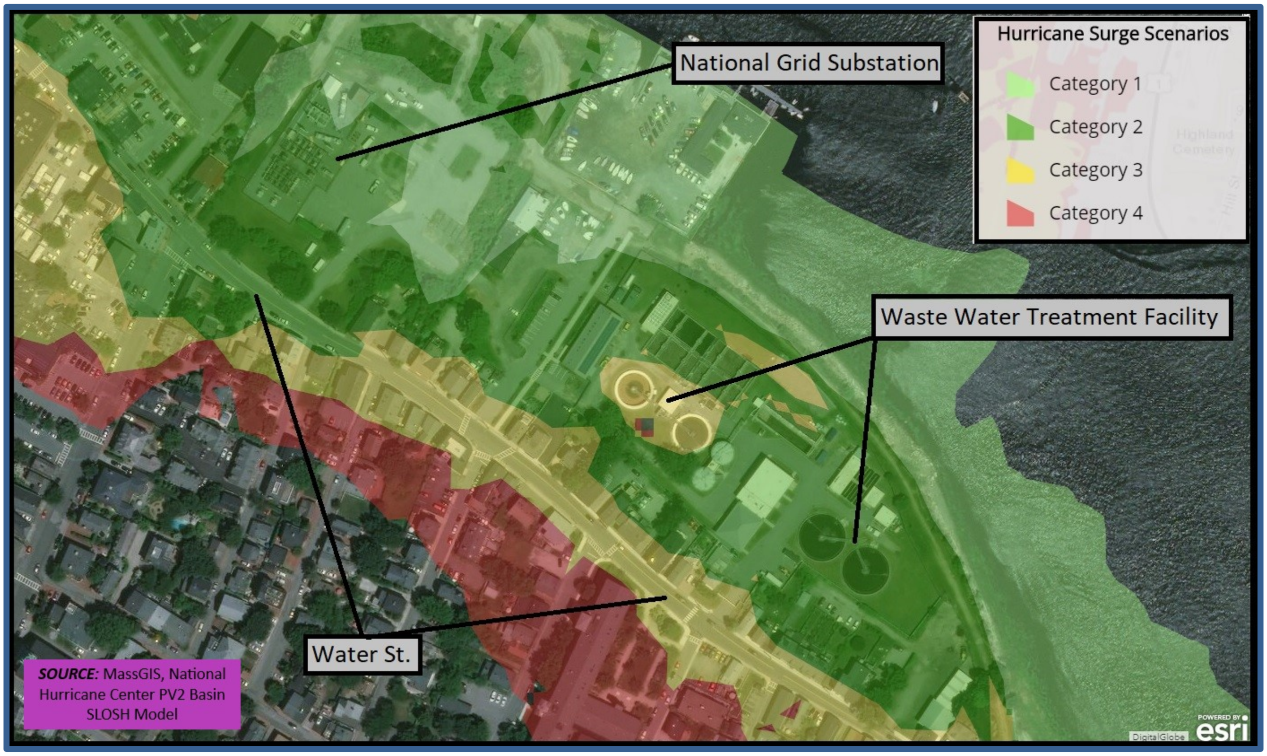

Figure 38. Hurricane Storm Surge Inundation - WWTF and National Grid Substation

Future Sea Level Rise

Though the facilities will be playing cat and mouse with the ebb and flow of each storm season, *Figure 39. Future Sea Level Rise – WWTF and National Grid Substation*, shows that if sea levels rise to about 6 feet (year 2100), sea water would nearly inundate the plant twice daily with the tide.

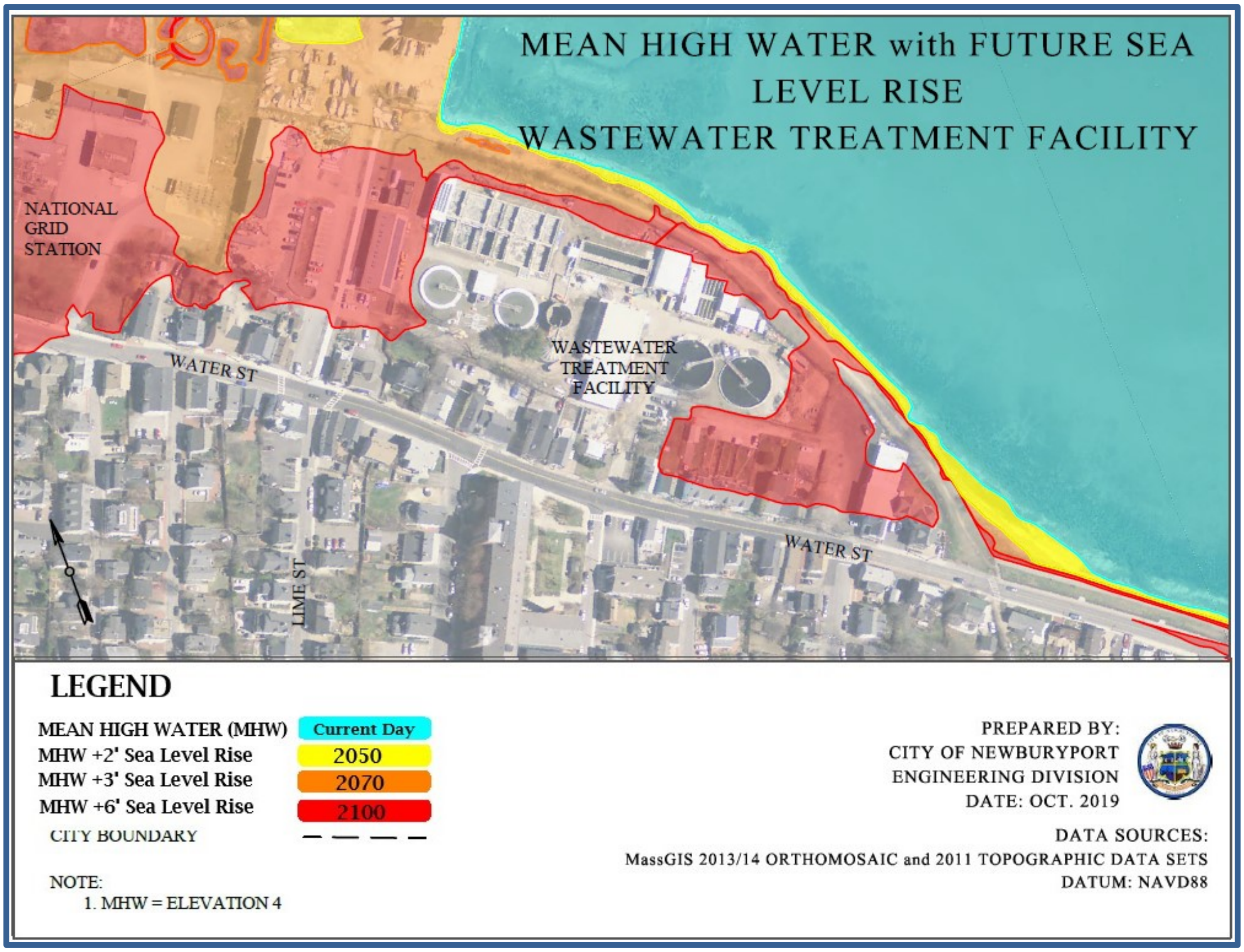

Figure 39. Future Sea Level Rise – WWTF and National Grid Substation

Future SLR plus Inundation - (Current FEMA)

Figure 40. Flood Inundation and Future Sea Level Rise – WWTF and National Grid Substation reveals that the WWTF and National Grid substation both reside within FEMA's 100-year flood zone today. Future sea level rise extends this flood zone further into the city by 2050-2070.

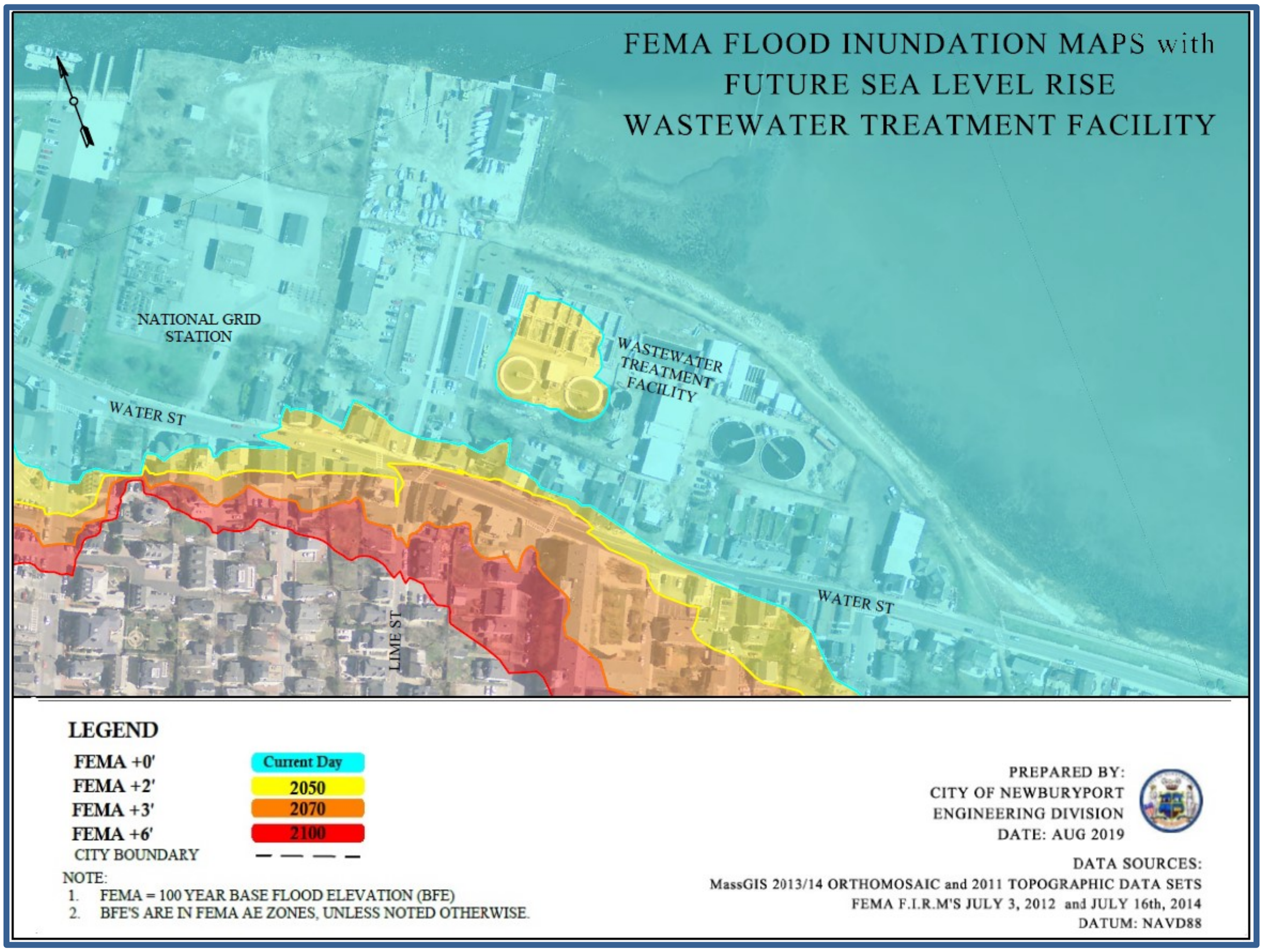

Figure 40. Flood Inundation and Future Sea Level Rise – WWTF and National Grid Substation

The previous graphics clearly indicate that while the plant needs to be protected today due to its current vulnerability, preparations also need to begin today to plan for the facility's relocation by mid-century.

2.2.3 Neighborhoods Vulnerable to Flooding

We have just examined the vulnerability of Newburyport's critical assets. However, less critical assets and private property are also vulnerable, and in the case of future development require guidance relative to the risk of developing in, or near, a floodplain. While many parts of the city are vulnerable to flooding due to river influences, sea level rise, and storm surge, the areas differ enough from one another such that the three variables contributing to flooding will not contribute equally within each neighborhood. As an example, the dynamics along the ocean shore of Plum Island are far different from those experienced in the area between Joppa and the Wastewater treatment facility. While wind fetch (distance over which the wind blows), wave setup (water piled up by waves) and run up (how far waves wash up along a shore) do impact Joppa to a great extent, the impact is significantly less than what is experienced on Plum Island, but significantly more than what is seen along the central waterfront and areas up river through Cashman Park and beyond. The Little River Watershed is again affected quite differently relative to those areas along the Merrimack and Atlantic Ocean. There, runoff and barriers to flow are the issue. Dividing the city into these regions of vulnerability subject to flooding sets the stage for fine tuning risk, adaptation strategies and zoning efforts that will guide the mitigation process (*Figure 41. Neighborhoods Vulnerable to Flooding*).

Neighborhoods Vulnerable to Flooding:

1. Plum Island and the Plum Island Turnpike
2. Joppa to the National Grid Substation
3. The National Grid Substation to the Route 1 Bridge – Downtown and Waterfront
4. The Route 1 Gillis Bridge to the I-95 Bridge – Cashman Park and Merrimac St.
5. The Surface Water Reservoirs (Critical Asset already discussed)
6. The Little River Watershed including the Business Park

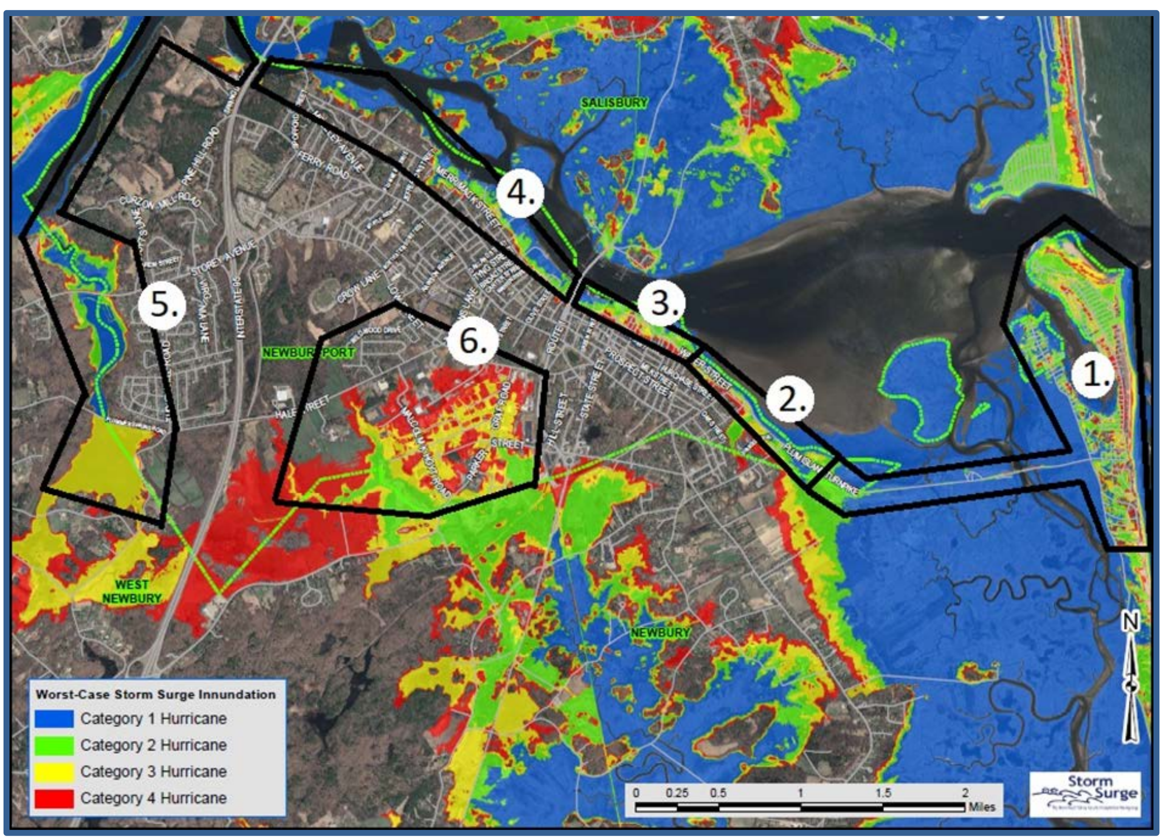

Figure 41. Neighborhoods Vulnerable to Flooding

2.2.3.a Plum Island and the Plum Island Turnpike

Plum Island is roughly an 8-mile-long barrier island, most of which falls outside the city's boundary to the south. However, the far northern extent of the island (the last ½ to ¾ of a mile) that extends into the Merrimack River inlet, falls within Newburyport's jurisdiction. A single low-lying causeway lined with telephone poles and a single power and communication line, along with a single draw bridge connect the Island to the mainland. Cell service is marginal, and the water/sewer service traverse the same single causeway as the power lines to the island. The developed areas of Plum Island (Newburyport and Newbury) are located within the river's historical delta, laced between the current inlet and an abandoned inlet, the Plum Island Basin. The area is under the influence of significant river flows, tides and open ocean wave activity. Given its location and history of repetitive episodes of erosion, one might conclude the area's geography to be changeable and therefore unstable. In fact, historical nautical charts suggest that prior to jetty construction, the river would migrate between its two inlets in 50 to 75-year cycles, a cycle that the jetty interrupts, and one which, given the chance, nature would likely resume (*Figure 42. Plum Island and The Merrimack River Delta*).

The following pages will discuss some of Plum Island's vulnerabilities namely erosion related to sea level rise, coastal storms and the developed area's its proximity to the river inlet, flooding from both the river and ocean, instability and barrier island movement in response to sea level rise, infrastructure impacts due to a rising water table driven by sea level rise, emergency and non-emergency access, as well as energy, communication and other utility vulnerabilities.

Figure 42. Plum Island and The Merrimack River Delta

Plum Island, Sea Level Rise and the Merrimack River Jetty

Key to understanding Plum Island's flooding vulnerabilities is to understand its behavior in a rising sea scenario, and the influence of the jetty at the inlet.

As sea levels rise, barrier islands move landward, or retreat from the ocean. Simply stated, over time the process involves waves eroding the foreshore and dunes to the point where waves can wash over the island in vulnerable areas, thereby moving sand from the foreshore to the rear of the island. (Pinet, Paul R. Invitation to Oceanography p 378-381). Provided the sands are being pushed onto a shallow substrate to the rear, like a salt marsh rather than a deep bay, the island remains, but over time is re-established in a different location. One can now imagine the conflict of fixing house lots on a moving piece of real estate. It is a conflict being realized by all barrier beach communities, not just Plum Island.

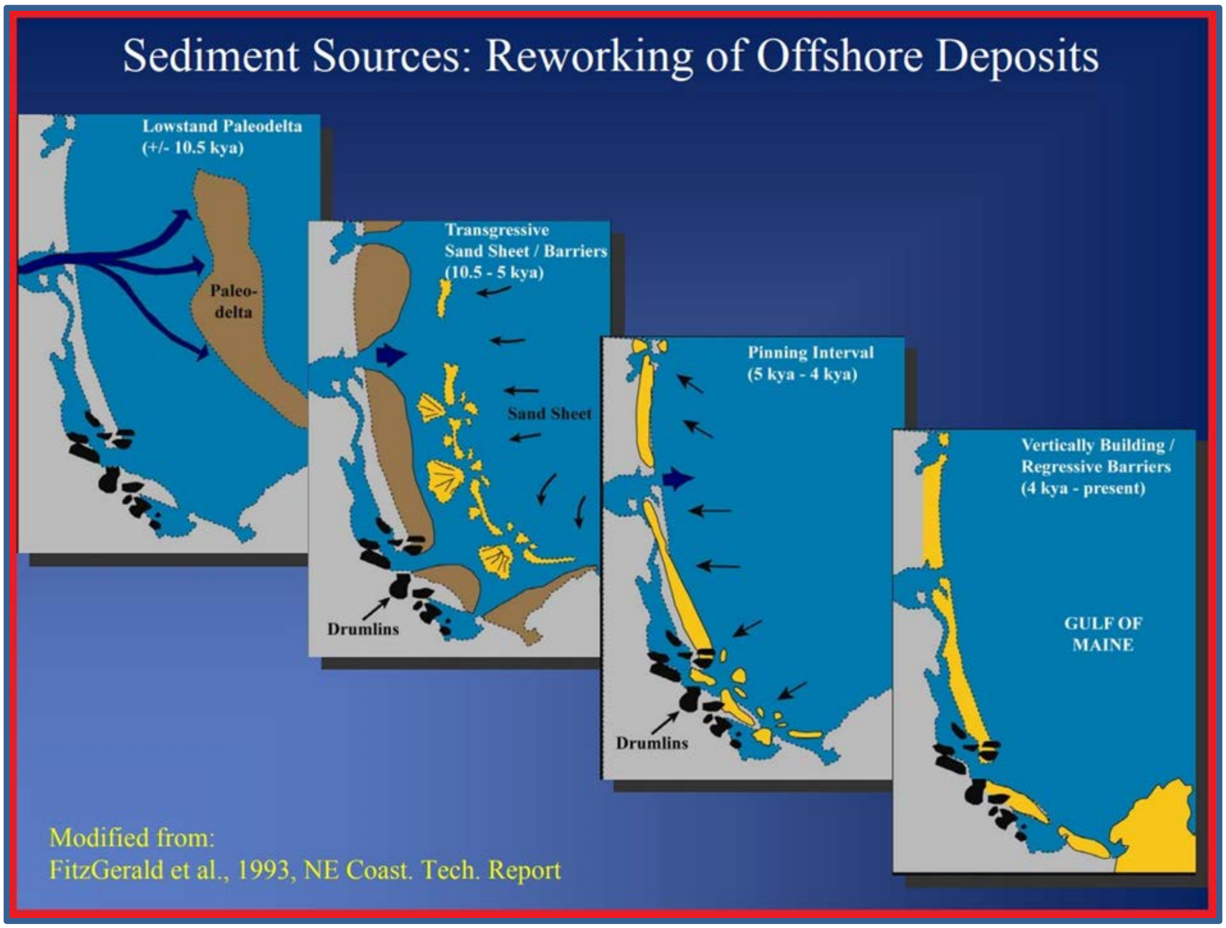

Figure 43. Evolution of a Barrier System in Response to Slow Sea Level Rise

SOURCE: Christopher J. Hein, Emily Carruthers, Duncan FitzGerald, Walter A. Barnhardt, and Byron D. Stone, Evolution of a Barrier System in Response to Slow Sea Level Rise and Back Barrier In-filling: Plum Island, Massachusetts. Search and Discovery Article #50235 (2009)

If we examine Plum Island's history, we might gain a sense of its future. Plum Island evolved in response to slowly rising sea levels following the conclusion of the last ice age, some 10,000 years ago. At that time, Ipswich Bay was a dry Tundra with the shores of the Atlantic lying east of Cape Ann. As sea levels slowly rose, wave action and coastal processes gathered and sorted glacial sediments, forming shallow areas that over time became the barrier Island. Over the centuries the island was occasionally overtopped by storm waves, foreshore sands were transported to the rear onto an infilling, and thus developing, salt marsh, vegetation would re-establish itself on the over washed sediment, and so on. In this manner the island slowly moved westward in response to rising sea level (*Figure 43. Evolution of a Barrier System in Response to Slow Sea Level Rise*). Over the last 4000 years, Plum Island transitioned from a retreating barrier island to a "regressive" barrier island – one that built seaward. This has happened as wave and river deposition of glacial sands along its shore outpaced sea level rise and erosion, allowing winds to incorporate those sediments into the island's dune system, thereby encouraging vertical growth and seaward expansion. The addition of the south jetty to the northern end of the island in the late 1800's further promoted this expansion, as the jetty acted as a terminal groin, capturing sands migrating towards the inlet.

Figure 44 illustrates how attaching the south jetty to the 1851 shoreline near 63rd Street caused the shore to expand. Homes and streets have populated this (manmade) land mass where 100 years ago water once was – and sea level then was about 1 foot lower.

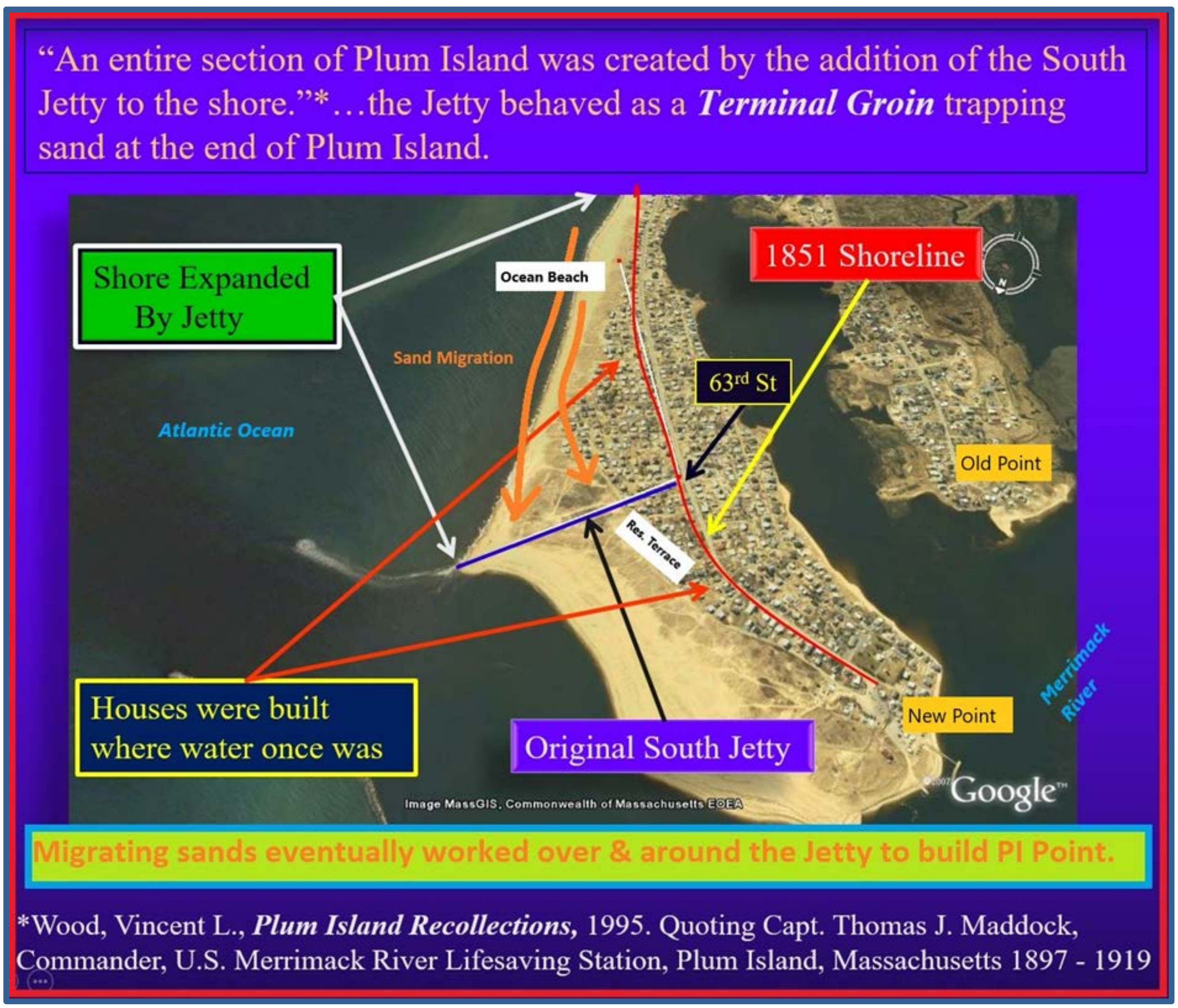

Figure 44. South Jetty Acting as a Terminal Groin, Plum Island Point

Historically, sand would work its way around and over the jetty, to shallow the river channel and expand the shore along Plum Island Point. Several extensions to the jetty were made since its initial construction to prevent this sand from entering the navigation channel. Over time the battering of waves combined with the pressure of migrating sands would work to topple the jetty's stones, forming a breach allowing once trapped ocean beach sand to again flow into the inlet**.** Based on historical observations and correlations of the Massachusetts Office of Coastal Zone Management's (CZM) shoreline change data with dates of past jetty repair and dredging, there is a strong association between beach erosion and the condition of the jetty (*Figure 45. Relative Shoreline Change, Plum Island Point, 1915-1994*). Shoreline growth along Plum Island Point historically accelerated during periods of jetty disrepair, while the concurrent loss of sand from the ocean beach quickly narrowed the shore there, threatening homes in the process. Repairing the jetty would reverse the process, cutting off the sand supply to the point and encouraging erosion along Reservation Terrace, while concurrently, albeit slowly, restoring the previously eroded ocean beach[3]

Figure 45 also illustrates that erosion along Plum Island Point hastened following past dredging programs and jetty repairs. Since the most recent jetty reconstruction efforts were completed by the US Army Corps of Engineers on the south jetty in 2013, and the north jetty in 2015, residents have noticed an astounding increase in erosion along the northern tip of Plum Island, particularly the Reservation Terrace and Old Point neighborhoods. According to some estimates by the Newburyport Resiliency Committee, portions of the dune crest have eroded as much as 300 feet since 2012. Erosion of this magnitude significantly threatens residents living on Plum Island Point and reduces the capacity of dunes and beaches to protect properties from increased storm surge.

Clearly, the stability of the developed shore is dependent on the integrity of the jetty system. Without it the river would assume its natural cycle of moving between its desired inlets – certainly a problem for the developed areas of Plum Island. More research is needed to identify a jetty design that better balances shoreline stabilization with navigational needs.

The Merrimack River Jetty System was highlighted as an area of concern in the 2017 NWF's Great Marsh Coastal Adaptation Plan not only because of its potential impact on erosion along Plum Island Point and the ocean beach, but also for it's potential to constrict river flow during times of heavy runoff. Until flood waters are of sufficient height to top the elevation of the jetties and their adjacent landmass and the beach causeways; they, along with the beach causeways act as a barrier to flow, possibly contributing to flooding along the back side of the Island and along Newburyport's waterfront. Such may have been the case during the Mother's Day Storm of 2006. It was observed in the early stages of the event, that the jetties appeared to slow the rate at which the ocean's surge entered the river basin. But once there, the constricted river mouth served to capture this ocean water within the river basin and marsh. As heavy storm water runoff flowed down the Merrimack, the river didn't efficiently discharge both the trapped sea water and accumulating rainwater. Appearing to be further hemmed in by the Plum Island turnpike and Beach Road causeway in Salisbury, these flood waters rose along the rear of the barrier beaches and Newburyport's waterfront, where significant flooding did occur. More study is needed to confirm or discount the effect of the inlet jetties and beach causeway's on flood water levels in this area.

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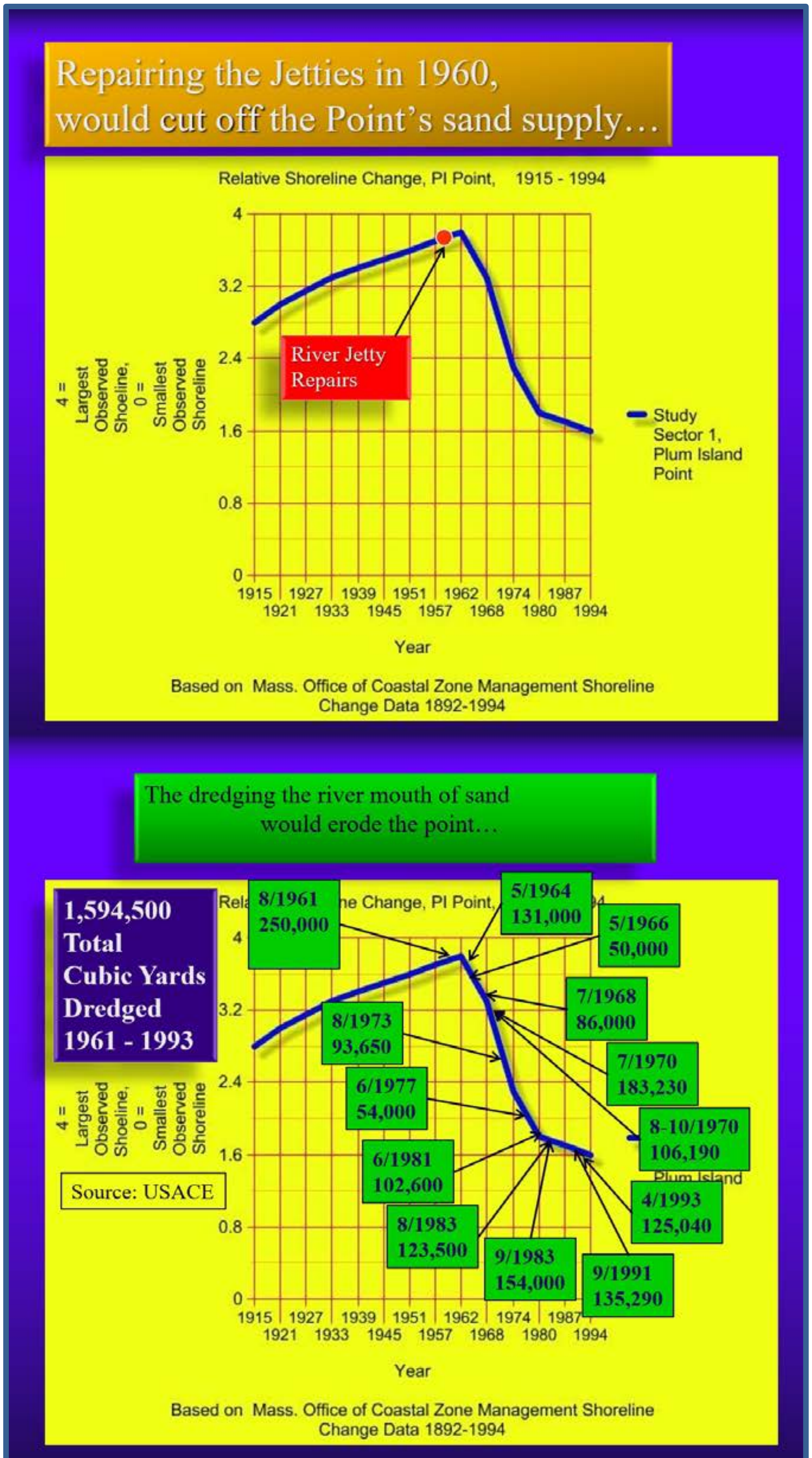
[3] Christopher J. Hein, Andrew R. Fallon, Peter Rosen, Porter Hoagland, Ioannis Y. Georgiou, Duncan M. FitzGerald, Michael Morris, Sarah Baker, George B. Marino & Gregory Fitzsimons. **Shoreline Dynamics Along a Developed River Mouth Barrier Island: Multi-Decadal Cycles of Erosion and Event-Driven Mitigation**. *Frontiers in Earth Science***,** May 2019, p11.



Source: Morris, Michael***, Plum Island Point Erosion,*** Public Presentation to Newburyport Conservation Commission, Newburyport, MA. February 2016

Figure 45. Relative Shoreline Change, Plum Island Point, 1915-1994

Rising Seas, Storm Surge, River Flooding and Rising Water Tables

Beginning on March 3rd, 2018, New England was impacted by the first of four significant storm systems that rode in atop of a nearly 10-foot tide (9.9 feet above mean low, low water or 5.6 feet NAVD88). Adding in a 2-3-foot storm surge resulted in a 12-13 foot storm tide (7.6-8.6 feet NAVD88). Aside from flooding the Plum Island turnpike, Old Point Road, and Sunset Boulevard, the combined level of the sea to the east and the river to the west, forced the water table under Plum Island to the surface to form ponds between dunes, streets and homes (*Figure 46. Water Table Ponding, Plum Island Point, March 5, 2018* and *Figure 47. Water Table Ponding on Annapolis Way, March 5, 2018*). This ponding was not as a result of rainfall.

Surface flooding aside, it is known that a rising water table under a barrier beach serves to destabilize it. Beach erosion increases as the level of the beach water table rises. "A wet sandy beach is eroded more rapidly by wave action than a dry one"[4]. As sea levels rise and storm tide events become more frequent so might flooding from a rising water table. At some point these events might likely compromise infrastructure and destabilize the barrier island itself.

Figure 46. Water Table Ponding, Plum Island Point, March 5, 2018

Figure 47. Water Table Ponding on Annapolis Way, March 5, 2018

[4] E. Bird and N. Lewis, *Beach Re-nourishment*, Springer Briefs in Earth Sciences Chapter 2 p23

The Plum Island Turnpike – Emergency and Non-Emergency Access

Aside from travel by boat, there is only one way to and from Plum Island and that is via the roughly 2-mile-long, two lane, flat and exposed Plum Island turnpike, and its Bascule draw bridge over the Plum Island River. In 2016, **on average some 11,846 vehicles traversed the turnpike bridge daily** (Source: MassDOT). The turnpike has historically flooded during storms and was impassable during and after the Blizzard of ’78 as it had been flooded and littered with giant ice cakes. When the draw bridge was constructed in 1973, the causeway’s approach to the bridge was elevated to accommodate the structure’s height, but the balance of the roadway is low and increasingly today becoming impassable during significant storm events due to flooding, river ice intrusion and blowing and drifting snow (Figures 48 through 51). Though infrequent and more often a vulnerability during the boating season, the draw bridge has broken down in its raised position cutting off access to the island for upwards of 6 hours.

Figure 48. Plum Island Turnpike - Surge Flooding, March 3, 2018

Figure 49. Plum Island Turnpike - Surge Flooding and Drifting Snow, January 4, 2018

Figure 50. Fire Fighters use Front End Loader to Respond to Fire, January 4, 2018

Figure 51. A Front-End Loader Struggles with Drifting Snow on the Turnpike in 2015

Convenience aside, the vulnerability here is emergency access, and access to repair infrastructure (powerlines and water/sewer infrastructure). Police, fire and ambulance services are only available from the mainland. When weather or flooding conditions require that the turnpike be closed, limited police, fire and rescue personnel remain on the Island. Department of Public Services and Utility (National Grid) only have access once the turnpike is deemed passable. Fording by boat from Plum Island Point may be possible, but unlikely during storm events and in the winter when there is river ice. Though the city owned Parking lot at Plum Island point could potentially serve as a helicopter landing area; it is currently laced with powerlines which would need to be relocated (*Figure 52. Plum Island Point Parking Lot – Power Lines Obstruct a Potential Helipad*). Access via the turnpike will only become more difficult in the future with sea level rise and increased coastal storm activity.

Figure 52. Plum Island Point Parking Lot – Power Lines Obstruct a Potential Helipad

Energy, Communication and Utility Vulnerability

Plum Island's electricity, Cable TV and internet communication lines are hung from a single row of utility poles that follow the turnpike from the mainland to Plum Island. The utility lines and poles themselves are vulnerable to wind, snow and ice as they are set to the side of the roadbed and into the underlying marsh, which is wet and soft, especially when flooded (*Figure 53. Utility Poles Bow to the Wind - Plum Island Turnpike March 2017*). The substrate where these poles are set will only become softer as sea levels continue to rise.

Weather and water levels aside, motor vehicle accidents today along the turnpike have shut down power and communication to the island for up to 6 hours during clear summer weather, as was the case in June of 2019 (*Figure 54. Turnpike Accident - Shuts off power to 1310 Plum Island Homes for 6 Hours*). Adding to the island's communication vulnerability is its "spotty" cellular phone reception. When the turnpike and its utility lines are compromised, the island and its residents can quickly become very isolated.

Figure 53. Utility Poles Bow to the Wind - Plum Island Turnpike March 2017

Figure 54. Turnpike Accident - Shuts off power to 1310 Plum Island Homes for 6 Hours

Water and Sewer Infrastructure

The Plum Island water and sewer systems are vulnerable due to the nature of where they are – on a barrier island with shifting topography and a coastal saline (i.e. corrosive) environment exposed to coastal storms. As part of a multi-year investigation to determine the cause of a premature failure of a water main along the Turnpike in April 2011, a settlement was made in 2016 and the City was awarded nearly $5 million. In general, the wrong type of metal was installed with no corrosion protection. The City used this money to repair the more critical components – it replaced all of the fire hydrants throughout the entire Island. This work was completed in the summer of 2019. The vast majority of the water and sewer piping (90% or more) is plastic pipe with some pipe joints having metallic components for restraints or valving. The City determined that no further mitigation to underground metallic components is warranted at this time and that the balance of the settlement is to be held in an account to be used for spot repairs needed in the future.

These utilities are uniquely vulnerable to coastal erosion from storms due to the physical instability of barrier islands. Shifting sands, erosion, and mayor breaches from storms are typical vulnerabilities that the city is concerned with – especially as our climate changes. Roads and underground utilities closest to the ocean, currently Reservation Terrace and parts of Northern Boulevard, are of immediate concern but as the Island shifts, other roads may end up being impacted.

The hazard of most concern is coastal flooding because that will impact the pumping station building on Olga Way and it could happen at any time. The tide nearly entered the building during the high tides of January 2018. Had that have happened, then the basement which houses the massive vacuum storage tanks and the main pumps on the ground floor level would have been badly damaged and would likely have shut down the Island. The building sits within a FEMA Flood Zone AE 13, which was revised upwards by FEMA after the building was built in 2004/05. The first floor is at approximately Elev. 9.5, which makes the sewage system and, therefore, habitation on the Island quite vulnerable to major flooding.

The underground utilities are generally not impacted by flooding unless a problem exists to these systems prior to or during the flooding event, such as a suction valve unable to close or a crack in the pipe or a valve manhole. On the Island, the sewer system is a closed, watertight piping system that runs from the home or building to a small holding tank structure where it remains until the vacuum sewer valve opens and the sewage gets sucked out due to negative pressure (a vacuum) imposed on the system from the vacuum pumps at the Olga Way Pumping Station. The sewage is transported to the pumping station where it is collected with other incoming sewage from throughout the Island. From there it is pumped into a force main that pushes the sewage to the WWTF. (*Figure 56. Winter Septic System Problems – Frozen Manholes*)

Current Flooding Risk– Plum Island

Today, virtually the entirety of Plum Island and the turnpike will be underwater during a 100-year flood event. During such an event, a significant portion of the island would be subject to significant wave action with a wave driven wash-over occurring along the entirety of the barrier dune and into the Plum Island Basin. The VE Zones are as high as Elevation 23 on the northeast shoreline and drop to Elevation 16 along the Reservation. Inland areas flood up to approximately Elevation 13 with many areas inundated by 2-feet of water, as shown in the AO Zones. During such an event, the Plum Island turnpike would become inundated and impassable, and the airport runways flooded. Damage will be extensive.

When hurricane surge potential is examined, the barrier island's vulnerability to coastal storms is again underscored (*Figure 55. Hurricane Storm Surge Inundation – Plum Island and the Plum Island Turnpike*). A worst-case scenario category 1 storm would flood the turnpike, the eastern most airport runway and inundate much of the island, especially from the rear. A worst-case category 2 storm would approach flooding levels associated with a FEMA 100-year event with significant wave driven wash over, especially with a strong and slow-moving category 2, or stronger storm.

Figure 55. Hurricane Storm Surge Inundation – Plum Island and the Plum Island

Figure 56. Winter Septic System Problems – Frozen Manholes

Future Sea Level Rise – Plum Island

Predicting where water levels will be on barrier islands after the seas rise is virtually impossible. Plum Island is largely comprised of sand, and sand is fluid and washes about through the combined actions of wind, waves, tides, currents and a rising water table. Ultimately the complex interaction of these processes will shape Plum Island's future, quite possibly long before sea level rise alone can inundate its topography. Visually, all that can be interpreted from future Plum Island SLR maps is where would water be today if the ocean were 2, 3, or 6 feet deeper. These flood inundation graphics are helpful for evaluating when the daily tide might compromise access via the turnpike and other roads on Plum Island.

Previous discussions and graphics have illustrated the causeway's current vulnerability to flooding. This vulnerability will only increase as sea levels continue to rise, and coastal storms become stronger. Figure 57 and Figure 58 reveal that with roughly 3 feet of SLR, possibly around 2070, the daily tide will begin to wash across the following roads twice daily, likely resulting in closures to traffic and eventually, the possible destabilization of the roadbed itself at:

- the Plum Island turnpike (up to Northern Blvd at Plum Island Center)
- Old Point Road and
- Sunset Blvd

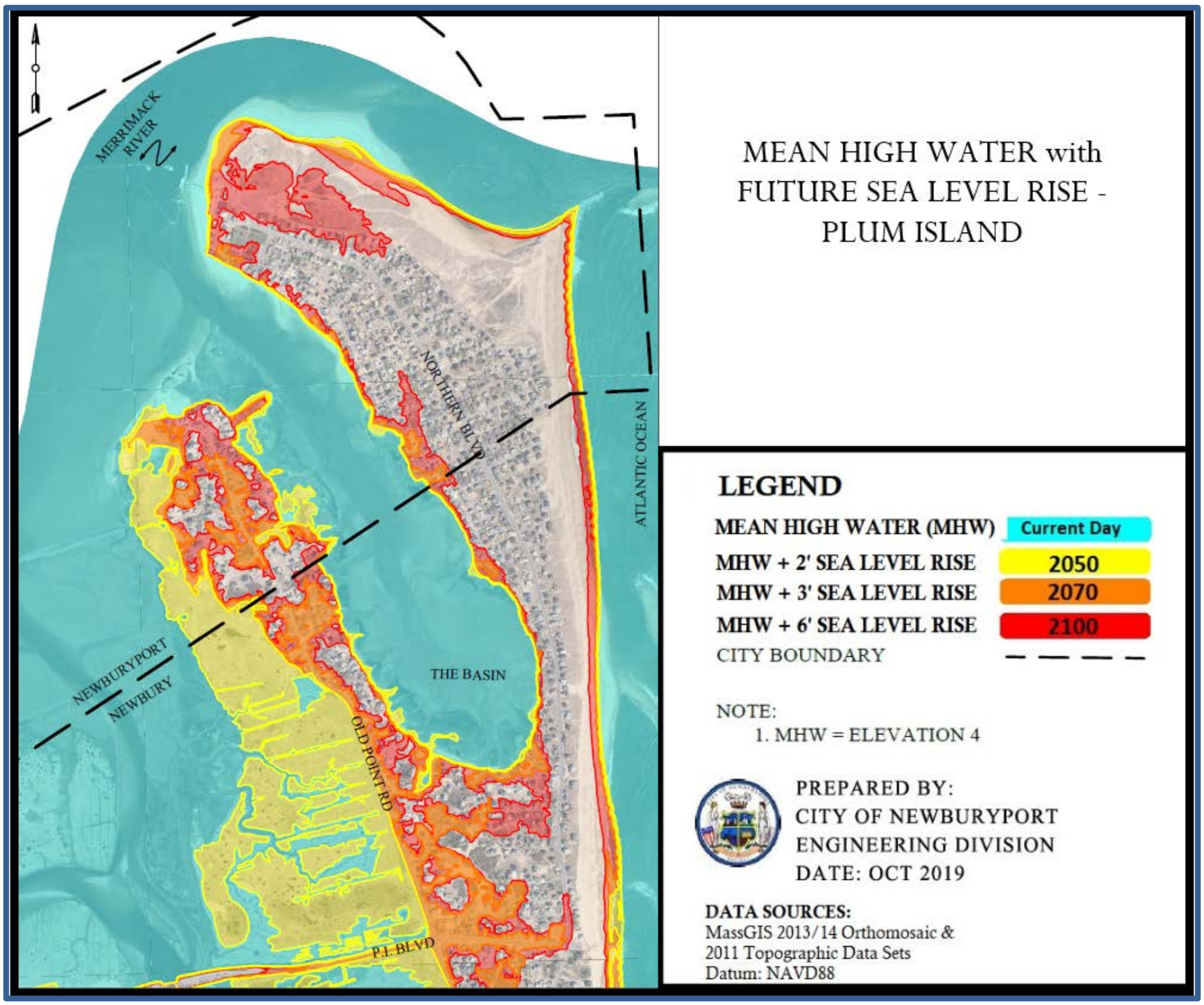


Figure 57. Future Sea Level Rise – Plum Island

Furthermore, at about the same time, the daily tide would inundate the runways of the Plum Island Airport, compromising access there as well. The king tides that coincided with the March storms of 2018 provided a glimpse of what that future would look like (*Figure 59. Plum Island Flooding March 3, 2018*).

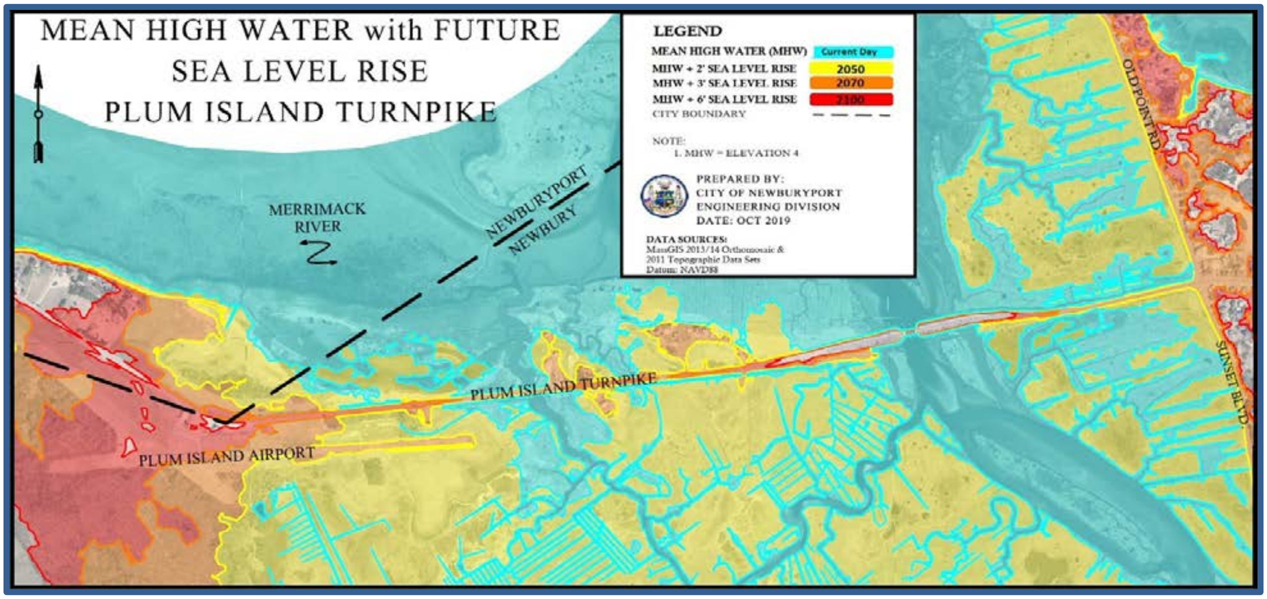


Figure 58. Future Sea Level Rise – Plum Island Turnpike

Figure 59. Plum Island Flooding March 3, 2018

Future SLR plus Inundation - (Current FEMA)- Plum Island

Previous graphics have illustrated that Plum Island today is critically vulnerable to the 100-year flood and Hurricane surge. This vulnerability only increases as sea levels rise and our climate continues to spawn stronger coastal storms. The most substantial influence of climate change upon storm-induced flooding will be the increase in sea levels, which will increase the baseline water depth upon which the storm tide, surge, and waves will ride in.

As today's FEMA 100-year inundation virtually overruns Plum Island, when future SLR is superimposed on this inundation (*Figure 60. Flood Inundation and Future Sea Level Rise – Plum Island*) today's already severe impacts are only exacerbated.

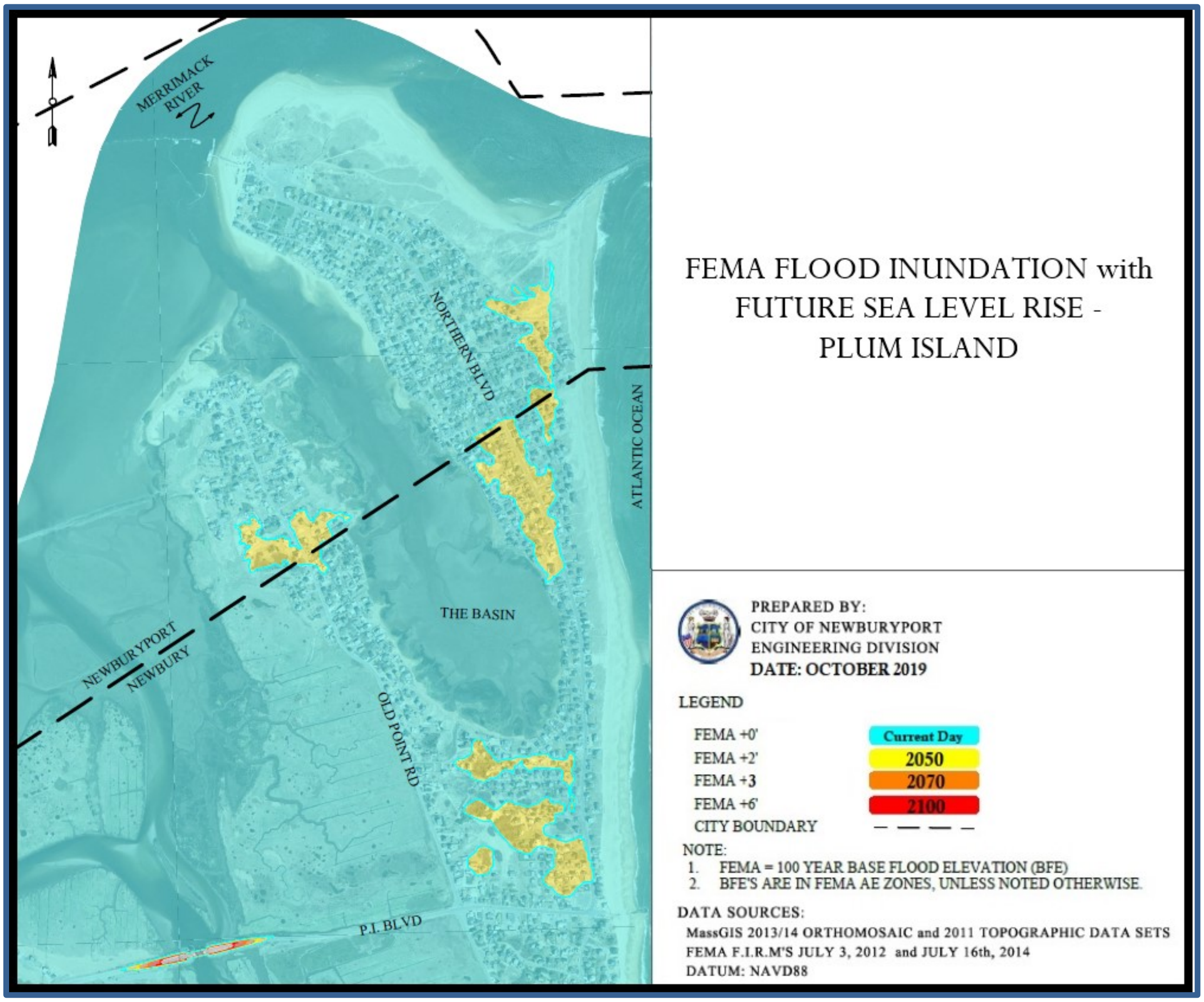


Figure 60. Flood Inundation and Future Sea Level Rise – Plum Island

Barrier Island Migration

Finally, the landward migration of barrier beaches in a rising sea scenario needs to be recognized as an evolving vulnerability to Plum Island. Earlier in this chapter the formation of Plum Island was discussed, and it described how, over the last 10,000 years, coastal processes (water, wind, waves, currents and storms) coupled with a slowly rising sea gathered glacial sediments and pushed them westward to form the barrier. In more recent history (last 4000 years) Plum Island grew seaward faster than it moved westward. This has happened as wave and river deposition of glacial sands along its shore outpaced sea level rise and erosion, allowing winds to incorporate those sediments into the island's dune system to build a relatively tall barrier beach. Today, the pace of sea level rise has accelerated in response to climate change and considering erosion and storm events over the last 15 years, one needs to question whether the island (and Salisbury Beach across the inlet) might be in the early stages of moving westward again.

Flood and sea level rise inundation maps fail to tell the entire story relative to what might happen when the forces of sea level rise, storm surge, wave activity, a flooding river and a rising water table ***interact*** sometime in the future. Inundation maps only paint where water will be, given certain depths and topographic heights. Barrier beaches, however, are made of sand, which when submerged in water becomes very fluid. Will Plum Island's foreshore and dune system be significantly compromised with 3 feet of sea level rise, or will it only take only an additional foot? Plum Island's historical response to sea level rise suggests that at some point in the future, the island may likely resume its westward migration in response to *accelerating* sea level rise, leaving infrastructure and house lots behind.

Given events of the past decade, one must consider whether this has already begun. Storm surge and waves today are riding in on waters that are already a foot deeper than they were 100 years ago. These forces are challenging the foreshore and barrier dune system of both Plum Island and the neighboring barrier island of Salisbury beach. Threatened homes along both shores, coupled with some evidence of a receding shoreline in the wildlife refuge, and the emergence of ancient marsh along the ocean shore of Salisbury beach hint that these barrier beaches may again be on the move, and are no longer expanding seaward, but rather are in the early stages of moving westward.

Camp Sea Haven – Plum Island

Located in the southern third of Plum Island, Camp Sea haven was once a summer camp for children with polio and other disabilities (Figure 61. Camp Sea Haven Location and Figure 62. Camp Sea Haven – View Westward. Polio was eradicated in the '50s and '60s and though the camp welcomed others with disabilities, the high cost of administration and the push by federal officials to develop a refuge for wildlife resulted in its closure and subsequent dismantling in 1988. Its former location might offer some insight as to the barrier island's geologic intentions.

Figure 61. Camp Sea Haven Location

Figure 62. Camp Sea Haven – View Westward

Following the dismantling of the camp, its saltwater swimming pool, septic system and more importantly a tall utility pole remained. It is these structures that serve as a reference point to track westward shoreline migration over the last 33 years (1985-2018). Using the utility pole as a fixed reference one can see how the barrier dune crest at the camp retreated some 72 feet during this 33-year period (**GRAPHIC 62:** Camp Sea Haven Shoreline Retreat 1985 and 2018).

It is important to note, that there is no evidence of an erosional "hotspot" in this area, rather, the entire shore along the wildlife refuge is rather uniform, suggesting the entire shoreline has stepped back towards the mainland. This is consistent with barrier island behavior in a rising sea scenario.

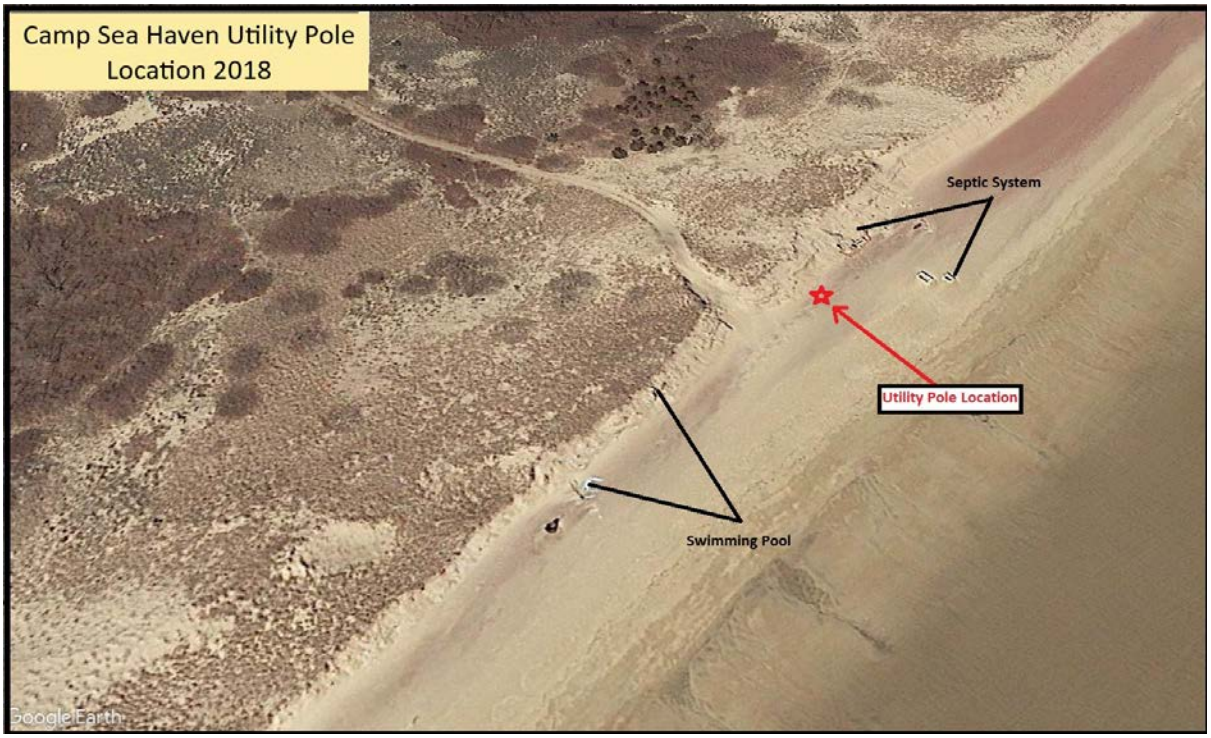


Figure 63. Camp Sea Haven Shoreline Retreat 1985 and 2018

Salisbury Beach – Evidence of Barrier Island Retreat

The barrier Island of Salisbury beach lies to the north of Plum Island across the Merrimack River Inlet (Figure 64. Plum Island and Salisbury Barrier Beaches). Like Plum Island, Salisbury Beach has been in the news relative to coastal storm impacts and its struggles with beach erosion. Like Plum Island, Salisbury's Barrier evolved in the same way as a result of coastal processes gathering glacial sediments and pushing them westward to form the barrier. Also, like Plum Island, Salisbury had, and still has an expansive salt marsh to its rear. Following the stormy winter of 2012-2013, erosion of Salisbury's foreshore began to reveal evidence of the barrier island's past – the remains of an ancient salt marsh (complete with horse hoof prints) that used to reside ***behind*** Salisbury's Barrier Island (Figure 65).

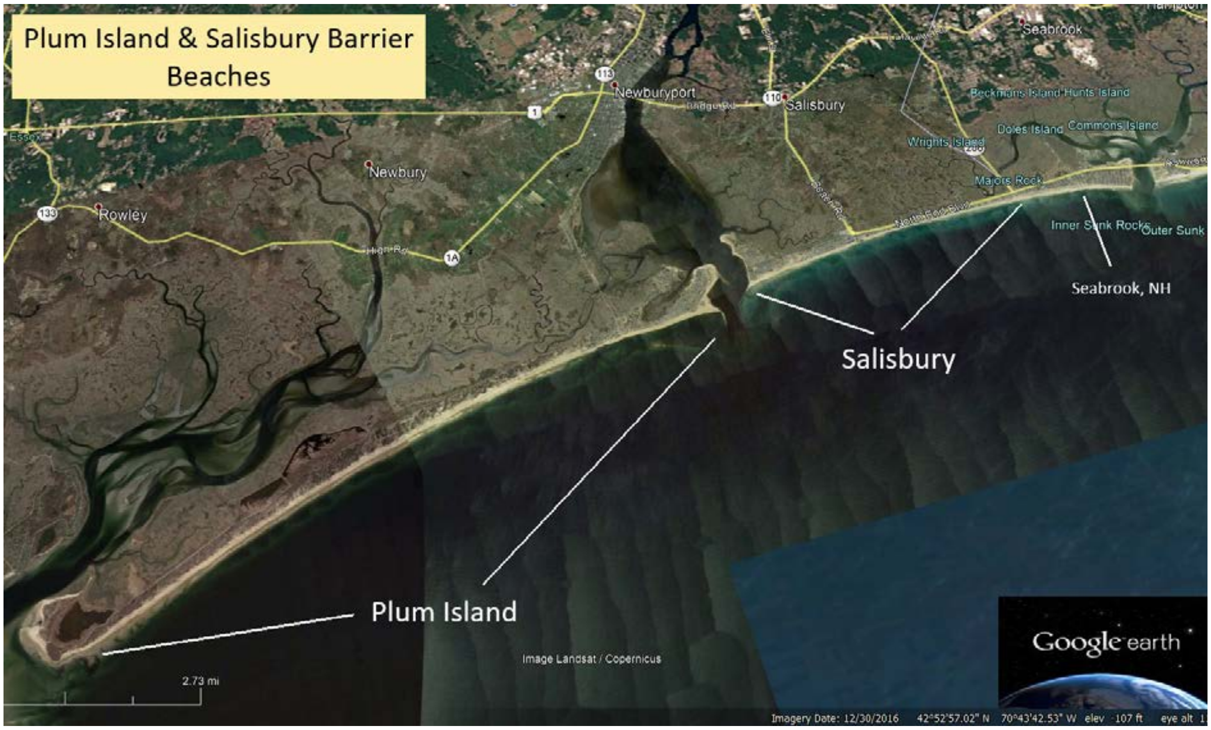


Figure 64. Plum Island and Salisbury Barrier Beaches

So how did a marsh that once resided behind an island emerge in front of it? The island traversed westward over it. And how was this accomplished? By waves and storm surge eroding the foreshore to a point where they overtopped the barrier dune, washing foreshore sands to the rear and over the existing salt marsh. Figure 65. Ancient Salt Marsh Beds, Near Shore and Onshore – Salisbury Beach) shows where Salisbury beach was over-washed at some point in its undeveloped past. Homes and other structures were subsequently developed atop of these sandy fans. John O'Connell, an engineer and member of Newburyport's Climate Resiliency Committee encountered salt marsh peat while excavating under those areas of Salisbury's over-wash fans.

Figure 65. Ancient Salt Marsh Beds, Near Shore and Onshore – Salisbury Beach

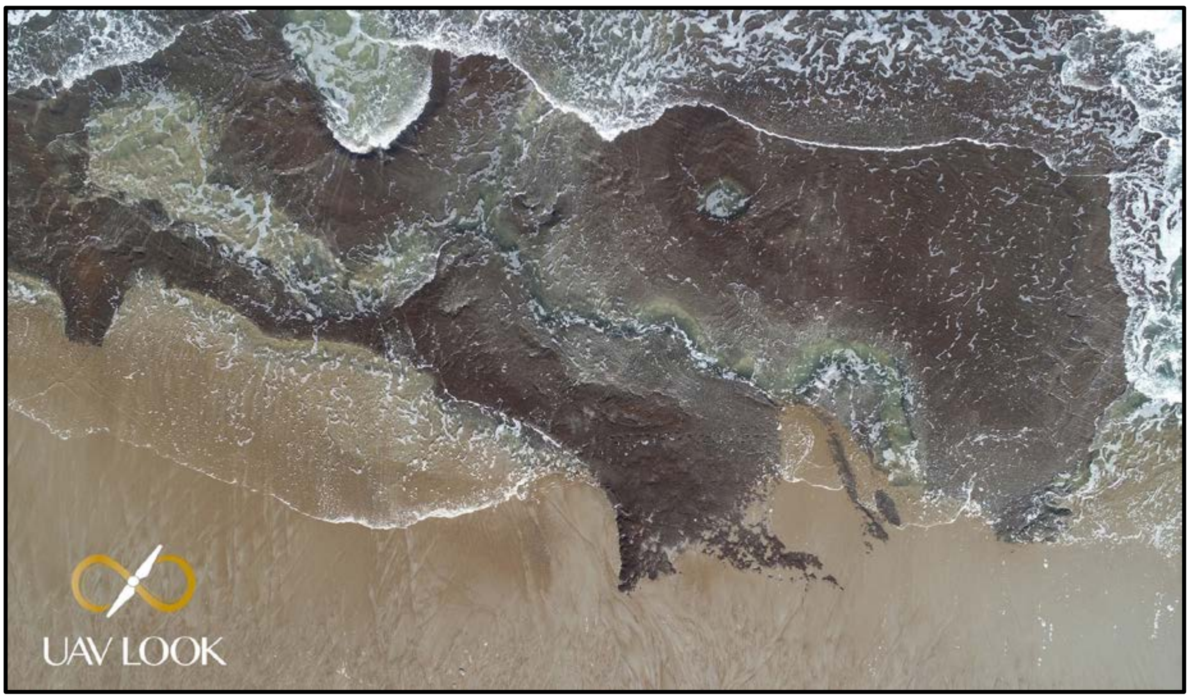


Figure 66. Onshore Ancient Salt Marsh Beds, Low Tide – Salisbury Beach

Figure 67. Onshore Ancient Salt Marsh Beds, Low Tide – Salisbury Beach - Photo: Sandy Tilton

Figure 68. Horse Hoof Prints – Ancient Salt Marsh – Salisbury Beach - Photo: Sandy Tilton

Figure 69. Salisbury Beach Ancient Over-wash Fans

It is important to recognize that Plum Island is a tall barrier island and contains an immense quantity of sand. It will likely take some time and many storms for it to experience a significant wash over and retreat in earnest. Camp Seahaven represents only one data point and so a more detailed assessment needs to be made to accurately quantify this shore's behavior.

However, it is also important to recognize the vulnerability here. Plum Island represents a significant portion of **this** city's, and more so Newbury's, tax base. Without fiscal countermeasures, the eventual erosion of the real-estate tax base on Plum Island will significantly impact the respective operating budgets of these two municipalities.

2.2.3.b Joppa to the National Grid Substation

The area known as Joppa spans from roughly Woodbridge Island all the way to the National Grid facility that borders Newburyport's Central Waterfront. Its vulnerability to flooding is unique from other areas of the city in that it is the only area of the city outside of Plum Island that is subject to flooding from wave activity. In addition to wave runup (how far waves wash up along a shore) and set up (the volume of water waves pile up along a shore), the area is exposed to storm and wind driven surge, river flooding and flooding from impervious surface runoff from the densely developed neighborhoods and streets uphill of Water Street.

The Merrimack River Delta, Wind Fetch, Wind Driven Surge and Wave Activity

After flowing past the area of the Wastewater treatment facility, the Merrimack fans out to form its delta which is flanked by salt marsh to the north and south. During high water levels, be it the daily tide, river run off, or ocean surge the area forms a large body of water that is subject to the wind. The fetch (distance over which the wind blows) within Joppa, can range from a low of 2.2 miles (Audubon Center to Salisbury Reservation) to a high of 2.8 miles (National Grid to the River Entrance) *Figure 70. Wind Fetch Across the Merrimack River Delta*.

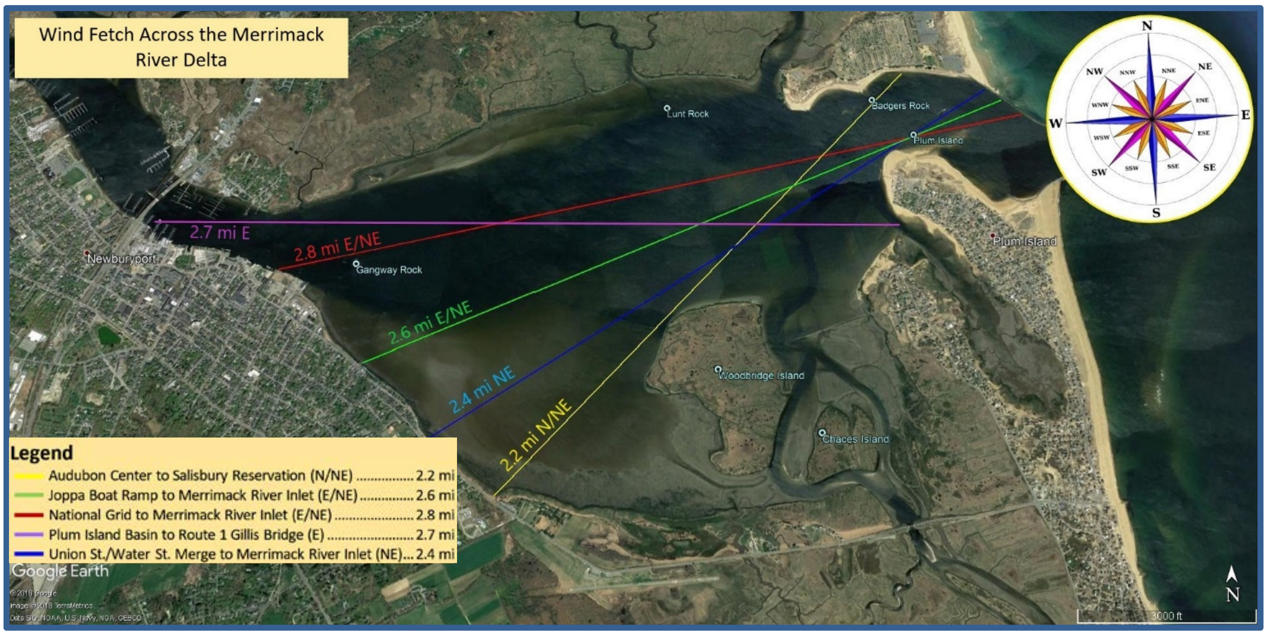


Figure 70. Wind Fetch Across the Merrimack River Delta

A significant fetch over a body of water can drive a wind driven surge and wave activity onto a shore, pinning it there, thereby flooding the area. In the case of Joppa, its exposure faces the northeast. When gales blow from this direction, water and waves are driven across the delta from Salisbury towards Newburyport, deepening waters there. Though the wind driven surge by itself can cause flooding, waves riding in atop of the surge's deeper waters are less attenuated by the once shallow river bottom, thereby enhancing their runup (reach). Overtime, a positive feedback loop is established where waves pile even more water along the shore (over and above the surge), allowing subsequent waves to wash even further inland. Historically, it is for this reason that the Joppa sea wall was built (*Figure 71. Wave Approach to Joppa - Water St. Sea Wall – Photos: John Morris*).

Figure 71. Wave Approach to Joppa - Water St. Sea Wall – Photos: John Morris

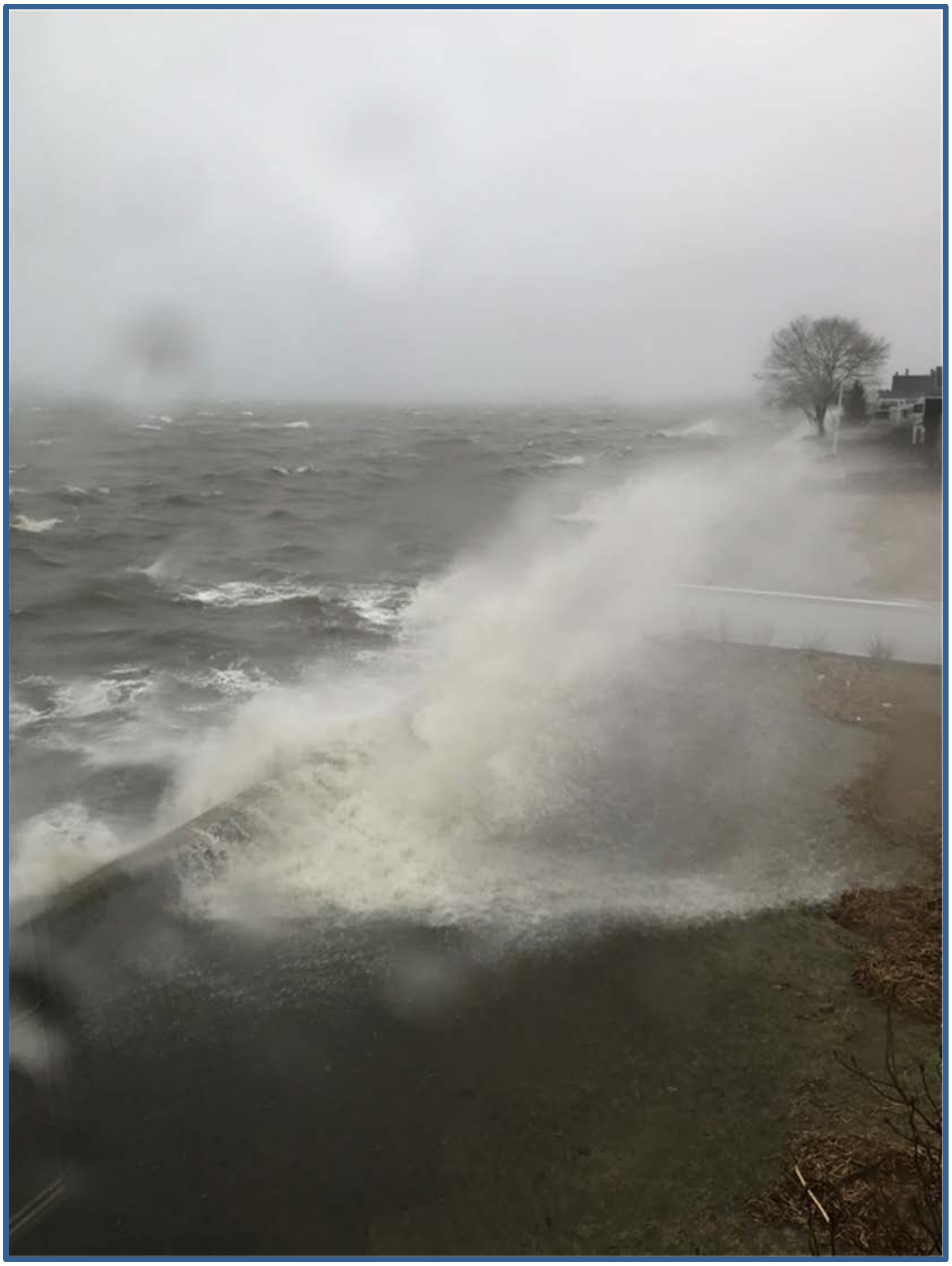


Figure 72. Wave Over-wash is Trapped behind Hale Park Seawall – Photo: John Morris

Wave size is governed by the interaction of three mathematical variables: wind speed, duration (time), and the distance (fetch) over which the wind blows. Fortunately for Joppa its relatively short fetch across the delta limits wave height. However, provided winds are strong and from the right direction, the distance is still large enough to develop significant waves whose splash over and spray overtop the Water Street sea wall, flooding the street and homes there (*Figure 72. Wave Over-wash is Trapped behind Hale Park Seawall – Photo: John Morris*). When the forces of wind driven surge and waves combine, we also see flooding near the intersection of Union and Water Streets and near the Mass Audubon Center, making roads impassable (*Figure 73. Joppa Surge and Wave Flooding near Mass. Audubon Center - March 2018*).

Figure 73. Joppa Surge and Wave Flooding near Mass. Audubon Center - March 2018

Though the National Grid Substation and Wastewater treatment facility are exposed to the longest measured fetch (2.8 miles), to date they have not yet been compromised, though they are vulnerable. There are two reasons for this. First, the wind fetch "window" is relatively narrow, meaning that the chances of a storm delivering that very narrow angle of "optimum" wind direction at the right speed for a significant period of time is statistically less likely than the area of Joppa park which has a wider window of exposure. Secondly, because the WWTF's shoreline does not face directly at incoming waves and wind, when significant wind and waves are generated, waves and surge can only deliver a "glancing blow".

Within the area of Joppa, if wind direction deviates from the longest measured fetch by 15-20 degrees, then the fetch is significantly reduced, and wave impacts subside. A significant amount of winter ice across Joppa or a low tide during the peak of a storm are also protective as they greatly reduce the fetch across open water. However, as the pictures reveal, nature often aligns the variables to effectively flood this area.

Impervious Surface Run-off

Moving west along Water Street from the Mass Audubon Center towards Market Square, we enter Newburyport's old "South End" which is densely populated with small house lots, closely spaced homes and streets. Here Newburyport's topography and the percentage of impervious surface area begins to rise. During coastal storms where there is significant wind driven surge, coupled with wave splash over along the sea wall and heavy precipitation and run-off, the three elements combine to flood Water Street from Joppa Park east through Hale Park (*Figure 73. Joppa Surge and Wave Flooding near Mass. Audubon Center - March 2018* and *Figure 74. Run Off, Surge and Wave Splash-over Trapped Behind the Seawall – March 2018*).

Figure 74. Run Off, Surge and Wave Splash-over Trapped Behind the Seawall – March 2018

Current Flood Risk – Joppa

Currently, a significant area of Joppa extending well across from Water St. is at risk for the FEMA 100-year flood. This vulnerability is further underscored when considering Joppa's vulnerability to Hurricane surge inundation (*Figure 75. Hurricane Storm Surge Inundation* - Joppa).

A worst-case scenario category one storm would deliver a surge comparable to a strong Nor'easter that the area already experiences. However, a worst-case scenario category 2 system with optimal approach would significantly flood properties along the seawall and Water St. itself. Particularly vulnerable areas include the low-lying area at the Union/Water St. merge, and the Joppa boat ramp where there is an opening in the wall that allows flood waters to surge in.

Future Sea Level Rise- Joppa

Around the year 2070, the daily tide is predicted to wash onto the vulnerable areas of Water St. near the Joppa Boat ramp, the Union/Water St. Merge and the Plum Island turnpike just west of the Massachusetts Audubon Center (*Figure 76. Future Sea Level Rise – Joppa*).

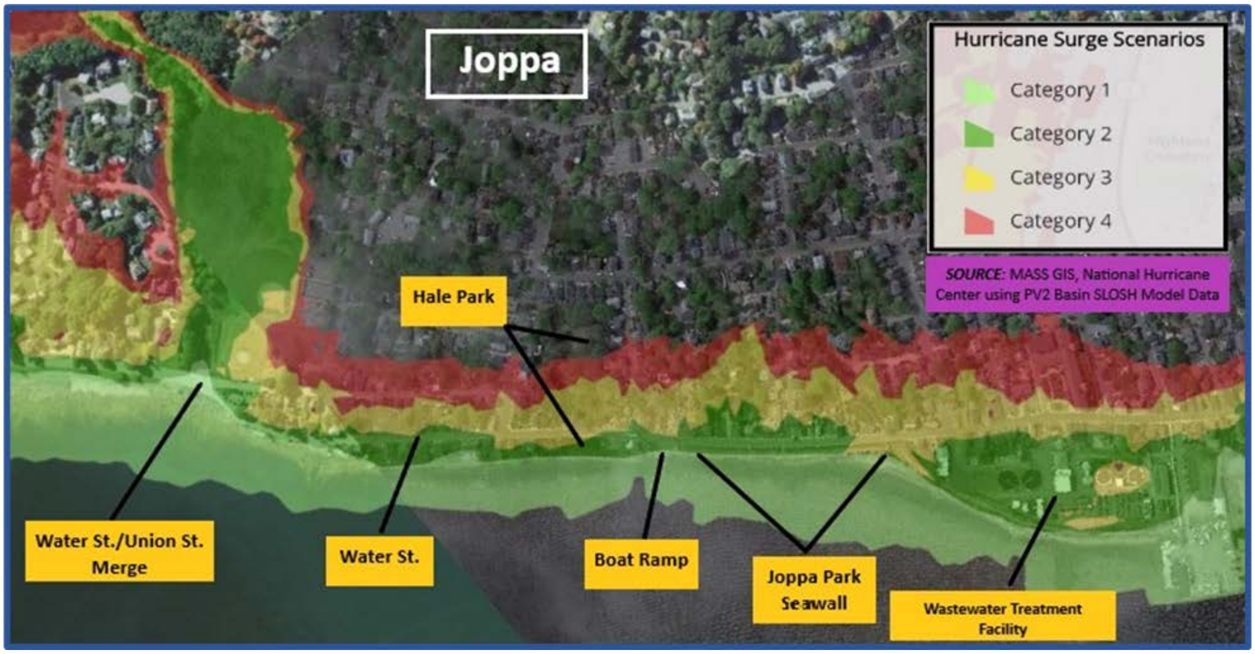


Figure 75. Hurricane Storm Surge Inundation - Joppa

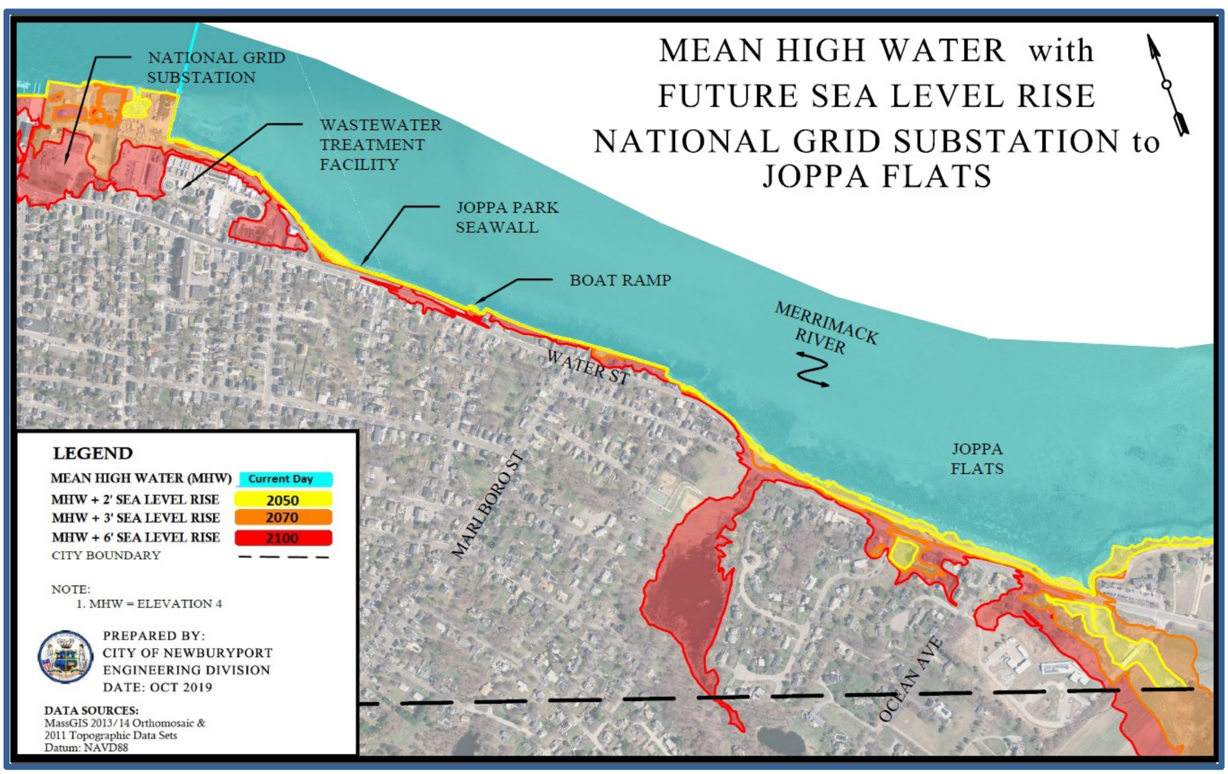


Figure 76. Future Sea Level Rise – Joppa

Future SLR plus Inundation - (Current FEMA) – Joppa

As was mentioned previously, the area just inland of Water St. is currently at risk for today's FEMA 100-year flood inundation. During the years 2050-2070 we see sea level rise extend the flood plain inland, further increasing the risk of areas currently within the FEMA 100-year flood zone and endangering others (*Figure 76. Hurricane Storm Surge Inundation - Joppa* and *Figure 77. Flood Inundation and Future Sea Level Rise – Joppa)*.

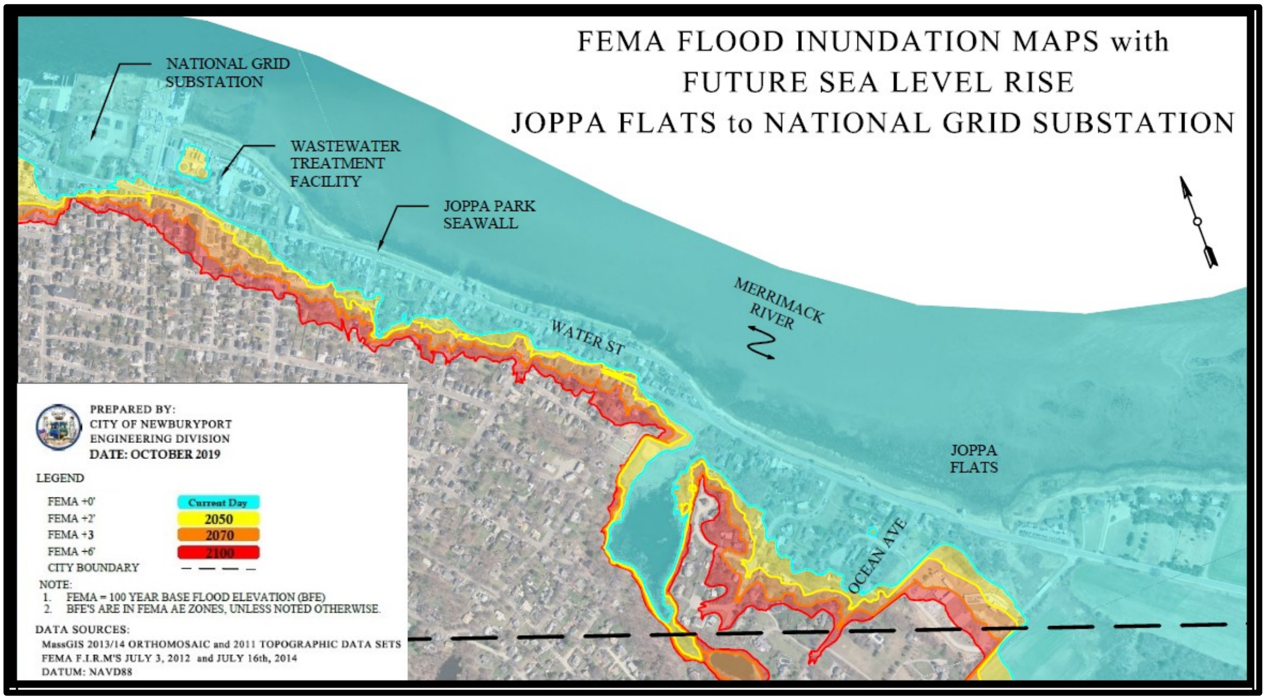


Figure 77. Flood Inundation and Future Sea Level Rise – Joppa

2.2.3.c The National Grid Substation to the Route 1 (Gillis) Bridge – Downtown and Waterfront

Much of Newburyport's historic downtown waterfront along Water Street is located at an elevation that is sufficiently protected from all but the most severe storm surges. Natural topography, combined with an array of bulkheads and other gray infrastructure, protect much of the downtown. However, infrastructure located immediately along the bank of the Merrimack, including the boardwalk, 54R Merrimac Street (the former location of the Black Cow Restaurant) and other bordering businesses, are quite vulnerable to flooding and sea level rise, though wave impacts are less than compared to Joppa (*Figure 78. Waterfront River and Surge Flooding March 3, 2018*).

Due to a narrowing of the river in this area, the shoreline here is a bit more protected from the wind than Joppa to the east. But a narrow window of exposure either side of 90 degrees (east) reveals a fetch of 2.7 miles to Plum Island. Though this fetch is a risk, two factors minimize wind driven wave and surge impacts. First, the fetch is directed more upriver than directly at the shoreline as in Joppa. Waves will travel past the area or impact it at an angle, and the wind driven surge, while raising water levels, would not be pinned to the shore as it is in Joppa. Secondly, the narrow window of exposure itself is protective as it requires that a very focused wind direction be sustained for a significant period. Winds during storms typically shift as the storm travels, so unless a system stalls in the "perfect" location, or winds from the east are incredibly intense, the potential of this fetch is often not realized. This may explain why this area and the abutting Wastewater treatment facility have largely been spared when compared to Joppa. Still, wind driven surge and wave setup and runup are factors here which are reflected in the higher FEMA base flood elevation (BFE) of this area when compared to Cashman Park on the other side of the Route 1 Bridge.

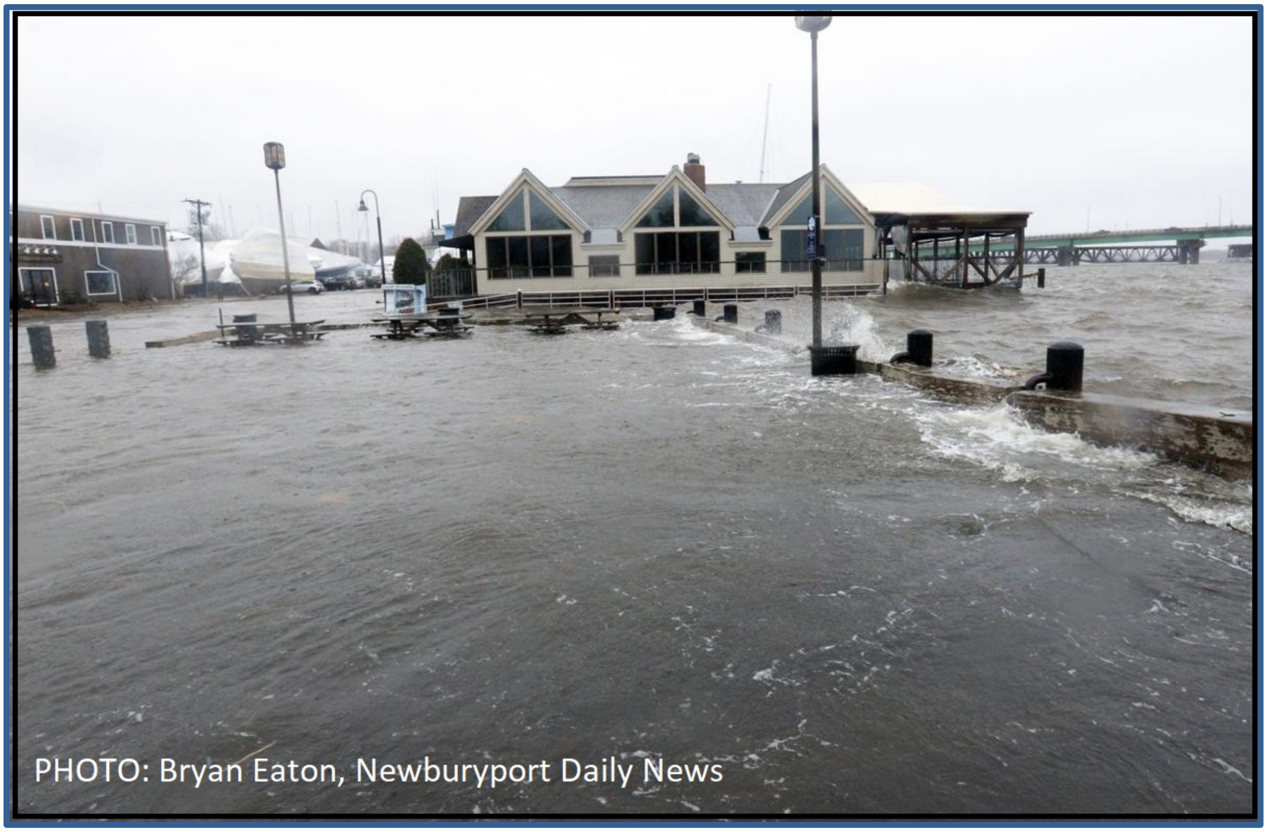


Figure 78. Waterfront River and Surge Flooding March 3, 2018

Impervious Surface Run-off

Newburyport's downtown area rises from the Central Waterfront towards High Street and, as is typical of urban areas, is densely developed with many streets, sidewalks, parking lots and other impervious surfaces. When subject to heavy rainfall, the city's older municipal drainage system is often overwhelmed as it isn't designed to accommodate today's increased rainfall amounts. The city's drainage system is designed to handle the peak runoff from a 10-year storm, and more often today, those rainfall volumes are exceeded. Additionally, the aging system of underground pipes are leaky and being infiltrated by water volumes beyond what the storm drains supply. The effects of climate change coupled with an aging drainage system, and large proportion of uphill impervious surfaces, greatly increases the vulnerability of the city's downtown areas such as Market Square to flooding. Figure 79 visually illustrates how little "open" ground there is relative to impervious roof tops, parking lots, sidewalks and roadways. Rainfall here must either find its way into the city's aging drainage system or run down the streets towards the river where, if it encounters barriers to flow, will pool and cause flooding. Figure 80 bears witness to such an event.

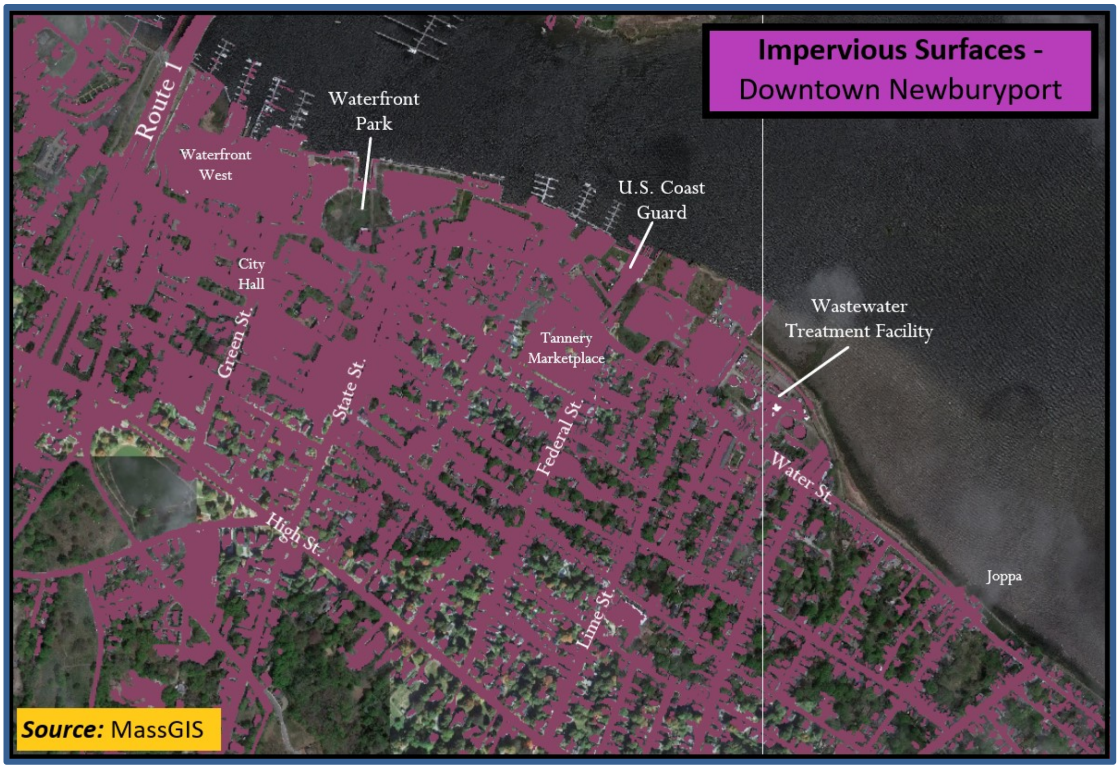


Figure 79. Downtown Newburyport's Impervious Surfaces

Figure 80. Market Square Runoff, Hurricane Florence Remnants, Sept 18, 2018

Current Flood Risk – Downtown Waterfront – (National Grid to Route 1 Gillis Bridge)

FEMA believes that the current 1% inundation would flood much of this area up to about Water and Merrimac Streets. *Figure 81. Hurricane Storm Surge Inundation – Downtown Waterfront* reveals that a worst-case scenario category 1 storm today would inundate much of the area to the west of Waterfront Park. A worst-case category 2 surge would drive flood waters across Water St. near the Federal St. and Fair St. intersections, and would inundate the remainder of waterfront west to the route 1 Gillis bridge.

Figure 81. Hurricane Storm Surge Inundation – Downtown Waterfront

Future Sea Level Rise – Downtown Waterfront

Sometime after 2050, if sea level rise exceeds 2 feet and approaches 3 feet (2070), the daily tide will encroach upon much of the area (*Figure 82. Future Sea Level Rise – Downtown Area* and *Figure 83. Future Sea Level Rise ZOOM – Central and Waterfront West*). Predicted year 2100 water levels of 6 feet would have daily tide inundations resembling today's worst-case category 2 storm surge. *Figure 83. Future Sea Level Rise ZOOM – Central and Waterfront West* provides a more detailed look at predicted future tidal inundation of this economically vital area. It is important to note that the area's popular boardwalk and riverfront businesses are first in line to be compromised by sea level rise, followed by the expansive waterfront parking area to the rear. The city will need to plan for the vulnerability, relocation or potential loss of these economically valuable amenities.

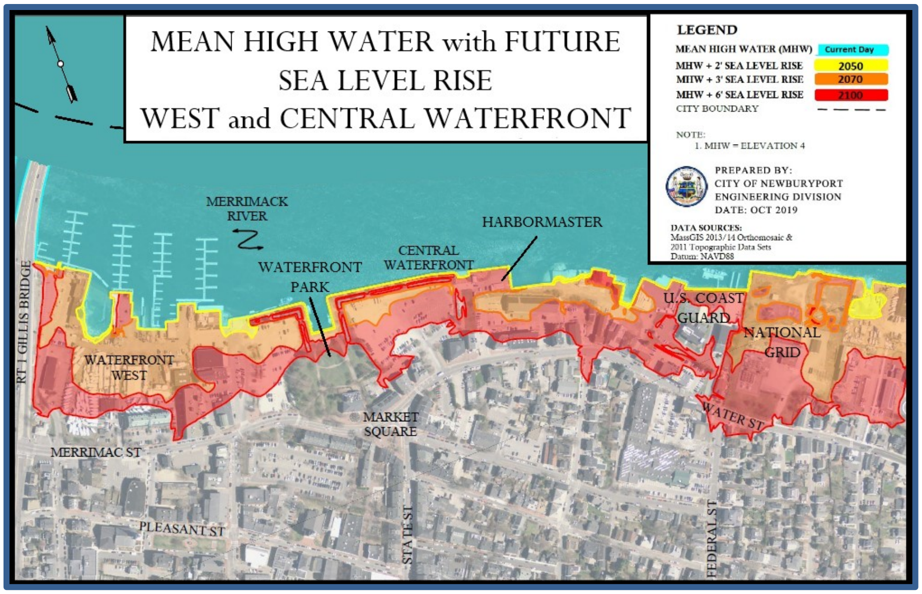


Figure 82. Future Sea Level Rise – Downtown Area

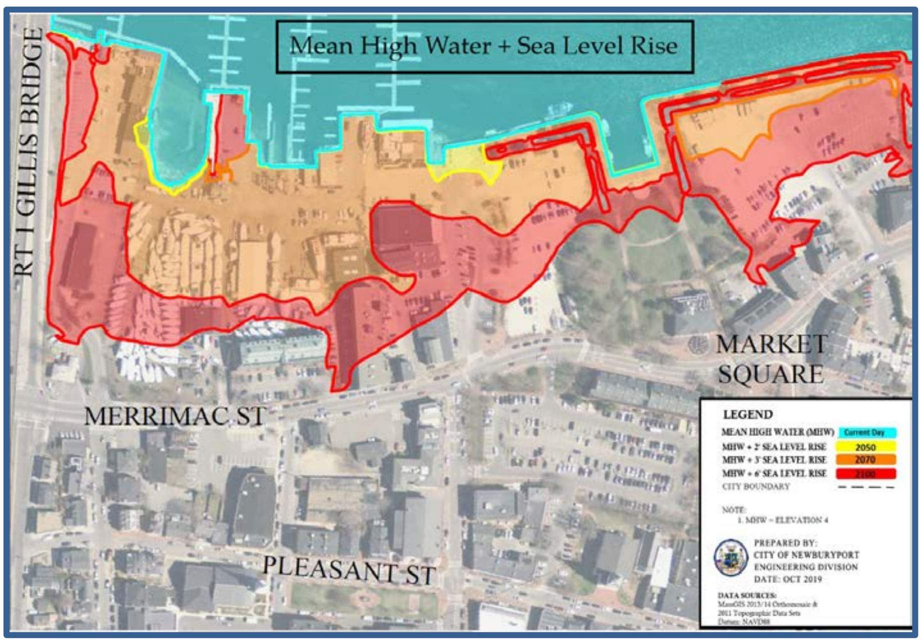


Figure 83. Future Sea Level Rise ZOOM – Central and Waterfront West

Future SLR plus Inundation - (Current FEMA) – Downtown Area

Future sea level rise greatly expands the 100-year flood plain into Newburyport's vibrant downtown district. By 2050 this zone is predicted to extend across Merrimac St. to the edge of the police station, well into Market Square, Liberty and Fair Streets, as well as much of the Tannery Marketplace (*Figure 84. Flood Inundation and Future Sea Level Rise – Downtown Waterfront*).

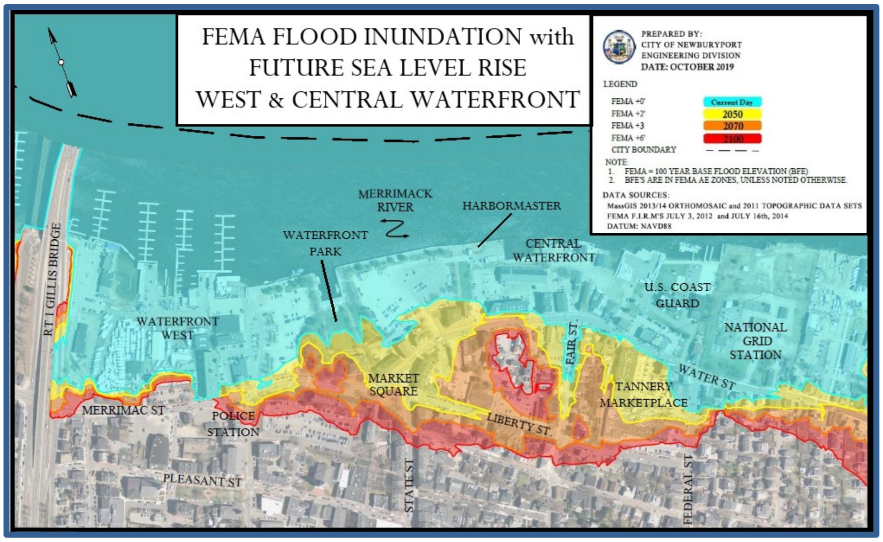


Figure 84. Flood Inundation and Future Sea Level Rise – Downtown Waterfront

A more detailed view of Waterfront West, the central Waterfront and Market Square is provided by *Figure 85. Flood Inundation and Future Sea Level Rise - Central and Waterfront West*. After 2050, future sea level rise increases the risk exposure of many more downtown properties and city infrastructure to the FEMA 100-year inundation. As the National Flood Insurance program is further stressed by future disaster claims, one would expect flood insurance rate increases to properties located in high risk zones. Therefore, the maps don't just illustrate the expanding future risk of inundation, they also illustrate the exposure of properties to increasing flood insurance premiums.

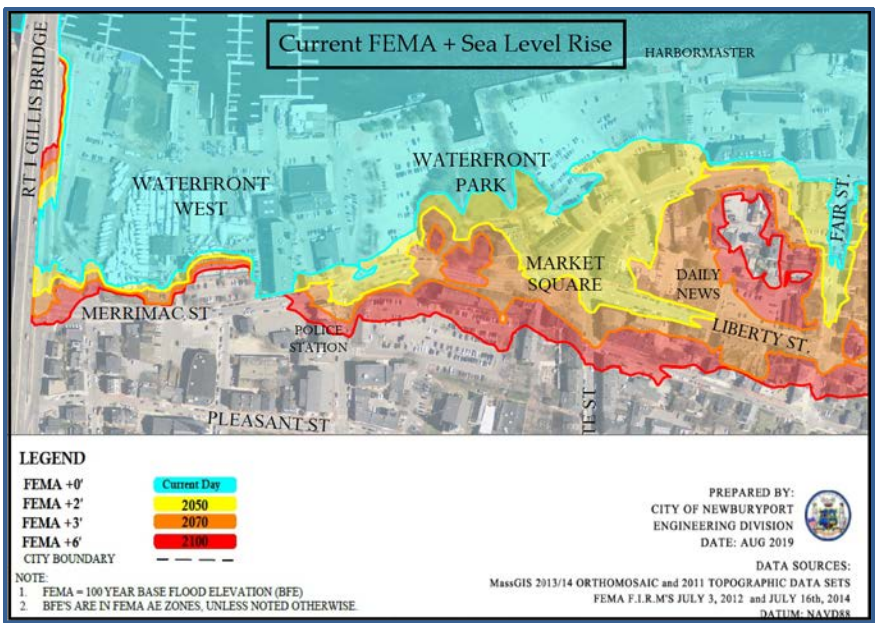


Figure 85. Flood Inundation and Future Sea Level Rise - Central and Waterfront West

2.2.3.d The Route 1 Gillis Bridge to the I-95 Bridge – Cashman Park and Merrimac St.

Like the city's downtown waterfront area, the Merrimack here is relatively narrow when compared to the delta near Joppa. The river in this area is also bisected by two islands with a large salt marsh located across the Merrimack in Salisbury. These features are protective as they don't allow for a significant wind fetch to generate waves. Therefore, flooding vulnerability here is primarily influenced by sea level rise, tides, storm surge, and river rain/storm water levels. Inundation by the 2006 Mother's Day Storm, the April 2007 Northeast Storm and the March 3rd 2018 coastal storm revealed vulnerable areas to include the River's Edge Condominiums just west of the Route 1 Bridge, Cashman Park and the Pentucket Medical – Towle Building parking lot, (including the Newburyport Landing condominium complex) the North End Boat Club property and other private river front properties located upriver. Figures 85 through 88 depict the extent of inundation of these areas during the previously mentioned storms.

Figure 86. River's Edge Condominiums Flood During the April 2007 Northeaster

Figure 87. Cashman Park Flooding April 2007 Northeaster

Figure 88. Flooding Cashman Park Boat Ramp March 3, 2018 Storm

Figure 89. Flooding North End Boat Club March 3, 2018

Current Flood Risk – The Route 1 Gillis Bridge to the I-95 Bridge – Cashman Park and Merrimac St.

As much of this area between the river and Merrimac St. lies within the current FEMA 100-year flood zone, virtually the entirety of Cashman Park is vulnerable to the surge of a worst-case scenario category 1 hurricane. A worst-case category 2 storm would inundate it entirely, along with adjoining properties (Figure 90. Hurricane Storm Surge Inundation – Cashman Park).

The portion of Merrimac Street landward of the Mersen Building (372 Merrimac St.) also resides within the FEMA 100-year flood zone and is therefore vulnerable to a worst-case category 1 and 2 hurricane inundation (*Figure 91. Hurricane Storm Surge Inundation – Mersen Area*).

Figure 90. Hurricane Storm Surge Inundation – Cashman Park

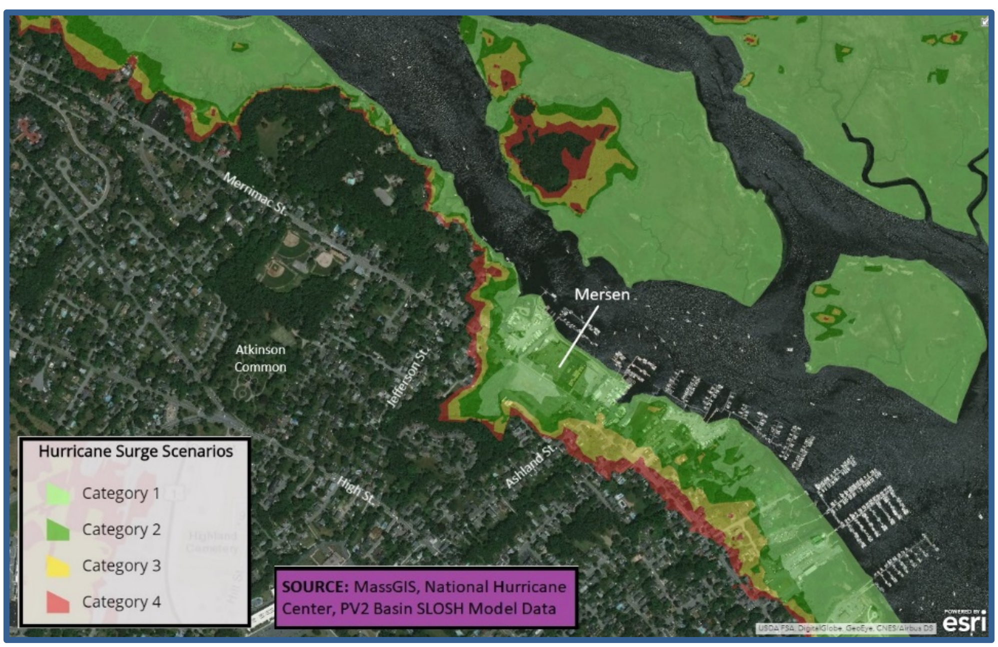


Figure 91. Hurricane Storm Surge Inundation – Mersen Area

Future Sea Level Rise- Route 1 Gillis Bridge to the I-95 Bridge – Cashman Park and Merrimac St

It is predicted that the daily tide might begin to encroach upon Cashman Park (likely spilling in through the two boat ramps) around the year 2050, when sea level might rise by an additional 2 feet. It is when sea level rises to 3 feet, possibly around the year 2070, that the daily tide will wash across nearly all of the park, significantly affecting its current utility (*Figure 93. Future Sea Level Rise ZOOM – Cashman Park to Mersen (372 Merrimac St.*).

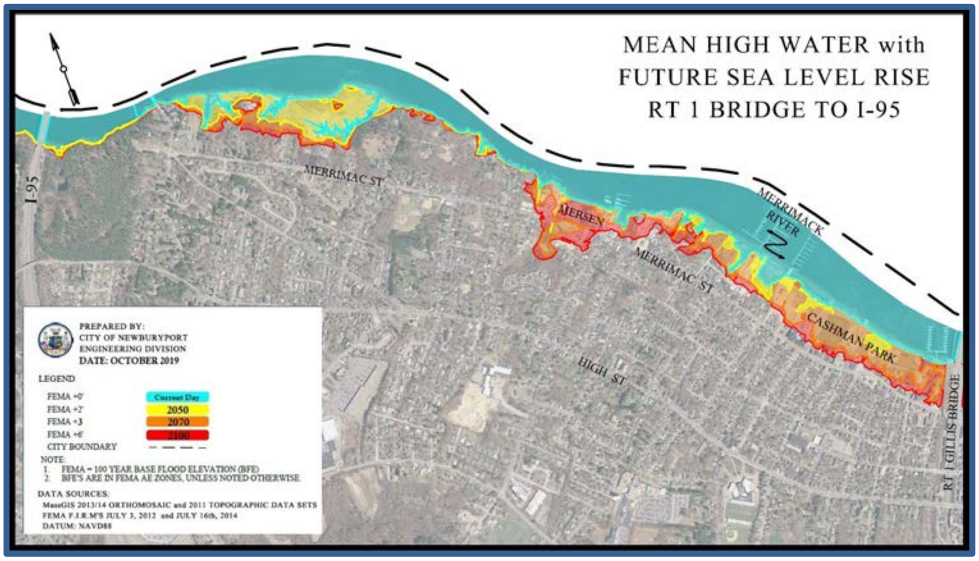


Figure 92. Future Sea Level Rise – Route 1 Gillis Bridge to I-95 Bridge

If sea level predictions hold true, it is expected that the daily tide will encroach upon Merrimac St. near Mersen (372 Merrimac St.) around the year 2070, and by 2100 it might be washing across the street into the Mersen parking lot twice daily. Year 2100 water levels of 6 feet would also have the daily tide inundate property from the River's Edge condominiums westward through Pop Crowley Way, Cashman Park, the North End Boat Club and Mersen itself. Because the area's topography begins to rise as one travels west on Merrimac St. past Mersen, sea level rise inundations are tempered and limited to marsh areas along the river (*Figure 92. Future Sea Level Rise – Route 1 Gillis Bridge to I-95 Bridge and Figure 93. Future Sea Level Rise ZOOM – Cashman Park to Mersen (372 Merrimac St.)*).

Future SLR plus Inundation - (Current FEMA) – Route 1 Gillis Bridge to the I-95 Bridge – Cashman Park and Merrimac St.

The FEMA floodplain is somewhat restricted in its expansion as the area's topography steepens upon nearing Merrimac St. Should SLR predictions hold true, properties currently bordering, but not currently within the FEMA zone, might likely be included in it by 2050, and more so by 2070. Those properties lying to the east of Mersen to roughly the North End Boat club will be most affected by the expanding floodplain in terms of both risk exposure and flood insurance premiums. The rising topography west of Ashland St. offers protection to the area between Ashland St. and I-95. (*Figure 94. Flood Inundation and Future Sea Level Rise - Route 1 Gillis Bridge to the I-95 Bridge*)

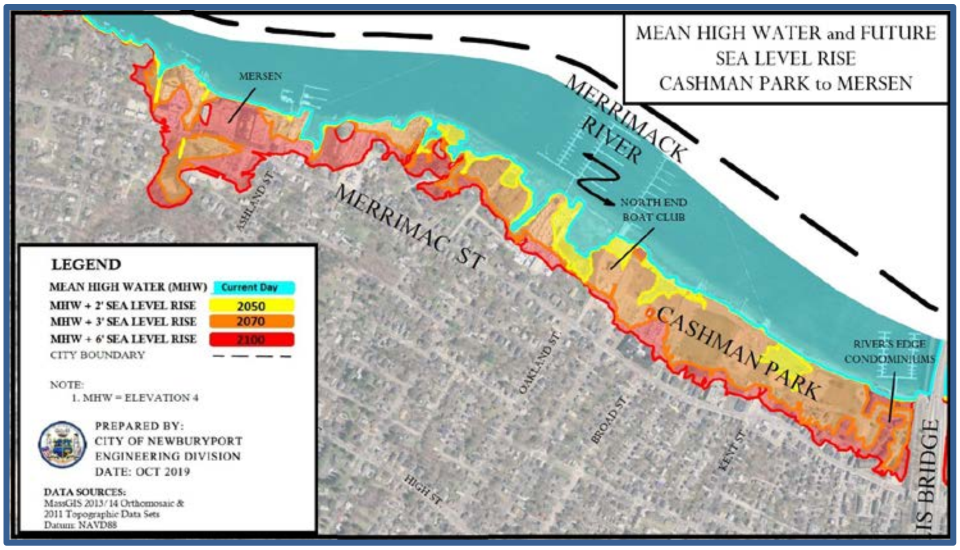


Figure 93. Future Sea Level Rise ZOOM – Cashman Park to Mersen (372 Merrimac St.)

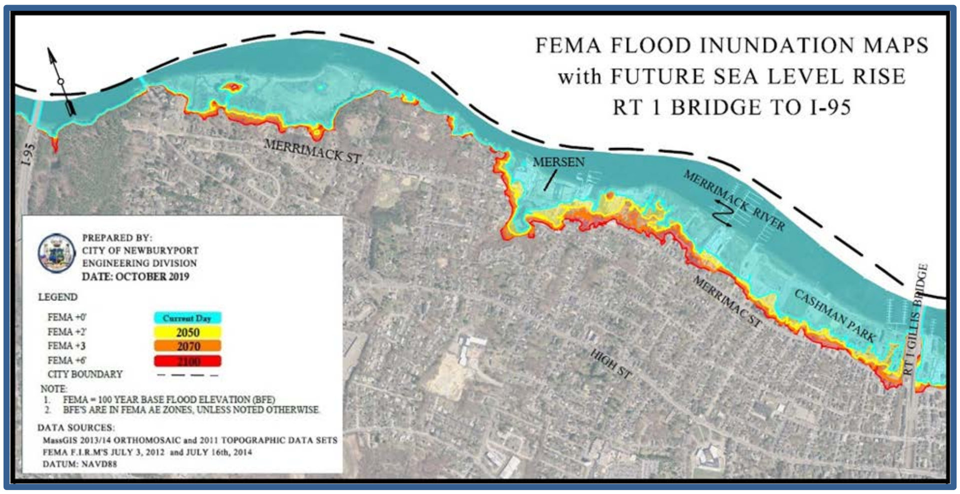


Figure 94. Flood Inundation and Future Sea Level Rise - Route 1 Gillis Bridge to the I-95 Bridge

2.2.3.e The Little River Watershed including the Business Park

The Little River watershed has a saucer-like form as it is bordered by the high terrain west of Interstate Highway I-95, and the elevation along Storey Ave and High Street. The area is subject to some impervious surface run-off from these roadways, adjacent businesses and parking lots, and the neighborhoods to southwest side of High Street. In total, the watershed's impervious surfaces is approximately 14% (see Malcolm Hoyt Drainage Improvements Flood Study, by Malcolm Pirnie/Arcadis, dated 2011) of its total area. The Little River also drains much of the wet meadows of the Common Pasture (*Figure 95. Little River Watershed*). Much of the Little River Basin and Business Park have silty clay and clay-like surficial soils that hinder water absorption, thereby greatly increasing stormwater runoff, pooling and flooding, far greater than the impact from impervious surfaces areas.

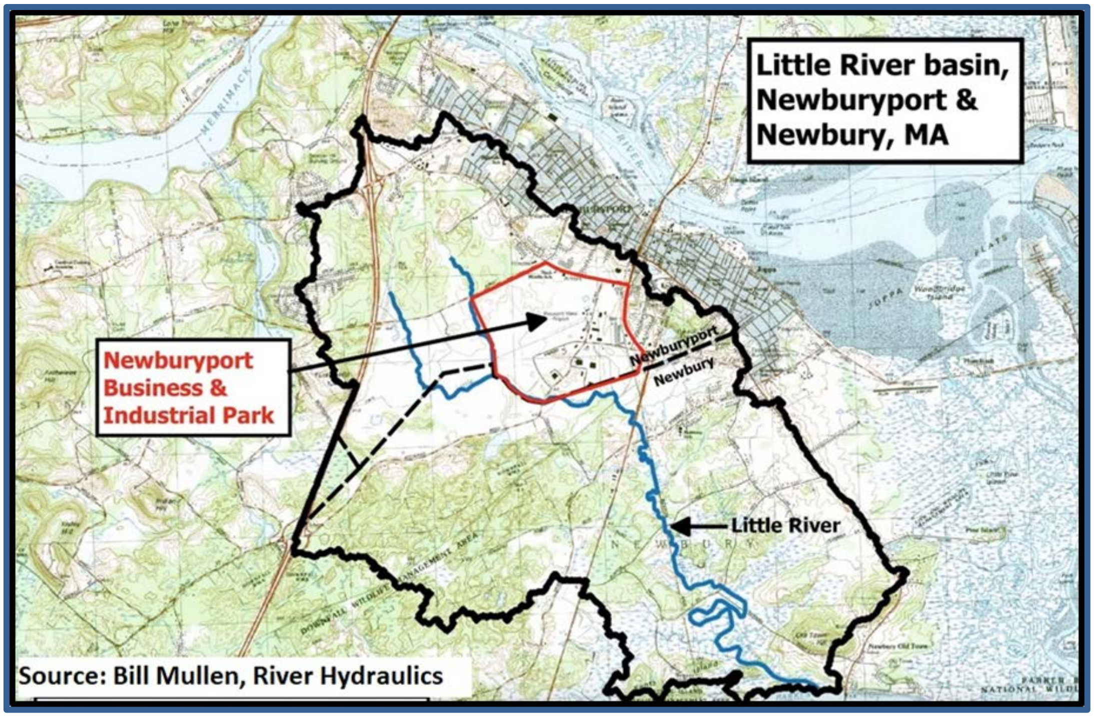


Figure 95. Little River Watershed

Beginning in the 1960s, parts of the Common Pasture and the Little River watershed were converted into a business park, the Lord Timothy Dexter Industrial Green (Business Park). The park's development required that a network of drainage ditches, or swales, be constructed to store and drain waters. Overtime, the swales filled with sediment trapping vegetation which reduced their storage capacity and flow. However, even if the swales were in optimum condition, major events like the Mother's Day storm would overwhelm this system's capacity, causing the flooding of roads within and around the Business Park, the Quail Run/Doe Run residential neighborhoods, and the nearby MBTA train station. Although the 2006 Mother's Day Storm forced the Little River and the park's swales to overflow, spilling across roadways and onto properties surrounding the park's buildings, there were only two properties that filed flooding claims with FEMA, and FEMA only made payments to one of those claims. (Figure 96. Mother's Day Storm 2006, The Little River Flows Across Parker St. and *Figure 97. Mother's Day Storm 2006, The Little River Flows Across Malcolm Hoyt Drive*)

Visit **www.Littleriverbasin.org** for additional flooding photos.

Figure 96. Mother's Day Storm 2006, The Little River Flows Across Parker St

Figure 97. Mother's Day Storm 2006, The Little River Flows Across Malcolm Hoyt Drive

Current Flood Risk – Little River Watershed and Business Park

Because the Little River is tidal, flooding can be exacerbated by normal tidal cycles and storm surge. Given this, areas of the park lie within the FEMA 100-year floodplain. A worst-case scenario Category 2 Hurricane today could force storm surge into the business park (*Figure 98. Hurricane Storm Surge Inundation – Business Park*). Future sea level rise might increase the likelihood that lesser storms will be able to do the same.

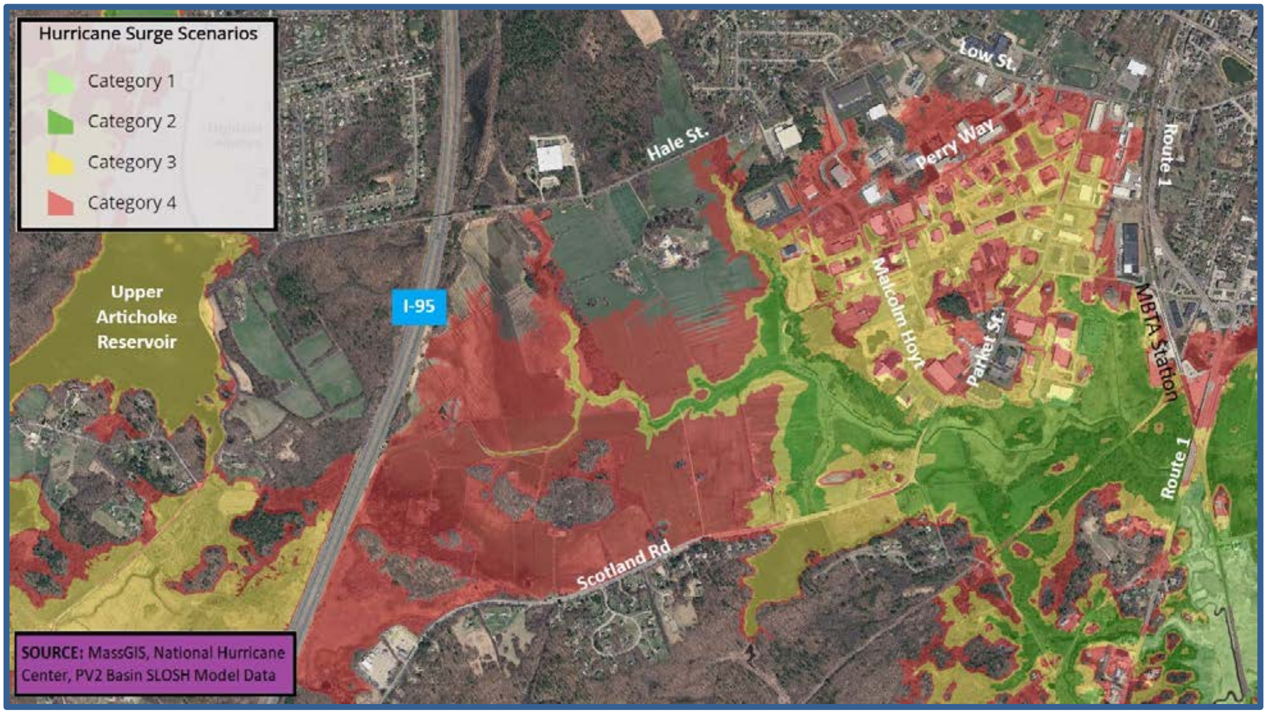


Figure 98. Hurricane Storm Surge Inundation – Business Park

Hydrologic Restrictions

A study commissioned by the city in 2011 and executed by Malcom Pirnie concluded that flooding in this area is exacerbated by several restrictive hydro-barriers. The *Malcolm Hoyt Drainage Improvements Flood Study* found the Parker Street-Scotland Road culvert to be the most critical flow restriction in the study area and is structurally deficient and should be replaced and upsized to reduce future flooding. *Figure 99. Little River Flood Model Scotland Rd, 2006 Mother's Day Storm* illustrates how this restrictive culvert forces waters to bypass the culvert and flow across the roadway. Additional improvements were recommended for the 6-7 hydraulic restrictions downstream of Parker Street and, the slightly less critical Hale Street culvert as well. Because the Little River runs through both Newburyport and Newbury, coordination between the communities is critical to addressing this vulnerability. It should be noted that increasing the hydraulic capacity of these culverts increases the vulnerability of the Business Park to saltwater flooding from future sea level rise and storm surge. It is critical that these hydro-barriers be addressed through a comprehensive watershed approach that considers the effects of climate change and sea level rise, as well as the Business Park's geology and substrate.

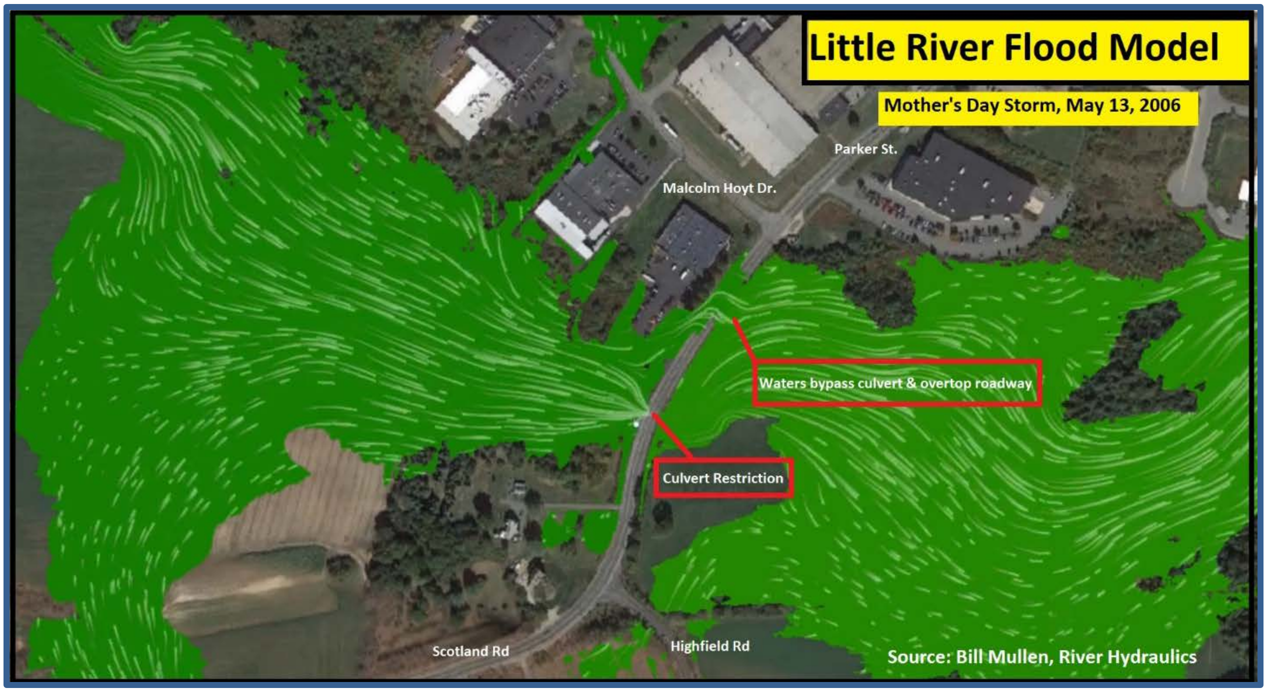


Figure 99. Little River Flood Model Scotland Rd, 2006 Mother's Day Storm

Future Sea Level Rise and Future Inundation – Little River Watershed and Business Park

As stated above, the Business Park will be affected by future sea level rise because its' watershed drains into the Little River and this river is tidally influenced. The *Malcolm Hoyt Flood Study* modeled the watershed's hydrology and the hydraulics of the streams and culverts. However, this Study did not run the model under future SLR scenarios nor future climate-change-driven storm events, which have much greater rainfall amounts and more intense storms and storm surges. This Study's model needs to be updated to reflect climate change impacts.

These flood inundation maps for the Business Park are similar to the other flood inundation maps prepared for this Plan in that they simply add SLR to the current FEMA flood zone elevations. Actual FEMA Flood Zones in the future will vary as FEMA updates their FIRMs to address changes in the climate and also when downstream restrictions are removed. (*Figure 100. Flood Inundation and Future Sea Level – Business Park*). Areas of the park currently reside within the FEMA 100-year flood plain. However, this flood plain and its associated risk is forecast to expand after 2050, thereby subjecting additional properties to flood insurance requirements and consequent insurance premium rate increases. These predictions, however, conflict with the stated goal of the city's 2017 Master Plan to "enable new and expanded commercial and industrial use at the Business Park to generate at least 15% of the city's property tax revenues." The city will need to reconcile how it will achieve these financial goals considering future climate predictions.

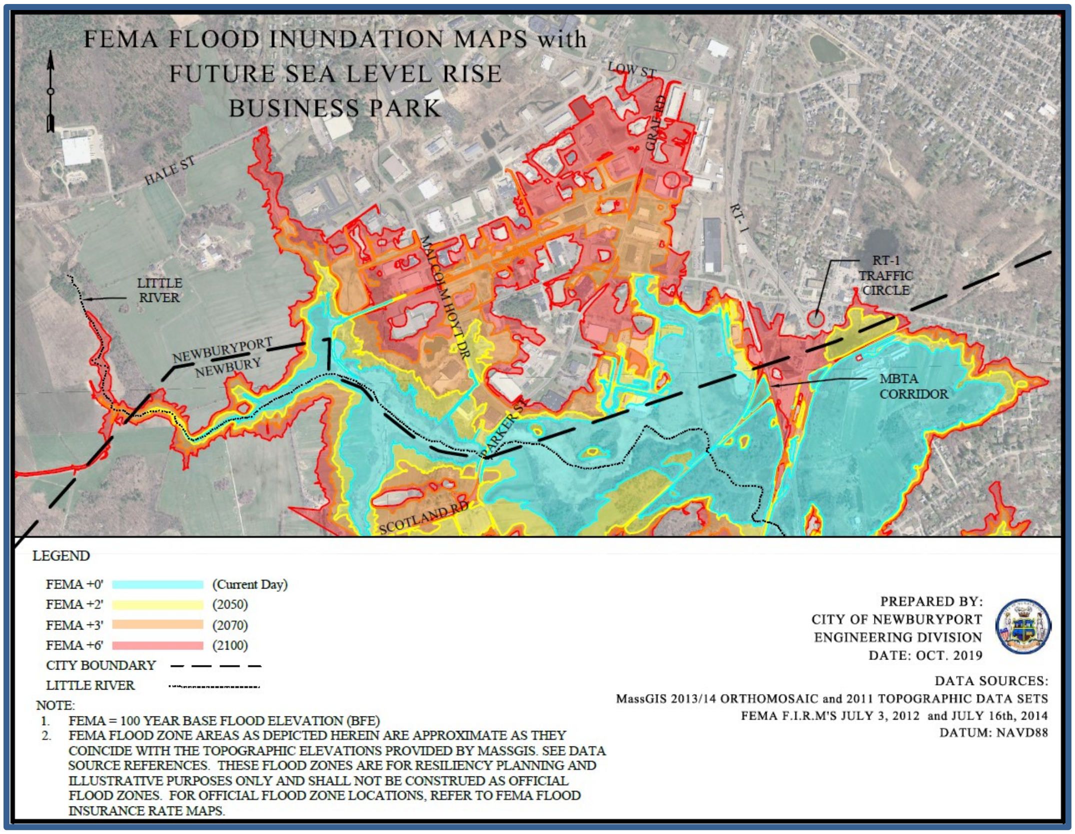


Figure 100. Flood Inundation and Future Sea Level – Business Park

Hazardous Materials

As hazardous materials are stored at the Business Park, Local Emergency Plan Committee (LEPC) plans must be reviewed on a regular basis to ensure compliance and to avert potential consequences from flooding (*Figure 101. Business Park Hazardous Waste Containing Facilities and FEMA Flood Hazard*).

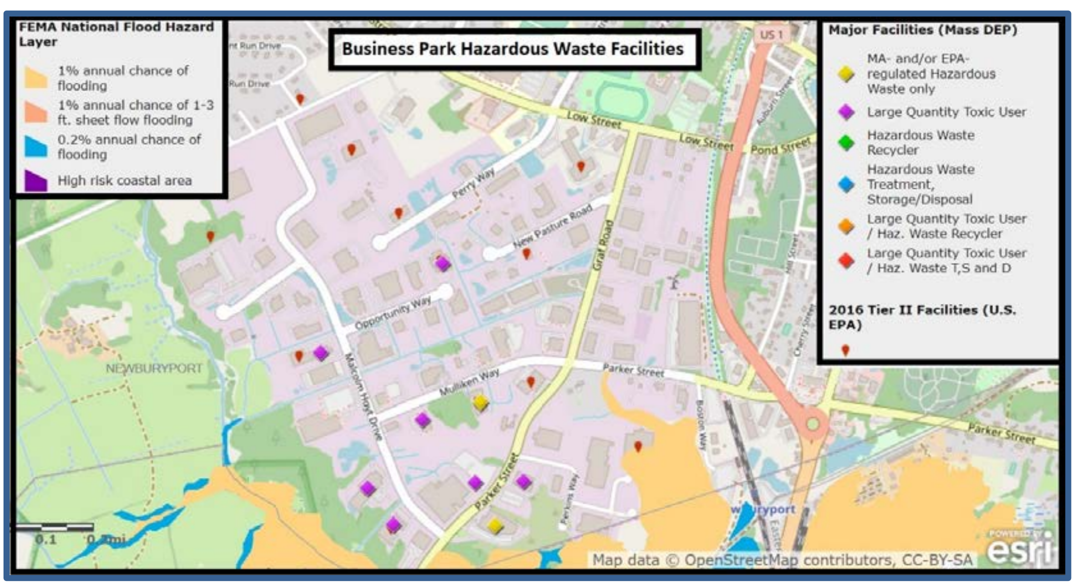


Figure 101. Business Park Hazardous Waste Containing Facilities and FEMA Flood Hazard

2.3 Community-wide Vulnerability

Beyond the flooding vulnerabilities already discussed, there are hazards to which the community and certain segments of its population are vulnerable, including those that live far from the water's edge.

2.3.1 Public Health and Safety

An Aging Population

The introduction of this document noted that by 2030, Newburyport's proportion of residents age 65+ would double – swelling from 16% (2913) of its 18,207 residents today, to 32% (5826) by 2030. This is significant from a vulnerability perspective as this population is less tolerant of temperature extremes, is less resilient to recovering from insect borne disease vectors and given that they predominantly live on fixed incomes are financially vulnerable to rising summer cooling costs as well as the demand of both physically and financially managing winter snow removal when winters are severe. Though other segments of Newburyport's population such as infants and toddlers, pregnant women, people with pre-existing medical conditions and disabilities, people living alone, and persons occupationally exposed to the outdoors are also vulnerable to climate extremes, it is the elderly that will represent the largest single segment of Newburyport's most vulnerable population.

Figure 102. Margette Leanna shoveling her walkway, February 5, 2015

Insect Disease Vectors

Newburyport has within its borders open spaces, parks and forest, numerous wetlands associated with the Artichoke Reservoir, the Merrimack and Little Rivers and the Great Marsh all of which harbor and spread insect disease vectors from ticks and mosquitos (West Nile Virus, EEE, Lyme Disease and parasites).

Figure 103. Common Local Area Insect Pests

Stagnant water in rain gutters, bird feeders, planters and rain barrels provide additional environments for mosquitos to breed in dry areas well removed from wetlands. Therefore, Newburyport residents are more exposed and vulnerable to insect disease vectors relative to residents living in drier or more urban landscapes. Residents and visitors alike enjoy warm summer evenings along Plum Island beaches and the Central Waterfront, however on some evening's mosquitos drive people away. Ticks are a hazard in most open green spaces and Greenhead flies, though they don't spread disease, can make a day at the beach or on the river intolerable. Given the susceptibility of all residents (especially Newburyport's growing elderly population) to these disease vectors, and since prevention strategies work well in controlling their spread, Newburyport should have a plan for handling these diseases in a warmer, wetter world.

CSOs – Combined Sewer Overflows

CSOs from wastewater facilities upstream on the Merrimack threaten river and beach recreation, and CSOs from wastewater facilities upstream on the Merrimack River are a longstanding threat to the water quality from Manchester, NH to the mouth of the river in Newburyport. Rain events overpower upriver infrastructure in wastewater treatment facilities and results in CSO discharges into the river impacting river and beach recreation for end users. During the summer season, Memorial Day through Labor Day, bacteria levels are tested weekly to ensure water quality is safe for beach users.

Fortunately, citizens have organized raising real concerns about CSOs and our legislature passed two important bills, one establishing the Merrimack River District Commission where stakeholders from MA and NH are working with a consultant team, Brown and Caldwell, collecting and assimilating data on studies of the river and developing a strategic plan. The other bill is to pilot a notification system in Newburyport. The Merrimack River Watershed Council is developing the system with the consultant team and city with a target to be operational by Spring of 2021.

The solution to update the large urban wastewater systems upstream represents major and costly infrastructure upgrades that have generated some federal interest but it won't be realized anytime soon. At best, we are making progress in CSO reporting and bringing NH communities to the table and noting the increase of public reporting of wastewater CSO releases. It is critical these efforts continue to build an effective public notification system of CSOs while working on an action plan for infrastructure upgrades with state and federal government to improve the over health of this important resource.

As the public health and environmental impacts of CSOs on the Merrimack River are presently being quantified, and given that the problem won't be immediately resolved, Newburyport must treat CSOs as a public health threat exacerbated by the effects of climate change. The city will continue to take a lead role in this regional effort.

Figure 104. The Merrimack River Voyagers

Left to right: Sen. Diana DiZoglio, Rep. Christina Minicucci, Dan Graovac, Lane Glenn, Derek Mitchell with his daughter, Rep. Jim Kelcourse, Doug Sherwood and Heather McMann on Plum Island after finishing the 117 mile journey down the length of the Merrimack River "to highlight economic and environmental issues related to the Merrimack." From the Merrimack Valley Magazine article "The Course of the Merrimack" by Doug Sparks. Photo by Glenn Prezzano.

Narrow streets and sidewalks become choked with snow after successive storms, narrowing access for emergency vehicles, traffic, and parking. Snowbank covered sidewalks force pedestrians into the narrow streets alongside traffic (*Figure 105. Winters Downtown*).

Figure 105. Winters Downtown

Side Walks and Bike Lanes. A strategy to reduce carbon emissions is to encourage people to walk or ride bikes vs. using their cars, especially for short trips where internal combustion engines experience their highest emissions and realize their worst fuel economy. To support that behavior, a safe and inviting infrastructure needs to exist to promote biking and walking as an alternative to driving.

Newburyport along with Newbury and Salisbury have made great progress expanding areas for walking and biking that are removed from vehicular traffic. The Clipper City Rail Trail, waterfront walk, and the newly completed Garrison Trail that links Salisbury and Newburyport via the newly reconstructed I-95 Bridge are recent examples. The MA Department of Transportation's Safe Routes to School project is making safety changes to area around the high school with completion expected in April of 2021.

Painted bike lanes on heavily traveled Storey Avenue and High Street are heavily used and increased efforts through our Traffic Safety Advisory Committee must continue to address safety concerns for cyclists here and throughout the city.

PHOTOS: Brickandtree.wordpress.com

Figure 106. Compromised Sidewalks

Though Newburyport has many sidewalks, and the city has embarked on a program to restore and them, many are still narrow and uneven, falling into disrepair or impinged upon by the roots of street trees (*Figure 106. Compromised Sidewalks*). In other parts of town, such as Low Street and the city's North End, sidewalks exist only on one side, and in some neighborhoods, they do not exist at all. The situation discourages walking, particularly among the elderly who are concerned about falling and crossing busy streets. Navigating the city's sidewalks is particularly challenging for people using walkers, strollers, and wheelchairs. The City has completed two studies with Beta Engineering evaluating and rating the condition of every sidewalk and road in Newburyport. This has assisted in creating 5-year plans for increased road and sidewalk work. While technically not a climate vulnerability, this undermaintained city infrastructure hinders other efforts to achieve the city's 2050 net-zero goals.

2.3.2 Wind, Weather, Trees and Energy Vulnerability

Most existing buildings and homes in town have not been built to withstand hurricane force winds. This is certainly the case with many of the city's historical homes. As storm intensities increase, so will their vulnerability to wind damage, raising the potential for families to be displaced from their homes.

Power lines located above ground are vulnerable to the storm effects of wind, snow and ice (*Figure 107. Snow and Wind Down Power Lines on Merrimac Street, March 2018*). Furthermore, Newburyport's tree lined streets are interlaced with these power lines. Both trees and electrical lines are therefore compromised, setting the stage for more frequent power outages. As is the case with most municipalities, electrical power within the city is centralized. When electrical power is interrupted, gas stations can no longer pump fuel to power vehicles and generators, supermarkets and businesses close, traffic lights stop working, HVAC systems fail, cell phones discharge and emergency communication is compromised. Relying on a central source of electrical power in a climate of increasing storm intensity is a vulnerability.

Figure 107. Snow and Wind Down Power Lines on Merrimac Street, March 2018

2.3.3 Impervious Surfaces - Stormwater Management, Snow Removal and Heat Island Effects

Much of heavily traveled High Street is between 35 and 40 feet in width, save for the area between Kent and Johnson Streets where it is almost 70 feet wide – an apparent remnant necessity of Newburyport's past. At that time, wide streets were required there to facilitate the transport and turning of large clipper ship masts from High Street onto Kent and Johnson Streets, following their manufacture near the current Business Park. Given today's requirements, High St. at that location and certain side streets such as Oakland and Tyng seem to be unnecessarily wide; 45-50 feet in width (*Figure 109. Wide Streets - Drive Stormwater Runoff, Heat Island Effects, and Road Maintenance*). Aside from providing on street parking (that already duplicates existing paved off-street parking), the added pavement only increases impermeable surface stormwater runoff, drives heat island effects that increase summer temperatures, increases road paving costs, and adds to the city's snow removal load. As precipitation volumes increase and aging underground drainage pipes can't handle the runoff (*Figure 108. Storm Drain Sinkhole - Created by Heavy Rains*), residents and businesses located downstream will suffer the consequences of these wide streets.

Figure 108. Storm Drain Sinkhole - Created by Heavy Rains

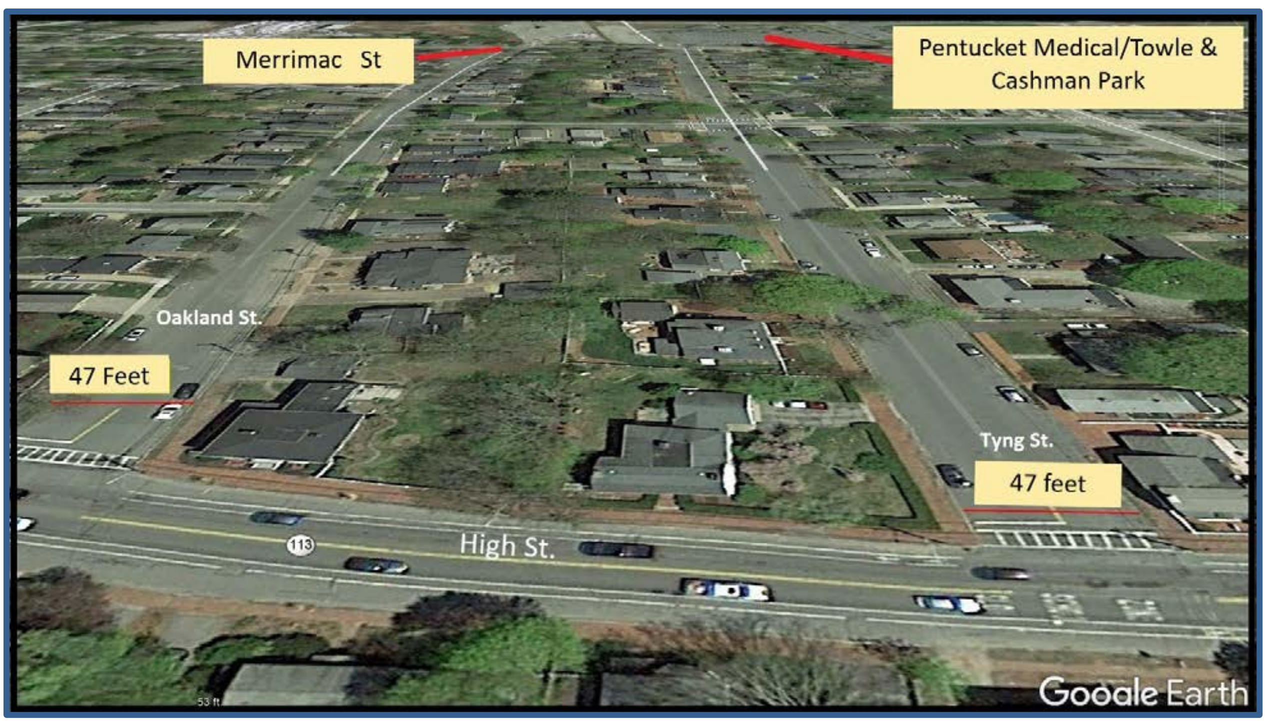


Figure 109. Wide Streets - Drive Stormwater Runoff, Heat Island Effects, and Road Maintenance

2.3.4 MBTA Commuter Rail Vulnerability

The MBTA commuter rail bed and track system that runs south from Newburyport is vulnerable to SLR and surge inundation. As the commuter rail serves an important function in providing public transportation to and from Newburyport, its compromise represents a vulnerability in access. (*Figure 110. Hurricane Storm Surge Inundation – MBTA Commuter Railway*) illustrates that the railbed would be compromised by the inundation of a category 1 storm today and will be inundated by 2050 with 2 additional feet of sea level rise. (*Figure 111. Sea Level Rise, 2050 – MBTA Commuter Railway*)

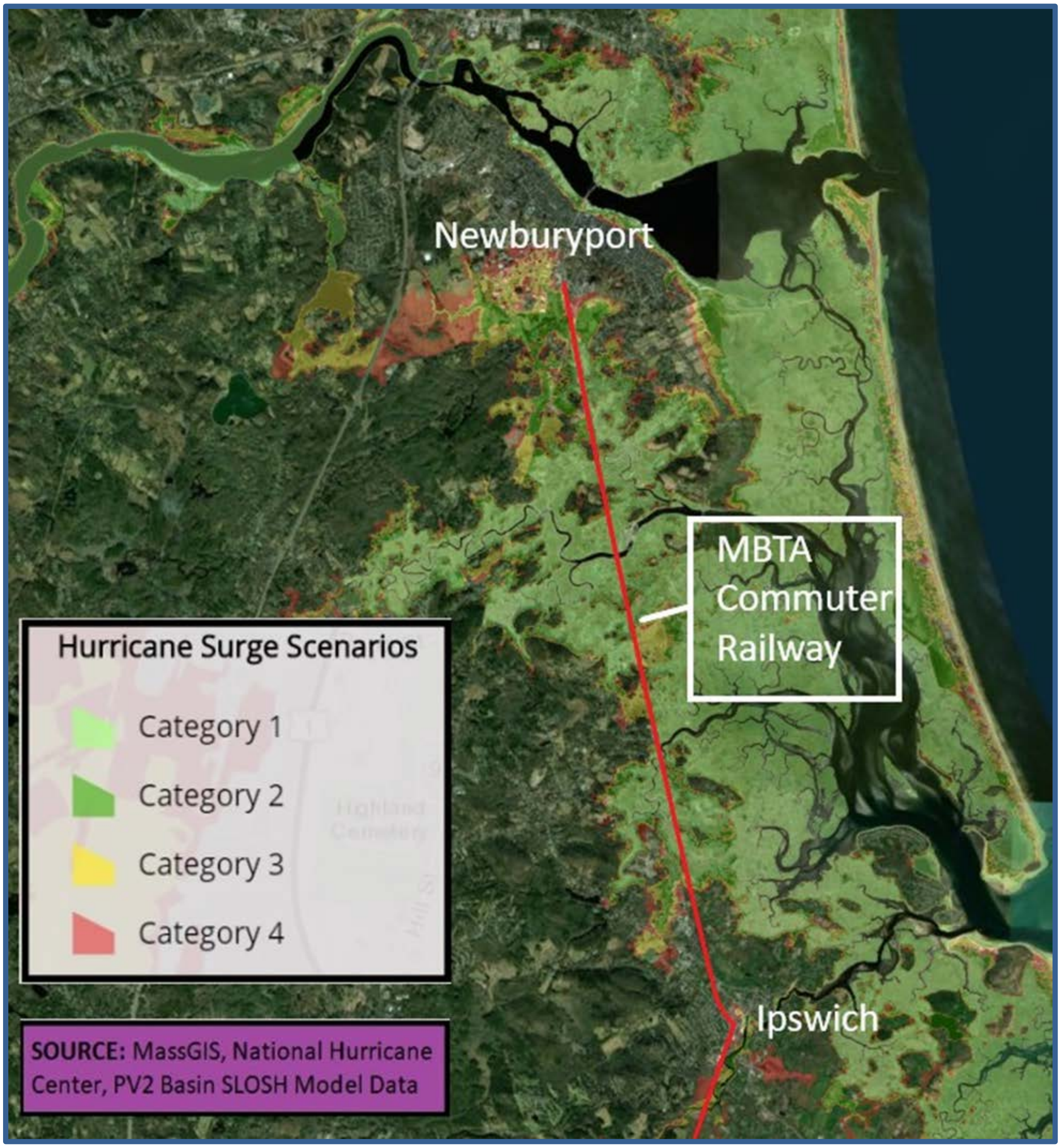


Figure 110. Hurricane Storm Surge Inundation – MBTA Commuter Railway

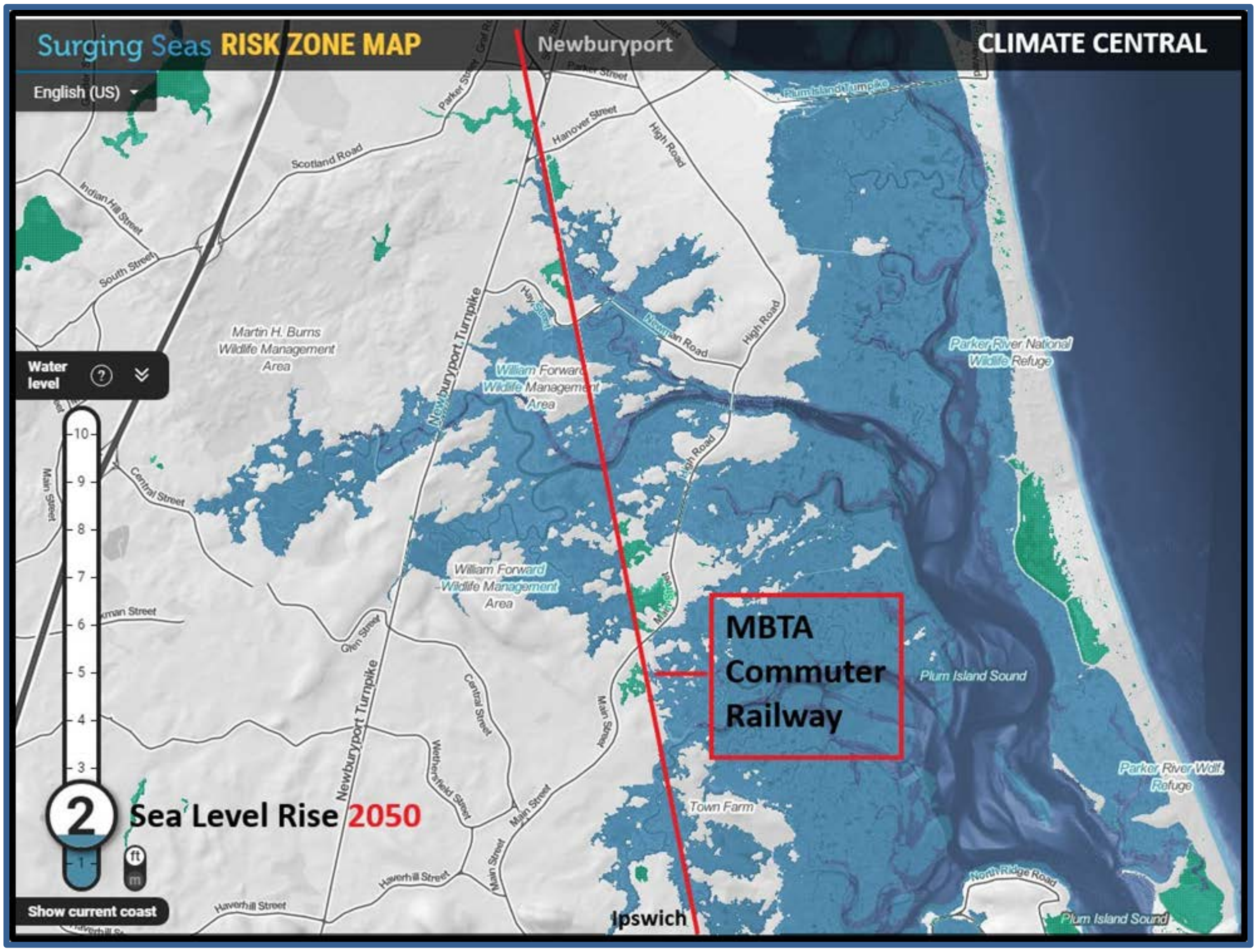


Figure 111. Sea Level Rise, 2050 – MBTA Commuter Railway

2.3.5 Economic Vulnerability

This chapter has identified many of the city's vulnerabilities to climate change and sea level rise. The concurrent cost to this community and others will challenge society's ability to fund all the required adaptation measures. Limited grant monies are currently available through the State's grant programs (MVP, DOE and others). However, funding resiliency efforts while concurrently managing immediate term climate hazard response costs is also a vulnerability.

Funding the resiliency effort will challenge the city's budget, but so will the eventual loss of its shoreline real estate tax base. A significant portion of Newburyport's tax base as well as some of its shoreline businesses lie within a flood zone that might succumb to sea level rise after 2050. Even Newburyport's Business Park will not be spared from these future effects. The tax value of this affected real estate and its proportion of the city's operating budget have yet to be determined. Hence, the effect that this future loss of tax revenue will have upon the city's operating budget is unknown, and therefore a vulnerability. Additionally, Plum Island and Waterfront Park, along with adjoining properties, are a significant draw for tourism that drives the city's tourist economy and supports its downtown shops and restaurants. This economic engine is therefore also vulnerable to the effects of sea level rise, more frequent flooding, power outages and successive heavy snow events. The city will need to anticipate and plan for these eventual financial impacts.

Figure 112. Snowfall Impacts Downtown Businesses

2.3.6 Food Security

Climate change is expected to threaten food production and certain aspects of food quality, as well as food prices and distribution systems. Many crop yields are predicted to decline because of the combined effects of changes in rainfall, severe weather events, and increasing competition from weeds and pests on crop plants (*Figure 113. Devastated corn field*). Livestock and fish production are also projected to decline. Prices are expected to rise in response to declining food production and associated trends such as increasingly expensive petroleum (used for agricultural inputs such as pesticides and fertilizers).

Rising water temperatures can lower oxygen levels and otherwise alter freshwater and marine ecosystems. Some species such as bass may flourish more readily in the Northeast's warming waters, but key ocean fisheries, such as cod and lobster south of Cape Cod, are expected to decline. The loss of coastal wetlands could harm bass, clams, and other commercially important fish.

Figure 113. Devastated corn field

Chapter 3 – Adaptation Strategies

There are essentially three strategies to deal with the threats and vulnerabilities associated with Climate Change:

- Protection: Protect vulnerable assets
- Adaptation: Create adaptations to be resilient to Climate Hazards
- Retreat: Retreat from vulnerable areas when protection and adaptation are no longer viable

Protection - Protection strategies attempt to prevent damage and harm by shielding people, property or infrastructure from climate hazards. Sea walls and revetments, temporary flood protection barriers, dune nourishment efforts, early warning systems (for weather, infectious disease exposure and water quality hazards) and road closures are all examples of protection strategies intended to shield people, property or infrastructure from exposure to climate hazards.

Adaptation – Adaptation strategies acknowledge that given their location, people, property and infrastructure will be exposed to climate hazards. Adaptation therefore seeks to accommodate those hazards by minimizing their impact, thereby allowing people, property and infrastructure to resiliently co-exist with hazards until retreat is necessary. Examples of accommodation strategies include raising structures above flood elevations, flood-proofing structures and utilities, instituting new building codes, zoning and setbacks, promoting community personal resiliency and behaviors that protect from exposure to disease carrying insects and polluted flood waters.

Retreat - Retreat recognizes that in some areas it will eventually become too dangerous, costly, technically impossible, or politically unrealistic to prevent damage and harm from climate hazards. In these instances, the best strategy is to retreat or relocate from harm's way. Examples of retreat strategies include property buyouts to create buffer zones, relocation of roads, buildings and infrastructure, and implementation of new regulation and zoning to limit new construction, reconstruction, or expansion of existing structures in hazardous areas.

3.1 Strategy Execution

Execution of the three strategies can employ Natural and Nature-Based methods or hardened, manmade methods also known as "Gray" approaches, or a combination of both, sometimes referred to as a "Hybrid" approaches. *Figure 114. Living Shoreline Continuum*.

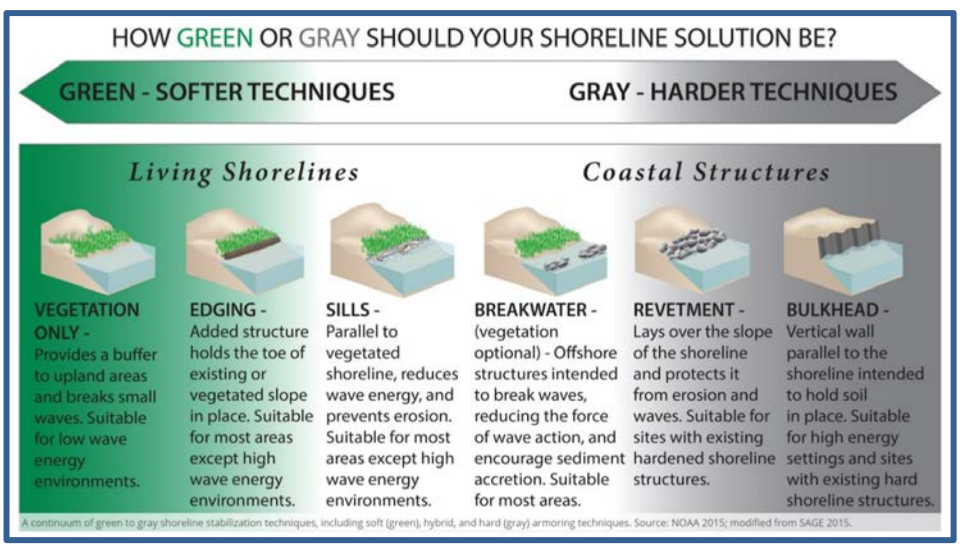


Figure 114. Living Shoreline Continuum

3.1.1 Natural and Nature-Based Strategies

"Natural and nature-based strategies can provide a multitude of short and long-term societal, economic, and environmental benefits. Natural strategies (often referred to as natural solutions) are those strategies that support pre-existing natural features like dunes, beaches, and salt marshes that provide risk reduction. Natural strategies maximize the effectiveness of coastal habitats to serve as "natural defenses" against sea level rise, increased erosion, and other climate-driven threats. Nature-based strategies, while similar, are created by human design, engineered, and constructed to provide specific services such as coastal risk reduction and other ecosystem services; examples of nature-based strategies include living shorelines, bio-swales, engineered dunes, and oyster reefs. Nature-based strategies are often designed using a hybrid of natural and nature-based features, where natural materials and non-natural material or synthetic materials are combined to reduce risk and maximize resilience. Both natural and nature-based strategies have the capacity to evolve naturally overtime, and are therefore inherently dynamic, suggesting that some management or maintenance may be required to sustain the function and desired services of such features. However, with the ability to evolve through a variety of natural processes, both natural and nature-based strategies have the potential to repair themselves from damage and even adapt to changing conditions over time. Such approaches can therefore offer equal if not more resilient protection to coastal hazards compared to hard or gray infrastructure." **Great Marsh Coastal Adaptation Plan –** National Wildlife Federation (NWF), Final Report issued December 2017, p 130.

3.1.2 Gray Infrastructure and Retrofits

"Historically, concrete structures - such as seawalls, revetments, bulkheads, groins, jetties, and breakwaters – were built along the coast of Massachusetts to protect buildings and infrastructure. These hard, engineered structures – also known as "gray infrastructure" – were installed for economic, recreational, and property-protection reasons. Expensive to implement and maintain, much of this gray infrastructure is now failing and deteriorating. In some cases, gray infrastructure techniques have had negative impacts on abutting areas. Bulkheads, for example, which are vertical sea walls built in high-energy settings to help stabilize the shoreline and reduce flooding, can increase erosion of adjacent areas. It has been well documented that many gray infrastructure techniques have ultimately caused more damage than they prevented. In contrast, natural and nature-based solutions can be more resilient, more cost effective, and provide a range of co-benefits in addition to providing comparable levels of protection. While this will require a broad-based cultural shift in how society views physical adaptation efforts, we should strive to have traditional gray infrastructure viewed as a last resort."

Source: Great Marsh Coastal Adaptation Plan – National Wildlife Federation (NWF), Final Report issued December 2017, p 138

Sometimes a melding of the methods can yield desired results. An example of a nature-based method might be to establish a system of offshore oyster reefs within a bay to attenuate wave energy and improve water quality. Still waters inside of the reefs would provide an environment to trap sediment where an environmentally friendly salt marsh could be established that would further tamp down waves and absorb wind driven surge. A gray strategy would simply be to build a hardened seawall in front of the vulnerable assets. A hybrid approach would employ the offshore reef and marsh system as the first and second line of defense, with a seawall as the tertiary structure. Alone, the seawall could succumb to the battering and undermining of waves sooner than if it were combined with the natural methods. In this instance the life expectancy of the wall and hence the assets behind it could be extended when natural and hardened methods are combined. Functionality aside, the hybrid approach provides additional habitat and water quality benefits, while also supporting the aesthetics of an area when compared to a sheet pile wall or rip rap revetment.

3.1.3 Resilient Adaptation

Examples of resilient adaptation include elevating structures above the reach of storm waves and flood waters. Another example would be to reduce storm related power outages by burying powerlines that are otherwise subject to the wind and fallen trees. Incorporating a nature-based approach would move all utilities below a sidewalk and an expanded green area which would not only offer protection to the utilities but would also reduce impervious surface area and storm water runoff.

3.1.4 Personal Resilience

It's also important to incorporate personal resilience and the ability to survive a short or long-term natural disaster, into a community's resilience tool kit. Some households that survived Super Storm Sandy for example, were without electrical power for three weeks or more and had to endure freezing temperatures. Sandy impacted a well populated area with many resources; however, the scale of the impact severely slowed recovery. Personal resilience strategies can include the purchase of a backup generator and other power supplies to bridge the gap of short term or even extended power outages. The organization of household personal resilience to storms should revolve around the CORE 4 of survival (Shelter, Water, Food and Fire - SWFF):

- Shelter – Exposed to the elements, one might survive for only 3 hours without shelter in extreme conditions.
- Water – Without water one might live for only 3 days.
- Food – One might survive for 3 weeks without food.
- Fire (energy) – This component of the core 4 supplements shelter, can purify water, and can cook food – it is essential to the enhancement of the first three of the Core 4.

If one organized the resiliency of their home along the Core 4, one could survive for weeks without power or access to external sources of food and water. Some examples include trimming trees to protect the "shelter", or using sandbags to divert flood waters. Planning for a lack of water to flush toilets or even for drinking can be accomplished by capturing roof runoff in a rain barrel or cistern and keeping a supply of bottled drinking water on hand when a storm is forecast. Maintaining a rotating store of dry and canned goods, drinking water, and fuel can keep a home in a state of readiness during storm season, thereby avoiding the "just before the storm" supermarket frenzy and rush to the filling station. The last of the Core 4, Fire, can also be interpreted as "energy" such as a wood stove to keep warm, a gas grille for cooking and boiling water (outdoors), a generator and back up portable battery power supply and so on. While survival might not be completely comfortable, it is possible to keep one's home heated and powered to some degree, while also having the ability to cook and eat food. See *Figure 115. Prepare Your Home – The 4 Core Elements of Survival*.

The goal of Protection and Resilient Adaptation is to protect and extend our time (or the existence of an asset) at a given location, thereby delaying the need to retreat or relocate. However, at some point in certain locations, climate hazards will make habitation and the continued function of assets impossible. At that point retreat or relocation will be the only option.

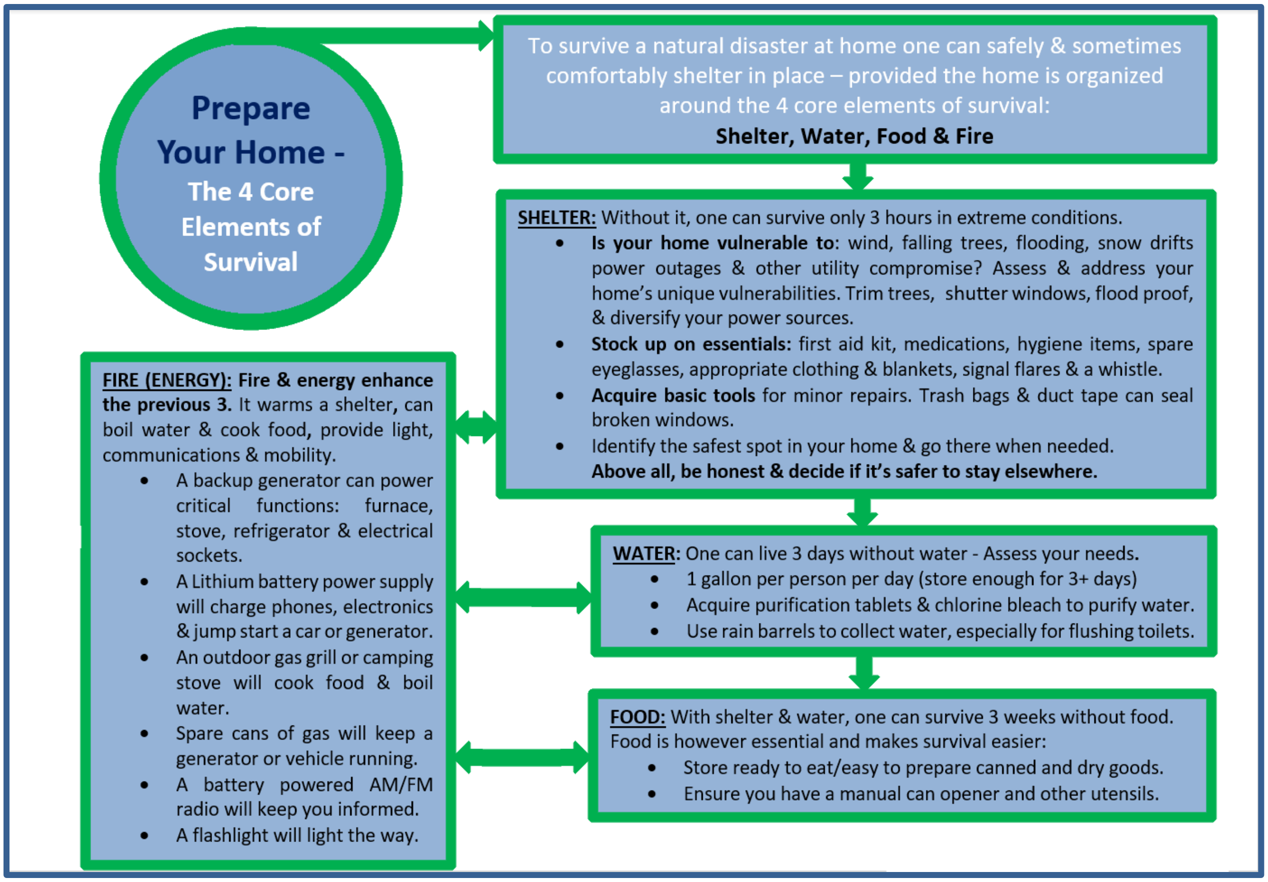


Figure 115. Prepare Your Home – The 4 Core Elements of Survival

3.1.5 Adaptation Timeline

Adaptation strategies specific to the city's Critical Assets, Neighborhoods Vulnerable to Flooding, as well as Community-wide Vulnerabilities are delineated according to the following timeline:

- Immediate – the situation or asset is urgently vulnerable today and strategies need to be executed now.
- Short-term – Strategies are to be employed from current day through 2030.
- Long-term – Strategies are to be employed from 2030-2070.

3.2 Critical Municipal Assets

3.2.1 Public Water Supply, Treatment and Distribution System

The Vulnerability Assessment demonstrated that the city's water supply was urgently vulnerable today to contamination by polluted flood waters. The existing dam at the Lower Artichoke Reservoir was last inspected in 2018 and was determined to be in poor condition (*Lower Artichoke Reservoir Dam, Phase I Inspection/Evaluation Report*, dated December 6, 2018, prepared by AECOM). Additionally, FEMA revised the flood zones for Newburyport in 2012-2014 revealing that the dam's spillway lies approximately 3 feet below the FEMA base flood elevation of 12 feet NAVD88 (North American Vertical Datum of 1988 – See Chapter 2, Vulnerability Assessment). Public water supplies and other critical assets are recommended to be protected to 3-feet above the FEMA 1% annual base flood elevation, which places the existing dam 6-feet below the recommended protection elevation.[5]

Immediate Strategies:

- Continue funding the Water Division's Public Water Supply Resiliency Plan Capital Improvement Program for work related to evaluation and implementation of resiliency measures.
- Prepare a Resiliency Plan for the city's water supply, treatment, and distribution systems.
    - Develop backup plans to provide residents with water should the water supply or wells no longer be available due to contamination, drought, or other compromise.
    - Assess all additional possible breach points.
    - Evaluate various permanent options and costs to defend against a surging river.
    - Evaluate future higher groundwater levels along the Merrimack River and the potential introduction of saltwater into our water supply.
- Develop and implement a monitoring and response plan to protect the Lower Artichoke from an influx of contaminants from a breach by the Merrimack River.
- Acquire technology that can be quickly deployed along the lower Artichoke Spillway to prevent river floodwaters from backing into the Reservoir.
- Evaluate options of collecting Indian Hill Reservoir water and bypassing the Artichoke Reservoirs in the event of a breach of the latter. This may entail an additional intake system leading to the Lower Artichoke Pumping Station.
- Update the city's current Artichoke Watershed Protection Plan (dated January 2005) and actively implement the proposed protection measures. Include the development of a program to manage watershed runoff, accumulation of sedimentation and contamination entering our reservoirs, and protecting the lands surrounding our water supplies. Evaluate the need and effectiveness of making zoning changes to land use for all properties within our water supply watershed. Work with West Newbury and MA DEP to provide protective measures.
- Review West Newbury's current wellfield and any future proposed wellfield expansion Plans for an excessive drawdown, or any other adverse impact, to the city's reservoirs.
- Consider creating a new committee whose members have first-hand experience in watershed management, water supplies and protection, groundwater recharge, zoning and watershed protection bylaws and ordinances, and land acquisition for water supply protection purposes.

[5] MassDEP 310CMR22.04(2) Construction, Operation, and Maintenance of Public Water Systems

Short-term Strategies (now-2030):

- Update and implement elements of the Water Division's Public Water Supply Resiliency Plan noted above.
- Implement the decided upon permanent protection strategy.
- Protect the water supply by purchasing properties abutting the reservoirs and turning those areas into undevelopable conservation land.
- Implement zoning changes within the public water supply watershed as recommended in the Artichoke Watershed Protection Plan.
- Develop programs to reduce water demand citywide. Consider implementing a water-neutral ordinance for both existing and new homes and businesses.
- Re-evaluate the vulnerability of Bartlett Spring Pond and if necessary, develop a plan to raise the road/berm separating the pond from the Merrimack River.
- As with the Wastewater treatment facility, considering viable resiliency measures, use an inundation/system failure timeline to project if at some point the Lower Artichoke and Bartlett Spring Pond may no longer be protected.
- Pursue new and additional drinking water supplies, particularly new groundwater supplies (i.e. wells) that are not hydrologically connected to the Artichoke or Bartlett Spring Pond.
- Evaluate a program to capture residential rooftop rainwater for storage in private or municipal cisterns.
- Review existing water use billing rates and determine what improvements can be made to promote water conservation by the end user while providing the necessary incentives – financial or otherwise – to conserve.

Long-term Strategies (2030-2070):

- Continue to update and implement the Water Division's Public Water Supply Resiliency Plan.
- Continue to protect and enhance the function of the city's surface water reservoir system.
- Continue the development of new and additional drinking water supplies.
- Raise the road/berm separating Bartlett Spring Pond from the Merrimack River.
- If feasible, implement a program to capture residential rooftop rainwater for storage in private or municipal cisterns.

3.2.2 The Wastewater treatment facility (WWTF), Pumping Stations and Collection Systems

The city's Wastewater treatment facility is in a vulnerable area along the river (FEMA high-risk Zones A and V) where it is susceptible to river water levels, wave fetch across the Merrimack River Delta and the surge of the open ocean. The river which flows alongside the plant is in FEMA high-risk velocity flood zone V, elevation 14, while the treatment plant and abutting properties reside within the FEMA high-risk flood zone A, elevation 12. Recognizing the plant's vulnerability, the city has expedited and completed (in June of 2019) a Resiliency Plan to evaluate climate change impacts upon the facility. This Plan located the vulnerable points of entry where floodwater will impact the plant's ability to function, and proposed both short- and long-term resiliency measures as summarized below. These recommendations may need to be updated as the climate and its impacts evolve overtime.

Immediate Strategies:

- Determine vulnerable points of entry to the city's sewer system through which floodwaters could enter and ultimately inundate the treatment plant. Evaluate each location and determine if the structure can be raised or isolated from floodwaters.

- Acquire portable flood barriers for emergency deployment during storms to protect critical components, such as, buildings, electrical equipment, and generators.
- Continue funding the WWTF Resiliency Capital Improvement Program (CIP) under the Sewer Enterprise Fund to pay for planning, design, construction, and implementation measures.
- Design and build an earthen berm on the west and east sides of the WWTF to protect the plant from storm surge and wave action. Consider/incorporate the following recommendations from the WWTF Resiliency Plan:
  - The berm height should be a minimum of Elevation 14 to meet the current FEMA V Zone Elevation.
  - Considering vulnerable points of entry as noted above, determine if the berm can be built to an elevation higher than 14. If so, perform a cost/benefit analysis of raising those vulnerable locations and the plant's perimeter berm.
  - Evaluate the need for a storm-water pumping station within the plant to prevent flooding from within. Design and build if necessary.
  - Provide shoreline protection to handle the WWTF's exposure to wave fetch across the Merrimack River Delta.
- Implement the 2019 MVP Action Grant Wastewater treatment facility Resiliency Recommendations
- Evaluate the locations of the city's 16 sewage pumping stations relative to their vulnerability to climate hazards. Prepare Resiliency Plans accordingly.

Short-term Strategies (now-2030):

- Considering viable resiliency measures use the inundation/system failure timeline to project when the plant's operations may no longer be maintained at its current location.
- Redesign, reconstruct, and if necessary, develop a timeline to relocate those sewage pumping stations that are in harm's way.
- Begin planning for WWTF relocation. Prepare a Feasibility Study and perform due diligence to locate the future WWTF:
  - Determine potential locations
  - Investigate new treatment technologies to assist in determining the physical footprint required for the facility.
  - Perform conceptual design.
  - Secure property rights for a preferred location.
  - Provide a cost-benefit analysis

Long-term Strategies (2030-2070):

- Implement any remaining resiliency measures as recommended in the WWTF Resiliency Plan.
- Monitor changes to climate change and modify the WWTF Resiliency Plan accordingly
- Prepare WWTF Relocation Design Plans and Specifications.
- Seek construction funding.
- Construct Relocated Plant
- Deconstruct existing plant
- Reconstruct and or relocate sewage pumping stations

3.2.3. The National Grid power substation at 95 Water Street

Immediate Strategies:

- Consult with National Grid to understand the impact of the facility's vulnerability on the City's power grid.
- Consult with National Grid to assess and understand the degree to which they are protecting this asset

Short-term Strategies (now-2030):

- As with the WWTF, develop an inundation timeline that projects a period when the facility will likely require relocation
- Work with National Grid to relocate the substation.

Long-term Strategies (2030-2070):

- Support relocation of the electrical substation

3.3 Neighborhoods Vulnerable to Flooding

3.3.1. Plum Island

Sea level rise coupled with wave and storm activity will over time eventually drive the island's sands west over the marsh towards the mainland. Recent erosion episodes over the last 10 years are related to the state of the river jetty system as it interrupts sand migration along the ocean beach and within the inlet. However, concurrently, mean high-water is now a foot higher than when the jetties were first constructed, beginning in 1881. Riding in atop of this rising ocean, storm waves and surge will increasingly play a greater role in shaping Plum Island's future. In order to delay storm driven wash over and barrier island migration:

- Complement and harness the available natural coastal processes to help the island accrete sand to build the tallest island vertically, with a robust barrier dune system.
- Work with the U.S. Army Corp of Engineers to maintain or redesign the jetty and inlet to allow it to function in a way as to maintain a navigable channel while not exacerbating erosion along the adjacent barrier beaches.
- Wherever possible, create vegetated dune buffer areas between the beach berm and inland structures, which may involve the acquisition of threatened waterfront properties and transitioning them to open spaces.
- All efforts related to river channel design, beach nourishment, barrier dune protection, planning, zoning and building codes need to align with this effort. Any methods that compromise the barrier beach resource and increase long-term erosion for short term protection should not to be pursued.

Immediate Strategies:

- Recognizing shared vulnerability, immediately create a joint Newbury and Newburyport task force to address Plum Island's challenges.
- Continue dune nourishment where necessary and continue dune grass planting and fencing to strengthen the barrier dune system.
- Reduce foot traffic on dunes.
- Continue to work with Department of Conservation and Recreation and the Merrimack River Beach Alliance (MRBA) to closely monitor storm damage and erosion rates along the ocean beach, within the Reservation Terrace dune system, the basin and other parts of the island, to support decisions regarding dune protection and potential emergency response actions.

- Prepare a Homeowner's Resiliency Guide that provides residents with options to protect their property. Include methods ranging from deployable flood barriers, to dune nourishment and planting, to raising their homes.

Short-term Strategies (now-2030):

- The primary goal of the Joint Task force is to develop a long-term Resiliency Plan for Plum Island that incorporates erosion rates, climate projections and necessary resiliency efforts to help delay retreat and anticipate when retreat might become necessary.
  - Engage the Department of Conservation and Recreation and the Merrimack River Beach Alliance (MRBA) to help with the development of this long-range plan.
  - Considering current climate projections, review, evaluate, and revise Plum Island zoning and regulations to guide development such that it promotes barrier island stability thereby delaying barrier island migration (discussed in Chapter 2 - Vulnerability) and protects the Plum Island beach resource. Developed regulations need to be consistent island wide for both Newburyport and Newbury.
  - Evaluate different shoreline protection systems for their ability to enhance and sustain the beach resource. Work with DEP to provide direction and certify allowed technologies.
  - Identify Infrastructure vulnerabilities:
    - Evaluate public utilities, including the sewer vacuum pump system, electrical power supply, and cell phone services.
    - Evaluate the need for on-island emergency response facilities – medical, fire and rescue and the need for a docking facility and helicopter landing area at Plum Island Point.
  - Work with residents, local and state government officials and other stakeholders to design a retreat plan that is equitable, acceptable and financially feasible.
    - Engage with the community to determine under what circumstances and resources, that a managed retreat would be acceptable.
  - Consider developing a process that allows residents, if they choose, to voluntarily convert their threatened homes to open space and protective dune, before urgent retreat is necessary.
- Stay abreast of ongoing studies concerning the Merrimac River inlet and adjacent beaches. Incorporate outcomes into ongoing plans and prepare to lobby the U.S. Army Corp of Engineers for a redesign of the jetty system.
- Ensure enforcement of existing State and local Wetlands Protection Act regulations governing barrier beaches and define enforcement responsibilities.
  - Maintain natural resource buffer zones and increase the capacity for enforcement of existing environmental regulations.
- Carry out a joint assessment with the town of Newbury of the economic factors impacted by climate change.
- Monitor updates to SLR projections and current flood frequency and depth to help with emergency access planning.
- Evaluate alternative Plum Island access strategies.
- Discuss culvert and bridge solutions for the turnpike to allow river flood waters to better flow across the marsh, vs. flowing over the roadway and backing into downtown Newburyport.

Long-term Strategies (2030-2070):

- Support a jetty redesign if deemed effective as the Merrimack River inlet jetties will likely need to be rebuilt during this period.
- Continue resiliency and shoreline maintenance efforts.
- Implement other measures as proposed in the Plum Island Resiliency Plan.
- Implement access options and Resiliency plans

3.3.2 Joppa to the National Grid Substation

Immediate Strategies:

- Maintain Joppa sea wall as necessary.
- Install scuppers in sea wall to allow trapped waters behind the wall to drain back into the river following splash over and collection of storm water runoff from uphill neighborhoods.
- To reduce wave fetch and attenuate wave energy, in cooperation with Mass. Audubon, design and implement a living shoreline demonstration project on the Audubon property.
- Prepare a Homeowner's Resiliency Guide that provides options of protecting their property. Include methods ranging from deployable flood barriers to raising their homes.

Short-term Strategies (now-2030):

- Concurrent with efforts to protect the WWTF, evaluate a living shoreline and offshore reef system to reduce fetch and attenuate wave energy.
- To address the increasing frequency of road closures due to current flooding episodes, elevate the low area at the Union/Water St. intersection to match the surrounding grade.
- Explore options to make existing buildings resilient to SLR and flooding.
- Consider incentives and if necessary, new regulations, within the FEMA high hazard flood areas to encourage the resiliency of private properties.
- Educate stakeholders, residents, and property owners to projected sea level rise and surge inundations.
- Work with residents, local and state government officials and other stakeholders to design a retreat plan that is equitable, acceptable and financially feasible.
- Engage with the community to determine under what circumstances and resources, that a managed retreat would be acceptable.
- Explore various strategies and design options to evaluate the feasibility of maintaining Water Street as a thru-way.
- As sea level rise and surge will make areas along Joppa uninhabitable at some point in the future, determine the financial impact that the loss of tax revenue will have on the city's operating budget.
- Develop financial strategies and revenue streams to deal with these impacts.

Long-term Strategies (2030-2070):

- Implement the most feasible strategies evaluated and developed during the short-term.

3.3.5 The National Grid Substation to the Route 1 (Gillis) Bridge – Downtown and Waterfront

Immediate Strategies:

- As part of a citywide stormwater management program, assess impacts of impervious surfaces uphill of the Waterfront and Market Square and develop a storm water management plan if deemed necessary and effective.
    - Evaluate and correct drainage capacity at Market Square.
- Educate stakeholders, residents, and property owners to projected sea level rise and surge inundations.
- Prepare a Homeowner's Resiliency Guide that provides residents with options to protect their property. Include methods ranging from deployable flood barriers to raising their homes and buildings.
- Explore options to make existing buildings resilient to SLR and flooding

Short-term Strategies (now-2030):

- Engage and educate central waterfront committees, associations, property owners, and the Waterfront Trust relative to projected SLR and surge inundations so that future planning and development consider these factors.
- Evaluate the Waterfront's financial contribution to the city's budget and local economy and what its loss might mean to the city.
    - Consider financial strategies and revenue streams to deal with these impacts.
    - Evaluate the cost and options available to preserve, or transition, the area under a rising sea and surge scenario.
- Consider incentives and if necessary, new regulations, within the FEMA A and V flood zones to encourage the resiliency of private properties.
- Explore various strategies and design options to evaluate the feasibility of maintaining Water/Merrimac Street as a thru-way.

Long-term Strategies (2030-2070):

- If feasible, implement plans to raise the waterfront bulkhead and park itself or transition the area as waters rise.

3.3.6 Route 1 (Gillis) Bridge to the I-95 Bridge – Cashman Park and Merrimack Street

Immediate Strategies:

- Educate stakeholders, residents, and property owners to projected sea level rise and surge inundations.
- Prepare a property owner's Resiliency Guide that provides options of protecting their property. Include methods ranging from deployable flood barriers to raising their homes and buildings.
- Explore options to make existing buildings resilient to SLR and flooding

Short-term Strategies (now-2030):

- Considering that the park currently supports a host of amenities which include boat launches, ball fields, a playground, a dog park, a bike and walking path, and piers; evaluate the cost and options available to either preserve Cashman Park, or transition the area under a rising sea and surge scenario. If the park is transitioned, determine where these amenities will eventually be relocated.

- Consider incentives and if necessary, new regulations, within the FEMA high hazard A and V flood zones to encourage the resiliency of private properties.
- In anticipation of future sea level rise and shorter-term storm related flooding, evaluate the feasibility of elevating Merrimack street in low areas, especially near the Mersen property (372 Merrimac St.) and assess impacts of raising the road on private property.
- As part of a citywide stormwater management program, inventory impervious surfaces uphill of Merrimack St. towards High St. Reductions in impervious surfaces would reduce heat island effects, storm water runoff, road maintenance and snow plowing costs. Consider methods to increase rainfall infiltration.
- Determine the financial impact that SLR and future flooding will have on the city's property tax income, operating budget, and local economy.
    - o Develop financial strategies and revenue streams to deal with these impacts.

Long-term Strategies (2030-2070):

- Maintain Cashman Park's open space
- Either raise Cashman Park if feasible and desired, or transition the park to alternate uses as sea levels rise.
- Elevate areas of Merrimack St. as necessary to maintain an open roadway.

3.3.7 The Little River Watershed including the Business Park

Immediate Strategies:

- Educate stakeholders, residents, and property owners to projected sea level rise and surge inundations.
- Improve drainage capacity of Business Park. Improvements to include:
    - o Swale restoration and maximization
    - o Install improved culverts to restore hydrology and reduce flooding at:
        - ▪ Graf Rd
        - ▪ Parker St./Scotland Rd.
        - ▪ Doe/Quail Run
        - ▪ Malcolm Hoyt Dr.
        - ▪ Hale St. (near pump station)
- Develop a hydrologic and hydraulic flood inundation model for the Little River Watershed. Incorporate the Woods Hole Group's coastal model and the hydrologic restrictions along the Little River.

Short-term Strategies (now-2030):

- Manage and attenuate storm water runoff into the watershed that contributes to flooding in the Business Park, and the Wildwood Drive, Quail and Doe Run Neighborhoods.
    - o As part of a citywide stormwater management program:
        - ▪ Inventory impervious surfaces that drain into the Little River Watershed from Storey Ave and other Newburyport neighborhoods.
        - ▪ Develop strategies to reduce impervious surfaces.
- Plant trees and vegetation that is particularly well suited to water absorption (such as willows for example).

- Create flood-storage opportunities within the Park through open space planning, including dual purpose parking lots.
- Encourage businesses to review possible building retrofits including drop-in flood barriers and longer-term flood proofing.
- Encourage/require Low Impact Development standards for any new buildings or upgrades.
- Improve the roadbeds within the Business Park and raise them as necessary such that they remain passable during flood events.
- Review and recommend changes if necessary, to emergency response plans to address the inundation of chemicals by flood waters.
- While working to reduce water flow into the watershed, concurrently work with Newbury to develop a plan to reduce downstream barriers to flow.
- Strategies to protect the watershed from storm surge and future sea level rise are in direct conflict with the short-term strategies to drain flooding rainwaters by opening barriers to flow. Opening these barriers increases the Business Park's vulnerability to sea water intrusion by storm surge and SLR.
    - In cooperation with Newbury evaluate strategies and the feasibility of developing a system of flood gates that could be timed to close in the event of an expected storm surge, and then opened to release runoff. The timing of weather events with the operation of such a system might not guarantee against some flooding within Newbury and Newburyport.
- Determine the financial impact that SLR and future flooding will have on the city's property tax income, operating budget, and local economy.
    - Develop financial strategies and revenue streams to deal with these impacts.

Long-term Strategies (2030-2070):

- Consider sea level rise projections and future storm impacts for long-term planning for the Business Park and associated access routes.

3.4 Community-wide Vulnerability

3.4.1 Public Health and Safety

Immediate/Short-term Strategies (now-2030):

- Vulnerable Populations
    - Elderly, infants and toddlers, pregnant women, people with pre-existing medical conditions and disabilities, people living alone, and persons occupationally exposed to the outdoors are especially vulnerable to climate extremes.
        - City EMS will continue to stay abreast of medical incidents initiated by extreme heat, cold, and storm impacts
        - The existing Council on Aging Program of community awareness to check and help vulnerable neighbors should be more widely promoted.
        - Encourage private citizens to become trained in CPR and first aid; specifically, in recognizing and treating heat stroke and heat exhaustion.
        - Enlist the Newburyport School System, Red Cross and YWCA to train students in first aid and CPR
- Stay abreast of Insect Disease Vectors

  - Continue to monitor state issued warnings relative to the prevalence of West Nile and EEE and other diseases within area insect populations. Communicate warnings to residents as necessary.
  - Develop a community education campaign to encourage residents to reduce mosquito breeding grounds around their homes. Eliminate standing water by discarding old tires, emptying uncovered buckets and barrels, unclog gutters and frequently change bird bath water.
  - Post educational signs regarding tick and mosquito safety/precautions at outdoor areas such as playing fields and parks.
- Continue to work locally and regionally to address the Combined Sewer Overflow (CSO) issue and Merrimack River water quality.
  - Gather pertinent facts to fully characterize and quantify the problem.
    - Commission a study to determine if there are correlations between local river water quality with the timing of reported CSO releases upstream.
    - Determine what impacts CSOs have on water quality at selected sites within the river and along Plum Island.
    - Determine the effect of tides and ocean water on river and beach water quality.
  - Based on the outcome of the water quality study, if necessary, develop an automated water quality testing program to alert residents of water quality issues.
  - Continue to work regionally to resolve the problem upriver.
- Reduce Snow-fall impacts on narrow downtown streets and sidewalks.
  - To reduce street congestion and the blocking of sidewalks with plowed snow, develop alternative snow removal strategies, for example:
    - Newburyport, like other cities enforces an on-street parking ban when significant snow is expected.
    - With the streets cleared of parked cars, snow removal operations would plow snow into the *center* of the street (vs onto the sidewalks). Then a giant snow blower would transfer the snow into a truck for transport to a disposal/melt location.
- Improve sidewalks and bike lanes.
  - Continue to support the Livable Streets initiative to promote the reduction of in town auto use and its associated carbon footprint.
  - Continue to improve sidewalks within town.
  - Support and enhance the Tree Commission to develop and evaluate strategies for the planting of street trees so that they do not damage sidewalks.
    - Evaluate options to plant tree species whose roots won't damage sidewalks.
    - Evaluate re-routing sidewalks if possible.
    - Evaluate planting trees to the side of sidewalks
- Improve and Enhance Emergency Preparedness
  - Develop a program to educate and promote personal emergency and storm preparedness.
  - Enhance municipal emergency preparedness and response procedures

- Improve participation in, and use of, Newburyport's Code Red System.
- Continue annual emergency response drills and develop a set of emergency response exercises based on an extreme weather event.
- Annually review and update mutual aid agreements with neighboring municipalities and states.
- Improve communications infrastructure between municipalities and facilities.
- Train residents and students in CPR and First Aid

3.4.2. Wind, Weather, Trees and Energy Vulnerability

Immediate/Short-term Strategies (now-2030):

- Where possible explore feasibility and cost associated with placing utilities underground and away from trees. Explore running utilities under sidewalks and crosswalks vs under streets
- Work with the Tree Commission to generally avoid planting trees underneath utility lines. If necessary, plant shorter trees, that concurrently don't block the line of sight of vehicles and force pedestrians from the sidewalks.
- Explore viability of micro grids and how to power them.
- Encourage residents to invest in backup generators and portable battery power supplies to power cell phones.
- Develop emergency backup electrical power to fuel key pumping stations so residents can obtain fuel for vehicles and generators.
- To improve the resiliency of existing homes to storm impacts, make available information on building retrofits, elevation of utilities and buildings themselves.

Long-term Strategies (2030-2070):

- Implement pilot projects to bury utilities
- Implement micro grid pilot project
- Have back up power in place for fuel pumping stations

3.4.3. Impervious Surfaces – Storm Water Management, Snow Removal and Heat Island Effects

All previously discussed *Neighborhoods Vulnerable to Flooding* are impacted by impervious surface runoff. In addition to enhancing stormwater runoff, impervious surfaces contribute to heat island effects driving up temperatures during heat waves and increase the cost of snow removal. The problem therefore is citywide and requires a citywide evaluation of impervious surfaces, its stormwater system and roadways which will be required to convey increasingly massive amounts of runoff from future storms.

Immediate/Short-term Strategies (now-2030):

- Inventory impervious surfaces across town and identify/estimate areas for impervious surface reduction.
- Design pilot projects for impervious surface reduction and evaluate their cost and effectiveness.
- Evaluate the capacity of our current stormwater conveyance systems to handle more water.
- Evaluate the feasibility and utility of a municipal roof/rainwater collection and storage system.
- Consider narrowing all unnecessarily wide streets.
    - Work with a neighborhood to develop a demonstration project to narrow a wide street. Run utilities under the sidewalks, expand green areas to where pavement once was, plant trees to the side of sidewalks, and install a municipal rainwater collection system as well

as rainwater catch basins. The design with some integrated along street parking would also serve to naturally slow vehicular traffic.

Long-term Strategies (2030-2070):

- Implement storm water utility with incentives to reduce impervious surfaces.
- Implement pilot projects for impervious surface reduction.
- Upgrade the city's stormwater conveyance system as necessary.

3.4.4. MBTA Commuter Rail Vulnerability

Immediate Strategy:

- The MBTA commuter rail bed and track system that runs south from Newburyport is vulnerable to SLR and surge inundation. As the commuter rail serves an important function in providing public transportation to and from Newburyport it is important for city officials to work with state representatives to encourage the MBTA to make their service resilient to climate hazards.

3.4.5. Economic Vulnerability

Executing resiliency strategies and managing increasing emergency response costs will tax the city's current operating budget and therefore require significant additional funding sources. Moreover, as sea levels rise and more frequent episodes of coastal flooding and erosion render properties uninhabitable, Newburyport will experience a reduction of its current property tax base which, without alternative funding sources, will negatively impact its operating budget. While State and Federal funds may help, they will not be consistently available when needed, and won't cover all costs.

Immediate/Short-term Strategies (now-2030):

- Conduct a thorough cost-benefit analysis for the resiliency strategies proposed. Weigh construction costs against the likelihood of losing property to the sea. Determine how much money should be spent.
- Quantify the value of the city's Waterfront and area beaches to the local tourist economy.
- Based on a SLR and inundation timeline, forecast losses in property tax income citywide. Quantify this potential revenue shortfall on the city's operating budget.
    - Determine the impact that the eventual loss of river front, Plum Island, and potentially Business Park properties will have on the city's finances and that of neighboring Newbury.
- Begin to identify new revenue streams to accommodate resiliency costs and future operating budget losses.
    - To help fund resiliency measures and emergency response efforts, design and implement a citywide storm water utility.
    - As properties located in flood zones are known to require more costly resiliency measures than those located outside of those areas, evaluate the city's tax rate and the benefits of a tax rate increase for all properties in the FEMA Design Flood Elevation (DFE) zones. These areas include all properties on Plum Island, properties along the Merrimack River, and within the Little River watershed.
    - Evaluate the necessity of a tax rate increase for all city properties as climate hazards ultimately affect everyone and funding will urgently be needed.
    - Impose taxes on certain uses (similar to the city's Meal's Tax).

3.4.6. Retreat from Vulnerable areas

At some point SLR and frequent inundations will make vulnerable areas uninhabitable. As some areas will become uninhabitable sooner than others, use SLR and inundation projections to illustrate a potential retreat timeline, and create a regulatory framework to slow further development in the FEMA A and V zones.

Immediate Strategies:

- Review to evaluate and revise zoning and building regulations to improve building resilience, water conservation and energy efficiency *and discourage development in high risk zones.*

Short-term Strategies (now-2030):

- Educate shoreline property owners and developers of SLR and inundation timelines. Encourage them to see when properties may become routinely inundated.
- Work with residents, local and state government officials and other stakeholders to develop a future vision of the community should sea level rise and frequent inundations eventually result in the loss many shoreline properties, municipal amenities and infrastructure.
  - How is Newburyport's character maintained?
  - Where will Newburyport's waterfront parks and their amenities be relocated to?
  - How will roads, traffic and emergency access be re-routed?
  - How will drinking water, wastewater and electrical power infrastructure and services be maintained?
- Work with residents, local and state government officials and other stakeholders to design a retreat plan that is equitable, acceptable and financially feasible.
  - Engage with the community to determine under what circumstances and resources, that a managed retreat would be acceptable.
    - To understand and identify local concerns and issues, convene local focus groups to discuss the topic of retreat.
    - Determine people's barriers to retreat.
    - Use this understanding to discuss the issues more broadly, addressing barriers to retreat, and develop strategies to gain support.
- Consider a sliding scale buyout program where residents are better compensated if they chose to convert their property to an open space buffer zone before urgent retreat is necessary. Monetary support would dwindle as the situation became more dire, with fines and demolition charges issued for abandoned and condemned properties, and those that compromise the shoreline resource if they fall into the sea.
- Explore and develop funding scenarios to support a managed retreat process.

3.4.7. Public Outreach and Education

Short-term Strategies (now-2030):

- Develop a Communication Subcommittee to develop and execute a communication plan for this resiliency plan.
- Organize education and outreach programs for personal preparedness, resiliency, natural hazard mitigation, CPR, First Aid training and calculating carbon footprints.
- Create school-based programs to educate future generations about climate change impacts and resiliency.

- Engage and educate Central Waterfront committees, Chamber of Commerce, business and property owners so that future development and planning reflects future climate impacts.
- Determine the best means of communicating risk to individual property owners and developers before they purchase property for a project in a vulnerable area.
    - Go beyond public meetings and engage residents at community events, churches, clubs and gatherings
    - Create visual art displays illustrating future high-water marks and water levels of past flood events.
- Assist with private resiliency efforts - encourage property owners to improve the resiliency of their buildings by providing a list of resources and retrofits, including drop in flood barriers and longer-term flood proofing that can be used to seal against water intrusion, strategies to elevate utilities, install backup generators etc. Involve CONCOM to detail requirements to be considered.

3.4.8. Carbon Footprint Assessments and Reduction

To apply the brakes to our changing climate and to secure a future for our children, Newburyport and its residents need to quantify their personal contributions to climate change, and then work to reduce their impact. The city is assessing its impacts by quantifying its municipal carbon footprint and taking actions to reduce it. If the city hopes to realize its net zero pledge by 2050, residents of Newburyport need to take responsibility and do the same.

Immediate Strategy:

- Have the Communications Subcommittee develop a plan to educate the community about the necessity to complete a carbon footprint assessment and provide methods for residents to reduce their impacts.
- Set municipal and residential goals for carbon footprint reductions to meet community net-zero goals.
- Develop a system to collect and monitor residential and municipal carbon footprint trends annually and widely publicize the aggregate results.

Short-term Strategies (now-2030):

- Select an online Carbon Footprint calculator that residents can use to quantify their personal impacts and report their status annually.
- Annually encourage schools to have students engage their parents in a homework assignment to calculate their household's carbon footprint.
    - Collect this data to estimate and track residential carbon footprint trends.
- Considering Global and National trends, determine whether additional incentives or regulations are needed for Newburyport residents to meet community net-zero goals.

Chapter 4 – Implementation

4.1 Organization

The preceding Chapters have illustrated in detail that climate change will have far-reaching impacts across the city. Impacts will not just be limited to the shore but will also extend to inland neighborhoods. Chapters 2 (*Vulnerability*) and 3 (*Adaptation Strategies*) underscore that a holistic approach to resiliency will be required to effectively prepare the city for current and mid-term (2030-2070) climate hazards. Concurrently, the mitigation of longer-term climate impacts (2070 and beyond) hinges upon motivating residents to manage their personal contributions to climate change, today. Efforts to carry out the strategies outlined in Chapter 3 will require a serious commitment from the city with coordination across many departments. Therefore, climate change resiliency will need to become a central theme throughout the city, its neighborhoods, government, and city departments. Specifically, departmental procedures and how they operate need to be evaluated considering climate change and fine-tuned to support the resiliency and mitigation effort.

The resiliency effort is currently being spearheaded by the Mayor's ad hoc Resiliency Committee. Most of its members, including its Co-Chairs, are volunteers; and with four city departments represented (Engineering, Conservation, Sustainability, Emergency Management). The Committee has jump started the resiliency effort and the four city departments have undertaken much of the workload. Given the breadth of the tasks that lie ahead, city leadership will need to decide whether this committee alone has the capacity to execute the necessary strategies to address the climate hazards identified in this plan.

Members of the Resiliency Committee have recommended that Newburyport create a salaried position for this function that would report directly to the Mayor's Office. Discussions over the years have considered sharing this position with other neighboring communities, such as Newbury and West Newbury, to maintain continuity of strategies, planning, funding, implementation and messaging. The position would be charged with implementing strategies of the Resiliency Plan and developing and managing the process.

Until city leadership specifically defines the structure of the resiliency function, it is recommended that the Resiliency Committee be maintained to meet its mission of advocating and overseeing the implementation of the Resiliency Plan and a department head to be responsible for resiliency plan implementation. Should the city create a position or department to coordinate implementation of the plan, the Resiliency Committee would be a key ally in executing this function. Regardless of which organizational path is chosen, to underscore resiliency's importance, the Mayor and city Council would need to strongly lead and support this effort.

To further legitimize the role of the Resiliency Committee it is recommended that volunteer members be provided term limits and their membership be evaluated for their expertise, gender, age, and other diversity considerations. Given the amount of work that is expected, the committee should continue to meet monthly or ensure that improvement projects are out-sourced. The use of volunteers for the organization should be extended as necessary, especially for short term project-oriented assistance. Annual meetings with the Administration, city Council and general public should also be scheduled.

4.2 Strategic Areas of Implementation

4.2.1 Communication and Community Education

Climate change resiliency and its mitigation is very much a challenge of social change, and one of "selling" that there is an urgent problem which requires immediate attention. However, there is a chasm of disconnect between the severity of the problem and society's perceived need to address it. Forty years ago, the world had the opportunity to solve climate change and truly minimize its impacts[6] However, that opportunity, along with others has slipped away, and according to the United Nations' Intergovernmental Panel on Climate Change[7], society has until 2030 to mitigate climate change to restrict global average temperature rise to a maximum of 1.5ºC. The report suggests human-caused CO_2 emissions will need to fall 45% from 2010 levels by 2030 in order to reach "net zero" by 2050. Considering this, one might conclude that we are well past the 11th hour of substantively addressing this global crisis.

In stark contrast is the public's perception of the problem. As a riverine and coastal community, the impacts of climate change are enhanced and therefore clearly visible and so the burden of demonstrating threats and hazards ought to be lessened. However, Yale's Climate Opinion project shows that while nearly ¾ of the population in Essex county believes climate change is happening, 50% believe it won't harm people in the U.S. for at least 25 years, if ever, and 2/3 don't perceive that it will ever harm them personally (*Figure 116. Yale Climate Opinion Survey 2018*). It is a tall order to sell expensive and inconvenient infrastructure projects along with behavioral changes to a public that doesn't perceive an urgent need for them.

It is therefore critical to educate people of the problem's urgency and translate that into behavioral action. Residents will not only need to feel compelled to reduce their carbon footprint but will also need to whole heartedly support costly and sometimes inconvenient resiliency projects. To rally the support of a community in these efforts, the problem and its solutions need to be effectively and efficiently communicated. More importantly, the community needs to be critically involved in the effort of mitigation and resiliency, especially when projects directly affect them.

A comprehensive communications program is required and as such, would be most effective economically and consistent in messaging if it were to address the goals of not only the Resiliency Committee, but also those of the Energy Advisory and Net Zero Committees. As this effort at social change is so critical, city leadership should seriously consider enlisting the support of experienced Public Relations experts, either hired or volunteers from within the community to develop and execute the effort.

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[6] Rich, Nathaniel, Losing Earth: The Decade We Almost Stopped Climate Change, The New York Times, August 1, 2018

[7] UN IPCC, Special Report on Global Warming of 1.5ºC, October 8, 2018

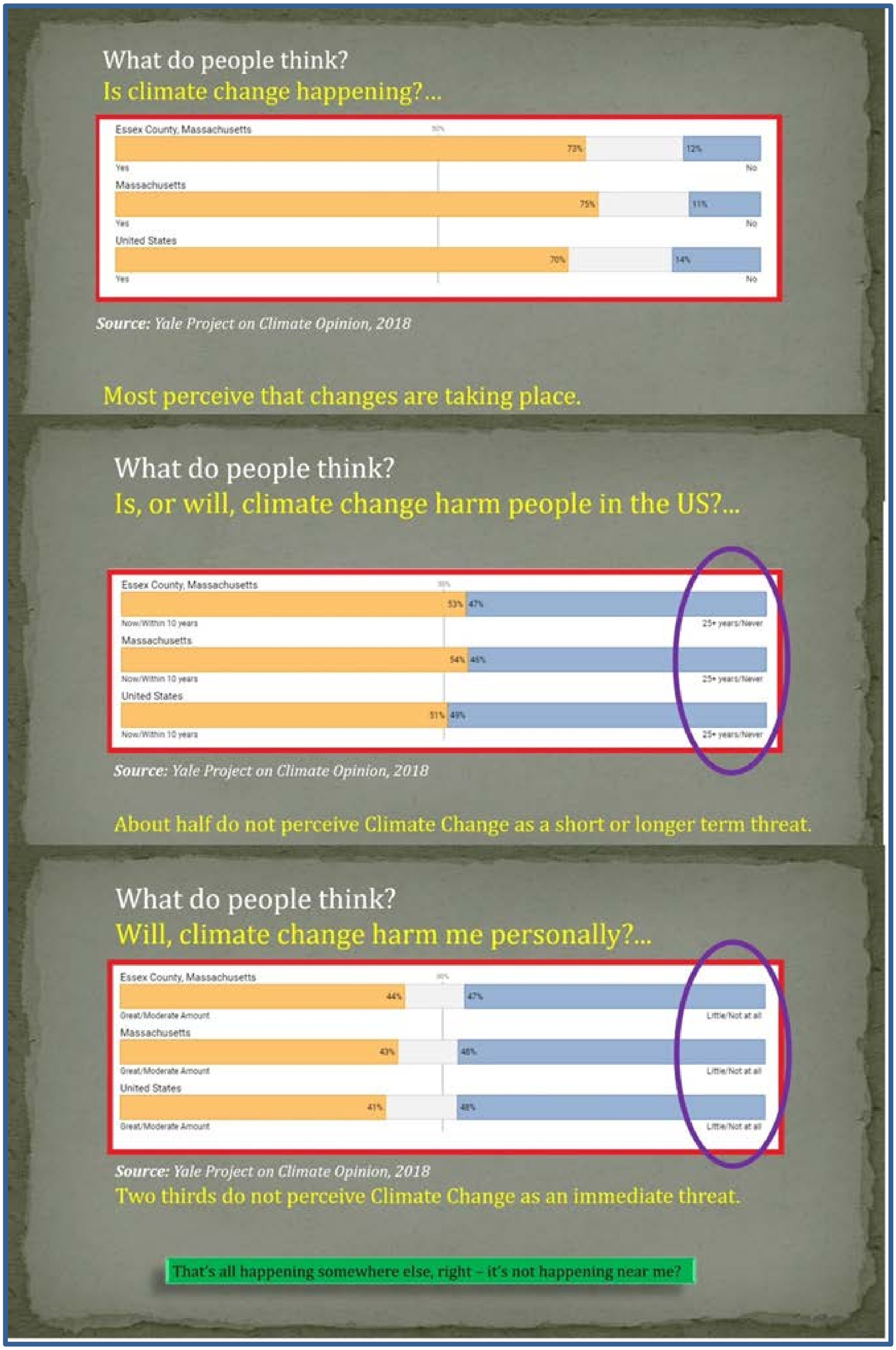


Figure 116. Yale Climate Opinion Survey 2018

In its very basic form, elements of the communication plan should include but not be limited to:

- Communication of the Resiliency Plan to city Administration, city Council, the General public and Chamber of Commerce et al.
    - The incorporation of climate change education into every Newburyport School and integrated into all disciplines.
- Education of city employees on climate change and their role in mitigation and resiliency.
- Coordinated awareness campaigns to keep desired messaging before the public.
    - Climate related messaging needs to be present on every municipal property, in every building and public area.
    - Sea level rise art exhibits developed along the waterfront
    - Climate change inspired art throughout city parks and downtown
    - Joint projects with the Energy Advisory and Net Zero Committees such as "No vehicle idling" ordinances and signage promoting voluntary idle reduction at traffic lights.
    - Frequent newspaper Op-Ed pieces by various city department heads illustrating why and how their departments are working on mitigation and resiliency.
    - Community education series individually tailored to the varying needs of public schools, community groups, property owners, realtors, developers and businesses.
        - Community education series targeted towards high risk neighborhoods illustrating sea level rise and storm surge impacts.
    - A personal *Storm Readiness* campaign - Emergency management for households and the community.
    - A list of actions that residents can take to reduce their personal contribution to climate change.
- Development of a Newburyport *Climate Ready* website with extensive links and resources.
- Video copies of critical presentations available on the website.
- Hard copy materials on identified critical behaviors, practices, and actions including:
    - Guidelines for builders and developers
    - Guidelines for potential purchasers of real estate in Newburyport
    - Shoreline and Dune Regulations
    - Conservation regulations
    - Building regulations and best practices to mitigate the impacts of climate change
- Close cooperation with other likeminded organizations with links to appropriate websites such as *Storm Surge* and the *Green Expo.*
- A long-term plan for communicating the inevitability of relocation from vulnerable coastal areas and a program of public participation to determine what form such a program should take.
- A program that communicates to councilors, state and congressional representatives what support Newburyport needs to become resilient and effective at mitigation. These needs could include funding sources, regulatory changes and agency support. Examples are FEMA changing its flood maps or accepting submitted changes, changes to State building regulation that consider future sea level rise, and the enforcement of emergency plan requirements for businesses to name a few.

4.2.2 Municipal Leadership

To achieve climate mitigation and resiliency goals, it will be critical to identify behaviors, practices and actions both within the city and its populace that currently exacerbate climate impacts and compromise resiliency. Before asking its populace to conform to desired behaviors, it is essential that the city and its departments lead by example. To that end city leadership and city departments alike must model desired behaviors, practices and actions. All city departments need to identify counterproductive procedures, regulations, actions and behaviors (municipal or public) within their purview and recommend the best possible strategies to deal with them.

Future sea level rise and climate hazards will have Newburyport evolve to appear much different in the future. Therefore, city leadership has the opportunity today to define what the city will look like in 2050, 2070 and beyond. To that end city leadership needs to not only develop a vision for what Newburyport will be, but also define the necessary steps to make in this evolution.

4.2.3 Regulatory Approaches

In some instances, awareness, communication and training alone will be enough to guide desired change. In other situations, enforcement of existing regulations may be all that's needed. However, at some point new procedures and regulations will become essential to achieving desired outcomes; and it will be important for city departments to identify those options. As an example, considering the city's vulnerability to sea level rise and climate hazards, the continued real-estate development within the current FEMA high risk zones is a liability to the city, and society in general. Properties in those areas will likely be subject to continued and increasing costs associated with resiliency efforts and protection, storm related emergency response, multiple flood insurance claims, eventual retreat and a possible taxpayer buy-out, followed by property demolition. It would therefore be more cost effective to enact regulation now to temper development in these high-risk areas, while concurrently promoting development in safer zones. To that end, the development of new regulations will require identifying a relevant legal resource and involve an extensive process of vision development, municipal planning and public engagement.

4.2.4 Infrastructure Installations/Improvements

In carrying out infrastructure related strategies of the Resiliency Plan, it will be necessary to continuously have at the ready, three top infrastructure improvement projects. As projects from this top tier are funded and executed, a lower ranked project can then be elevated to the group. Each of these top-ranking projects are to be defined relative to their design and scope, including the magnitude of their cost. It will be essential to monitor a broad range of funding sources for these projects, including Federal, State and Private grant programs, bond bills, buy back and the city's own capital budget. It is important to designate who will monitor these likely funding sources. To qualify for potential funding, it is critical to have the top their projects "shovel ready", complete with implementation plans, likely permit requirements and an identified public involvement process. Most projects will lend themselves to a phased approach; consequently, the resiliency strategy portfolio will need to be managed and updated periodically throughout the year.

4.2.5 Mitigation through Carbon Footprint Reductions

In 2014, the city developed a clean energy roadmap, including a commitment to net-zero where all energy for electricity, heat and transportation will be derived from renewable resources https://www.cityofnewburyport.com/sites/newburyportma/files/pages/roadmap_newburyport_0.pdf.

The recently adopted master plan also commits the city to becoming a net-zero community, thereby applying the brakes to the community's contribution to climate change. Mayor Donna Holaday is one of the first mayors to sign the C40 agreement, obligating all new construction in Newburyport to be net-zero by 2030 and the rest of the building stock to become net-zero by 2050.

Chapter 3 *Adaptation Strategies* stated that a critical step to achieving net-zero was for Newburyport and its residents to quantify their personal contributions to climate change by calculating their carbon footprint, and then working to reduce it. The city is leading this effort by quantifying municipal impacts and taking actions to reduce it. *Residents of Newburyport need to take responsibility and do the same.*

Hence the opportunity exists to develop a plan to educate the community about the necessity to complete a carbon footprint assessment and provide methods for residents to reduce their impacts. Setting municipal and residential goals for carbon footprint reductions is critical for meeting community net-zero goals. To track the city's progress towards its net-zero commitment, Newburyport needs to develop a program to collect and monitor residential and municipal carbon footprint trends annually, and widely publicize the aggregate results.

The IPCC Special Report on Global Warming of 1.5C compiles the strongest evidence to date that governments, businesses and society must bring net carbon emissions down to zero as soon as possible and certainly early (2050) in the second half of the century to prevent global temperature rises of more than 1.5C. In order to limit postindustrial warming to 2 degrees by 2100, and thereby avoiding the worst of climate change impacts, net-zero must be achieved by 2070; in addition to the global community removing carbon from the atmosphere. This is a tall order, and the window of opportunity to effectively mitigate the problem is quickly closing.

APPENDIX 1 – Newburyport Parks and Open Space Inventory

City Parks and Recreational Areas

Location Name or Description	Open Space Acreage
Atkinson Common (includes so called Lower Atkinson Common)	21.14
Moseley Woods	13.00
Cashman Park	12.52
Bradley Fuller Park	10.00
Cherry Hill Athletic Fields	9.50
Woodman Park	9.37
Perkins Park	8.00
Clipper City Rail Trail- Phase 2	7.65
Bartlet Mall (including Frog Pond)	7.27
March's Hill	6.34
Former NRA lots	5.10
Clipper City Rail Trail- Phase 1 and Harborwalk	5.00
Market Landing (Waterfront Park)	4.12
Cushing Park (including Ayer's Playground)	1.83
Inn Street Mall (including playground)	1.25
270 Water Street	1.06
Mayor Peter J. Mathews Memorial Boardwalk	1.00
Atwood Park (including Garrison Gardens)	0.66
Brown Square	0.59
Harborwalk	0.50
Joppa Park	0.50
Moulton Square	0.45
Newburyport Skate Park	0.30
Brown School Playground	0.25
Jason Sawyer Playground	0.25
Cornelius Doyle Triangle	0.22
Market Square Bullnose	0.20
Washington Park	0.17
Patrick Tracy Square	0.15

Conservation Land

Macomber property, 97 High St and former Wheelwright property, 75 High St	TBD
Common Pasture -- Wet Meadows	125.76
Common Pasture -- Cooper North	101.76
Little River Nature Trail	55.81
City Forest	40.36
Common Pasture -- Coffin's Island	13.58
Former Hiller Property	13.50
Curzon Mill Rd Conservation Land	5.85

Private Open Space

Privately held vacant land	1184.00
CHAPTER 61 / 61A / 61B	251.50
Joppa Flats Education Center (Mass Audubon)	53.54
Oleo Woods, Russell Terrace Ext.	35.95
Plum Island Turnpike land	34.57
Plum Island Airfield	8.81
Sawyer Hill Cemetery	3.55
Brown Street/Wills Ln	2.40
223 High Street	1.40
Hale Park	1.25
52 Ferry Road	0.60

Public and Private Cemeteries

Oak Hill Cemetery	34.77
St. Mary's Cemetery	23.70
Cherry Hill Open Space/Daniel Lucy way	14.00
Belleville Cemetery	13.00
Highland Cemetery	12.63
Old Hill Burial Ground	5.31

School Property

Nock-Molin Schools	6.75
Bresnahan Elementary School	5.25
Newburyport High School	3.50

State, Federal and Military Land

Maudslay State Park	488.12
Newburyport Beach (Plum Island)	59.36
Arrowhead Farm	28.00
Ferry Landing Farm	25.00
Parker River NWR Visitor Center (USFWS)	10.17
Plum Island Coast Guard Station	3.20

Water Department Water Resource Land

Ferry Road abutting Moseley Woods	34.80
Plummer Spring Road	28.28
Land along Artichoke River and Storey Ave	25.77
Ferry Road former well	16.30
Old Ferry Road	11.08
March's Hill Water Tower	2.34

APPENDIX 2 - Climate Change Summary

Overview – Climate Impacts on Our Weather Systems

Among the public there is a blurring and confusion regarding the differences between climate and weather. Hence, some (like a US Senator from Oklahoma) might use the example of a record snowfall as proof that the climate *is not* warming, while others might cite the existence of a tropical storm that the climate *is* warming. So, what is the difference between Climate and Weather?" While weather and climate describe the same thing—the state of the atmosphere—they do so along different time scales. Weather is what we experience day to day, but Climate describes how the atmosphere behaves over a longer period. Another way to look at it is in terms of a party or concert. One might describe the "Climate" of a Boston Pops concert as "generally relaxing" peppered with some Beatles hits to add some rhythm and spice. The general "feel" of the concert is the "Climate" while the individual songs could be considered "weather" events. Over the last 10,000 years humanity has been living in a Boston Pops Climate that has generally been relatively mild and consistent; but was peppered by some noteworthy rhythms. Today's climate is playing a bit more rock and roll, and in the future will be even more so. While the future climate will feature some slow-moving ballads, it most certainly will drive some fast and heavy beats along with some painfully long drum solos. It certainly won't be the Climate of the last 10,000 years.

Climate Change Summary

Greenhouse gases emitted through the burning of fossil fuels since the beginning of the industrial age have accumulated and trapped heat in our atmosphere, much like placing a blanket on a bed. This added heat energy has been absorbed by our land and atmosphere, and to a greater extent by our oceans. It has altered the jet stream that guides our weather and storm tracks, has infused more water vapor and energy into storm systems, and is contributing to sea level rise through thermal expansion of our oceans, the slowing of nearby ocean currents and the melting of our polar ice caps. Continued greenhouse gas emissions will continue to drive sea level rise well into the future and will cause all sorts of weather conditions to persist – be it hot, cold, wet or dry – any of which can become extreme.

The following sections will examine some of the factors impacting our climate, its weather systems and how they give rise to the hazards we are planning for.

1.1 Climate Change Made Simple – Like Placing a Blanket on a Bed

1.2 Heating Our Atmosphere and Oceans – Adding More Energy to the System

1.3 The Arctic, the Jet Stream and Our Changing Weather

1.4 The Jet Stream and Shifting Storm Tracks

1.5 Ocean Currents, the Gulf Stream and Sea Level Rise

1.1 Climate Change Made Simple – Like Placing a Blanket on a Bed

Every day the sun streams an immense amount of energy to our planet. This energy warms our world and swirls its great air masses and oceans. Without this energy, and the cycles it drives, life here would not exist. However, not all the sun's energy remains on our planet. The sunlight that we see with our eyes penetrates our atmosphere in very short wavelengths, and while some of it is reflected directly by clouds, most is absorbed and stored by water, land and atmosphere. A portion of this stored energy is then radiated back into space as long wave radiation. If this process of absorption, storage and re-radiation did not exist, the earth would simply overheat after sunrise, and conversely, become intolerably cold after sunset. Important regulators of earth's temperature are the Greenhouse Gases (GHGs) that reside high up in our atmosphere. Their nature is to allow the sun's short-wave rays to pass through, while intercepting and absorbing the longwave heat energy trying to escape back into outer space. GHGs therefore act much like a blanket on a bed. A thin blanket traps moderate amounts of heat, while a thicker blanket will trap more. Since the industrial age, the earth's blanket of greenhouse gases has grown thicker and so our world has been warming.

Many GHGs like Carbon dioxide, methane, water vapor, and nitrous oxide are naturally present in our atmosphere. They are the result of plant and animal bio chemical processes (respiration), occasional volcanic activity and forest fires to name a few. The other greenhouse gases we find today, such as chlorofluorocarbons (CFCs), hydro fluorocarbons (HFCs), per-fluorocarbons (PFCs), and sulfur hexafluoride (SF6), are synthetic products of our industrial revolution. GRAPHIC A2.1: (Greenhouse Gas Atmospheric Lifetime and Global Warming Potential) lists the most common GHGs, their expected lifetime once introduced to our Atmosphere, and their Global Warming Potential (GWP) relative to CO2. It's quite apparent that the GWP of the manmade gases is incredibly potent.

GHG Expected Atmospheric Lifetime & Global Warming Potential relative to CO2

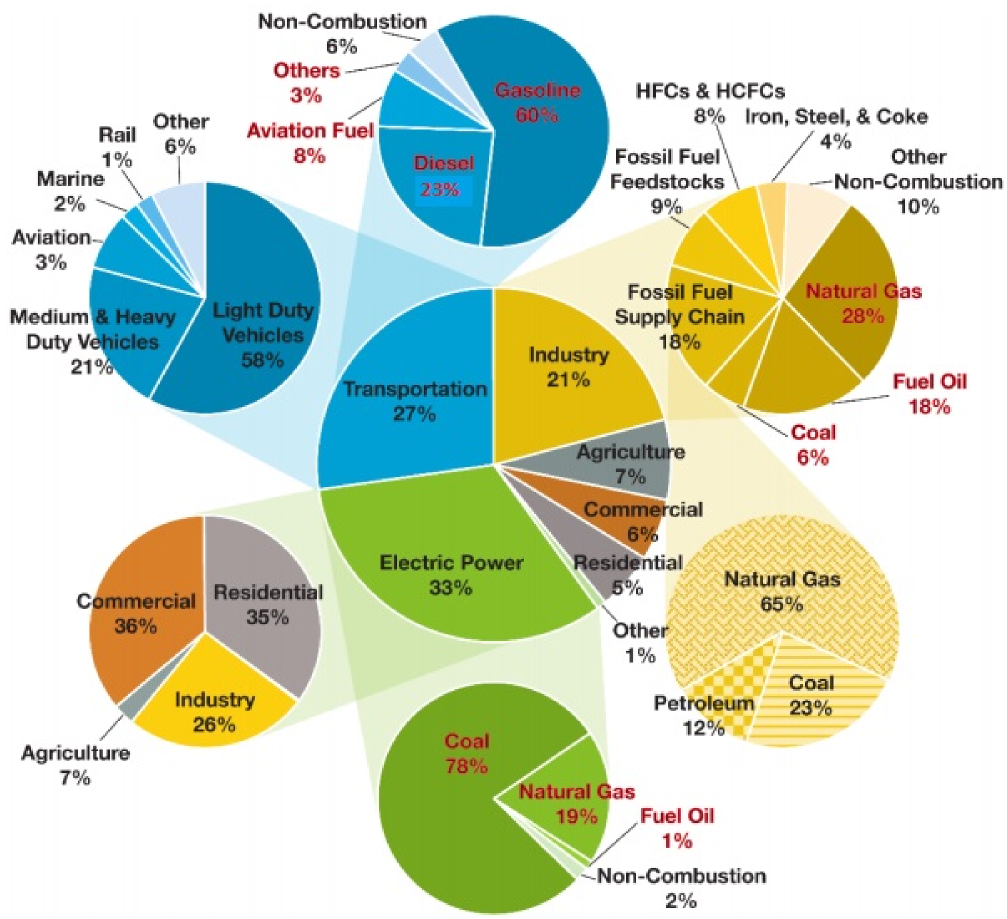
Gas name	Chemical formula	Lifetime (years)[22]	Global warming potential (GWP) for given time horizon		
			20-yr[22]	100-yr[22]	500-yr[39]
Carbon dioxide	CO_2	30–95	1	1	1
Methane	CH_4	12	84	28	7.6
Nitrous oxide	N_2O	121	264	265	153
CFC-12	CCl_2F_2	100	10 800	10 200	5 200
HCFC-22	$CHClF_2$	12	5 280	1 760	549
Tetrafluoromethane	CF_4	50 000	4 880	6 630	11 200
Hexafluoroethane	C_2F_6	10 000	8 210	11 100	18 200
Sulfur hexafluoride	SF_6	3 200	17 500	23 500	32 600
Nitrogen trifluoride	NF_3	500	12 800	16 100	20 700

22 SOURCE: "Appendix 8.A". Intergovernmental Panel on Climate Change Fifth Assessment Report (PDF). p. 731

GRAPHIC A2.1: Green House Gas (GHG) Atmospheric Lifetime and Global Warming

Where to Apply the Brakes to Greenhouse Gas Emissions

To mitigate, or put the brakes on Climate Change, humanity will need to quickly address its GHG emissions. **GRAPHIC A2.2:** (US GHG Emissions by Economic Sector, 2015) categorizes CO2 emissions by sector in the US (Central Sphere) and breaks it down further by use and fuel type. For example, the center sphere reveals that transportation represented 27% of U.S. GHG emissions. Of the fuel burned for transportation, 60% was gasoline and light duty vehicles (cars) were responsible for 58% of all transportation emissions. Largely, the burning of fossil fuels in the sectors of Transportation and Electricity production account for 60% of the nation's GHG emissions. Major strides here will have the greatest mitigating effect.



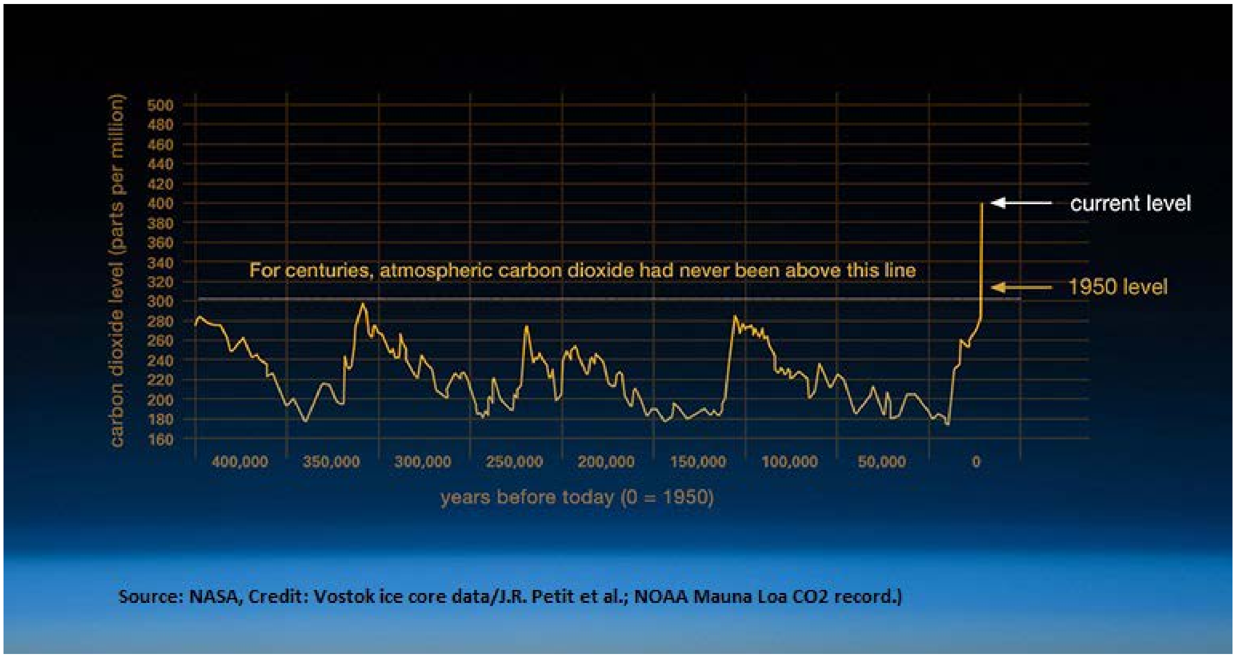
Breakdown of U.S. greenhouse gas emissions by sector and fuel type.
Red typeface indicates greenhouse gases produced from fossil fuel combustion.

SOURCE: Supekar, Sarang D., *ENVIRONMENTAL & ECONOMIC ASSESSMENT OF CARBON DIOXIDE RECOVERY AND MITIGATION IN Industrial & Energy Sector.* Argonne National Laboratory Centertr for Energy, Environmrental & Econonomic Systems Analysis, University of Michigan 2015

GRAPHIC A2.2: US Greenhouse Gas Emissions by Economic Sector and Fuel Type, 2015

Atmospheric concentrations of both natural and man-made GHGs have been rising over the last few centuries due to the concurrent and compounding effects of our growing population and the industrial revolution. Beyond introducing new, manmade, GHG's, our consumer driven population and economy has developed an insatiable appetite for energy which is driving CO2 concentrations higher. Transportation, food, heating and air-conditioning, all the products we produce and buy – our lives in general - require energy, which has largely come from burning fossil fuels like coal, natural gas and petroleum.

Through the mining and burning of fossil fuels, humans have altered the earth's carbon cycle. https://earthobservatory.nasa.gov/Features/CarbonCycle. In the blink of a geologic eye, we've taken ancient carbon that was locked and sequestered within the Earth and put it into the atmosphere as CO2 - and in immense quantities. Over the past ***800,000 years*** CO2 has ranged from a low of 180 ppm to a high of 300 ppm, with the changes gradually taking place over hundreds of thousands of years. ***Since 1950 (CO2 280ppm) we've driven atmospheric CO2 to 409 ppm in 2017 - completely unprecedented in the past 800,000 years of earth's history*** **(GRAPHIC A2.3).**



GRAPHIC A2.3: Earth's Atmospheric CO2 History 400 years ago to the Present

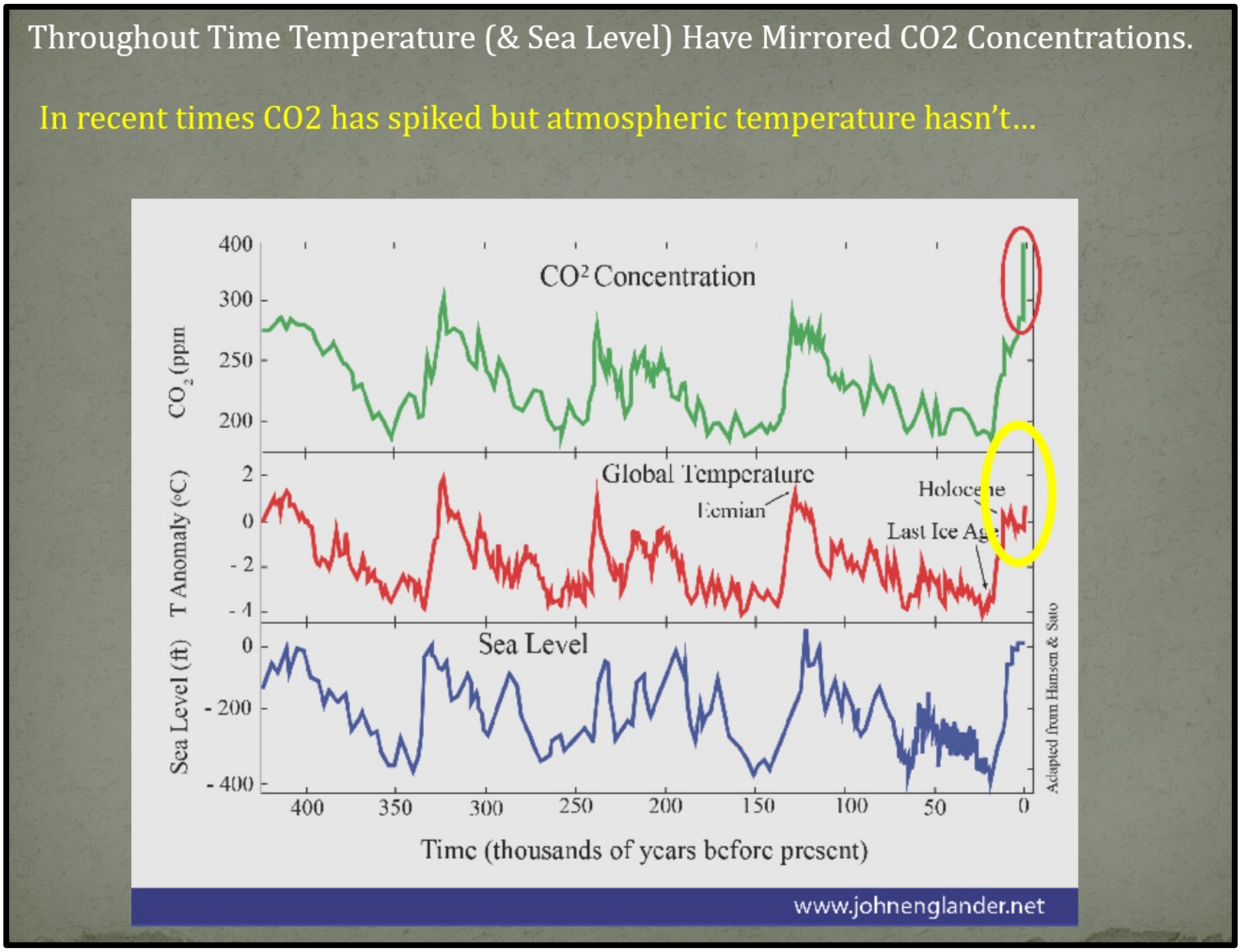
Water Vapor as a Greenhouse Gas

Water vapor is the most abundant greenhouse gas in the atmosphere. Human activities have only a small direct influence on atmospheric concentrations of water vapor, primarily through irrigation and deforestation. However, the indirect action of surface warming caused by human production of other greenhouse gases, leads to an increase in atmospheric water vapor as warmer temperatures make it easier for water to evaporate and stay in the air as vapor. This creates a positive "feedback loop" in which warming leads to more warming. Furthermore, more water stored in the atmosphere increases the potential for extreme precipitation events.

1.2 Heating Our Atmosphere and Oceans – Adding more energy to the system

Located along the Merrimack river and seacoast, Newburyport is sensitive to the great expanse of the Atlantic Ocean, its coastal storms and heavy rainfall. Our warming climate is not only affecting our stormy weather, but also the periods of calm weather in between. Climate change is increasing the heat content in our air and oceans, the moisture content of the atmosphere, and thus the behavior of our jet stream that moves weather systems along.

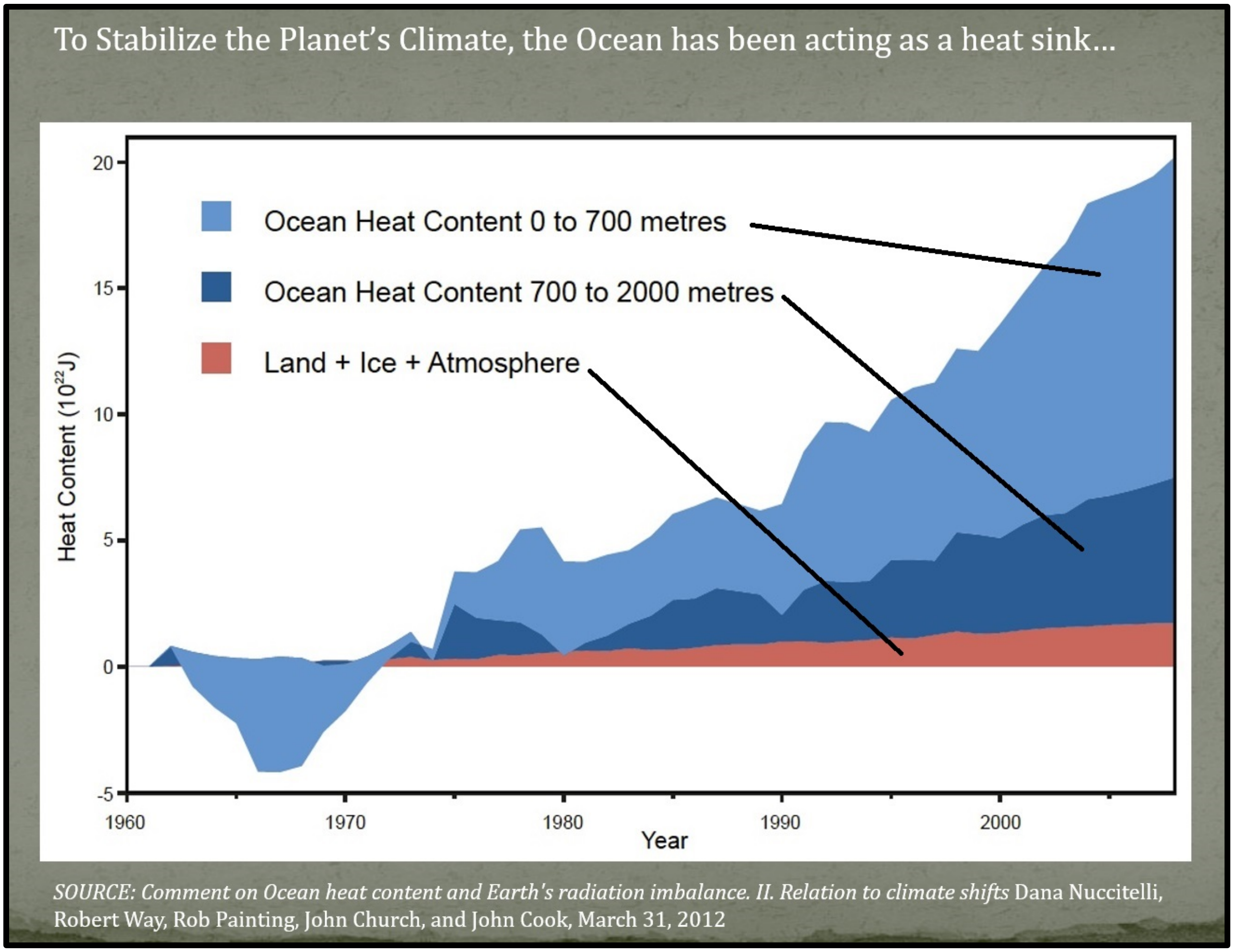
According to the fossil record, global temperature has closely followed the rise and fall of CO2 in our atmosphere, as did sea level. However, these changes took place gradually over 1000's of years, allowing for the heating of the atmosphere to keep pace with changing CO2 levels, and sea level to follow closely behind the warming atmosphere. Since the industrial revolution, CO2 concentrations have outpaced atmospheric temperatures. **GRAPHIC A2.4** (Global CO2 PPM vs Temp vs Sea Level – 400K years ago-present).



GRAPHIC A2.4: Global CO2 PPM vs Global Temperature vs Sea Level – 400K years ago to present

So why hasn't the atmosphere warmed more quickly?

While GHGs have accumulated and trapped heat, the oceans have acted to moderate air temperature increases by acting as a heat sink (GRAPHIC A2.5: The Oceans Stabilize the Earth's Climate by Acting as a Heat Sink). While we've quickly turned up the thermostat on our climate, the furnace, if you will, is still catching up to warm the atmosphere and melt all that land ice to raise sea levels.



GRAPHIC A2.5: The Oceans Stabilize the Earth's Climate by Acting as a Heat Sink

The accumulating heat in our oceans represents an incredible reservoir of energy for storms to tap. Moreover, the warmer surface waters are more readily producing water vapor, a natural greenhouse gas, which further drives the warming of our planet. Increased water vapor and heat in our atmosphere are the fuel of storms and is associated with heavier precipitation events. The heat energy in our oceans and atmosphere also provide for a greater contrast to the cold and dry polar air masses. This contrast is a great motivator of convection and so another ingredient for potent storms.

Finally, the Jet Stream which governs our weather, is being affected by our warming world. This is significant as it affects all aspects of our weather from spawning storms to causing weather patterns to persist. Behavior of our Jet Stream it turns out, has much to do with the rate at which the Arctic is warming.

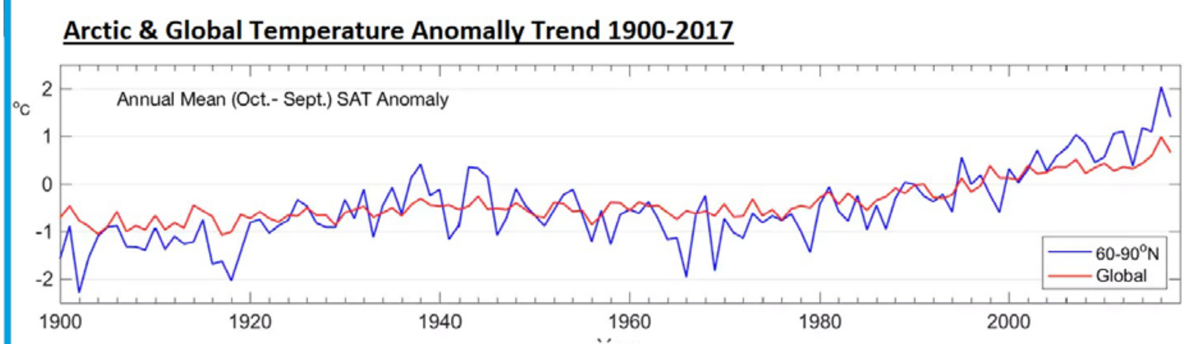
Why is the Artic Warming so Fast?

Since the year 2000, the Arctic has been warming at a rate that is more than double that of the rest of the planet (**GRAPHIC A2.6**: Artic vs Global Temp Anomaly Trend 1900-2017). According to NASA's Goddard Institute for Space Studies in Manhattan, the Earth has warmed about 1.44 degrees Fahrenheit during the last 40 years, while during the same period the Arctic warmed by more than 3.5 degrees. Part of the reason is due to the melting of reflective sea ice that allows the polar ocean and land to absorb the sun's heat energy. But Patrick Taylor, a scientist at NASA's Langley Research Center in Hampton, Va., suggests that polar warming is largely a result of heat energy from the mid-latitudes and equator being transported to the poles through large weather systems (storms).

https://www.nasa.gov/topics/earth/features/warmingpoles.html .

Our earth is unevenly heated by the sun – the equator is sunny and hot while the poles are dark and cold. Weather systems and storms serve as a mechanism to mix the temperatures of the planet's extremes thereby creating a habitable climate. As the temperature of the oceans and atmosphere have warmed, weather systems have had to transport more heat to the poles, warming them disproportionately.

Additionally, large storms forcing into the polar region have precipitated sudden stratospheric warming events, increasing Arctic temperatures by 40-60 degrees F in the middle of winter, as happened during early February of 2018 https://robertscribbler.com/2018/02/28/sudden-stratospheric-warming-and-polar-amplification-how-climate-change-interacts-with-the-polar-vortex/ . The warming is akin to Florida's 70-degree winter weather suddenly spiking to 110-130 degrees Fahrenheit.



Arctic (land stations north of 60° N) and global mean annual land surface air temperature (SAT) anomalies (in °C) for the period 1900-2017 relative to the 1981-2010 mean value. Note that there were few stations in the Arctic, particularly in northern Canada, before 1940. The data is from the CRUTEM4 data set, which is available at www.cru.uea.ac.uk/cru/data/temperature/. (NOAA, Arctic Climate Report Card 2017.)

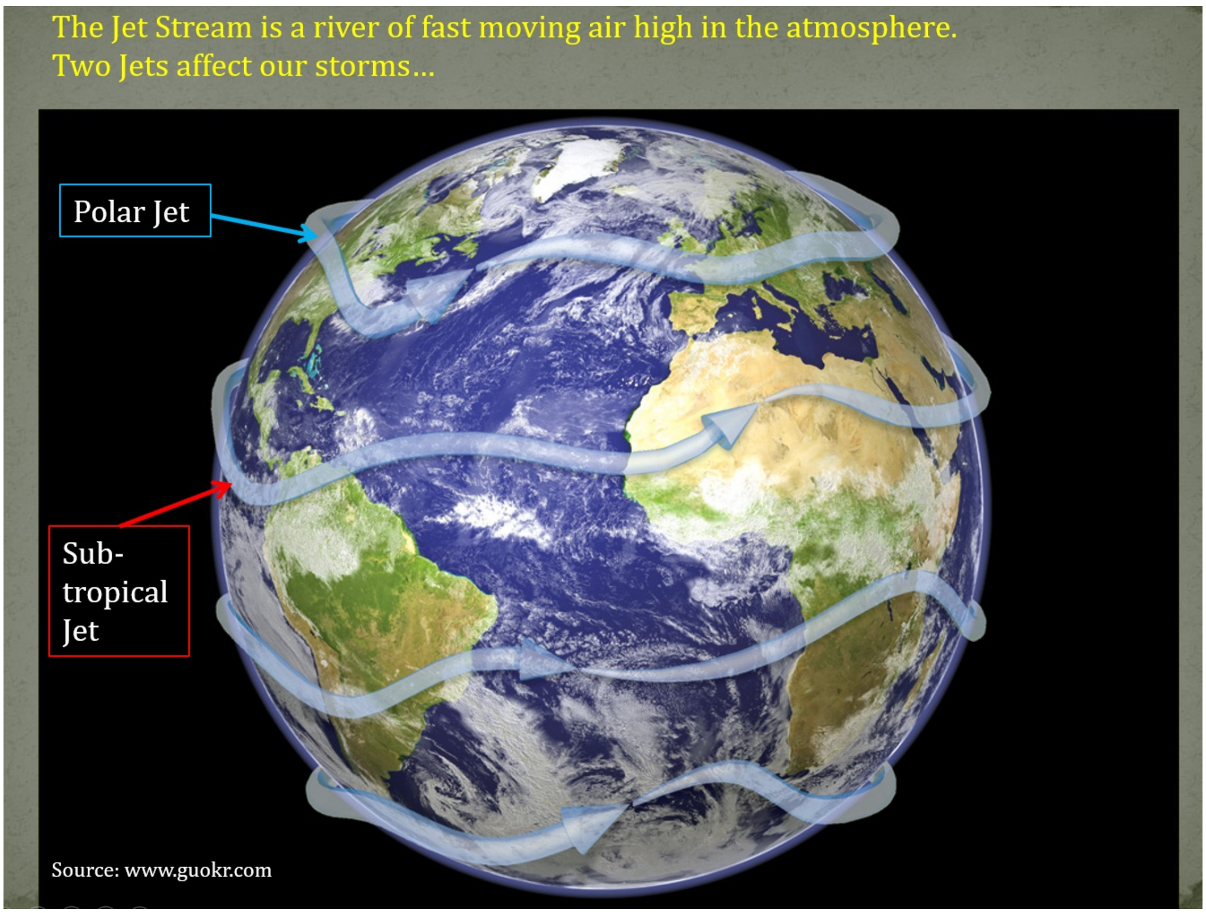
GRAPHIC A2.6: Arctic vs Global Temp Anomaly Trend 1900-2017

1.3 The Artic, the Jet Stream and our Changing Weather

The significance of a warming Arctic to our weather is important. Research shows that changes in Arctic sea ice and temperature can alter the jet stream, a major factor in U.S. weather and climate patterns. Severe winter weather is two to four times more likely in the eastern United States when the Arctic is abnormally warm than when the Arctic is abnormally cold.

https://news.rutgers.edu/news/warm-arctic-means-colder-snowier-winters-northeastern-us-study-says/20180309#.W55VJOhKiUm

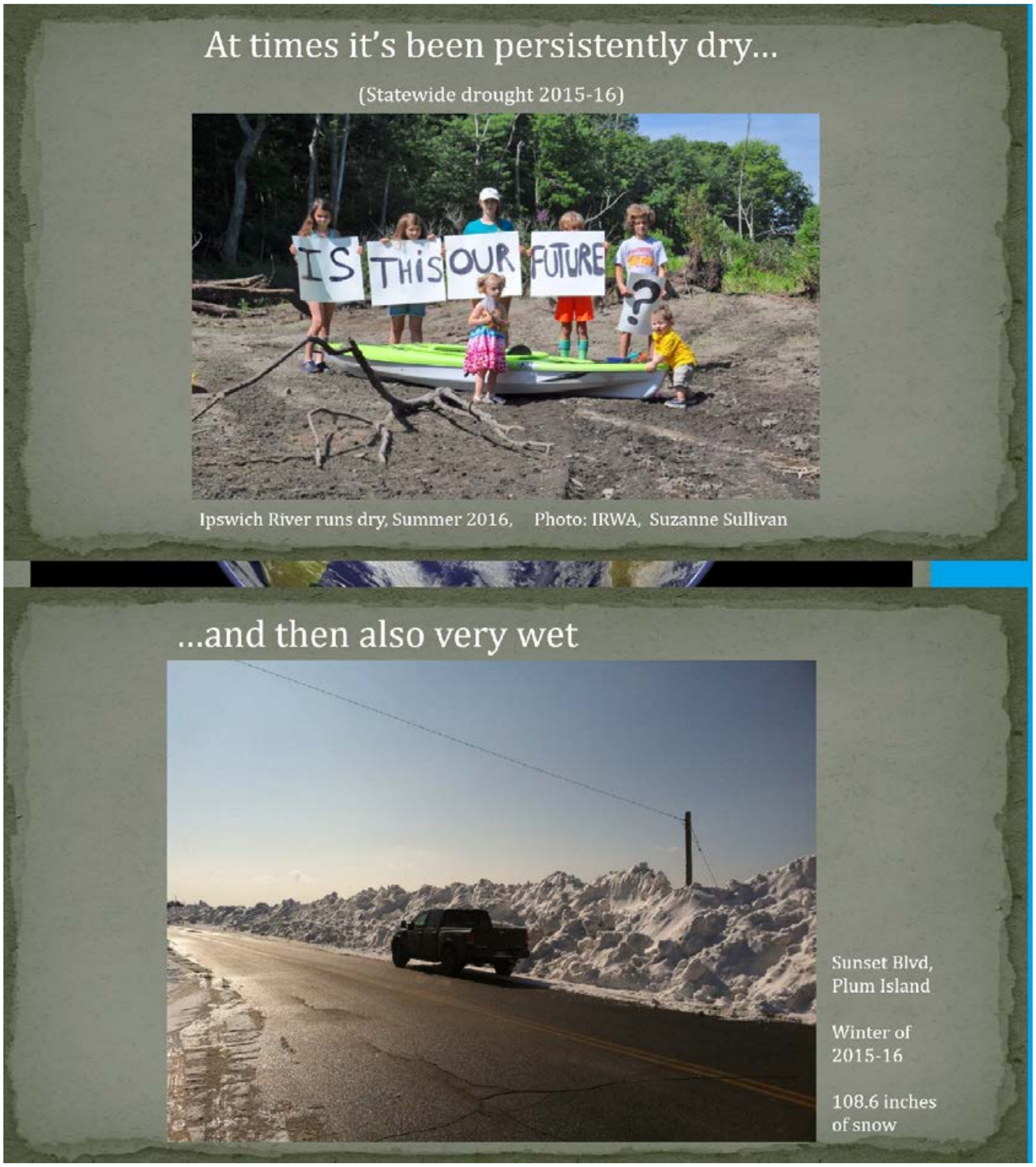
In the northern hemisphere our weather is affected by the Polar and the Subtropical Jet Streams **(GRAPHIC A2.7:** Polar and Subtropical Jet Streams.) The jet stream(s) is a high-speed, constantly shifting river of air located about 30,000 feet above the ground that guides storm systems and cool air around the globe. When it moves away from a region, high pressure and clear skies predominate. While the Jet Stream generally flows west to east, at times it may develop large oscillations or Rossby waves which are conducive to spawning storms. When these Rossby waves are large they allow for the fusion of the polar and subtropical jet streams, further amplifying storm intensity.



GRAPHIC A2.7: The Polar and Subtropical Jet Streams

Beyond amplifying storms, a wildly undulating jet Stream can often run in fits and stalls (sometimes even flowing in reverse), which results in weather patterns that can become stuck (persistently wet or dry, hot or cold) and bi-polar. Recent local examples were the persistent statewide drought of 2015-16 which that winter was followed by extreme snowfall (**GRAPHIC A2.8:** Drought then Record Snowfall). The destructive March 2018 procession of winter storms was preceded in February by 80-degree warmth. This example of bi-polar weather was ushered in by a wildly swinging Jet Stream that had responded to a sudden stratospheric warming event in the Arctic in early February of 2018.

"As we continue to emit these (greenhouse) gases, expect further Arctic warming to make all sorts of weather conditions stick around longer – be it hot, cold, wet or dry – any of which can become extreme." Jennifer Francis, Professor, Rutgers University Department of Marine and Coastal Sciences.

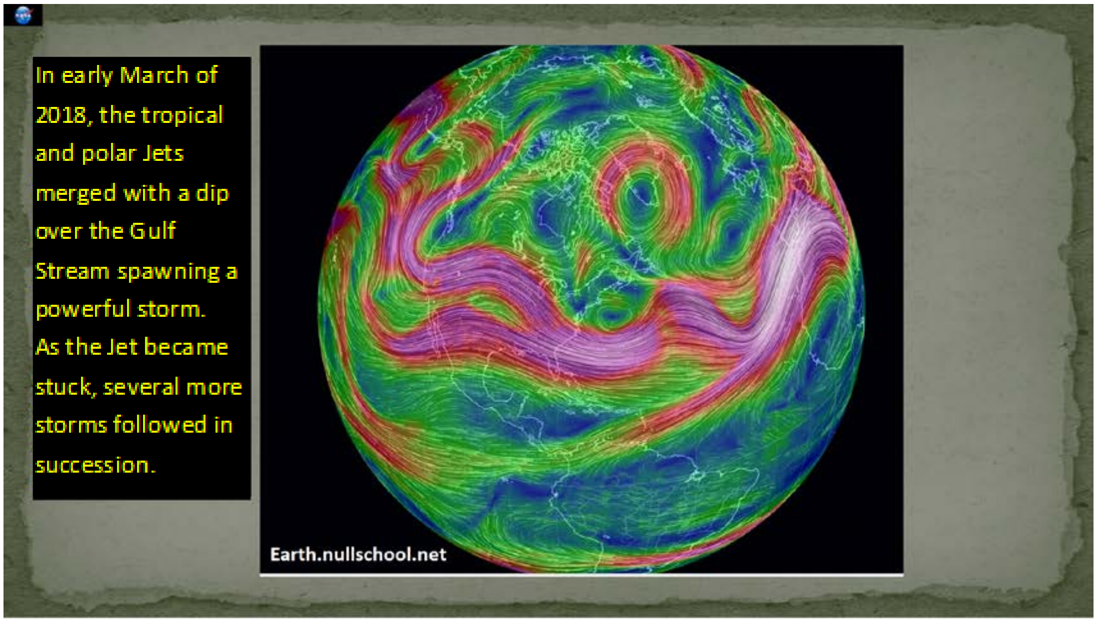


GRAPHIC A2.8: Drought then Record Snowfall (Photo – Mike Morris)

1.4 The Jet Stream and Shifting Storm Tracks

Here in New England when we think of coastal storms we think of Northeasters and Hurricanes. Both systems serve to liberate the moist heat of the tropics and mix it with the cold and dry air at the poles, thereby moderating the globe's temperature extremes.

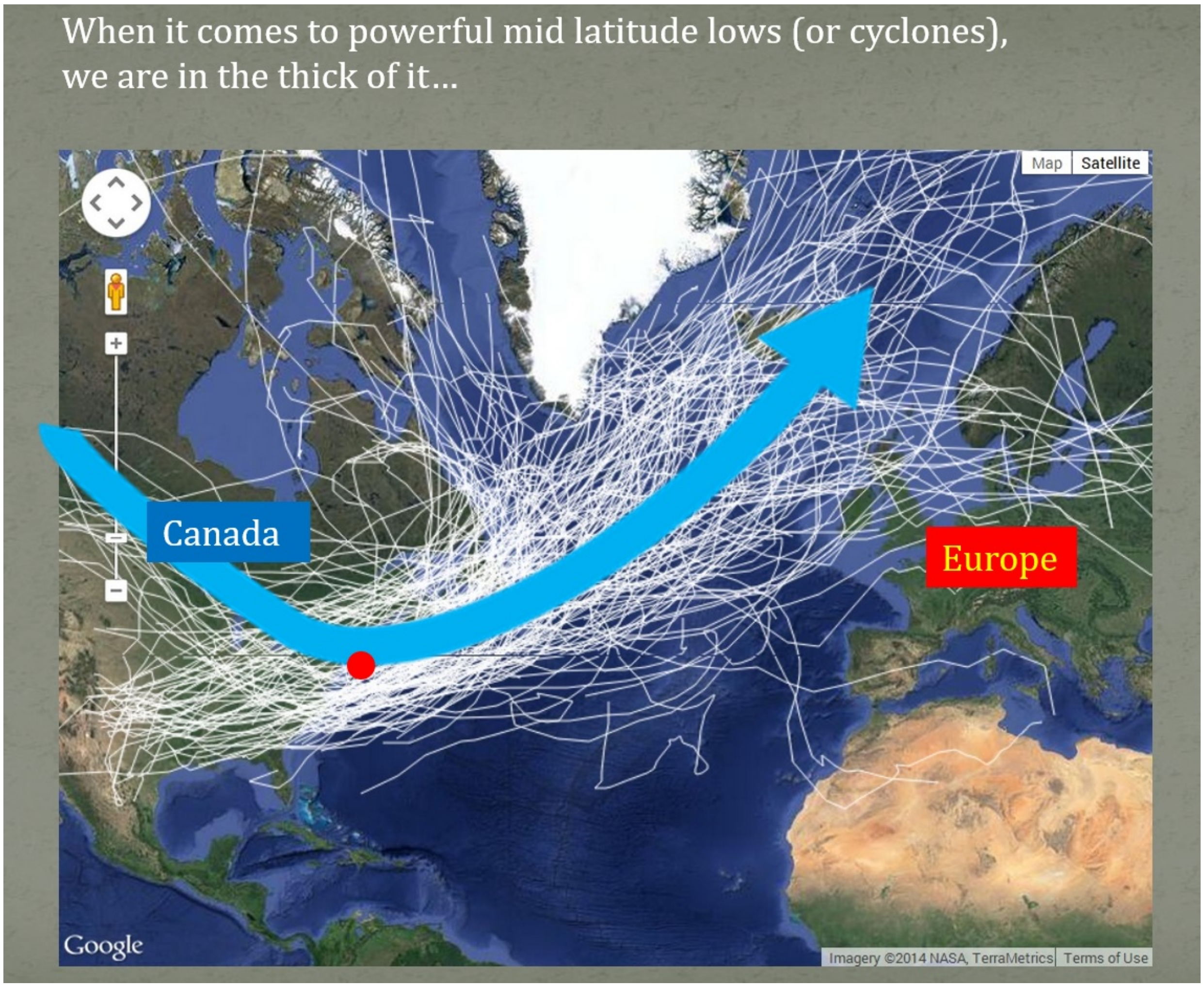
Northeasters (extratropical or midlatitude cyclones) are formed through the clash of the contrasting polar and tropical air masses. When the air mass ingredients come together with a large dip and coupling of the Tropical and Polar Jets over the Gulf Stream, incredible amounts of energy are released, and huge storms are spawned. (**GRAPHIC A2.9**: March 2018 Jet Stream and Resulting Storm)



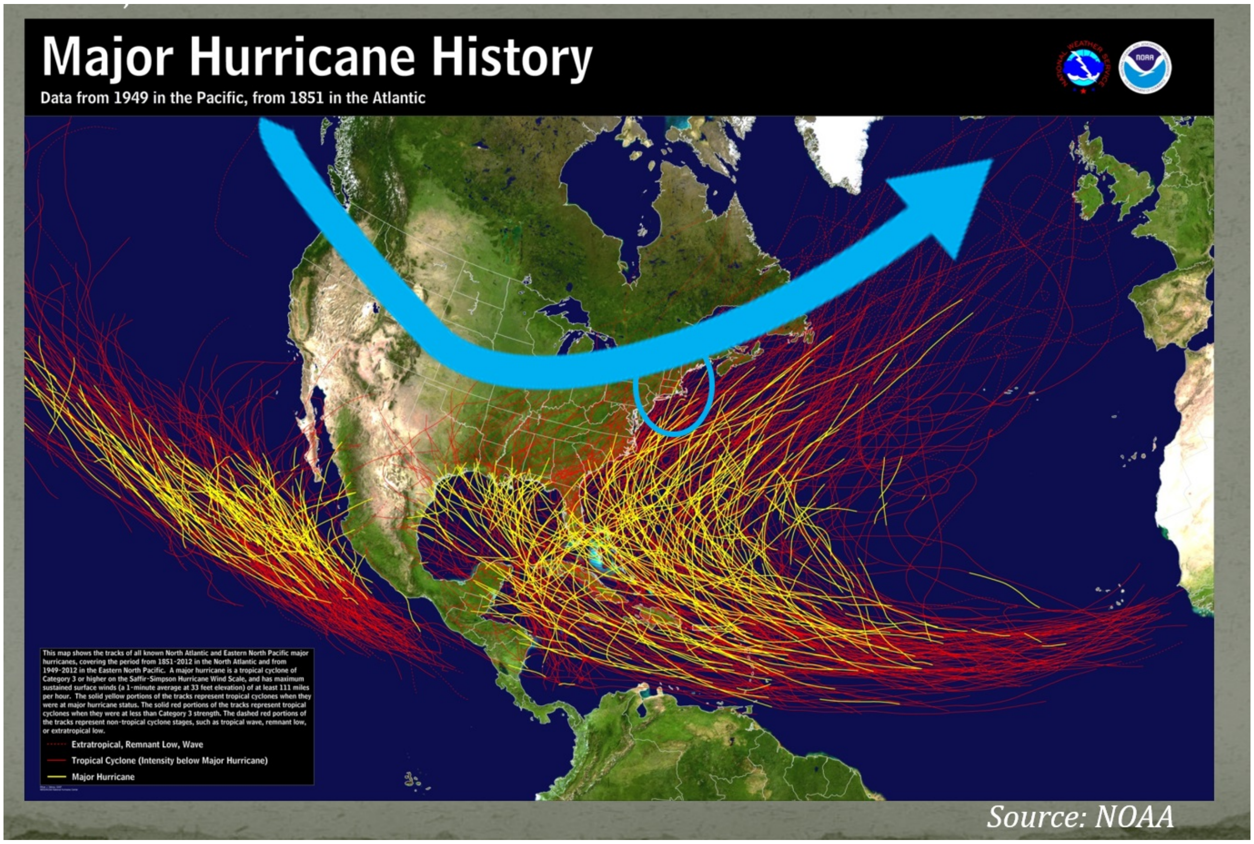
GRAPHIC A2.9: March 2018 Jet Stream and Resulting Storm

Hurricanes, on the other hand, are strictly formed from the convection motivated by very warm ocean water. When the numerous variables align for their development, they can also spawn incredibly powerful storms. As hurricanes travel toward the poles, they often transition into extratropical systems themselves, as Hurricane Sandy did, or they become absorbed by extra-tropical systems, infusing an espresso shot of energy as happened when Hurricane Grace became absorbed by the Halloween Gale of 1991, otherwise known as the Perfect Storm.

The two types of storms have historically followed different tracks. (**GRAPHIC A2.10:** Historical Mid-Latitude Cyclone/Northeaster Tracks) and (**GRAPHIC A2.11:** Historical Major Hurricane Tracks).



GRAPHIC A2.10: Historical Mid Latitude/Northeaster Storm Track – Directed by the Jet Stream



GRAPHIC A2.11: Historical Major Hurricane Tracks – also directed by the Jet Stream

Research from Scientists at the Carnegie Institution suggest that these historical storm tracks for both types of storms are shifting in response to climate change, increasing Newburyport's exposure to both. Over a 23-year span from 1979 to 2001 the jet streams in both hemispheres have risen in altitude and shifted toward the poles. Additionally, the jet stream in the northern hemisphere has weakened. These changes fit the predictions of global warming models and have implications for the frequency and intensity of future storms, including hurricanes. Storm paths in North America are likely to shift northward as a result of the jet stream changes. Hurricanes, whose development tends to be inhibited by jet streams, may become more powerful and more frequent as the jet streams lifts north and away from the sub-tropical zones where hurricanes are born. https://carnegiescience.edu/news/changing-jet-streams-may-alter-paths-storms-and-hurricanes

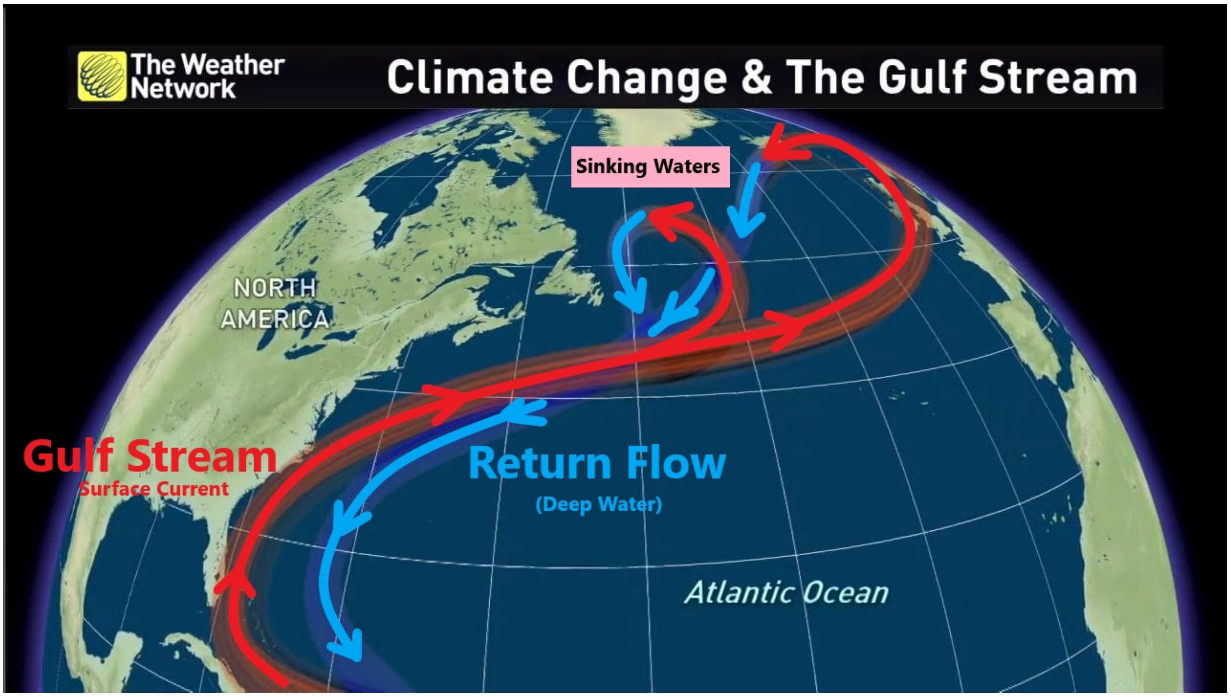
The northward shift in both storm tracks keeps Newburyport firmly in the path of Northeasters. However, while Newburyport and New England have historically resided on the edge of the Hurricane track, research suggests that they now, and increasingly in the future, will be in the path of tropical systems.

1.5 Ocean Currents, the Gulf Stream and Sea Level Rise

The Gulf stream flows from the tropics just southeast of the New England coast off towards Europe where its waters sink and flow back along the ocean floor towards the Antarctic. The Gulf Stream is just one piece of a larger global ocean circulation known as the Atlantic Meridional Overturning Circulation (AMOC) (**GRAPHIC A2.12**).

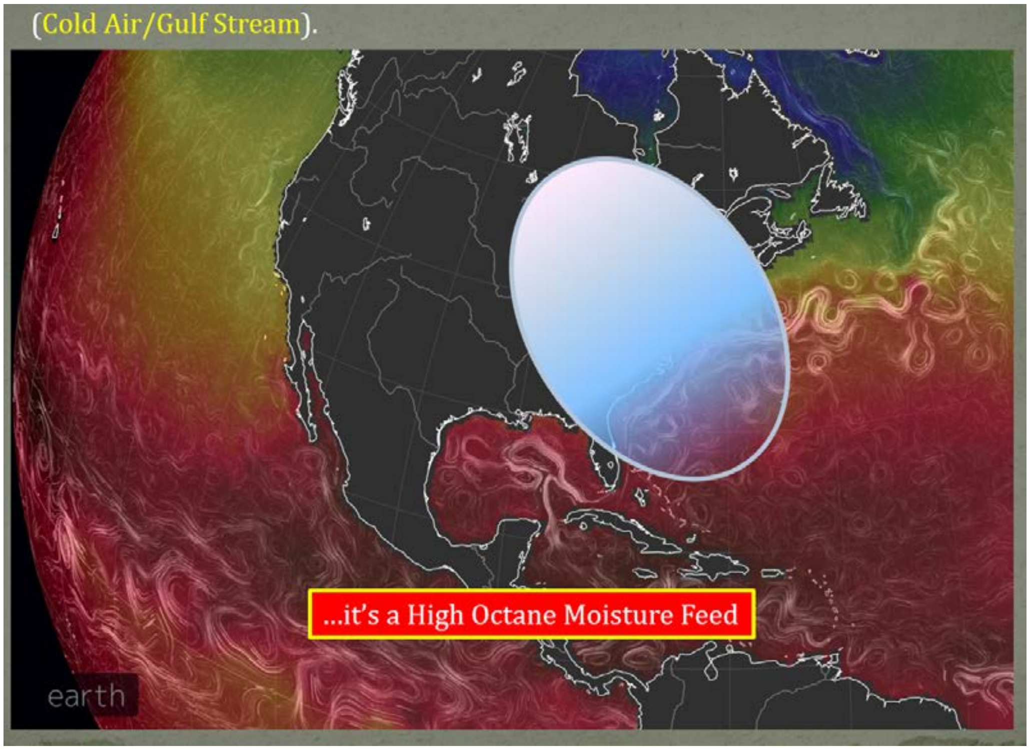
"The AMOC is a large system of ocean currents, like a conveyor belt, driven by differences in temperature and salt content – the water's density. As warm water flows northwards it cools and some evaporation occurs, which increases the amount of salt. Low temperature and a high salt content make the water denser, and this dense water sinks deep into the ocean. The cold, dense water slowly spreads southwards, several kilometers below the surface. Eventually, it gets pulled back to the surface and warms in a process called "upwelling" and the circulation is complete. This global process makes sure that the world's oceans are continually mixed, and that heat and energy are distributed around the earth. This in turn contributes to the climate we experience today."

https://www.metoffice.gov.uk/learning/ocean/amoc



GRAPHIC A2.12: Atlantic Meridional Overturning Current (AMOC) and the Gulf Stream

Because of its proximity to New England and the Polar Jet Stream, **the Gulf Stream represents a potent reservoir of heat energy** that often clashes with polar air masses shifting south east from Canada (**GRAPHIC A2.13**). It also provides heat energy for tropical systems giving them the ability to sustain their intensity as they travel into the northern latitudes – especially if the system is slow moving.



GRAPHIC A2.13: Cold Air and the Gulf Stream

Beyond its effect on our weather, the Gulf Stream can also dramatically affect sea level rise if its forward speed changes - sometimes even year to year. As it flows towards Europe off our east coast, the Gulf Stream's speed allows its water column to maintain some height along the ocean surface. Consider water flowing from a garden hose lying on a driveway. As water exits the hose, its stream has height, which, after it slows on the asphalt, collapses and diminishes as the water column fans out. If the hose were close to a curbing one could envision that fanning column of water gathering along the curb. So too is the relationship of the Gulf Stream to the east coast. As it slows in response to climate effects on the AMOC, its water column collapses, loses height and spreads out, bumping up along the coastline. This raises sea level in the short term, until current velocity increases and draws it back down.

The phenomenon described above actually happened during the period 2009-2010 when a slowdown in the Gulf Stream (associated with an observed 30% downturn of the AMOC during 2009–10, and a significant negative North Atlantic Oscillation index.) resulted in a 5-inch spike in sea level rise north of New York. "The coastal sea levels along the Northeast Coast of North America show significant year-to-year fluctuations and a general upward trend. This magnitude of interannual SLR is unprecedented (a 1-in-850-year event) during the entire history of the tide gauge records." https://www.nature.com/articles/ncomms7346 An extreme event of sea-level rise along the Northeast coast of North America in 2009–2010 Paul B. Goddard, Jianjun Yin, Stephen M. Griffies and Shaoqing Zhang. Nature Communications volume 6, Article number: 6346 (2015).

Scientists expect the Atlantic Meridional Overturning Circulation (AMOC) to weaken over the course of the 21st century due to the continued influx of cool freshwater from the melting Greenland ice sheet into the North Atlantic.

https://www.climatesignals.org/climate-signals/atlantic-meridional-overturning-circulation-weakening

So, while sea level is generally rising, there will likely be spikes in sea level in response to the fits and stalls of the Gulf Stream. Hopefully these episodes don't coincide with periods of coastal storms.

Summary

Humanity's continued burning of fossil fuels during and since the industrial age has increased the quantity of greenhouse gases in our atmosphere. As greenhouse gases by nature trap heat, humanity has effectively placed a thick, warm blanket over the planet. This excess of trapped heat energy has been absorbed by our atmosphere and land, but mostly by our oceans, which represents a large powder keg of stored energy.

Our warmer oceans have distorted the planet's jet stream which moves our weather along. These warmer oceans are also spawning intense storms and extreme precipitation events that continue to warm the artic at a disproportionate rate, further altering the jet stream and our weather.

As the artic warms, the Greenland ice sheet continues to melt, introducing abnormal amounts of freshwater into the North Atlantic, slowing the nearby Gulf Stream, which can and has, abruptly raised sea levels along our coast.

This scenario of a warming world presents Newburyport with a potent cocktail of escalating climate hazards.

APPENDIX 3 – Future Local Sea Level Rise

In late October 2018, Mayor Donna Holaday requested that the Newburyport Resiliency Committee (NRC) recommend a Design Flood Elevation (DFE) that should be applied to the Waterfront West Project as there currently were no such design parameters that accounted for future sea level rise (SLR) and other climate impacts. The NRC convened a Technical Subcommittee made up of the following NRC members:

Jon-Eric White, PE (Civil), City Engineer

Diane Gagnon, Assistant Engineer

John O'Connell, PE (Civil), Principal Construction Engineering Services (CES), Newburyport

William Mullen, PE (Civil), Hydraulic Engineer, River Hydraulics

Michael Morris, NRC Co-Chair and Chairman, Storm Surge

The group agreed that structures built today would likely still exist 100 years from now, and if enough elevation was not recommended, these structures would eventually be compromised by rising seas, storms and flooding, potentially leaving the city with increasing emergency response costs, future protection and adaptation costs, as well as a blight of uninhabitable properties and their associated cost of demolition. Given that, the group felt that design elevations ought to minimally reflect projected sea levels for the area in 2100. Furthermore, the group agreed that three variables synergistically combine to give rise to flooding in Newburyport and should be factored into the Design Flood Elevation (DFE):

1. Storm Surge
2. River Influences
3. Sea Level Rise

However, at the time no suitable model existed to provide a visualization of the interaction of these three variables in a climate of increasing storm intensity, precipitation and river flow within a rising sea scenario. Without a suitable model to rely on, the subcommittee proposed to use the current FEMA Base Flood Elevation (BFE) and **add** a projected sea level rise (SLR) height to calculate a Design Flood Elevation (DFE) to be imposed on the development:

FEMA BFE + Future SLR = DFE

The group did acknowledge that ***current FEMA values would likely underestimate future impacts***, but it was the best available information. The benefit of this approach lied in its ease of understanding, and ability to incorporate updated FEMA and sea level rise projections as they became available.

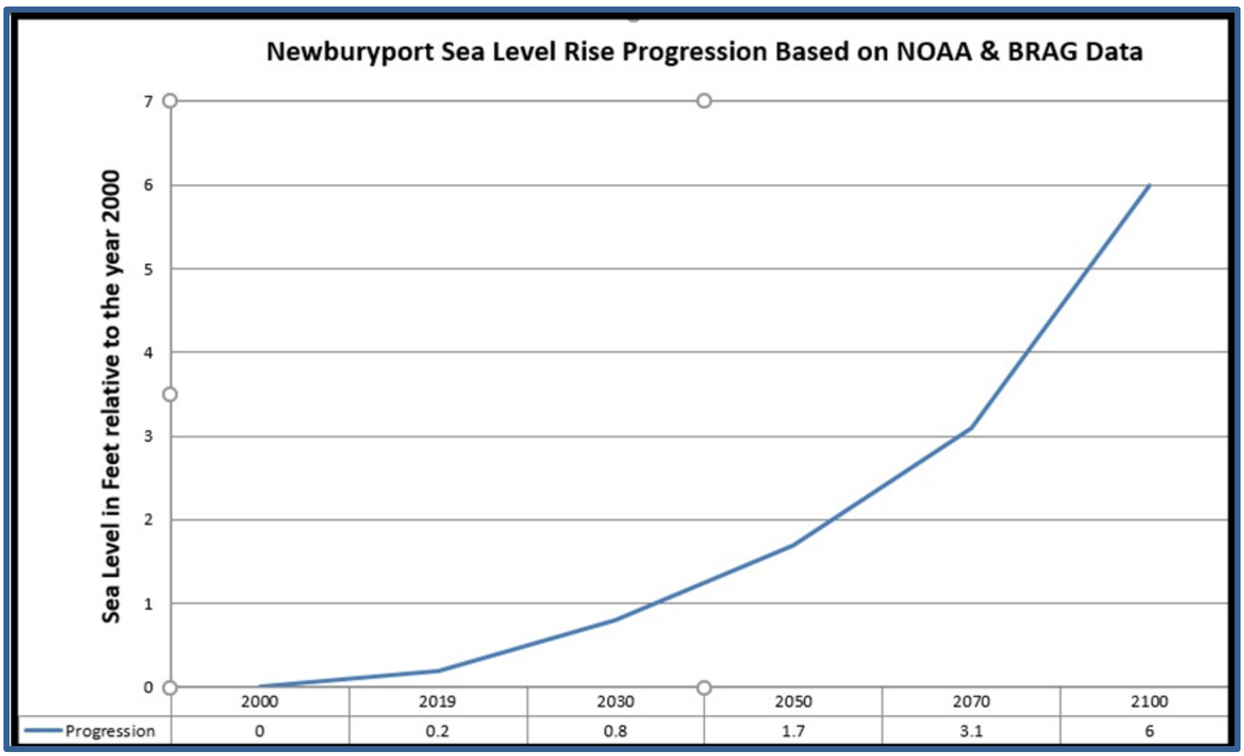
The next step was to project how high sea level might rise around the year 2100. Details of this exercise are presented in the subcommittee's final report in **APPENDIX 4 – Recommendation of Sea Level Rise for Waterfront West.** In general, sea level rise (SLR) projections are all based on those developed by NOAA through the U.S. Interagency Sea Level Rise Task Force which was charged with developing Global Sea Level Rise scenarios for the 2018 National Climate Assessment. Differences among sea level rise scenarios are based upon emissions assumptions and local factors[8].

[8] ***Global and Regional Sea Level Rise Scenarios for the United States.*** Sweet, W. V., R. E. Kopp, C. P. Weaver, J. Obeysekera, R. M. Horton, E. R. Thieler, and C. Zervas, 2017. NOAA, National Ocean Service.)https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

Output from the Interagency SLR report was used by the **Boston Research Advisory Group (BRAG)** to develop regional sea level rise scenarios for Boston[9].

Due to the influence of regional-scale processes such as land subsidence, variations in the speed of the Gulf Stream, and the gravitational effect of melting ice sheets, Regional Sea Level Rise (RSLR) in Boston will likely exceed the global average throughout the 21st century, regardless of which emissions trajectory is followed. BRAG's RSLR projections for Boston are applicable to Newburyport not only because of geographic proximity (Boston lies only some 30 miles to the south), but also because an extensive panel of experts incorporated a suite of regional and global scale processes into the Global Sea Level Rise data used by the 2018 National Climate Assessment to develop RSLR projections for Boston. Subcommittee members evaluated data from these two sources to conclude that sea level (relative to year 2000) could rise by up to 6 feet locally by the year 2100.

To better visualize increasing risk and project when assets and property might become inundated by the tide twice daily, it was necessary to develop a ***progression*** of sea level rise to 6 feet by 2100. This output is depicted visually for areas within the city using sea level rise maps in Chapter 2, Vulnerability Assessment, and becomes essential to conceiving a timeline for action in Chapter 3, Adaptation Strategies. Starting with 6 feet of SLR in 2100 and working backwards through the BRAG and Interagency SLR tables allowed for the development of a SLR progression depicted in **GRAPHIC A3.1:** Sea Level Rise Progression for Newburyport**.**



GRAPHIC A3.1: Sea Level Rise Progression for Newburyport

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[9] Climate Change and Sea Level Rise Projections for Boston. The BRAG Report June 1, 2016.)
https://www.boston.gov/sites/default/files/document-file-12-2016/brag_report_-_final.pdf

GRAPHIC A3.2:(Regional Sea Level Rise Projections, Boston - by Emissions and Exceedance Probability) illustrates the range of future local (Boston) sea level rise given various emissions scenarios. The figures were well researched by the Boston Research Advisory Group that developed these projections for Boston's adaptation plan, and the figures were adopted by the National Wildlife Federation in completing Newburyport's portion of the *Great Marsh Regional Coastal Adaptation Plan*, December 2017.

Current State of Global Emissions

To estimate future sea level rise, it is important to characterize the state of the drivers behind our warming world – human greenhouse gas emissions. Despite strides in employing green energy initiatives, society's economies are emitting CO2 at the highest rate ever[10]. Atmospheric carbon dioxide continued its rapid rise in 2019, with the average for May peaking at 414.7 parts per million (ppm), which was not only the highest seasonal peak recorded in 61 years of observations, but also the highest level in human history, and higher than at any point in millions of years. Furthermore, the concentration of CO_2 in the atmosphere has increased every year, and the rate of increase is accelerating[11]. Finally, the climate action pledged by nations is "inadequate to bridge the emissions gap" and that if actions are not strengthened before 2030, the 1.5 C target set by the Paris Accord will slip out of reach. Overall, it suggests that current Paris commitments would need to be tripled to reach a 2 C target and increased fivefold to reach the 1.5 C target[12]. Future "hope" for rapid change not-withstanding, it is difficult to argue that the world is currently operating under an intermediate or low emissions scenario. Referencing **GRAPHIC A3.2**, under a high emissions scenario (RCP 8.5), there is an 83% probability that sea level will exceed an additional 0.3 feet by 2030 and a 16.7% chance it will exceed 0.7 feet. Factoring in instability of the polar ice sheets, exceeding 1.2 feet of SLR over year 2000 levels, is possible by 2030, but unlikely. Significant strides in emissions would need to be made soon to throttle back sea level rise figures to an intermediate emissions scenario of 0.7 feet to a maximum of 2.3 feet by 2050. The more time society continues along a high emissions pathway now, the likelier a rise of 1.5-4.8 feet by 2070, and 3.2-10.5 feet by 2100.

Historically sea level has closely trailed global temperatures. If we reference the fossil record, the previous interglacial period (the Eemian) was atmospherically just a couple of degrees warmer than today, yet sea level was some 26 feet higher. Given how quickly we've warmed our planet, there's been a lag in ice melt and thermal expansion of the oceans. At some point, like a furnace catching up to a recently dialed up thermostat, these factors will close in on CO2 concentrations and atmospheric heat, delivering that 26 feet or more of sea level rise. The challenge today lies in predicting how fast that rise will arrive considering any change (or not) in our global emissions of GHGs[13].

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[10] Harvey, Chelsea, E&E News, ***CO2 Emissions Reached an All-Time High in 2018,*** Scientific American, Dec 6, 2018. https://www.scientificamerican.com/article/co2-emissions-reached-an-all-time-high-in-2018/

[11] NOAA Research News. ***Carbon dioxide levels hit record peak in May.*** June 4, 2019. https://research.noaa.gov/article/ArtMID/587/ArticleID/2461/Carbon-dioxide-levels-hit-record-peak-in-May

[12] United Nations Environment Programme. ***Emissions Gap Report 2018.*** November 2018. https://wedocs.unep.org/bitstream/handle/20.500.11822/26879/EGR2018_ESEN.pdf?sequence=10

[13] Englander, John. ***High Tide on Main Street.*** Chapter 4 Page 29. 2012. ISBN 978-0615637952.

The great range of SLR projections are related to uncertainties about the instability of the polar ice sheets and when they might reach a tipping point where they collapse and slide (vs melt) into the sea. "The projections and results presented in several peer-reviewed publications provide evidence to support a physically plausible Global Mean Sea Level (GMSL) rise in the range of 2.0 meters (6.7 feet) to 2.7 meters (8.9 feet), and recent results regarding Antarctic ice-sheet instability indicate that such outcomes may be more likely than previously thought. To ensure consistency with these recent updates to the peer-reviewed scientific literature, we recommend a revised 'extreme' upper-bound scenario for GMSL rise of 2.5 meters (8.2 feet) by the year 2100"[14].

Regional Sea Level Rise Projections for Boston (in feet. rel. to yr. 2000) by Emission Pathway, Categorized by Exceedance Probability

Emissions Pathway	Exceedance Probability		Likely Range					Maximum
	0.99	0.95	0.833	0.5	0.167	0.05	0.01	0.001
RCP8.5								
2030	-0.1	0.1	0.3	0.5	0.7	0.9	1.0	1.2
2050	0.1	0.4	0.7	1.1	1.5	1.8	2.1	2.4
2070	0.6	1.0	1.5	2.2	3.1	3.7	4.3	4.8
2100	1.6	2.4	3.2	4.9	7.4	8.6	9.5	10.5
2200	18.9	19.9	21.4	26.1	32.8	34.1	35.3	36.9
RCP4.5								
2030	-0.1	0.1	0.3	0.5	0.7	0.9	1.0	1.2
2050	0.1	0.4	0.7	1.0	1.4	1.7	2.0	2.3
2070	0.4	0.9	1.3	1.9	2.6	3.1	3.6	4.1
2100	0.9	1.7	2.4	3.6	5.1	6.1	7.0	8.0
2200	5.5	6.2	7.2	10.9	16.5	18.0	19.3	20.9
RCP2.6								
2030	-0.1	0.1	0.3	0.5	0.7	0.9	1.0	1.2
2050	0.1	0.4	0.6	1.0	1.4	1.7	2.0	2.3
2070	0.3	0.7	1.1	1.7	2.3	2.7	3.1	3.6
2100	0.4	1.2	1.8	2.8	3.8	4.6	5.3	6.2
2200	3.6	4.4	5.2	6.4	7.7	8.8	9.9	11.8

SOURCE: *Climate Change and Sea Level Rise Projections for Boston.* The BRAG Report June 1, 2016.

GRAPHIC A3.2: Regional Sea Level Rise Projections, Boston - by Emissions and Exceedance Probability

METHODOLOGY for Developing Newburyport's Future Sea Level Rise Progression:

It is important to remember that these SLR figures do not include possible short-term weather-related storm surges, riverine flooding, or the effects of a fluctuating Gulf Stream. ***Those short-term effects will ride in atop of SLR projections and will likely affect the area well before the daily tide becomes a nuisance.***

Summary:

The SLR progression developed for Newburyport starts at baseline year 2000 (0 feet) and ends in year 2100 (6 feet). Intermediate points in the progression are 2030, 2050 and 2070. The Technical Subcommittee's agreed upon year 2100 SLR height of up to 6 feet was used as the starting point to calculate the progression backwards toward the year 2000. To achieve this the BRAG and NOAA SLR values

[14] Interagency Sea Level Rise Task Force, ***Global and Regional Sea Level Rise Scenarios for the United States, Executive Summary***. Sweet, W. V., R. E. Kopp, C. P. Weaver, J. Obeysekera, R. M. Horton, E. R. Thieler, & C. Zervas, 2017. NOAA, National Ocean Service

were averaged at the intermediate points (years 2030, 2050 and 2070) to calculate the values for Newburyport's projected SLR progression from 2000-2100.

STEP 1:

6ft of SLR for the year 2100 was found in the BRAG (**GRAPHIC A3.3**) and NOAA **(GRAPHIC A3.4)** tables and used as the starting point.

The BRAG Table correlated with 6.1 feet of SLR by 2100 (red) w/ a progression back to 2030 highlighted in green:

Table 1-1. *RSL projections for Boston, MA (in ft, relative to 2000) categorized by exceedance probabilities.*

			Likely range					Maximum
	0.99	0.95	0.833	0.5	0.167	0.05	0.01	0.001
RCP8.5								
2030	-0.1	0.1	0.3	0.5	0.7	0.9	1.0	1.2
2050	0.1	0.4	0.7	1.1	1.5	1.8	2.1	2.4
2070	0.6	1.0	1.5	2.2	3.1	3.7	4.3	4.8
2100	1.6	2.4	3.2	4.9	7.4	8.6	9.5	10.5
2200	18.9	19.9	21.4	26.1	32.8	34.1	35.3	36.9
RCP4.5								
2030	-0.1	0.1	0.3	0.5	0.7	0.9	1.0	1.2
2050	0.1	0.4	0.7	1.0	1.4	1.7	2.0	2.3
2070	0.4	0.9	1.3	1.9	2.6	3.1	3.6	4.1
2100	0.9	1.7	2.4	3.6	5.1	6.1	7.0	8.0
2200	5.5	6.2	7.2	10.9	16.5	18.0	19.3	20.9
RCP2.6								
2030	-0.1	0.1	0.3	0.5	0.7	0.9	1.0	1.2
2050	0.1	0.4	0.6	1.0	1.4	1.7	2.0	2.3
2070	0.3	0.7	1.1	1.7	2.3	2.7	3.1	3.6
2100	0.4	1.2	1.8	2.8	3.8	4.6	5.3	6.2
2200	3.6	4.4	5.2	6.4	7.7	8.8	9.9	11.8

GRAPHIC A3.3: BRAG Sea Level Rise Table

NOAA's Table first required *converting* the units of meters to feet and then averaging 2 emissions scenarios (intermediate high and high) to achieve the starting point year (2100) SLR height of roughly 6ft (5.8ft) (red). SLR heights of these two emissions scenarios were subsequently averaged for the intermediate points of 2030, 2050 and 2070 to develop a progression from the NOAA data (Green):

Table 5. GMSL rise scenario heights in meters for 19-year averages centered on decade through 2200 (showing only a subset after 2100) initiating in year 2000. Only median values are shown.

GMSL Scenario (meters)	2010	2020	2030 **0.7 ft Avg**	2040	2050 **1.6 ft Avg**	2060	2070 **3.0 ft Avg**	2080	2090	2100 **5.8 ft Avg**	2120	2150	2200
Low	0.03	0.06	0.09	0.13	0.16	0.19	0.22	0.25	0.28	0.30	0.34	0.37	0.39
Intermediate-Low	0.04	0.08	0.13	0.18	0.24	0.29	0.35	0.4	0.45	0.50	0.60	0.73	0.95
Intermediate	0.04	0.10	0.16	0.25	0.34	0.45	0.57	0.71	0.85	1.0	1.3	1.8	2.8
Intermediate-High	0.05	0.10	0.19 **0.6 ft**	0.30	0.44 **1.4 ft**	0.60	0.79 **2.6 ft**	1.0	1.2	1.5 **4.9 ft**	2.0	3.1	5.1
High	0.05	0.11	0.21	0.36	0.54	0.77	1.0	1.3	1.7	2.0	2.8	4.3	7.5
Extreme	0.04	0.11	0.24	0.41	0.63	0.90	1.2	1.6	2.0	2.5	3.6	5.5	9.7

0.7 ft **1.8 ft** **3.3 ft** **6.6 ft**

Source: NOAA Technical Report NOS CO-OPS 083: Global and Regional Sea Level Rise Scenarios for the United States, Silver Spring, Maryland, January 2017.

GRAPHIC A3.4: NOAA Sea Level Rise Table

STEP 2:

BRAG and NOAA values were averaged to develop Newburyport's SLR Progression (**GRAPHIC A3.5**). To develop Newburyport's SLR curve, the values from the NOAA and BRAG tables were averaged for the intermediate point years (2030, 2050 and 2070). These are summarized in the Table below with the average of the BRAG and NOAA highlighted in Blue. (SLR from 2000-2019 was also estimated and included using actual SLR rates).

SLR LINE GRAPH - Using the values calculated above, excel was employed to develop the previously depicted line graph **(GRAPHIC A3.1)** that visually depicts future SLR in Newburyport,

Proposed SLR Progression in Feet, Newburyport, 2000-2100

	2000	Calculated 2019 Actual *	2030	2050	2070	2100
BRAGG	0		0.9	1.7	3.1	6.1
NOAA	0		0.7	1.6	3	5.8
Average	0	0.2	0.8	1.7	3.1	6.0

*Relative SLR Boston 2000-2019 Calculation from NOAA SLR rate Data, Boston
https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8443970

		1921-2008	2009-2018
Rate	mm/yr	2.63	2.82
		thus	thus
		2000-2008	2009-2019
		23.7 mm	31.0 mm

thus

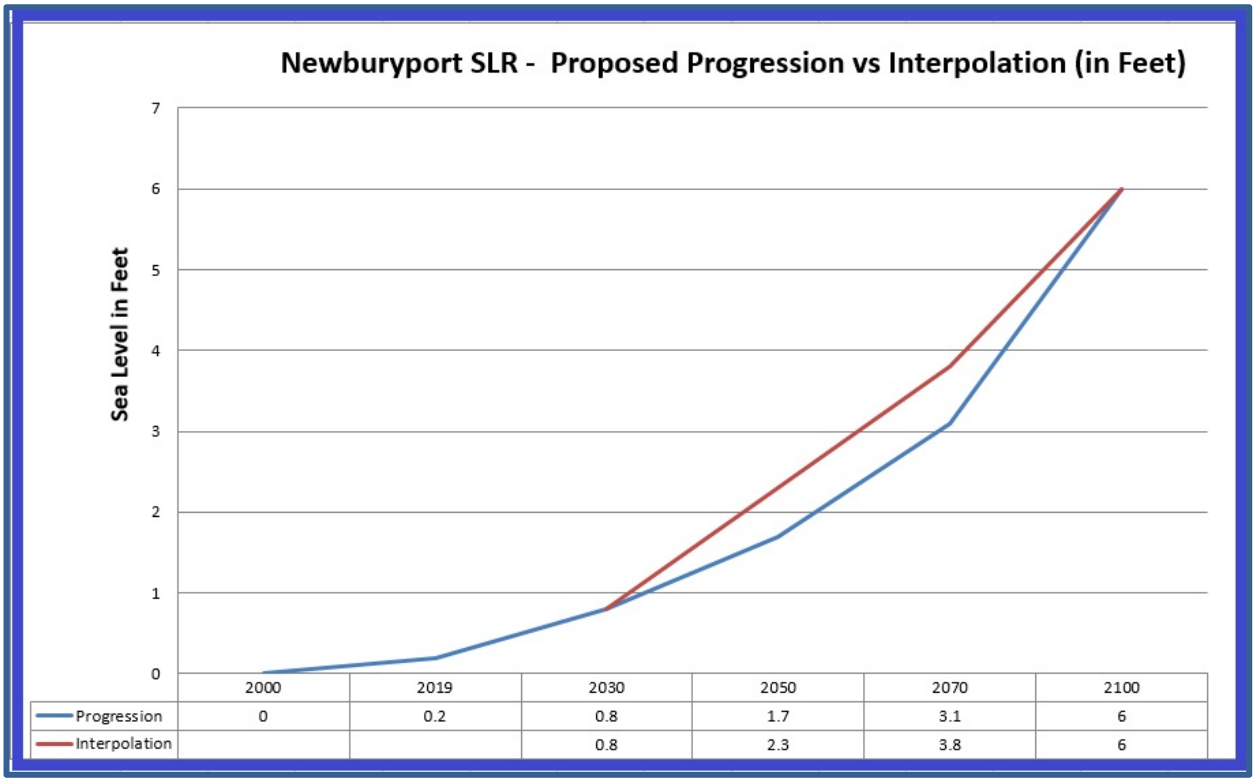
2000-2019

54.7 mm or **2.2 inches** or **0.2 feet**

GRAPHIC A3.5: Newburyport Sea Level Rise Progression – Averaged BRAG and NOAA Data

SLR Progression vs. Interpolation:

The committee debated a simple linear interpolation backwards from 6ft, but as **GRAPHIC A3.6** reveals, the resulting (red) curve was a bit aggressive and might therefore overstate the rate of rise. More importantly, as the progression was developed using BRAG and NOAA data, the Technical Subcommittee's result is not alarmist, but based on the best actual data and the likely current state of global emissions. This progression was used by Newburyport's Department of Engineering to develop the city's sea level rise maps, which can be viewed in Chapter 3 - Vulnerability Assessment. Those resulting visualizations help the reader understand when certain areas, roads and other infrastructure will be awash with the tide, twice daily.



GRAPHIC A3.6: Sea Level Rise Progression vs. Interpolation

APPENDIX 4 - Recommendation of Sea Level Rise for Newburyport's Waterfront West

Recommendation of Sea Level Rise for Newburyport's Waterfront West
TECHNICAL REPORT

Prepared by:
Newburyport Resiliency Committee's Technical Subcommittee on Sea Level Rise

February 4, 2019

Subcommittee's Mission

The Newburyport Resiliency Committee (NRC) convened a technical subcommittee to determine a flood elevation that should be required on waterfront properties to address sea level rise resulting from changes to our climate. Currently, the FEMA Flood Insurance Program does not consider sea level rise in their flood mapping so municipalities are vulnerable to constructing to floodplain elevations that will be many feet below the projected flood elevations years down the road. This subcommittee was tasked to determine a flood elevation for which major development projects – such as the one currently being proposed by New England Development – in the Waterfront West District.

Therefore, this Report specifically evaluates the Waterfront West (WW) properties for implementing a new flood elevation to address future SLR. The methodology used herein could be used elsewhere in the city but site-specific analysis must be made to ensure that there are not alternative recommendations better suited for those areas.

The subcommittee members are as follows:

- Jon-Eric White, PE (Civil), City Engineer
- Diane Gagnon, Assistant City Engineer
- John O'Connell, PE (Civil), Principal Construction Engineering Services (CES), Newburyport
- William Mullen, PE (Civil), Hydraulic Engineer, River Hydraulics
- Michael Morris, Chairman Storm Surge

Subcommittee's Recommendation

The subcommittee's proposed design flood elevations* for the Waterfront West properties are as follows:

SLR Height:	**6 feet**
Landward of the river's edge:	**Design Flood Elevations 18' and 19'**
Within the River:	**Design Flood Elevation 20'**

**Notes:*

1. *Elevations based on NAVD88 Datum.*
2. *Design Flood Elevations (DFE) 18' and 19' shall replace the current FEMA AE Elevations 12' and 13', respectively. DFE 20' in the river replaces current FEMA VE Elev. 14'. The horizontal limits for these proposed DFEs shall follow the same horizontal limits as shown on the current FEMA flood maps.*
3. *Due to the uncertainty of emissions and rate of SLR, the subcommittee decided not to propose an elevation to the nearest tenth or hundredth of a foot as that would suggest a level of accuracy to a tenth or hundredth of a foot, which is not our intention.*

Background

Federal Emergency Management Agency (FEMA) and MA State Building Code have requirements for construction of buildings and structures in areas prone to flooding. Generally, the lowest floor of a building or structure, including basement, shall be at or above the FEMA Base Flood Elevation, or BFE, for a storm event having a 1% probability of occurrence (aka 100-year storm). BFE's are presented on FEMA's Flood Insurance Rate Maps (FIRMs or flood maps).

FEMA has identified three flood zones for the Waterfront West (WW) properties as shown on FIRM Panels 25009C0128F effective date July 3, 2012, and 25009C0136G revised date July 16, 2014: 1) Zone VE EL 14 which encompasses the river up to the bulkheads; 2) Zone AE EL 13 which encompasses the area landward of the bulkheads and river's edge; and, 3) Zone AE EL 12 which is further landward from AE13. See FIRMette produced from the FEMA website that combines these panels for the WW properties in Appendix A.

At this time, the City does not have any future flood inundation models at our disposal. The flood inundation maps prepared by the Woods Hole Group for the Great Marsh Resiliency Project were based on a coastal model that looked at coastal flooding only. They did not take into account *inland* flooding so it may not be suitable for our city along the Merrimack River. Our city's location is at the confluence of the tide and a river so the model should be sophisticated enough to evaluate both inland (riverine) flooding as well as coastal flooding.

The Woods Hole Group is, in fact, currently performing a hybrid coastal and inland model in our area but that model is not expected to be complete until early 2019. In addition, we will not know if this model will be suitable for us until we review the parameters that went into it.

Methodology

Without a suitable model to rely on, the subcommittee proposes to use the current FEMA Base Flood Elevation (BFE) and ADD a projected sea level rise (SLR) height to determine the future flood elevation to be imposed on the development project, herein forward referred to as the Design Flood Elevation (DFE):

FEMA BFE + Future SLR = DFE

The benefit of this approach is that it is simple to understand and easy to update when BFE's and SLR's are changed. FEMA BFE's are already used in building codes to define the elevations for which building structures are to be built within flood hazard zones and to determine flood insurance rates. Generally, you cannot obtain a building permit unless you comply with all FEMA requirements for building in a flood plain.

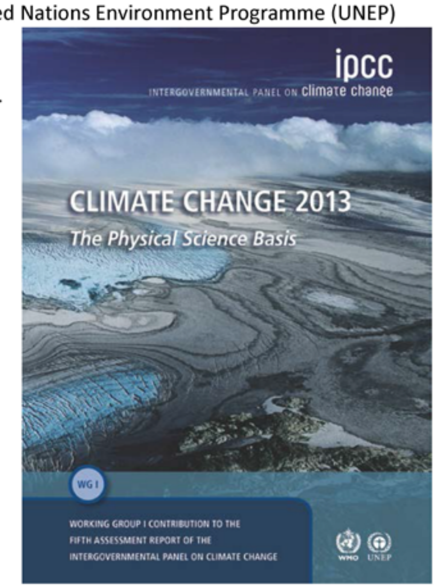
FEMA hydrologic models take into account the various components of hydrology and hydraulics along our coast, such as storm surge, wave setup and runup, as well as the riverine components from the Merrimack River. Adding SLR to the BFE provides a reasonably accurate flood elevation that can be used to estimate future flood elevations or DFE's.

The disadvantage of this approach is that it is not as accurate as a model would be because the impact of sea level rise on flood elevations is not linear – the impacts get worse with each additional height in SLR. "Higher sea levels worsen the impacts of storm surge, high tides, and wave action (e.g., Theuerkauf et al., 2014), even absent any changes in storm frequency and intensity. Even the relative small increases in sea level over the last several decades have led to greater storm impacts at many places along the U.S. coast (Parris et al., 2012; Miller et al., 2013; Seet et al., 2013)." [1]

Sea Level Rise – Which Scenario to Choose?

Determining the SLR to use has been the most time-consuming task by the subcommittee. There are a number of SLR projections out there from which to choose and we debated many of them. The following are the most credible publications that the subcommittee used for reference material.

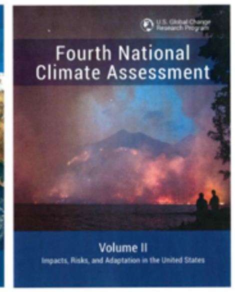
In 1988, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) formed the Intergovernmental Panel on Climate Change (IPCC) to "provide policymakers with the most authoritative and objective scientific and technical assessments" on impacts from climate change. The IPCC formed working groups that includes scientists and engineers worldwide to study, research, and report on their findings in a number of reports and technical papers. The most referenced reports are the Assessment Reports (AR), the latest being *IPCC Climate Change 2013, The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the IPCC.*



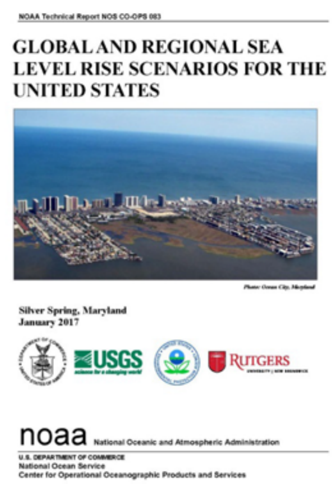
Nationally, the Global Change Research Act of 1990 mandates that the U.S. Global Change Research Program (USGCRP) delivers a report to the U.S. Congress and the President no less than every four years, which essentially analyzes the effects of climate change on all aspects of our lives.

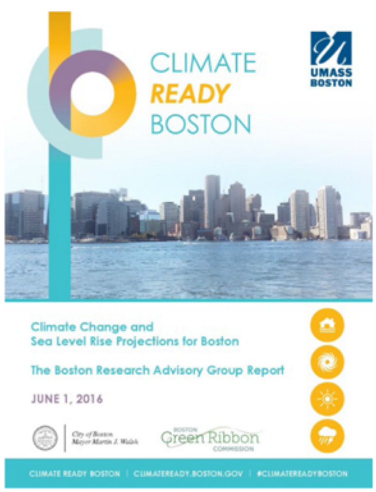
Footnotes:
[1] *NOAA Technical Report NOS CO-OPS 083: Global and Regional Sea Level Rise Scenarios for the United States, Silver Spring, Maryland, January 2017.*

These reports are called National Climate Assessments (NCAs) and they recently published NCA4 (August 2018) in two volumes, see below. The National Oceanic and Atmospheric Administration (NOAA) serves as the administrative lead agency for the preparation of these reports with many other agencies assisting in the overall development of the report.



NOAA provided the SLR projections used throughout NCA4 and their projections seem to be the most referenced of all SLR projections published worldwide. The NOAA document summarizing their findings is *Technical Report NOS CO-OPS 083: Global and Regional Sea Level Rise Scenarios for the United States, Silver Spring, Maryland, January 2017*.





To further complicate the matter for our subcommittee, Boston tapped into a number of additional experts in the field to come up with their own SLR projections suitable to Boston proper and they published their findings in what is known as the "BRAG Report", titled *Climate Ready Boston, Climate Change and Sea Level Rise Projections for Boston, The Boston Research Advisory Group Report, June 1, 2016*. BRAG used its team of experts to account for regional-scale processes (such as land subsidence, variations in the speed of the Gulf Stream and the gravitational effect of melting ice sheets) by modifying NOAA's global figures as published in their *Technical Report NOS CO-OPS 083 Global and Regional Sea Level Rise Scenarios for the United States*.

The NRC Subcommittee members used either the NOAA SLR projections or the BRAG Report's SLR projections to determine recommended flood elevations, based on their own personal preference. Each member justified their use of said projections in their supporting documentation.

The NOAA SLR[1] projections used are provided below:

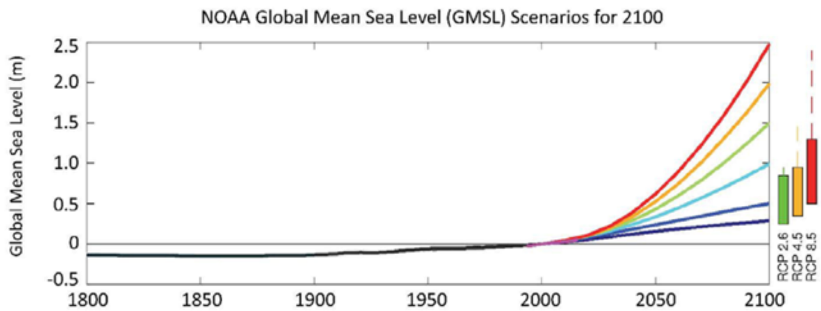


Figure 8. This study's six representative GMSL rise scenarios for 2100 (6 colored lines) relative to historical geological, tide gauge and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines; as in Figure 3a) and central 90% conditional probability ranges (colored boxes) of RCP-based GMSL projections of recent studies (Church et al., 2013a; Kopp et al., 2014; 2016a; Slangen et al., 2014; Grinsted et al., 2015; Mengel et al., 2016). These central 90% probability ranges are augmented (dashed lines) by the difference between the median Antarctic contribution of Kopp et al. (2014) probabilistic GMSL/RSL study and the median Antarctic projections of DeConto and Pollard (2016), which have not yet been incorporated into a probabilistic assessment of future GMSL. (A labeling error in the x-axis was corrected on January 30, 2017).

Table 4. Probability of exceeding GMSL (median value) scenarios in 2100 based upon Kopp et al. (2014).

GMSL rise Scenario	RCP2.6	RCP4.5	RCP8.5
Low (0.3 m)	94%	98%	100%
Intermediate-Low (0.5 m)	49%	73%	96%
Intermediate (1.0 m)	2%	3%	17%
Intermediate-High (1.5 m)	0.4%	0.5%	1.3%
High (2.0 m)	0.1%	0.1%	0.3%
Extreme (2.5 m)	0.05%	0.05%	0.1%

Table 5. GMSL rise scenario heights in meters for 19-year averages centered on decade through 2200 (showing only a subset after 2100) initiating in year 2000. Only median values are shown.

GMSL Scenario (meters)	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2120	2150	2200
Low	0.03	0.06	0.09	0.13	0.16	0.19	0.22	0.25	0.28	0.30	0.34	0.37	0.39
Intermediate-Low	0.04	0.08	0.13	0.18	0.24	0.29	0.35	0.4	0.45	0.50	0.60	0.73	0.95
Intermediate	0.04	0.10	0.16	0.25	0.34	0.45	0.57	0.71	0.85	1.0	1.3	1.8	2.8
Intermediate-High	0.05	0.10	0.19	0.30	0.44	0.60	0.79	1.0	1.2	1.5	2.0	3.1	5.1
High	0.05	0.11	0.21	0.36	0.54	0.77	1.0	1.3	1.7	2.0	2.8	4.3	7.5
Extreme	0.04	0.11	0.24	0.41	0.63	0.90	1.2	1.6	2.0	2.5	3.6	5.5	9.7

Figure 8, Table 4, and Table 5 are extracted from *NOAA Technical Report NOS CO-OPS 083: Global and Regional Sea Level Rise Scenarios for the United States, Silver Spring, Maryland, January 2017*.
The BRAG SLR[1] projections are provided below:

Table 1-1. RSL projections for Boston, MA (in ft, relative to 2000) categorized by exceedance probabilities.

			LIKELY RANGE					MAXIMUM
	0.99	0.95	0.833	0.5	0.167	0.05	0.01	0.001
RCP8.5								
2030	-0.1	0.1	0.3	0.5	0.7	0.9	1.0	1.2
2050	0.1	0.4	0.7	1.1	1.5	1.8	2.1	2.4
2070	0.6	1.0	1.5	2.2	3.1	3.7	4.3	4.8
2100	1.6	2.4	3.2	4.9	7.4	8.6	9.5	10.5
2200	18.9	19.9	21.4	26.1	32.8	34.1	35.3	36.9
RCP4.5								
2030	-0.1	0.1	0.3	0.5	0.7	0.9	1.0	1.2
2050	0.1	0.4	0.7	1.0	1.4	1.7	2.0	2.3
2070	0.4	0.9	1.3	1.9	2.6	3.1	3.6	4.1
2100	0.9	1.7	2.4	3.6	5.1	6.1	7.0	8.0
2200	5.5	6.2	7.2	10.9	16.5	18.0	19.3	20.9
RCP2.6								
2030	-0.1	0.1	0.3	0.5	0.7	0.9	1.0	1.2
2050	0.1	0.4	0.6	1.0	1.4	1.7	2.0	2.3
2070	0.3	0.7	1.1	1.7	2.3	2.7	3.1	3.6
2100	0.4	1.2	1.8	2.8	3.8	4.6	5.3	6.2
2200	3.6	4.4	5.2	6.4	7.7	8.8	9.9	11.8

Table 1-1 is extracted from The BRAG Report: *Climate Ready Boston, Climate Change and Sea Level Rise Projections for Boston, The Boston Research Advisory Group Report, June 1, 2016.*

In reading these reports, it is apparent the degree of complexity in determining SLR projections and the difficulty communities face in deciding which projection to use. Two key factors in choosing an SLR are global emission rates and exceedance probabilities. The emission scenarios are classified with the prefix "RCP"[2] and are noted herein. The rates reflect whether the world will scale back emissions or will continue emitting 'business as usual'. Exceedance probabilities were calculated by these agencies to address the likelihood of occurrence and most of our subcommittee members used these probabilities to determine their proposed elevation. Additionally, many of the reviewed reports refer to data from other reports which further complicate things.

Footnotes:

[1] *The SLR projections provided in both the NOAA table and the BRAG Report table above are referenced to the year 2000, which is estimated as the average sea level over the decadal time period 1990 – 2010. The average rate of SLR for Boston during this period 2.1 inches per decade. Adjustments must be made when comparing these SLR projections to SLR projections made using a different baseline. Reference: p. 6, Section 1.b.1. Definitions, Climate Change and Sea Level Projections for Boston, The BRAG Report, June 1, 2016*

[2] *Representative Concentration Pathway scenarios (RCPs): A series of possible climatic conditions that attempt to project an escalating range of severity of effects as greenhouse gas emissions increase. Reference: p. 29, Climate Change 2013, The Physical Science Basis, by Working Group I, IPCC*

BRAG decided to create their own SLR projections in order to better-reflect the local conditions in Boston. They evaluated such things as land subsidence, local ocean conditions, and more. Refer to the BRAG Report for more details.

Not all of the subcommittee members used the same SLR projection table or data for various reasons. Therefore, the subcommittee decided not to use one specific SLR projection but rather allow each member to submit a SLR height to be added to the FEMA BFE.

Individual and Final Subcommittee Recommendations

Each member provided their proposed flood elevation as summarized in the table below. Each member provided backup documentation supporting their decision. Their proposals and the group's average are as follows sorted from lowest to highest:

Member	Current FEMA Base Flood Elevation (BFE) (feet)	Proposed SLR (feet)	Proposed Design Flood Elevation (DFE) (feet)
1	AE 12/13	4	16/17
2	AE 12/13	4.9	16.9/17.9
3	AE 12/13	5.1	17.1/18.1
4	AE 12/13	5.3	17.1/18.1
5	AE 12/13	8	20/21
***Subcommittee Recommendation:**		**6**	**18/19**

General Comments and Points to Consider:

1. Each subcommittee member has prepared their own supporting documentation justifying their proposals. Refer to Appendix B.

2. There will always be a debate whether or not a municipality should allow building in a coastal flood plain in today's weather climate with perpetually-rising seas. Some of our members feel it is not advisable and should only be allowed if absolutely necessary. Others feel that a development should be allowed if it can last a handful of decades and if it benefits the city, residents, users, and the overall community. The difficulty is determining when the tipping point will be between a benefit and a liability. At some point the city will likely be left with an abandoned development and will need to address who pays for its removal or redevelopment. The larger the project, the larger the problem. Residential and commercial buildings are known to last hundreds of years if built to the building code. Therefore, the subcommittee urges the City to seriously consider the development being proposed and to address, legally and otherwise, how the development will be made resilient and who pays for future resiliency efforts. The City need not be the recipient of an abandoned development along our waterfront.

3. As the property owner has decided to build in a rising floodplain, the DFE provides guidance to construct a project that can be utilized for approximately 80 years before it is projected that resiliency measures, including raising buildings and structures, are needed. Therefore, the intent of this flood-elevation constraint is being provided to encourage the most resilient project from its inception, which in the long-term will only benefit the property owner. However, the City shall not be held liable for any damage caused by the

property owner's-decision to construct within a constantly rising and therefore, changing, coastal flood plain. The property owner accepts all risks and responsibility for developing within these areas, including the likely possibility that public access roads to these areas may eventually become submerged and may therefore no longer be passable.

4. The City shall not be held liable for any damage caused by the property owner's desire to construct within a constantly-rising coastal flood plain. The property owner accepts all responsibility for developing within these areas, including the fact that public access roads to these areas may be underwater and no longer available in the future.

5. These flood elevations must be recalculated on a regular basis as more information has been presented by various experts and agencies. At the minimum, the subcommittee recommends reviewing these numbers with every revision to the National Climate Assessment and/or with changes to the FEMA BFE. In the event that construction of the Waterfront West is delayed, the City should reserve the right to revise the DFE as necessary.

6. These DFE's should be used in the same manner in which the FEMA BFE's are used – namely, but not limited to, to control first floor elevations for new construction. Existing building structure owners will have to address future sea level rise and future flood elevations as they see fit. Currently the city does not have any ordinance or regulation requiring any action to properties or buildings within the flood plain and/or below the FEMA BFE. As the seas rise and FEMA revises the BFE's, property owners will then have to address the problems associated with having their structure below the BFE, including the need to comply with the FEMA Flood Insurance Policy.

7. Individual property owners, including municipal properties, should always evaluate the value of their assets on their property to determine the risk they take when dealing with sea level rise, flooding, and other climate change impacts. The higher the value, the higher the assets should exist on the property. Critical infrastructure should be built or raised higher than the DFE being proposed herein. Cost-benefit analysis should be done by each property owner to determine the value of flood proofing or raising their assets above the future flood elevations.

Implementation of Proposed Design Flood Elevations

The subcommittee was not tasked with determining the means for which to implement their proposed elevations. Their goal was to determine future flood elevations based on projected SLR. Nonetheless, the following provides suggestions for implementation:

- It is the subcommittee's understanding that state law allows municipalities to adopt their own wetland protection by-laws or ordinances (and associated regulations) that may be more restrictive than the Massachusetts Wetlands Protection Act (WPA). Currently, the WPA Regulations do not provide performance standards for projects that take place within the wetland resource area titled "Land Subject to Coastal Storm Flowage," also known as the FEMA coastal floodplain. This resource area includes all the coastal VE and A flood zones. Newburyport has already adopted a local Wetlands Protection Ordinance and regulations that impose performance standards and buffer zones more restrictive than what is in the WPA for most wetland resource areas in the city, with the exception of the coastal floodplain. Because there has been no guidance from DEP or other state agencies on what such performance standards should entail, most coastal communities have not adopted regulations for this resource area. However, now that the Resiliency Committee is determining guidance for elevation of structures, etc. at Waterfront West, it is our understanding that the Conservation Commission could incorporate these as new regulations for Land Subject to Coastal Storm Flowage, and thereby begin requiring developers to adhere to the new recommendations.

- It is also the subcommittee's understanding that expanding the floodplain beyond FEMA's flood zones cannot be accomplished in the same manner as above. Therefore, implementing higher flood elevations beyond the existing flood zones may present a legal challenge for the city. The subcommittee recommends retaining real estate or land use attorneys to come up with a way to implement these proposed flood elevations beyond the current floodplains.

- Sea level rise will probably continue for centuries and municipalities should be allowed to modify flood elevations to address these changes at the local level without any exposure to legal action by property owners claiming we are restricting their development rights. The subcommittee urges the city to determine how to revise the flood elevations beyond the existing floodplain limits.

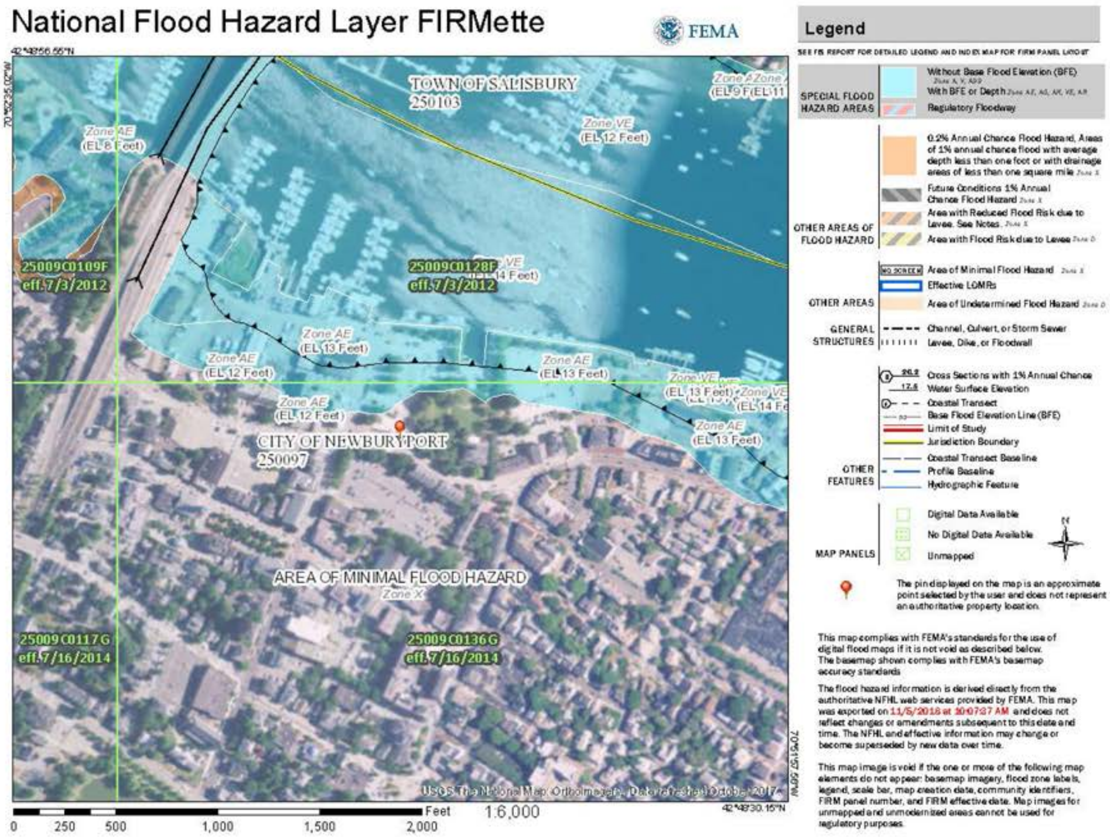
- Figure 4 in Appendix A shows graphically how FEMA flood zones should be interpreted. Using this same logic, Figure 1 in Appendix A illustrates what the higher flood elevation (FEMA BFE + SLR) would look like. Raising the flood elevation within the limits of the current FEMA floodplain and not expanding the floodplain elevation horizontally to its matching topographic height contour would imply that a vertical wall of water would exist at the current floodplain boundary, which is not physically possible. As the future flood elevation will "seek its own level" horizontally, the subcommittee proposes extending the DFE landward until it meets its matching elevation.

Appendix A

FEMA Flood Map 'FIRMette' of Waterfront West Properties

FEMA Interpretation of Flood Zones Figure 4

Implementation of DFE


National Flood Hazard Layer FIRMette
FEMA
Legend
SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT
SPECIAL FLOOD HAZARD AREAS
Without Base Flood Elevation (BFE)
With BFE or Depth
Regulatory Floodway
0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile
Future Conditions 1% Annual Chance Flood Hazard
Area with Reduced Flood Risk due to Levee. See Notes.
Area with Flood Risk due to Levee
OTHER AREAS OF FLOOD HAZARD
Area of Minimal Flood Hazard
Effective LOMRs
OTHER AREAS
Area of Undetermined Flood Hazard
GENERAL STRUCTURES
Channel, Culvert, or Storm Sewer
Levee, Dike, or Floodwall
Cross Sections with 1% Annual Chance
Water Surface Elevation
Coastal Transect
Base Flood Elevation Line (BFE)
Limit of Study
Jurisdiction Boundary
Coastal Transect Baseline
Profile Baseline
Hydrographic Feature
OTHER FEATURES
Digital Data Available
No Digital Data Available
Unmapped
MAP PANELS
The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.
This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards
The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 11/5/2018 at 10:07:37 AM and does not reflect changes or amendments subsequent to this date and time. The NFHL and effective information may change or become superseded by new data over time.
This map image is void if the one or more of the following map elements do not appear: basemap imagery, flood zone labels, legend, scale bar, map creation date, community identifiers, FIRM panel number, and FIRM effective date. Map images for unmapped and unmodernized areas cannot be used for regulatory purposes.
TOWN OF SALISBURY
250103
CITY OF NEWBURYPORT
250097
AREA OF MINIMAL FLOOD HAZARD
Zone X
Zone AE
(EL 8 Feet)
Zone VE
(EL 12 Feet)
Zone AE
(EL 13 Feet)
Zone AE
(EL 12 Feet)
25009C0109F
eff. 7/3/2012
25009C0128F
eff. 7/3/2012
25009C0117G
eff. 7/16/2014
25009C0136G
eff. 7/16/2014
Feet
1:6,000
0 250 500 1,000 1,500 2,000

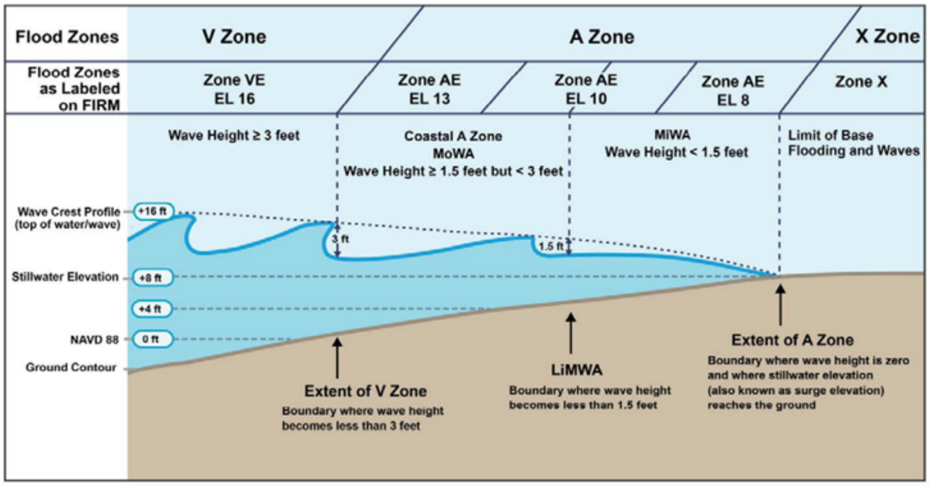


Figure 4. Cross-sectional diagram of flood zones on a gently sloping ground profile with no runup. Profile elevations and Base Flood Elevations are shown in feet above the NAVD 88 datum (as indicated with 0 ft, +4 ft, +8 ft, +16 ft). Although the BFE for the seaward portion of this V Zone is 16 feet NAVD 88 (as indicated by the Zone VE EL 16 on the FIRM), the V Zone does not reach as far landward as the 16-foot ground elevation. Instead, as waves break and wave heights diminish in the landward direction, the V Zone ends where wave heights become less than 3 feet, and the flood designation becomes an A Zone (with decreasing A Zone elevations—13, 10, then 8 feet NAVD 88) that extends landward to the 8-foot ground elevation. The LiMWA marks the landward limit of the Moderate Wave Action (MoWA) area, where wave heights are between 1.5 and 3.0 feet. Landward of the MoWA and the LiMWA boundary is the Minimal Wave Action (MiWA) area, where wave heights are less than 1.5 feet.

Reference: *Interpreting Federal Emergency Management Agency Flood Maps and Studies in the Coastal Zone, Publication date: June 2017*, by Massachusetts Office of Coastal Zone Management (CZM)

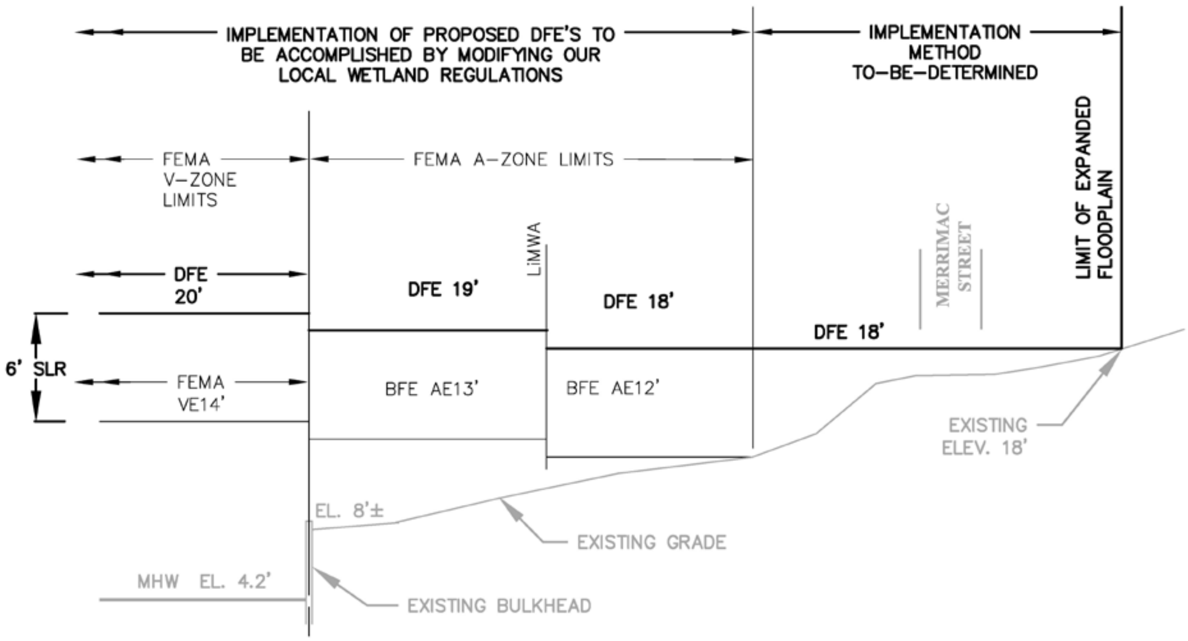


FIGURE 1 — IMPLEMENTATION OF PROPOSED DFE'S

NOTES:

1. FIGURE IS NOT TO SCALE. IT IS EXAGGERATED VERTICALLY FOR CLARITY AND PRESENTATION PURPOSES ONLY.
2. IMPLEMENTATION OF PROPOSED DFE'S WITHIN THE HORIZONTAL LIMITS OF THE EXISTING FEMA FLOODPLAIN TO BE ACCOMPLISHED BY MODIFYING THE CITY'S LOCAL WETLAND REGULATIONS IN ACCORDANCE WITH MA DEP WETLAND PROTECTION ACT.
3. MEANS OF IMPLEMENTING THE PROPOSED DFE BEYOND THE HORIZONTAL LIMITS OF EXISTING FEMA FLOODPLAIN HAS YET TO BE DETERMINED.

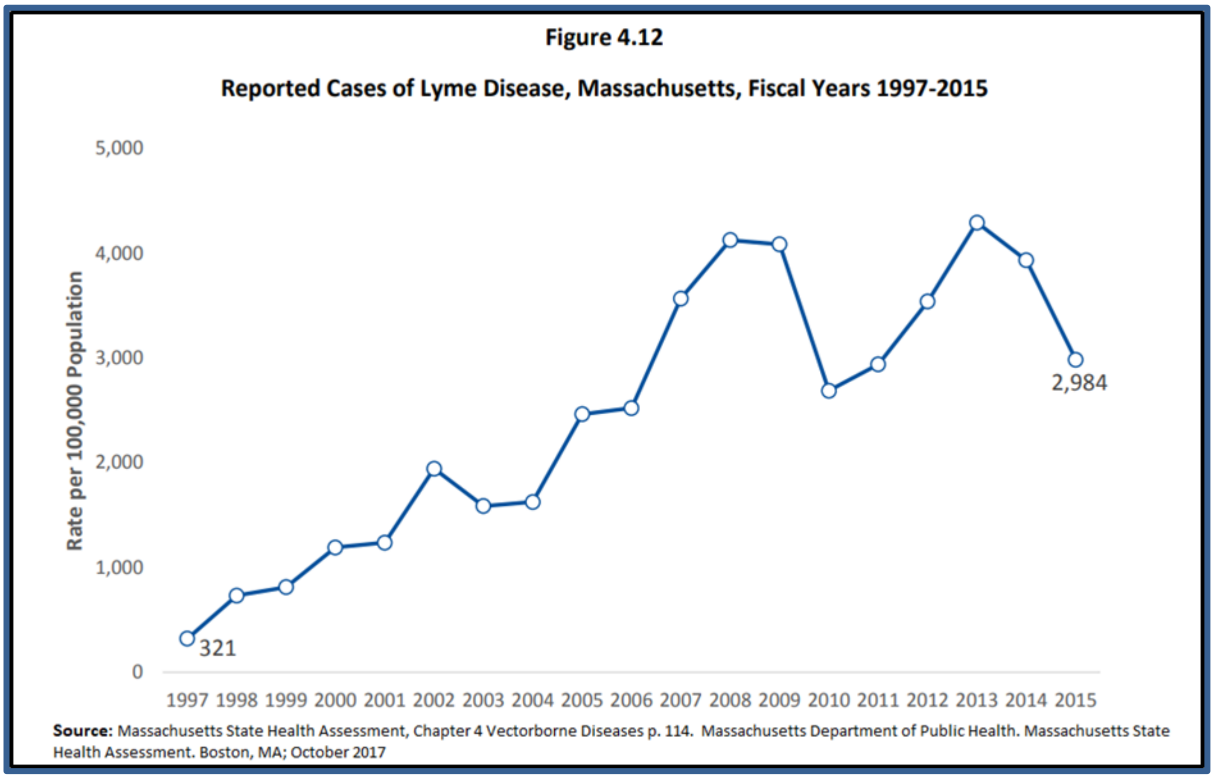
Recommendation of Sea Level Rise for Newburyport
December 5, 2019

APPENDIX 5 – Insect Disease Vectors, Tick and Mosquito Related Illnesses

Tick Borne Diseases

“Lyme disease has become hyperendemic (**GRAPHIC A5.1:** Reported Cases of Lyme Disease, Massachusetts 1997-2015) and two other vector-borne diseases have increased in Massachusetts in recent years: human granulocytic anaplasmosis and babesiosis.”[15]

Lyme disease is a controversial and debilitating disease if left untreated. The disease when delivered via a tick bite may also pass along a cocktail of parasites including Babesiosis, Human Granulocytic Anaplasmosis, and Ehrlichiosis. As with the mosquito borne diseases, these diseases spread by ticks are particularly harmful to the elderly and immune-compromised individuals.



GRAPHIC A5.1: Reported Cases of Lyme Disease, Massachusetts 1997-2015 (see footnote 15 below)

Lyme Disease

Lyme disease is caused by the bacterium Borrelia burgdorferi and is transmitted to humans through the bite of infected ticks who obtain the bacterium from feasting on mice as nymphs. Adult black legged (or deer ticks) are then distributed to the limits of their range by larger animals such as deer, fox, moose, bear etc. Early Signs and Symptoms (3 to 30 days after tick bite) include fever, chills, headache, fatigue, muscle and joint aches, and swollen lymph nodes. After about 7 days following the tick bite an Erythema Migrans

[15] ***Massachusetts State Health Assessment*****,** Chapter 4 Vector-borne Diseases p. 114. Massachusetts Department of Public Health. Massachusetts State Health Assessment. Boston, MA; October 2017

(EM) bull's eye rash occurs at the site of the bite in approximately 70 to 80 percent of infected persons. Left untreated, later symptoms (days to months after tick bite) include severe headaches and neck stiffness, additional EM rashes on other areas of the body, arthritis with severe joint pain and swelling, particularly the knees and other large joints, facial palsy (loss of muscle tone or droop on one or both sides of the face), intermittent pain in tendons, muscles, joints, and bones, heart palpitations or an irregular heart beat (Lyme carditis), episodes of dizziness or shortness of breath, inflammation of the brain and spinal cord, nerve pain, shooting pains, numbness, or tingling in the hands or feet and problems with short-term memory. Lyme is effectively treated with antibiotics, but there is great disagreement about how long patients need to be treated. Furthermore, antibiotic treatment during the later stages of Lyme won't undo the damage already done to the human body. Prevention and early treatment yield the best outcomes.

Babesiosis

According to the CDC, many people who are infected with *Babesia Microti* feel fine and are asymptomatic. Some people develop nonspecific flu-like symptoms, such as fever, chills, sweats, headache, body aches, loss of appetite, nausea, and especially fatigue. Because *Babesia* parasites infect and destroy red blood cells, babesiosis can cause a special type of anemia called hemolytic anemia. This type of anemia can lead to jaundice (yellowing of the skin) and dark urine. Babesiosis can be a severe, life-threatening disease, particularly in people who do not have a spleen; have a weak immune system due to cancer, lymphoma, or AIDS; have other serious health conditions (such as liver or kidney disease); or are elderly.

Granulocytic Anaplasmosis

Early signs and symptoms of Granulocytic Anaplasmosis (days 1-5) are usually mild or moderate and may include: fever, chills, severe headache, muscle aches, nausea, vomiting, diarrhea, loss of appetite. Prompt treatment with antibiotics is successful. Rarely, if treatment is delayed or if there are other medical conditions present, anaplasmosis can cause severe illness including respiratory failure, bleeding problems, organ failure and death.

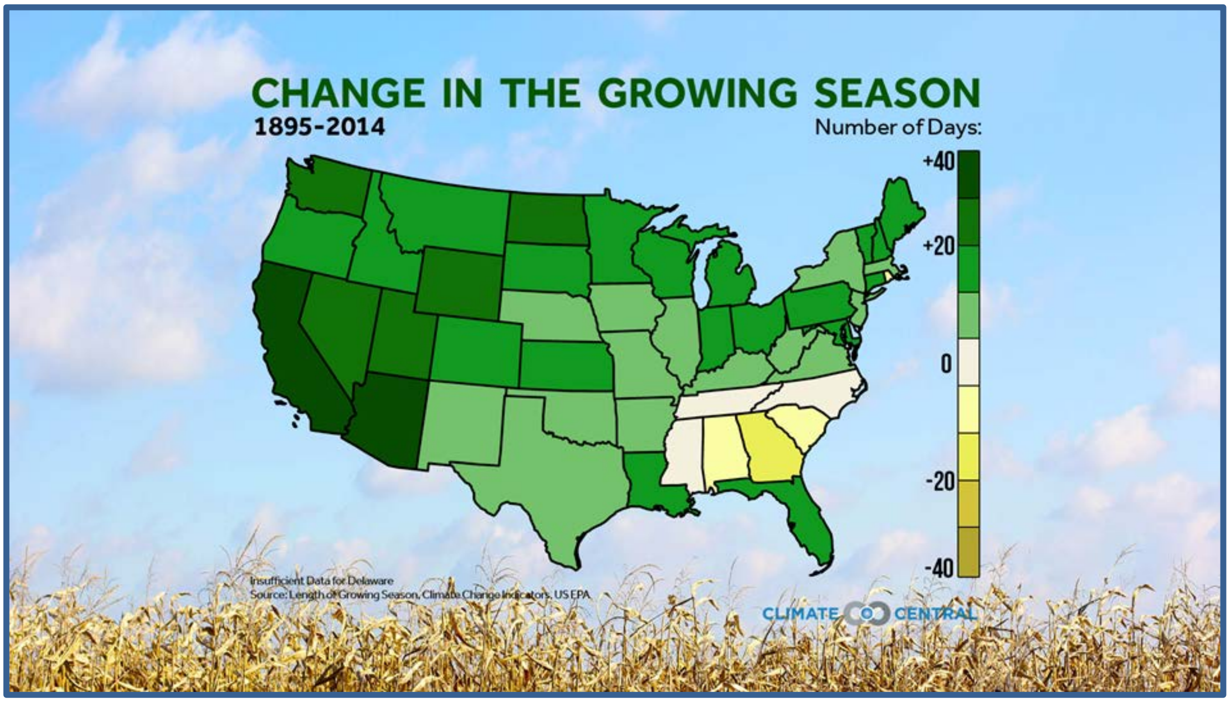
Ehrlichiosis

Ehrlichiosis is a serious illness that can be fatal if not treated correctly, even in previously healthy people, but is obviously a danger to immune-compromised people and the elderly. Symptoms mimic those of the other tick-borne parasites and include fever, headache, chills, malaise, muscle pain, nausea, vomiting, diarrhea, confusion, conjunctival injection (red eyes), and a rash. The disease can be successfully treated with antibiotics. Problems with diagnostic testing can produce false negative results, delaying early treatment, which is critical, especially if tested early, before 7-10 days following infection. Patients who are treated early may recover quickly on outpatient medication, while those who experience a more severe course may require intravenous antibiotics, prolonged hospitalization or intensive care.

Mosquito Disease Vectors

About 3000 different species of mosquitoes have been identified worldwide. Of the 150 varieties common to the United States, 51 different species mosquitoes live in Massachusetts. Mosquitoes are most active during our growing season that is defined by the last hard frost in April and the first hard frost – usually in October. **GRAPHIC A5.2:** Growing Season trend 1895-2014, US EPA 2015, shows that since 1895 the growing season, and hence the mosquito's ability to transmit disease, is extending. In fact, locally, mosquitoes are observed to be active even in mid-winter, during periods of unusual warmth.

In Massachusetts, the diseases linked to mosquitoes are West Nile virus (WNV) and eastern equine encephalitis (EEE) virus. Mosquitoes transmit the WNV and EEE to humans by first biting an infected bird.



GRAPHIC A5.2: Growing Season trend 1895-2014, US EPA 2015

The elderly and people with suppressed immune systems are most susceptible to WNV. Symptoms include fever, headache, muscle pains, and various neurological diseases such as meningitis. According to the CDC, about 1 in 150 people who are infected develop a severe illness affecting the central nervous system such as encephalitis (inflammation of the brain) or meningitis (inflammation of the membranes that surround the brain and spinal cord. No vaccine or specific antiviral treatments for West Nile virus infection are available. Over-the-counter pain relievers can be used to reduce fever and relieve some symptoms. In severe cases, patients often need to be hospitalized to receive supportive treatment, such as intravenous fluids, pain medication, and nursing care.

While anyone can acquire EEE, especially if they are frequently exposed to mosquitoes, children and those over age 55 are more susceptible to serious illness. 80% of EEE survivors in Massachusetts are left with permanent neurological damage. The risk of getting EEE is highest during the warmest months from late July through September. As with WNV, there is no specific treatment for EEE. Antibiotics are not effective against viruses, and no effective anti-viral drugs have yet been discovered for this disease. Care of patients centers around treatment of symptoms and complications.

To shed some perspective on risk, according to the CDC, the prevalence of WNV in Massachusetts lies between 0.01-0.24 cases per 100,000 population. The rate for EEE is 0.01-0.19 cases per 100,000 population within the seven counties in central and eastern Massachusetts harboring the disease. Comparatively, the rate of heart disease events in Massachusetts lays either side of 1000 cases per 100,000 population. It is worth noting however, that of the 28 EEE cases reported in New England from 2008-17, 39% (11) were from seven counties in Massachusetts, including Essex County.

Newburyport has within its borders open spaces, parks and forest, numerous wetlands associated with the Artichoke Reservoir, the Merrimack and little Rivers and the Great Marsh (GRAPHIC A5.3). Given this geography, Newburyport residents are more exposed to these disease vectors relative to communities with drier or urban landscapes. Given the susceptibility of Newburyport's growing elderly population to these disease vectors, and since prevention strategies work well in controlling their spread, Newburyport should have a plan for handling these diseases in a warmer, wetter world.

GRAPHIC A5.3: Wetlands of the Great Marsh

APPENDIX 6 - Combined Sewer Overflows (CSOs)

One might not classify a CSO as a climate hazard, but rather a public health and infrastructure problem. However, Climate Change has been the driving force behind increasing episodes of heavy precipitation, which in turn have led to an increase in the volume of CSOs into the Merrimack River. Hence Climate Change, by making the problem worse, has taken an issue that's long been relegated to the shadows and put a spotlight on it. As the public health and environmental impacts of CSOs on the Merrimack have not been adequately quantified, and given that the problem won't be immediately resolved, Newburyport must treat CSOs as a public health threat exacerbated by the effects of Climate Change.

A combined sewer system collects rainwater runoff, domestic sewage, and industrial wastewater into a single system or pipe (*Figure A6.1 CSO System Explained*). Under normal conditions, it transports all the wastewater it collects to a Wastewater treatment facility for treatment and then discharges that treated water to a water body. At times the combined volume of wastewater can exceed the capacity of the combined sewer system or treatment plant (e.g., during heavy rainfall events or snowmelt). When this occurs, a mix of untreated stormwater and wastewater are discharged directly to nearby streams, rivers, and other water bodies to relieve the system. These CSOs are generally part of the engineering designs of the combined sewer systems, which predate our current understanding of pollution control and our current environmental and land development conditions. Combined sewer overflows (CSOs) contain untreated or partially treated human and industrial waste, toxic materials, and debris as well as stormwater. According to the US EPA, they are a priority water pollution concern for the nearly 860 municipalities across the U.S. that have combined sewer systems. However, they are an expensive and sometimes complicated infrastructure problem, especially in larger communities that have an expansive system of pipes.

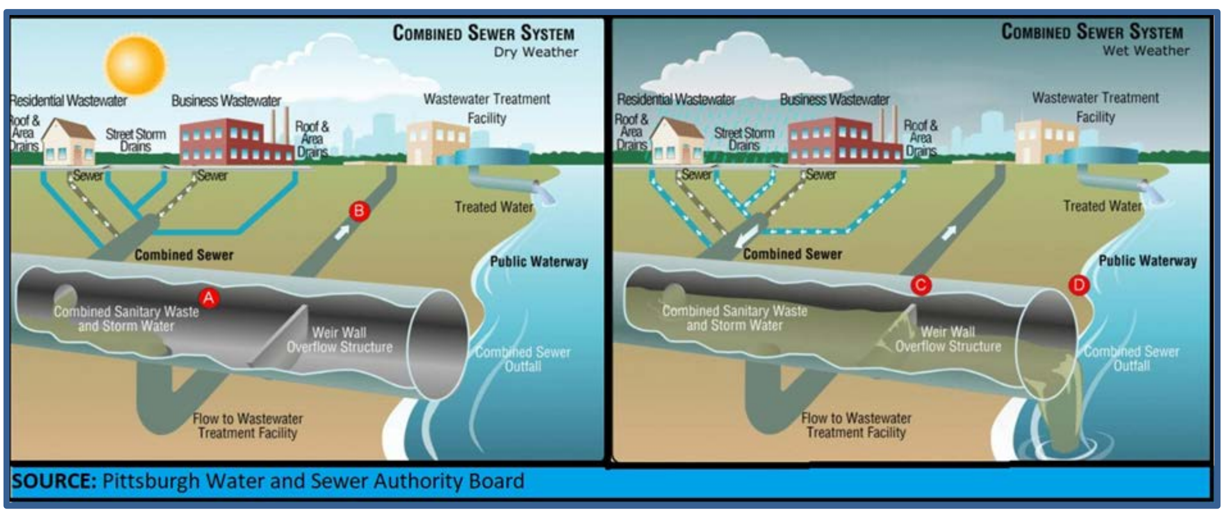


Figure A6.1 CSO System Explained

While Newburyport's Wastewater treatment facility has been updated and is not a CSO contributor, there are six urban sewage treatment systems in the Merrimack River watershed that frequently discharge large quantities of raw sewage during rainstorms: Manchester and Nashua, N.H., Lowell, the Greater Lawrence Sanitary District, and Haverhill (all on the Merrimack River), and Fitchburg (on the Nashua River, a Merrimack tributary) (*Figure A6.2: Lower Merrimack River Water Utilities*) CSOs are frequent and significant. In 2018, these six sewage treatment systems experienced hundreds of overflow events, which the Merrimack River Watershed Council (MWRC) estimated as a discharge of some 770 million gallons of untreated sewage into the river. These wastewater treatment facilities are under government order to eliminate most of their CSOs, but without additional federal and state funding, it may likely be 25 years before these systems are brought into compliance.

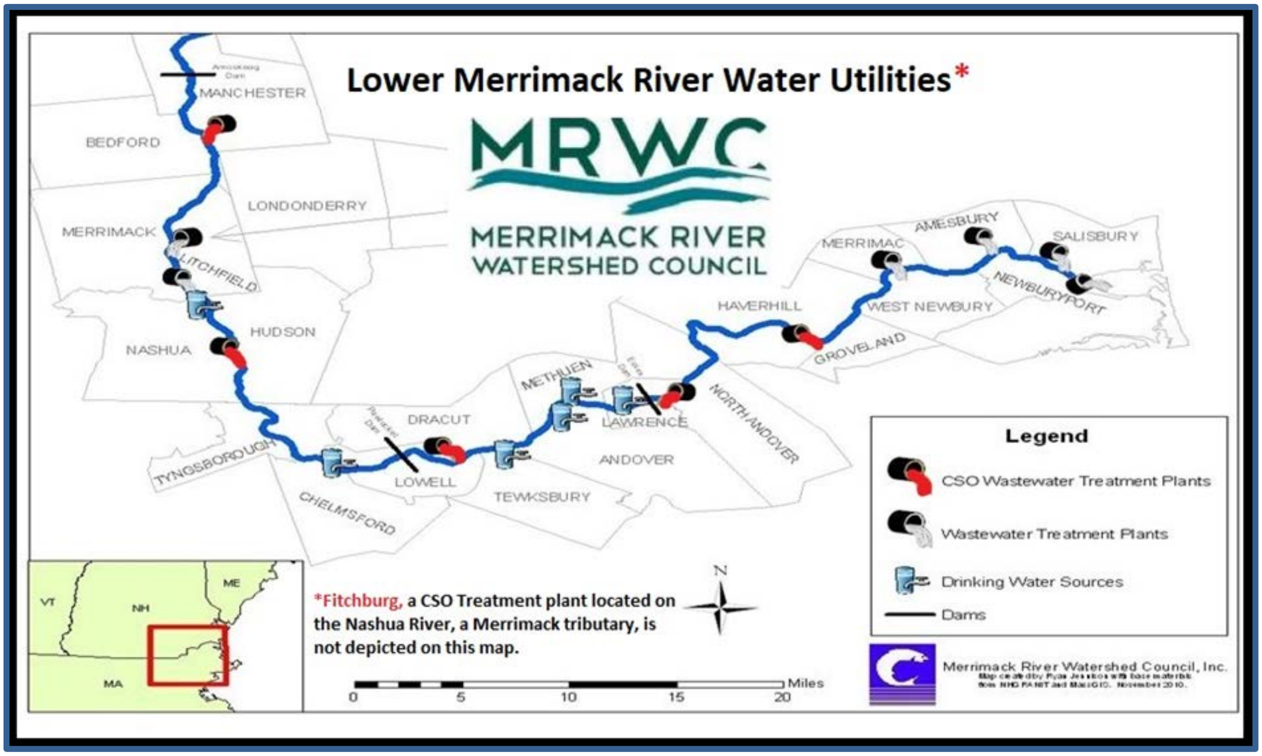


Figure A6.2 Lower Merrimack River Water Utilities

The most immediate problem is a dearth of information. Public notice of CSO events is incomplete and inconsistent, as is the effect on water quality following an event. According to the MRWC most wastewater treatment facilities notify only a small group of officials when a CSO occurs. The largest polluter on the river, the Manchester, N.H. treatment plant, is required to report its wet-weather CSO events only once a year—in January. Moreover, many wastewater treatment facilities can only provide crude estimates of their CSO discharges.

In regard to water quality, www.swimguide.org reports that the county department of health, and the Massachusetts Department of Conservation and Recreation (DCR) monitor beach water quality in Massachusetts. The monitoring period is June through September. Beaches in Newburyport are tested on a weekly basis on Tuesday and water quality results are posted by Thursday. Plum Island - Plum Island Point and the ocean beach at 55th St. are sampled weekly from May 20th to September 1st. The site reports as of August 29, 2018 Plum Island passed water quality tests 95% of the time.

It is unknown:

- How long it takes for CSO contaminated water to travel to Newburyport.
- Whether a CSO discharge is sufficiently diluted or not to pose a health problem once it arrives.
- What effect the tides and mixing influence that sea water has on river water quality

Therefore, testing water quality once a week (independent of the tides, weather events and CSO events) will yield inaccurate results. For example, depending on the location of discharge, a CSO's waters might find their way to a beach the day after water is tested, or if testing occurs at high tide when sea water predominates, water may be graded as clean with a change in water quality as soon as the tide turns.

Additionally, it is unknown whether harmful bacterial blooms occur following CSO events when river water temps are well above 80, and sometimes 90 degrees F.

As the CSO problem is so expansive and costly, the problem will not be resolved soon. Clearly the effect of CSOs on water quality needs to be better quantified to determine whether there is a serious public health problem or not. As the Merrimack's waters flow past Newburyport's numerous marinas, boat ramps waterfront parks and beaches, it is a problem of concern to everyone.

APPENDIX 7 – List of Acronyms

AE	FEMA Flood Zone Designation - see "Definitions of FEMA Flood Zone Designations"
AO	FEMA Flood Zone Designation - see "Definitions of FEMA Flood Zone Designations"
BFE	Base Flood Elevation
BRAG	Boston Research Advisory Group
CFC	Chlorofluorocarbon
CO2	Carbon Dioxide
CSO	Combined Sewer Overflow
CZM	Coastal Zone Management (Commonwealth of Massachusetts)
DCR	Department of Conservation and Recreation (Commonwealth of Massachusetts)
DEP	Department of Environmental Protection (Commonwealth of Massachusetts)
DFE	Design Flood Elevation
DPS	Department of Public Services (City of Newburyport)
EEE	Eastern Equine Encephalitis
ENE	East-North-East
EOEEA	Executive Office of Energy and Environmental Affairs (Commonwealth of Massachusetts)
EPA	Environmental Protection Agency
ESE	East-South-East
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map (FEMA)
FY	Fiscal Year (typically July 1 - June 30)
GHG	Greenhouse Gas
GIS	Geographic Information System
GMSL	Global Mean Sea Level
GWP	Global Warming Potential
HFC	Hydrofluorocarbon
HTL	High Tide Line
ICU	Intensive Care Unit
IPCC	Intergovernmental Panel on Climate Change
LEPC	Local Emergency Plan Committee
LiMWA	Limit of Moderate Wave action
MASSGIS	Massachusetts Geographic Information System
MBTA	Massachusetts Bay Transportation Authority
MEMA	Massachusetts Emergency Management Agency
MG/D	Million Gallons per Day
MHHW	Mean Higher High Water
MHW	Mean High Water
MLLW	Mean Lower Low Water
MLW	Mean Low Water
MRBA	Merrimack River Beach Alliance

MS4	Municipal Separate Storm Sewer System
MVP	Municipal Vulnerability Preparedness (Commonwealth of Massachusetts)
MVPC	Merrimack Valley Planning Commission
MWA	Minimal Wave Action
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NCA	National Climate Assessment
NEMA	Newburyport Emergency Management Agency
NGVD29	National Geodectic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System (EPA)
NRC	Newburyport Resiliency Committee
NWF	National Wildlife Federation
NWS	National Weather Service
PFC	Perfluorocarbon
PPM	Parts Per Million
RCP	Representative Concentration Pathway
REPC	[Northern Essex] Regional Emergency Planning Committee
SLOSH	Sea, Lake, and Overland Surge from Hurricanes
SLR	Sea Level Rise
USACE/USACOE	United States Army Corps of Engineers
VE	FEMA Flood Zone Designation - see "Definitions of FEMA Flood Zone Designations"
WPA	Wetlands Protection Act
WTP	Water Treatment Plant
WWTF	Waste Water Treatment Facility

APPENDIX 8 – FEMA Flood Zone Definitions

Definitions of FEMA Flood Zone Designations

Flood zones are geographic areas that the FEMA has defined according to varying levels of flood risk. These zones are depicted on a community's Flood Insurance Rate Map (FIRM) or Flood Hazard Boundary Map. Each zone reflects the severity or type of flooding in the area.

Moderate to Low Risk Areas

In communities that participate in the NFIP, flood insurance is available to all property owners and renters in these zones:

ZONE	DESCRIPTION
B and X (shaded)	Area of moderate flood hazard, usually the area between the limits of the 100-year and 500-year floods. B Zones are also used to designate base floodplains of lesser hazards, such as areas protected by levees from 100-year flood, or shallow flooding areas with average depths of less than one foot or drainage areas less than 1 square mile.
C and X (unshaded)	Area of minimal flood hazard, usually depicted on FIRMs as above the 500-year flood level. Zone C may have ponding and local drainage problems that don't warrant a detailed study or designation as base floodplain. Zone X is the area determined to be outside the 500-year flood and protected by levee from 100-year flood.

High Risk Areas

In communities that participate in the NFIP, mandatory flood insurance purchase requirements apply to all of these zones:

ZONE	DESCRIPTION
A	Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. Because detailed analyses are not performed for such areas; no depths or base flood elevations are shown within these zones.
AE	The base floodplain where base flood elevations are provided. AE Zones are now used on new format FIRMs instead of A1-A30 Zones.
A1-30	These are known as numbered A Zones (e.g., A7 or A14). This is the base floodplain where the FIRM shows a BFE (old format).
AH	Areas with a 1% annual chance of shallow flooding, usually in the form of a pond, with an average depth ranging from 1 to 3 feet. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Base flood elevations derived from detailed analyses are shown at selected intervals within these zones.
AO	River or stream flood hazard areas, and areas with a 1% or greater chance of shallow flooding each year, usually in the form of sheet flow, with an average depth ranging from 1 to 3 feet. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Average flood depths derived from detailed analyses are shown within these zones.
AR	Areas with a temporarily increased flood risk due to the building or restoration of a flood control system (such as a levee or a dam). Mandatory flood insurance purchase requirements will apply, but rates will not exceed the rates for unnumbered A zones if the structure is built or restored in compliance with Zone AR floodplain management regulations.
A99	Areas with a 1% annual chance of flooding that will be protected by a Federal flood control system where construction has reached specified legal requirements. No depths or base flood elevations are shown within these zones.

High Risk - Coastal Areas

In communities that participate in the NFIP, mandatory flood insurance purchase requirements apply to all of these zones.

ZONE	DESCRIPTION
V	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. No base flood elevations are shown within these zones.
VE, V1 - 30	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Base flood elevations derived from detailed analyses are shown at selected intervals within these zones.

Undetermined Risk Areas

ZONE	DESCRIPTION
D	Areas with possible but undetermined flood hazards. No flood hazard analysis has been conducted. Flood insurance rates are commensurate with the uncertainty of the flood risk.

From FEMA Map Service Center:
http://msc.fema.gov/webapp/wcs/stores/servlet/info?storeId=10001&catalogId=10001&langId=-1&content=floodZones&title=FEMA%20Flood%20Zone%20Designations