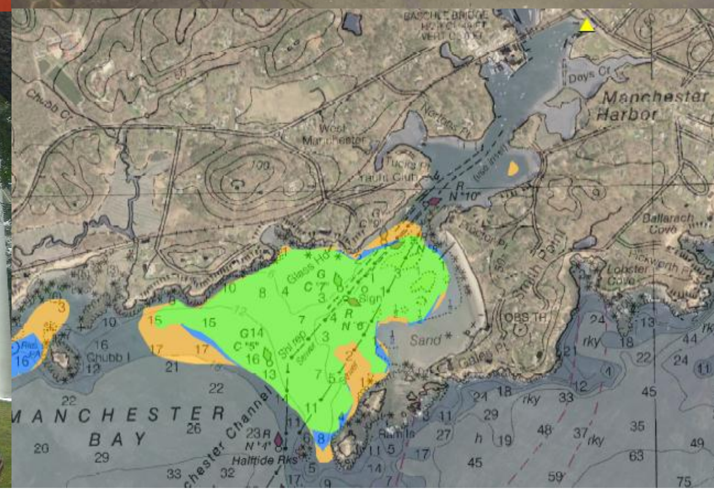




FEMA Hazard Mitigation Plan Enhancement: Task 3 Vulnerability and Risk Assessment Manchester-by-the-Sea

Prepared For:

Town of Manchester-by-the-Sea
Massachusetts

August 2016
Updated February 2017 to include adaptation summaries

Vulnerability and Risk Assessment

TO: Mary Reilly, Manchester-by-the-Sea, Grants Administrator

FROM: Margaret Hernandez, Gabrielle Belfit, Tighe & Bond

COPY: David A. Murphy, P.E.

DATE: August 12, 2016, *updated February 15, 2017*

The Town of Manchester-by-the-Sea has received a Federal Emergency Management Agency (FEMA) Pre-Disaster Mitigation (PDM) Grant to enhance the Town's current Hazard Mitigation Plan (HMP). The tasks include evaluating potential climate change impacts to the Town and completing a Vulnerability and Risk Assessment (VRA) of the Town's critical sectors. This memo summarizes the results of the Vulnerability and Risk Assessment completed as part of Task 3 of the grant.

1 Summary of Task 2

The Task 3 Vulnerability and Risk Assessment builds directly off of the work completed in Task 2, which helped to predict where, when, and to what degree future climate impacts related to flooding may be experienced. A summary of Task 2 is as follows:

1. Identify Critical Sectors: The current Manchester-by-the-Sea HMP includes a listing of 35 identified critical infrastructure facilities and provides a summary of natural hazards impacting these critical facilities. As part of Task 2, the list of critical facilities was re-examined and updated to include additional community assets following the guidelines included in the 2012 FEMA Local Mitigation Handbook. The initial effort identified 70 community assets, which were evaluated for flooding impacts under climate change for 3 planning periods, 2025, 2050 and 2100.

2. Climate Change Model Selection: A comparative evaluation of climate change modeling was presented to the Community Resiliency Advisory Group (CRAG) in August 2015. The climate change models selected by the Town and the CRAG were the Inundation Risk Model (IRM) that includes modules for both sea level rise and storm surge and the Oyster River Culvert Evaluation Project (ORCEP) for the extreme precipitation model. A separate watershed assessment using the US Army Corps of Engineers HEC-RAS model was developed for the Sawmill Brook Watershed to capture the inland impacts of increased precipitation on riverine flooding. The watershed modeled future conditions output for 2025, 2050 and 2100 included the extreme precipitation values from the ORCEP, and both sea level rise and storm surge data to modify tail water conditions at the mouth of Sawmill Brook.

3. Analysis of Impacts: The model outputs from the coastal flooding and watershed models were utilized to complete an analysis of the flooding hazards due to climate change for all 70 community assets. The spatial location of each critical sector was evaluated in relation to the 5 different model outputs: sea level rise, shallow coastal flooding, storm surge, Category 1 hurricanes, and upland flooding. The model output contained 4 probabilities of flooding for each of the five coastal flooding sources:

    - 1-10% = low risk, highly unlikely to unlikely
    - 33% = medium risk, as likely as not

- 66% = medium-high risk, likely
- 90-99% = high, very likely to certain

The modeling results were used to narrow down the list of sites for the VRA. Sites that were not impacted, or minimally impacted by coastal or upland flooding, will be kept in the HMP but excluded from the focused VRA. The CRAG and the Town discussed each of the locations with respect to anticipated mitigation value. Ultimately, the list of 70 community assets was reduced to 26 and these locations were further evaluated in the VRA described in this technical memo.

2 Methodology

Before beginning the Vulnerability and Risk Assessment, a methodology was developed to frame and guide the assessment and data collection process. This methodology was based on "Preparing for Climate Change, A Guidebook for Local, Regional, and State Governments," September 2007.

The VRA is broken down into 2 components: a risk assessment and a vulnerability assessment. Each is explained below.

2.1 Risk Assessment

Risk is defined as the function of the **likelihood** of flooding and the potential **consequence** of flooding. To determine likelihood and consequence, the following methodologies were used:

1. **Likelihood** – The modeling results generated under Task 2 were used to determine ratings for **likelihood of flooding due to impacts of climate change** for each asset. Each flooding source was weighted based on the anticipated frequency of occurrence. Each asset location was given a numeric value for each of the 3 planning periods, based on the weighted frequency of the specific flooding source, and probability of occurrence. That numeric value was generated based on the following procedure:
    a. First, the different sources of inland and coastal flooding were weighted based on the **frequency of flooding**, as follows:
        i. Sea Level Rise, anticipated to occur daily – 4
        ii. Upland Flooding, anticipated to occur 3 to 4 times per year – 3
        iii. Shallow Coastal Flooding, anticipated to occur twice per year – 2
        iv. Storm Surge, anticipated to be an annual occurrence - 1
        v. The Category 1 Hurricane scenario was not included because the model was only available for current risk; future probabilities are not available.
    b. Second, the **probability of flooding** was assigned a value, as follows:
        i. 90-99% = high, very likely to certain to occur – 4
        ii. 66% = medium-high risk, likely occurrence - 3
        iii. 33% = medium risk, as likely as not to occur - 2
        iv. 1-10% = low risk, highly unlikely to unlikely occurrence - 1

c. The weighted value for **frequency of flooding** (described in paragraph a, above) was multiplied by the value for **probability of flooding** (described in paragraph b, above) for each flooding source at each asset location.

d. The results for each flooding source (sea level rise, storm surge, etc.) were then added for an **overall weighted score** for the different climate change planning periods: near-term (2025), mid-term (2050), and long-term (2100). When complete, each asset was assigned a numeric value ranging from 1 to 31 for near term, mid-term, and long-term likelihood of flooding.

Once the values for the different time periods were assigned, the assets were given an overall flood rating for each time period. Ratings were assigned based on the following:

a. High (3): Total score of 18 or greater.

b. Medium (2): Total score greater than or equal to 6, but less than 18.

c. Low (1): Total score of 5 or less.

> Example: The Fire Department was assigned a high flood rating in 2050 because it has a total weighted flooding score of 20 in 2050 from all flooding sources.

2. **Consequence** – For this exercise, **consequence is estimated based on how a flood may affect the functionality of the community asset and the consequences that may arise if the asset were to be damaged or out of service and not functioning under normal operating conditions**. Consideration is given to economic, ecological, social, cultural, historical, public health, and public safety consequences. The scale of the impact (e.g., size of the population, land area, etc.) is also taken into consideration. Ratings for consequence were assigned based on the following:

a. High (3): Major disruption, normal operation of the facility or natural system cannot be restored without repair/corrective action or after a long period of time; numerous impacts to the community.

b. Medium (2): Some disruption, but can be restored after some time, may require minor repair/corrective action; some impacts to the community.

c. Low (1): Little or no disruption to normal operation of the facility or natural system and therefore no consequences to the community.

> Example: The rating for consequence of flooding at the Fire Department is high due to the essential public safety function of the facility, and that there is no alternate location.

Once ratings are assigned for both likelihood and consequence, the 2 numbers are multiplied and the result is the **risk rating**.

Risk = likelihood x consequence

2.2 Vulnerability Assessment

Vulnerability is the function of **sensitivity** to flooding and the **capacity to adapt**. To determine likelihood and consequence, the following methodologies were used:

1. **Sensitivity** – The **sensitivity of a system is evaluated based on the existing exposures to flood waters and any history of flooding**. When rating sensitivity, one must consider how much the asset and its contents are exposed. For instance, are the critical components or contents of the building exposed and vulnerable to flooding or have they already been protected? Has flooding occurred in the past and what were the impacts? Ratings for vulnerability were assigned based on the following:

    a. High (3): Critical components of the facility/natural resource are vulnerable to flood waters; there is a history of flooding.

    b. Medium (2): Some non-critical components of the facility may be impacted by flood waters; minor flooding in the past.

    c. Low (1): Location is already protected from flood; flood waters cannot reach critical components of the building; no history of flooding.

> Example: The rating for sensitivity of the Fire Department is medium due to past actions to protect of some critical components. The generator is still at risk.

2. **Adaptive Capacity** – The **adaptive capacity of a system is evaluated based on its existing abilities to accommodate flooding with minimum loss of function or loss of value (value can be either monetary or a non-monetary value to the community).** If an asset does not already have the ability to adapt to flooding, then it is assumed it will require outside intervention. Outside intervention includes an upgrade or improvement to the asset to protect it from flooding. Ratings for adaptive capacity were assigned based on the existing ability to adapt and the scale of outside intervention/improvements required. Large scale improvements include major changes to the asset and may have high costs or lengthy time commitments. Smaller scale improvements are moderate changes to the asset and less costly or time consuming. A community asset with a low capacity to adapt (outside intervention is required) is given the highest score, while an asset with a high adaptive capacity is given the lowest score. Ratings were assigned as follows:

    a. Low (3): Large scale improvements are required; the asset does not have any existing abilities to adapt (low adaptive capacity).

    b. Medium (2): Smaller scale improvements are required; the asset may or may not have the ability to adapt.

    c. High (1): Little or no outside intervention is required; the asset already has the ability to adapt (high adaptive capacity).

> Example: The rating for the Fire Department's adaptive capacity is medium because only small scale improvements are required to mitigate flooding.

Once ratings are assigned for both sensitivity and adaptive capacity, the 2 numbers are multiplied and the result is the vulnerability rating.

Vulnerability = Sensitivity x Adaptive Capacity

2.3 Overall VRA Rating

Once a community asset is assigned 2 separate risk and vulnerability ratings, they must be combined into an overall rating. Therefore, at the end of our evaluation, each community asset is assigned 1 rating, summarizing its overall risk and vulnerability.

Having 1 rating assigned to each community asset allows for a side by side comparison.

The complete process is shown below.

Likelihood	X	Consequence	=	Risk
Sensitivity	X	Adaptive Capacity	=	Vulnerability
Risk	+	Vulnerability	=	Overall VRA Rating

3 Data Collection

Each of the selected community assets were evaluated and given rankings for likelihood, consequence, sensitivity, and adaptive capacity. In order to do so, Tighe & Bond underwent a large data collection effort. This effort included the following:

1. A more refined evaluation of the modeling results of Task 2.
2. A more refined evaluation of the mapping results of Task 2.
3. Site visits.
4. Phone calls and in-person interviews with those knowledgeable about the community assets including staff members, property owners, and Town employees. Interviews were conducted with the following Town personnel:
    a. Sue Brown – Town Planner
    b. Carol Murray – Department of Public Works Director
    c. Bion Pike – Harbormaster
    d. Rick Gibson – CRAG member
    e. Chief Kramlinger – Fire Department
    f. Lt. Fitzgerald – Police Department

All of the data collected was then gathered, compiled, and evaluated. This data collection process allowed for ratings to be assigned using the methodology described above.

After a first draft of the VRA was developed, it was distributed to the CRAG for review. This allowed for another level of information gathering and critical feedback to the ratings.

4 Findings

Once the data collection effort was complete and community assets were assigned ratings, the results were sorted and analyzed. The results of the data collection effort and assigned ratings are compiled in Table 1.The table lists the rating (1 through 3) and main discussion points that led to the rating for each category (Likelihood, Consequence, Sensitivity, and Adaptive Capacity). The "discussion" column in Table 1 is a summary of the information gathered about the community asset during the data collection effort that helped determine the rating.

Recall that Likelihood was given a score for 3 different time periods because the data was available from the modeling completed in Task 2. Note that because Likelihood was given a score for the 3 different time periods (2025, 2050, and 2100), it was also given 3 different ratings. Therefore, the "overall ratings" were also computed for the 3 different time periods for comparison purposes.

Table 1 is sorted by community asset category (Built Environment, Economy, Natural Resources, and Social Environment) and sorted from highest to lowest based on the mid-term (2050) results. Basing the vulnerability risk assessment on anticipated mid-21st century flooding impacts was a decision based on the consensus of the Town and the CRAG. The premise is that 2050 is just far enough into the future to plan mitigation projects. The HMG plan will be updated every 5 years, so there will be ample opportunities to reevaluate asset exposure under revised flooding projections as climate science evolves.

VRA Reference Sheets

After the results were sorted, VRA Reference Sheets were developed, compiling the relevant data for the top 10 highest rated community assets. The Reference Sheets will be incorporated into Manchester's Hazard Mitigation Plan to provide content for the mitigation strategy. The Community Asset Reference Sheets are enclosed in Appendix A.

The Community Asset Reference Sheets provide a summary of the information gathered about the location and the explanation as to how and why the community asset was given a rating in each of the 4 categories. They also include the most pertinent mapping results as well as some informational photos. *Adaptation summaries including objectives, recommended adaptation projects and steps for short-term implementation are included. (added 2/15/2017).*

5 Summary

The overall ratings are summarized in Table 2 below. Rankings do not change dramatically over the course of the 3 time periods. The top 10 rated assets in all 3 time periods include: Central Street Dam, the Wastewater Treatment Plant, the Downtown Stormwater Drainage System, Town Hall/Police/Emergency Operations, the Fire Department, Route 127, the Downtown Businesses, Sawmill Brook, Manchester Harbor, and Singing Beach.

Table 2: Summary of Vulnerability and Risk Assessment Results

Category	Community Asset	Overall Rating 2025	Overall Rating 2050	Overall Rating 2100
Built Environment	Central Street Dam	15	18	18
Built Environment	Manchester Wastewater Treatment	12	15	15
Built Environment	Downtown Stormwater Drainage System	15	15	15
Built Environment	Town Hall / Police Headquarters / Emergency Operations Center	13	13	13
Built Environment	Manchester Fire Department	10	13	13
Built Environment	Route 127	12	12	12
Built Environment	MBTA Tracks/Bridge	9	9	9
Built Environment	School Street and Bridge	8	8	10
Built Environment	Lincoln Street Well & Pumping Station	7	7	10
Built Environment	Lincoln Street	4	4	6
Economy	Downtown Businesses	13	13	13
Economy	Manchester Marine	10	10	10
Economy	Crocker's Boat Yard	10	10	10
Natural Resources	Sawmill Brook	12	12	12
Natural Resources	Manchester Harbor	12	12	12
Natural Resources	Singing Beach	12	12	12
Natural Resources	Bennet's Brook and Marsh	10	10	10
Natural Resources	Millet's Swamp and Brook	6	6	6
Social Environment	First Baptist Church	5	5	5
Social Environment	First Parish Church and Magic Years School	4	4	4
Social Environment	The Plains Seniors Housing	3	3	3
Social Environment	Landmark School	2	3	3
Social Environment	Summer Street Apartments	3	3	4

Manchester-by-the-Sea was recently awarded a second PDM Grant to complete a 5-year update to the Town's Hazard Mitigation Plan. The Reference Sheets will be a useful resource when updating the Plan and will be used for the focused adaptation strategy. Additionally, the results of the VRA can guide the Town's planning efforts regarding mitigation actions and adaptation strategies. The community assets with the highest VRA ratings should be considered for adaptation projects.

APPENDIX A

Vulnerability and Risk Assessment

Central Street Dam

Summary

The Sawmill Brook culvert under Central Street consists of a seawall, tide gate structure, culvert and stream bed/weirs. Based on a review of documents available from the Town, it appears the tide gate was originally installed in the early 1900's for the purpose of creating a skating pond in the downtown area. This structure provides control for flooding caused by tides and maintains the elevation in Central Pond. The structure currently overtops during extreme storm events. Additionally, when not completely open, the tide gate design obstructs fish passage to upstream segments of Sawmill Brook that are known spawning habitat for Rainbow Smelt.

The Town has recognized that the Central Street tide gate, seawall and related structures are in need of modification to provide better functionality with respect to drainage and fish passage. This location has been identified for many years as a source of flooding upstream by causing a hydraulic restriction, particularly during large rainfall events. The elevated water behind the tide gate is also putting pressure on the seawall at Central Street, causing seepage though the rock voids in the wall.

Likelihood — 3 - High

Modeling results indicate that there is a high probability this location will flood from Upland Flooding in 2050. There is a medium risk of flooding due to Storm Surge, Shallow Coastal Flooding, and Sea Level Rise in 2050.

The overall weighted score increases from 17 in 2025 to 18 in 2050 to 20 by 2100. The score of 18 in 2050 gives the Central Street Dam a high rating for likelihood of flooding.

Consequence — 3 - High

Damage to the dam could result in damage to Central Street, potentially causing the road to be impassable. Because of the proximity to the Police Station and downtown area, this could have public safety impacts and economic consequences.

Sensitivity — 3 - High

The structure overtops during extreme storm events and has been proven to be a hydraulic restriction in Sawmill Brook during large rainfall events.

Adaptive Capacity — 3 - Low

Major upgrade and large investment would be required. Grant funding may be available for the removal of the tide gate structure and rehabilitation of the dam.

Category	Component	2050 Rating	2050 Category Total	2050 Overall Rating
Risk	Likelihood	High = 3	9	18
	Consequence	High = 3		
Vulnerability	Sensitivity	High = 3	9	
	Adaptive Capacity	Low = 3		

Vulnerability and Risk Assessment

Central Street Dam

View from the south.

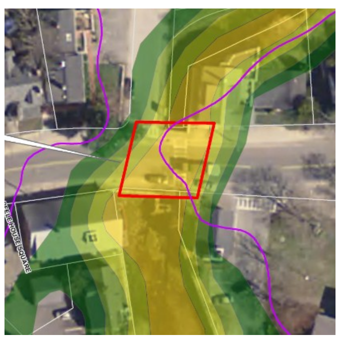
Existing tide gate.

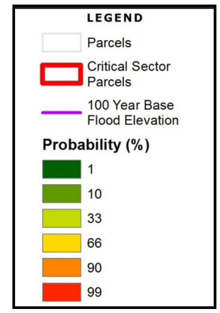
View from the north.

Seepage at the seawall.

Vulnerability and Risk Assessment

Central Street Dam

Planning Period	Coastal Flood Hazard Sea Level Rise	Coastal Flood Hazard Storm Surge
2025		
2050		
2100		



These figures depict the extent of currently defined flood hazard area, including the 100-year base flood elevation shown in purple and the future flooding hazards for storm surge and sea level rise. Exposure vulnerability for near, mid and long term climate change planning periods is represented based on probability of occurrence from 1% (very unlikely) to 99%, (extremely likely). The figures show that there is a 66% probability that the dam will be impacted by sea level rise and 90% probability that it will be impacted by storm surge across the three time periods. This location is also subject to inland flooding from extreme precipitation events.

Vulnerability and Risk Assessment

Central Street Dam

ADAPTATION OBJECTIVES:

- Mitigate flooding along Central Street, lower School Street, and the Town Hall parking lot.
- Address deteriorating condition of the seawall under the Central Street Bridge.
- Improve fish passage for federally listed rainbow smelt to reach spawning beds.

ADAPTATION PROJECTS:

Tide Gate Removal and Culvert Widening – Three alternatives concepts for removal of the tide gate were explored to mitigate flooding, address roadway safety, and improve habitat:

1. Removing the tide gate and keeping the configuration of the culvert, potentially with a rock riffle to keep Central Pond full of water.
2. Removing the tide gate, widen the culvert, removing the dam, and changing the entire crossing to be a bridge to restore the historic stream channel.
3. The preferred option, which includes removing the tide-gate, widening the culvert, repairing and restoring the seawall (dam), and making improvements to Central Pond including deepening the historic stream channel and restoring salt marsh habitat on the shores of the pond.

Alternatives #2 and #3 had the largest impact on reducing water surface elevations upstream compared to a selection of other flood mitigation projects based on watershed modeling under existing conditions and under future conditions that accounted for increased precipitation and sea level rise. Under worst case future storm conditions, even with modifications to the Central Street Bridge, the roadway would still overtop because the surge elevation exceeds the roadway centerline elevation for 2050 and beyond.

Culvert enlargements and the tide gate removal will result in significant reductions in water surface elevation upstream, limit the hydraulic pressure behind the seawall, and reduce safety concerns. Repairs to the existing seawall (dam) were preferable to complete bridge replacement for historic and permitting reasons. All improvement alternatives will improve smelt passage and spawning potential restoring the stream crossing to historic conditions. Extreme storm surge impacts may be addressed with use of a reconstructed tide gate that operates more fluidly and opens a different way, use of a hurricane barrier installed further out in the harbor, or raising the elevation of Central Street.

SHORT-TERM IMPLEMENTATION STEPS:

- The Town should seek funding for implementing tasks needed for feasibility evaluation including complete survey of infrastructure elevations, hydraulic and hydrologic modeling, and a sediment survey.
- The Town should seek funding for implementing tasks to complete the final design and permitting.
- The Town should seek funding for construction.

Vulnerability and Risk Assessment
Wastewater Treatment Plant

Summary

The Manchester-by-the-Sea Wastewater Treatment Plant (WWTP) serves approximately half of the Town. It is located in very close proximity to Manchester Harbor and is entirely within the FEMA 100-year flood zone. The headworks building contains pumps and equipment located below grade that are critical to operation. If this building were to flood, the WWTP would become inoperable. Flood events may also increase the amount of inflow and/or infiltration entering the sewer collection system. High influent flows and diluted wastewater will impact the WWTP's treatment ability to operate effectively and may result in a bypass of wastewater.

In June 2015, the Environmental Protection Agency assisted the Town in completing a Climate Resilience Evaluation and Awareness Tool (CREAT) report. Findings indicate that in order to protect the WWTP, the Town must either build a flood wall surrounding the WWTP or relocate it to a different area of town. In addition, the revised NEIWPCC TR-16 "Guidelines for the Design of Wastewater Treatment Works" recommends that critical equipment be protected against damage to 3 feet above the 100-year flood elevation.

The overall VRA evaluation was based on the following criteria and 2050 likelihood for this location:

Likelihood — 2 - Medium

Modeling results indicate that there is a medium probability of flooding due to Storm Surge in 2050, but only a low probability of flooding due to Sea Level Rise and Shallow Coastal Flooding.

The overall weighted score in increases from 4 in 2025 to 8 in 2050 to 17 in 2100. Therefore, the WWTP was assigned a medium rating for likelihood of flooding in 2050.

Consequence — 3 - High

If the WWTP becomes inoperable, there is a high risk to public health and environmental consequences. If influent wastewater flows exceed the treatment capacity it may resulting in a bypass at the plant and direct discharge of sewage to the environment. In addition, if capacity in the collection system is exceeded, there may be sanitary sewer overflows (SSOs) out of manholes or from pump stations or

Sensitivity — 3 - High

In the past, the adjacent parking lot has flooded, damaging the meters and electrical conduit located in manholes. The headworks pumps and other process equipment critical to the function of the WWTP are exposed, as they are located below grade. The back-up generator and other electrical equipment are also located in the yard and are susceptible to flooding.

Adaptive Capacity — 3 - Low

Solutions identified in the CREAT report indicate that the WWTP must either be relocated or a seawall should be installed surrounding the property. Both options would be considered a major adaptation upgrade and require a significant investment. Other smaller scale solutions are more feasible but do not protect the WWTP from flooding impacts.

Category	Component	2050 Rating	2050 Category Total	2050 Overall Rating
Risk	Likelihood	Medium = 2	6	15
	Consequence	High = 3		
Vulnerability	Sensitivity	High = 3	9	
	Adaptive Capacity	Low = 3		

Vulnerability and Risk Assessment
Wastewater Treatment Plant

Manchester-by-the-Sea
Wastewater Treatment Plant

Emergency generator and other outdoor electrical equipment

View of Manchester Harbor from the walkway above process equipment

Vulnerability and Risk Assessment

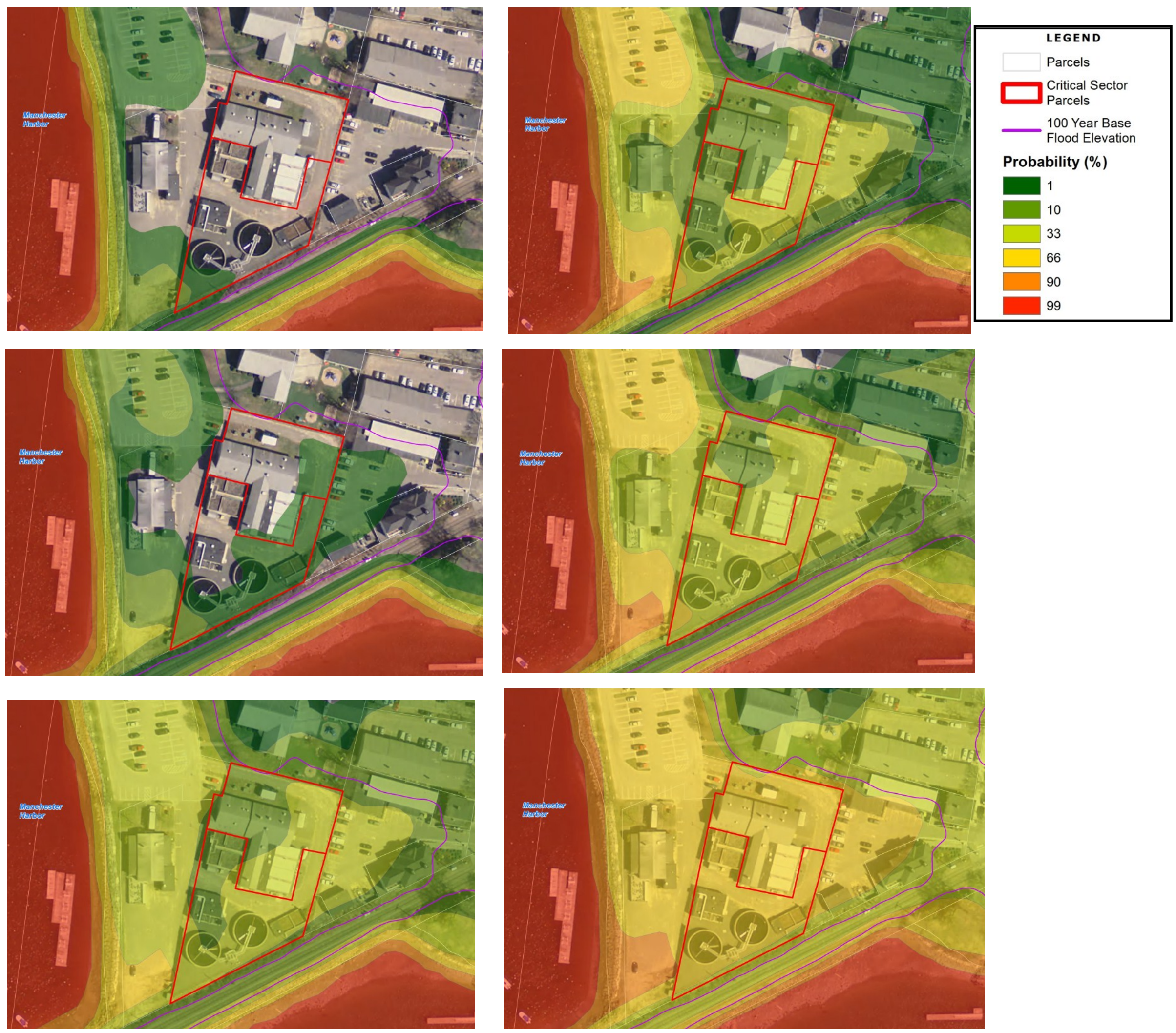
Wastewater Treatment Plant

Planning Period | **Coastal Flood Hazard Sea Level Rise** | **Coastal Flood Hazard Storm Surge**

2025

2050

2100



The figures above depict the extent of flood hazard areas, including the current 100-year base flood elevation shown in purple and the future flooding hazards for storm surge and sea level rise. Exposure vulnerability for near, mid and long term climate change planning periods is represented based on probability of occurrence from 1% (very unlikely) to 99%, (extremely likely). The figures show that sea level rise will not significantly impact the site until 2100. In the near term, there is a 10-33% probability for storm surge impacts, and by 2100, there is a 66% probability that the entire site will be impacted by coastal flooding. The risk of flooding is concentrated in the southeast corner of the site. This graphic does not account for the location of underground utilities that may be impacted by coastal flooding. For example, the wet well is located 2 feet below mean sea level.

Vulnerability and Risk Assessment
Wastewater Treatment Plant

ADAPTATION OBJECTIVES:

- The WWTP should provide uninterrupted treatment and be protected from physical damage due to sea level rise, storm surge, and wave action.
- Protect all first floors, tank walls, and structural openings from damage at the 100-year flood elevation.
- Provide flood-proofing (e.g., stoplogs at garage entrances, raised motor drives and pumps, lab cabinets with positive latching systems to prevent lab chemicals from mingling with floodwaters, storage at the highest practical elevation in a facility, and adequate structural strength to buildings) to above the 100-year flood elevation.
- Protect critical facility equipment against damage up to a water surface elevation that is 3 feet above the 100-year flood elevation. Non-critical equipment should be protected against damage up to a water surface elevation that is 2 feet above the 100-year flood elevation, or to the extent feasible.
- Maintain backup power sources with sufficient capacity to maintain normal operation of the treatment processes. In addition, at least 3 days of fuel storage shall be properly stored on-site to operate the backup power supply.

ADAPTATION PROJECTS:

Manchester-by-the-Sea engaged in a climate risk assessment using the EPA's CREAT tool. The risk assessment considered the impact of intense precipitation events and coastal storm surge in 2035 and sea level rise in 2060 on their WWTP. Based on the results of the CREAT model, implementation of potential adaptive measures included constructing sea walls and asset relocation. With these adaptation measures, potential consequences of future coastal storm surge events and intense precipitation events to their headworks building were lowered from 'Very High' to 'Low', while the consequences from sea level rise itself in the 2060 time period were 'Low.'

The following projects are recommended for the short term to develop a phased approach to resiliency in conjunction with a cost and benefit evaluation of facility relocation.

1. Conduct a detailed evaluation of the WWTP to determine feasible flood proofing options, including adding flood proof doors, moving equipment and electrical, flood proof hatches, etc.
2. Complete a topographic survey of the WWTP that includes elevations of locations that have the potential to be impacted by sea level rise and storm surge (i.e. doors, windows, other openings, equipment, electrical and controls, etc.).
3. Assess the building structure to determine whether the WWTP can withstand the forces that could be caused by storm surge and sea level rise. Evaluate the efficacy of seawall construction for flood and surge protection.
4. Define the magnitude, elevation and duration of flooding, including wave impact, on specific portions of the WWTP.
5. Complete a capacity assessment of the collection system and pump stations to understand how they could be impacted by sea level rise and storm surge.
6. Continue to implement infiltration and inflow reduction measures, increase community outreach, and join the mutual aid network, Massachusetts Water/Wastewater Agency Response Network (MAWARN).

SHORT-TERM IMPLEMENTATION STEPS:

Within the next five years, Manchester-by-the-Sea should complete a comprehensive alternatives and cost/benefit analysis for mitigation improvements to determine what can be done, what flooding types and elevations can be addressed, and when projects should be implemented versus moving the WWTP. The analysis should consider both physical elements and operations. The possible vulnerability and the differential cost of increasing the level of protection above the 100-year flood elevations for uninterrupted operation and protection from damage, respectively, should be weighed in selecting the level of flood protection for facility upgrades.

Vulnerability and Risk Assessment

Downtown Stormwater System

Summary

The downtown stormwater system drains the areas of Bridge Street, Central Street, Church Street, Elm Street, and School Street. This is the main economic center of Town with many businesses, shops, and restaurants located in the area. The downtown area is prone to flooding due to its proximity to Sawmill Brook, Central Pond, and Manchester Harbor. The system has proven to be undersized and has surcharged during recent storm events. Because the catch basin invert elevations at many locations are close to sea level, the system can become surcharged from the ocean outfalls from extraordinary events.

The overall VRA evaluation for this location is based on the following criteria:

Likelihood — 3 - High

Modeling results indicate that there is a high probability of Upland Flooding in 2050. Modeling results were not defined for the other categories of flooding due to the variability of results since the system is spread out over a large area.

The likelihood rating could not be assigned based on the overall weighted score since modeling results are not available. Instead, the stormwater system was assigned a high rating for likelihood of flooding based on the knowledge of the system and proximity to Sawmill Brook and Manchester Harbor.

Consequence — 2 - Medium

If the streets in the downtown area were to flood and become unpassable, there would be negative impacts on the community because the downtown area is the major economic center.

Additionally, if the stormwater system is surcharging, it may result in property damage to nearby property owners.

Sensitivity — 3 - High

The system has surcharged in the past and does not have enough capacity to handle large storms.

Adaptive Capacity — 3 - Low

The Town can make improvements to the system, but they would be costly and disruptive to the community. Opportunities for Green Stormwater Infrastructure may reduce localized flooding and improve water quality.

Category	Component	2050 Rating	2050 Category Total	2050 Overall Rating
Risk	Likelihood	High = 3	6	15
	Consequence	Medium = 2		
Vulnerability	Sensitivity	High = 3	9	
	Adaptive Capacity	Low = 3		

Vulnerability and Risk Assessment
Downtown Stormwater System

a

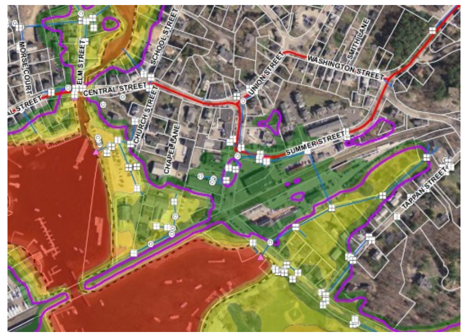
Storm Drainage system on School Street with direct discharge to Sawmill Brook

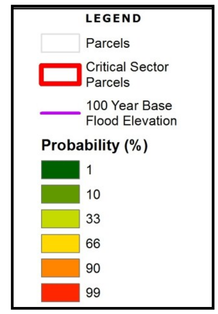
Storm drainage from Central Street with direct discharge to Sawmill Brook

Vulnerability and Risk Assessment
Downtown Stormwater System

Planning Period	Coastal Flood Hazard Sea Level Rise	Coastal Flood Hazard Storm Surge

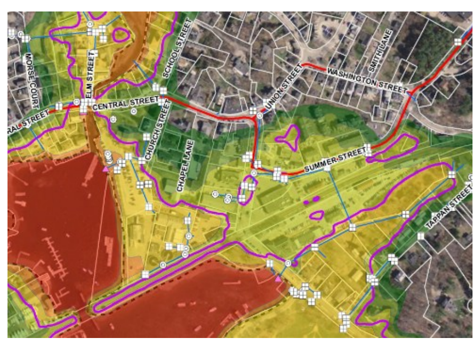
2025





2050

2100



This figure depicts locations of stormwater catchbasins and outfalls and the extent of flood exposure due to storm surge for existing conditions, shown in purple and the future flooding hazards for storm surge and sea level rise. Exposure vulnerability for near, mid and long term climate change planning periods is represented based on probability of occurrence from 1% (very unlikely) to 99%, (extremely likely). Although not shown, it is important to note that the stormwater system is also subject to flooding from Upland Flooding sources. As shown, there is a chance of storm surge impacting the stormwater system as early as 2025. Sea level rise is less likely to impact the system until 2100. However, the low-lying catch basins can become surcharged from the ocean outfalls from extraordinary events.

Vulnerability and Risk Assessment
Downtown Stormwater System

ADAPTATION OBJECTIVES:

- Reduce the quantity of runoff generated by impervious surfaces in the downtown area.
- Prevent and/or reduce flooding along low lying areas of downtown including Pine Street, Beach Street, and the Town municipal parking lot.
- Provide improved water quality treatment for stormwater discharging directly to Sawmill / Cat Brook and Manchester Harbor.

ADAPTATION PROJECTS:

Under a 2015 Coastal Pollution Remediation Grant, the opportunity to reduce flooding and improve water quality was explored within the downtown area. The study showed that it is feasible to install "low impact development" or stormwater "best management practices" (BMPs) in the downtown area. BMPs will improve the quality of stormwater runoff entering local waterbodies, thereby addressing water quality impairments and improving rainbow smelt habitat, and will reduce the quantity of stormwater runoff that overwhelms the Brook's narrow channel, undersized culverts, and outdated tide gate. In addition, proactive installation of BMPs will help alleviate potential impacts arising from climate change and anticipated sea level rise.

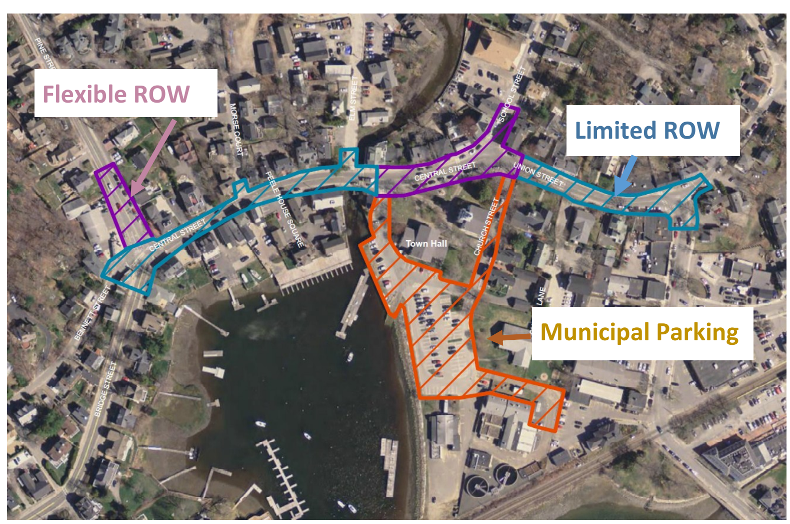
BMP retrofits were recommended in key areas shown in the diagram and table below, as the best solution to achieve multiple stormwater improvements and conceptual plans were developed based on a limited feasibility analysis.

Additional adaptation actions include a video inspection of the stormwater system to make sure drainage capacity is optimal and the installation of stormwater outfall duckbills to prevent storm surge from flowing back into the storm drainage system.

Stormwater Drainage Corridor	Applicable LID BMPs
Limited Right of Way	Option A: Structure Filter Option B: Tree pit (Filterra ® or Engineered Tree Box) Option C: Permeable Paver Sidewalks Option D: Modular Wetlands
Flexible Right of Way Corridor	Option A: Tree trench (extended tree pit) Option B: Porous asphalt under parking stalls
Municipal Parking Lot	Option A: Rain Garden Option B: Porous asphalt under parking stalls Option C: Porous asphalt throughout

SHORT-TERM IMPLEMENTATION STEPS:

The Town should seek grant funding to design and construction projects. As funding becomes available, implement some or all recommendations for improving downtown stormwater drainage.



Vulnerability and Risk Assessment

Town Hall, Police and Emergency Operations

Summary

The Town Hall is home to the Police Headquarters, the Town's Emergency Operations Center, and multiple Town offices. At its closest point, the building sits approximately 20 yards from where Sawmill Brook meets Manchester Harbor. The emergency generator is located on the west side of the building, closest to the Harbor. There is a boat ramp within the parking lot behind the building and adjacent to the Harbor. Flood waters often enter the parking lot via the boat ramp. The backside of the building is at an approximate elevation of 4 to 5 feet. The basement (or ground floor) contains vehicles, offices, and storage. The Emergency Operations as well as mechanical and electrical systems for the entire building are located on the first floor.

The overall VRA evaluation for this location is based on the following criteria 2050 likelihood :

Likelihood — 3 - High

Modeling results indicate that in 2050 there is a medium probability of flooding due to Sea Level Rise, a medium-high probability for Shallow Coastal Flooding and Storm Surge, and a high probability of flooding for Upland Flooding.

The overall weighted score increases from 20 in 2025 to 23 in 2050 to 27 in 2100, giving the Town Hall a high rating for likelihood of flooding for 2050.

Consequence — 3 - High

If the Town Hall building were to flood and become impaired, it would impact the operation of the Town, the Police Department, and Emergency Operation Center. This disruption would put the entire community at a public safety risk and would also have economic and social consequences.

Sensitivity — 2 - Medium

The emergency generator is located on the west side of the building, closest to the Harbor and Sawmill Brook. The parking lot has flooded on many occasions in the past. Flood waters have not reached the first flood of the building in recent memory, with the exception of the elevator shaft, which is below grade.

Adaptive Capacity — 2 - Medium

Smaller scale improvements can be made to flood proof the building and emergency equipment. Grant funding from FEMA may become available to relocate and improve the emergency generator. Flood doors could be installed to protect the building or sandbags could be used as temporary measures.

Category	Component	2050 Rating	2050 Category Total	2050 Overall Rating
Risk	Likelihood	High = 3	9	13
	Consequence	High = 3		
Vulnerability	Sensitivity	Medium = 2	4	
	Adaptive Capacity	Medium = 2		

Vulnerability and Risk Assessment
Town Hall, Police and Emergency Operations

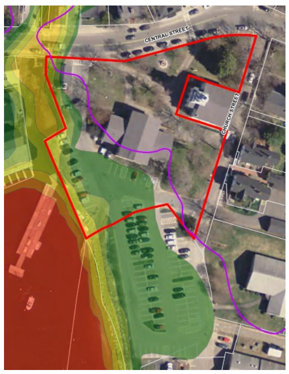

Town Hall and Police Station. View of front entrance on left, and back entrance on right.

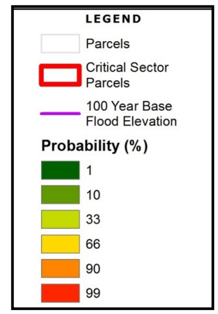

Town Hall and Police Station. Views of emergency generator located behind Town Hall adjacent to the Harbor.


Views shows the change in elevation from the front to rear of the building (left) and proximity to harbor (right)

Vulnerability and Risk Assessment

Town Hall, Police and Emergency Operations

Planning Period	Coastal Flood Hazard Sea Level Rise	Coastal Flood Hazard Storm Surge
2025		
2050		
2100		



This figure depicts the extent of currently defined flood hazard area, including the 100-year base flood elevation shown in purple and the future flooding hazards for storm surge and sea level rise. Exposure vulnerability for near, mid and long term climate change planning periods is represented based on probability of occurrence from 1% (very unlikely) to 99%, (extremely likely). The figures show that sea level rise will not significantly impact the site until 2100, but there is a much stronger possibility that the building will be impacted by storm surge in the near and mid-term.

Vulnerability and Risk Assessment

Town Hall, Police and Emergency Operations

ADAPTATION OBJECTIVES:

- The Police and Emergency Operations must be able to provide uninterrupted service.
- Prevent physical damage to the building as a result of flooding.

ADAPTATION PROJECTS:

- Conduct a comprehensive evaluation to determine feasible flood proofing options and identify how the building may be impacted by flood waters based on existing site conditions, architecture, structural systems, location of utilities (water, wastewater, mechanical, plumbing, gas, and electric), and emergency response (alarms and communications).
- Based on the results of the evaluation, implement physical improvements such as elevating records storage and fuel tanks in basements and elevating electrical and mechanical systems, including generators, to 2 feet above the BFE.
- Upgrade generator and relocate to higher ground.
- Flood proof doors and other openings on the ground floor or stockpile emergency flood protection measures such as sand-bags.

SHORT-TERM IMPLEMENTATION STEPS:

- The evaluation should be completed.
- The flood mitigation measures should be implemented.
- The Town should be aware that funding may be available through FEMA for the generator upgrade.

Vulnerability and Risk Assessment

Fire Station

Summary

The Fire Station is located directly adjacent to Central Pond. During large storms, water from Central Pond overtops the retaining wall behind the Fire Station and floods the parking lot. On a few occasions, the water has reached the basement; however, the curb in the garage has prevented water from entering the mechanical room located on this level. The dispatch and emergency response systems have already been relocated to the second floor. The emergency generator is undersized and located outside the building and could potentially be impacted by flood waters.

The overall VRA evaluation for this location is based on the following criteria:

Likelihood — 3 - High

Modeling results indicate that there is a medium probability of flooding due to Sea Level Rise, Shallow Coastal Flooding, and Storm Surge in 2050. There is a high probability of flooding at the Fire Station from Upland Flooding.

The overall weighted score increases from 13 to 20 to 28 across the 3 time periods. The Fire Station was assigned a high rating for likelihood of flooding based on a weighted score of 20 in 2050.

Consequence — 3 - High

This is the only Fire Station in Town. Any disruption to service puts the community at a severe public safety risk.

Sensitivity — 2 - Medium

The emergency generator is vulnerable to flooding.

Flood waters have breached the retaining wall and reached the building in the past.

Mechanical and electrical systems are located on the lowest level, but are protected by a curb within the garage.

The dispatch and emergency response systems have already been moved upstairs.

Adaptive Capacity — 2 - Medium

Smaller scale improvements can be made to protect from flooding. Grant funding from FEMA may become available to relocate and improve the emergency generator.

Flooding may be mitigated by culvert and tide gate improvements on Sawmill Brook.

Category	Component	2050 Rating	2050 Category Total	2050 Overall Rating
Risk	Likelihood	Medium = 2	6	10
	Consequence	High = 3		
Vulnerability	Sensitivity	Medium = 2	4	
	Adaptive Capacity	Medium = 2		

Vulnerability and Risk Assessment

Fire Station

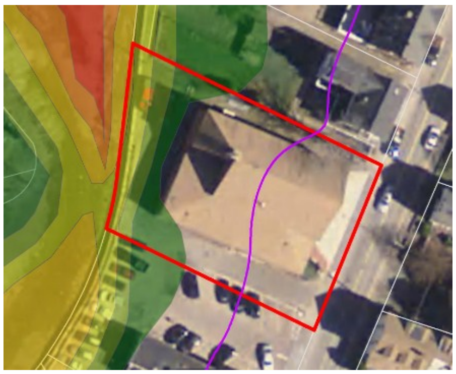
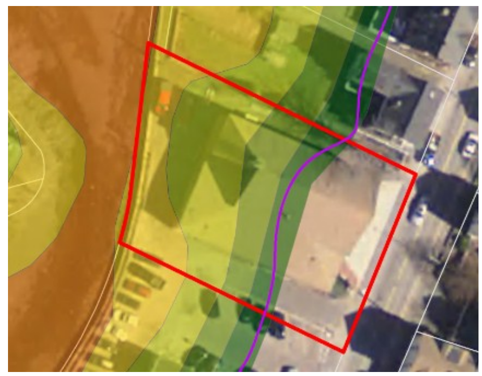
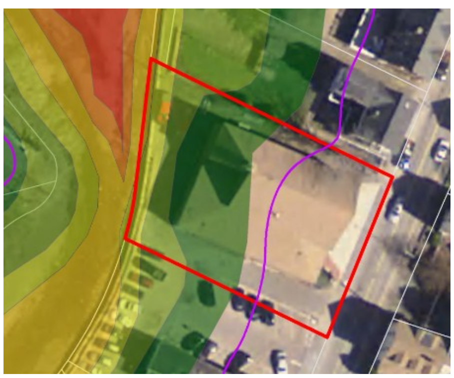
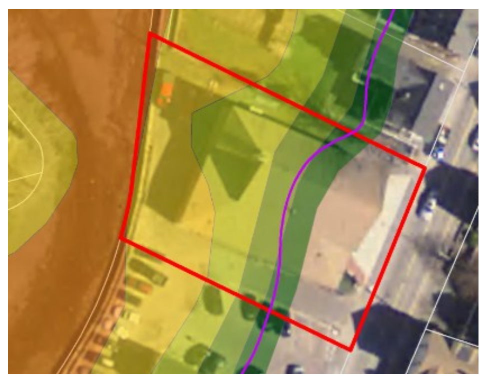
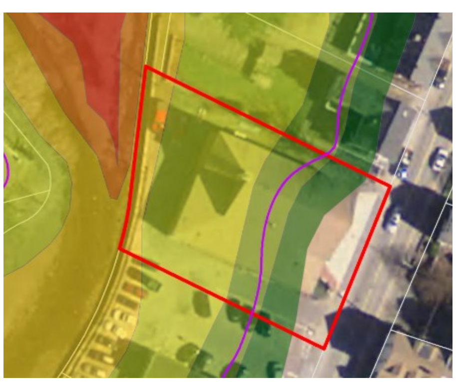
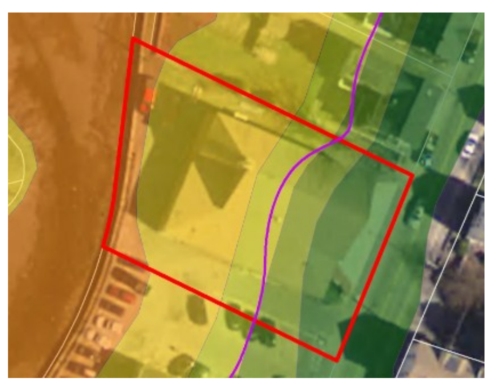
Left: View of the Fire Station from the east on School Street. Central Pond is behind the building.

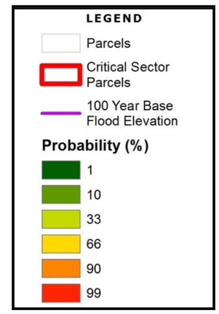
Right: View of the parking lot that has flooded in the past and the garage door opening vulnerable to flooding.

Left: Extreme rain event on 2/11/16, coupled with high tide, elevated Sawmill Brook to within inches from the curb behind the Fire Station.

Right: The north side of the building where the emergency generator is located.

Vulnerability and Risk Assessment
Fire Station

Planning Period	Coastal Flood Hazard Sea Level Rise	Coastal Flood Hazard Storm Surge
2025		
2050		
2100		



The figures above depict the extent of flood hazard areas, including the current 100-year base flood elevation shown in purple and the future flooding hazards for storm surge and sea level rise. Exposure vulnerability for near, mid and long term climate change planning periods is represented based on probability of occurrence from 1% (very unlikely) to 99%, (extremely likely). As shown, there is a significant risk of flooding due to Storm Surge by 2050. Sea Level Rise will likely not significantly impact the building until later in the century.

Vulnerability and Risk Assessment
Fire Station

ADAPTATION OBJECTIVES:

- The Fire Department must be able to provide uninterrupted service.
- Prevent physical damage to the building as a result of flooding.

ADAPTATION PROJECTS:

- Conduct a comprehensive evaluation to determine feasible flood proofing options and identify how the building may be impacted by flood waters based on existing site conditions, architecture, structural systems, location of utilities (water, wastewater, mechanical, plumbing, gas, and electric), and emergency response (alarms and communications).
- Based on the results of the evaluation, implement physical improvements such as elevating fuel tanks in basements and elevating electrical and mechanical systems, including generators, to 2 feet above the BFE.
- Upgrade generator and relocate to higher ground.
- Flood proof garage doors and other openings on the ground floor or stockpile emergency flood protection measures such as sandbags.

SHORT-TERM IMPLEMENTATION STEPS:

- The evaluation should be completed.
- The flood mitigation measures should be implemented.
- The Town should be aware that funding may be available through FEMA for the generator upgrade.

Vulnerability and Risk Assessment

Flood Risk Locations Along Route 127

Summary

Route 127 runs east-west across Manchester-by-the-Sea, almost paralleling Route 128 to the north. Although a named state route, there are parts that are owned and maintained by the Town. Also known as Bridge Street, Central Street, Union Street, and Summer Street, Route 127 is an important transportation corridor as it serves the downtown area and across the entire Town. Traveling northeast on Route 127 will bring you to Gloucester and to the southwest is Beverly.

The following areas have been identified as having a history of localized flooding.

1. Route 127 at Chubb Creek
2. Route 127 at Bennett Brook
3. Route 127 at Causeway Brook
4. Route 127 at Causeway Brook Branch
5. Route 127 at Raymond Street

Figures showing the impacts of storm surge at these locations are shown on the following pages. Note that figures are not available for Route 127 at Raymond Street as this location is outside of the modeled area.

The overall VRA evaluation Route 127 is based on the following criteria:

Likelihood 3 - High

Modeling results indicate that in 2050 there is a high probability of flooding for Sea Level Rise, Shallow Coastal Flooding, Storm Surge, and Upland Flooding.

The overall weighted score for this location is 31 across all time periods, giving it a high rating for likelihood of flooding.

Consequence 2 - Medium

If Route 127 were to flood and become unpassable, alternate routes are available, however, emergency services (police, fire, etc.) would be unable to quickly access certain points in Town. It would likely have economic impacts as the downtown area would not be as easily accessible. Also, it serves as an evacuation route for the

Sensitivity 2 - Medium

There is a history of minor localized flooding, most notable at the locations listed above.

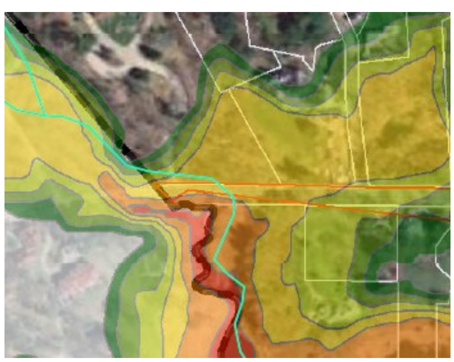
Adaptive Capacity 3 - Low

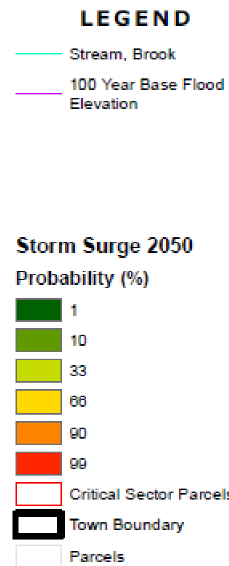
Major upgrades such as raising the road and stormwater system improvements would be required. Improvements can only be made on the sections of roadway that are maintained by the Town; projects within the State-owned sections would have to be implemented by the State.

Category	Component	2050 Rating	2050 Category Total	2050 Overall Rating
Risk	Likelihood	High = 3	6	12
	Consequence	Medium = 2		
Vulnerability	Sensitivity	Medium = 2	6	
	Adaptive Capacity	Low = 3		

Vulnerability and Risk Assessment

Flood Risk Locations Along Route 127

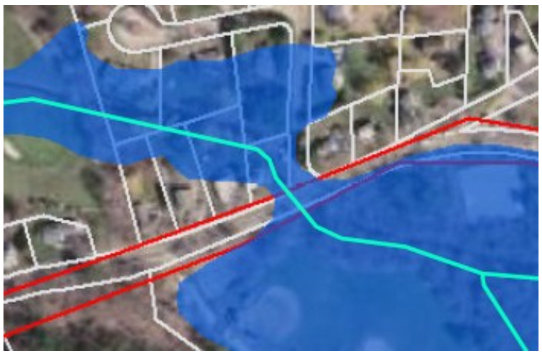
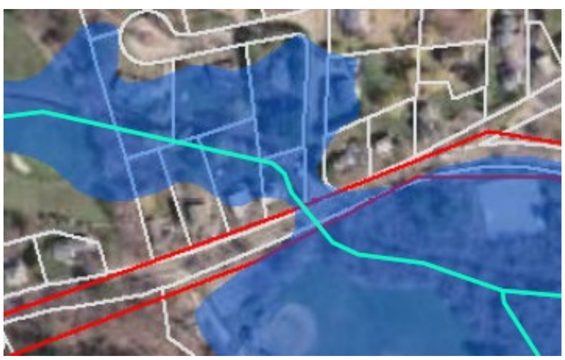
Planning Period	Route 127 at Chubb Creek Storm Surge	Route 127 at Bennett Brook Storm Surge
2025		
2050		
2100		

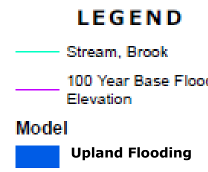


The figures above depict the extent of flood hazard areas, including the current 100-year base flood elevation shown in purple and the future flooding hazards for storm surge. Exposure vulnerability for near, mid and long term climate change planning periods is represented based on probability of occurrence from 1% (very unlikely) to 99% (extremely likely). Storm surge is likely to impact Route 127 at both the Chubb Creek and Bennett Brook crossings in 2025. The area of impact at the Chubb Creek location will expand as time progresses.

Vulnerability and Risk Assessment

Flood Risk Locations Along Route 127

Planning Period	Route 127 at Causeway Brook Upland Flooding	Route 127 at Causeway Brook Branch Upland Flooding
2025		
2050		
2100		



The figures above depict the extent of Upland Flooding impacts at the Causeway Brook and Causeway Brook Branch crossings on Route 127. As shown, the areas of impact change only slightly over the course of time. Both locations have a history of minor localized flooding.

Vulnerability and Risk Assessment
Flood Risk Locations Along Route 127

ADAPTATION OBJECTIVES:

- Prevent flooding of Route 127 and mitigate damages.
- Address potential roadbed undermining.
- Address high groundwater and sea level rise impacts on drainage system.
- Address sand/debris impacts on drainage system.

ADAPTATION PROJECTS:

Route 127 at Chubb Creek and Bennetts Brook have a 90-99% probability of flooding with storm surge due to the roadway elevation and proximity to coastal waters. Storm surge impacts can undermine the roadway and deposit sand and other debris on the roadway, clogging catch basins and diminishing infiltration. As sea level rises, the seasonal high groundwater level will also rise, compromising drainage. Route 127 at Causeway Brook floods across the road and 127 at Causeway Brook Branch partially floods during extreme precipitation events. Sand and debris from flooding decreases the capacity of the drainage system, and overflowing drainage basins can damage the roadway and adjacent properties. There are multiple potential retrofit options that will help to mitigate flooding and roadway damages, however a comprehensive drainage survey is needed for specific solutions. Vulnerabilities from climate change, potential impacts, and example adaptation projects are summarized below.

Vulnerabilities from Climate Change	Potential Impacts	Example Adaptation Project
Submerged outfalls due to sea level rise	Increased groundwater inundation time, reduced hydraulic head through drainage system, and decreased flow rate of water through the drainage system. Outfalls are submerged.	Install duck bills on exposed outfalls. Elevate roadway and fortify with seawall. Size drainage to accommodate increased inflow in coastal locations that are impacted by sea level rise.
High groundwater elevations	Drainage and flood impacts by increased groundwater influenced by sea level rise and extreme precipitation.	Elevate roadways and protect roadbed with stabilization measures. Select and size drainage practices to avoid infiltration.
Increased intensity, frequency, and duration of storms	Decreased capacity of stormwater drainage system and BMPs, which results in decreased ability to manage quantity and quality of stormwater.	Select and size drainage practices to manage wetter conditions.
Salt, sand and debris impacts from flooding and storm surge	Decreased capacity of stormwater drainage system and BMPs, which results in decreased ability to manage quantity and quality of stormwater. Physical damages to roadbed including undermining structures and erosion.	Increase inspection and maintenance of drainage system, add physical barriers to manage or deter sediment and debris from entering drainage structures and system (e.g. sediment forebays and deep sump catch basins), and protect road. Choose materials that do not corrode from salt exposure.

SHORT-TERM IMPLEMENTATION STEPS:

Manchester-by-the-Sea should conduct a comprehensive drainage survey and feasibility evaluation for retrofits.

The Town should seek funding for design, permitting, and construction of roadway retrofits.

Vulnerability and Risk Assessment

Downtown Businesses

Summary

The downtown area is the main economic center of Manchester-by-the-Sea. Business are located primarily along Beach Street and Central Street, with additional shops along Union Street. The majority of the shops are just outside of the 100-year flood base flood elevation of 10 feet above mean sea level, according to the recently revised FEMA FIRM maps. The map revisions are supported by the lack of repetitive loss flood insurance claims from FEMA. Climate change modeling is not based on the historic flood elevations, but rather on anticipated impacts from increasing intensity and duration of storms and sea level rise. The elevation of businesses is the most important factor in forecasting future risk, but it is impossible to assign an overall rating criteria for Downtown Businesses due to the variable results. To assist in an evaluation of vulnerability, an analysis of commercial property value at elevations 10-14 were summarized. Results from the IRM indicate there is a moderate risk of coastal flooding for businesses below elevation 12. Inland flooding impacts business along School and Central Street.

The overall VRA evaluation for this location is based on the following criteria:

Likelihood — 3 - High

Modeling results are not available since the business-es are spread out over a large area.

The likelihood rating could not be assigned based on the overall weighted score since modeling results are not available. Instead, the it was assigned a high rating for likelihood of flooding based on the proximity to Sawmill Brook and Manchester Harbor.

Consequence — 3 - High

The downtown businesses provide essential goods and services and disruption of economic activity would negatively impact the entire community. There are $19 million dollars of commercial assets located in the 0-10 foot elevation, and nearly $25 million from 0-16 feet.

Sensitivity — 2 - Medium

In the short term, only the properties at the lowest elevations may be impacted by localized flooding including flooding of basements and low spots on the property. Buried utilities may be at risk.

Adaptive Capacity — 2 - Medium

Privately owned business are responsible for maintaining flood insurance. Recent revisions to the FEMA 100-year flood plain have removed the flood insurance requirement for many locations. Drainage improvements including LID stormwater BMPs may be implemented as part of the Downtown Improvement projects with grant funds.

Category	Component	2050 Rating	2050 Category Total	2050 Overall Rating
Risk	Likelihood	High = 3	9	13
	Consequence	High = 3		
Vulnerability	Sensitivity	Medium = 2	4	
	Adaptive Capacity	Medium = 2		

Vulnerability and Risk Assessment

Downtown Businesses

Downtown - Beach Street commercial area, south view at Union Street/Beach Street intersection

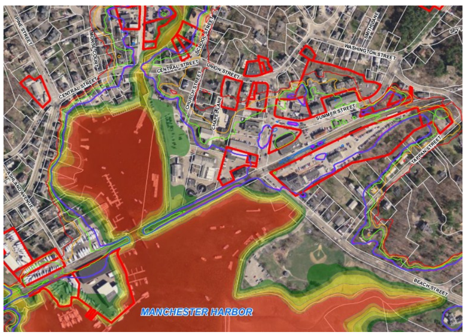
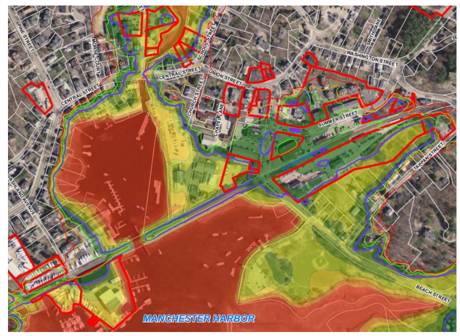
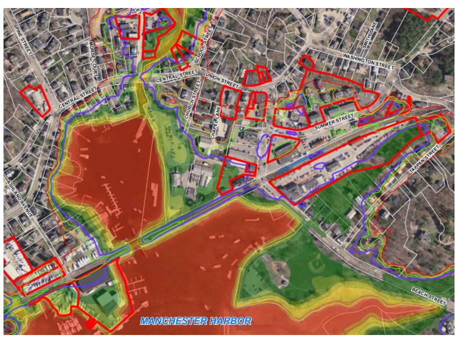
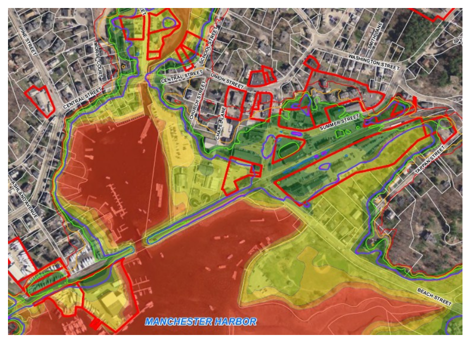
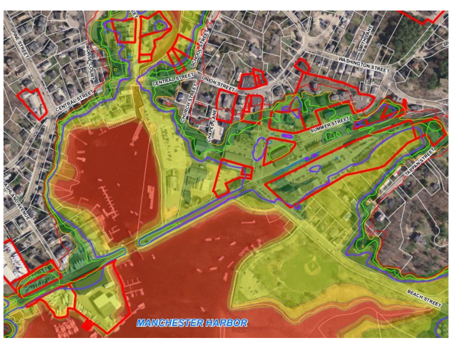
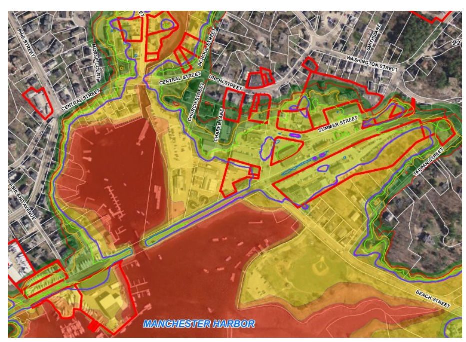
Downtown - Beach Street commercial area adjacent to Manchester Harbor

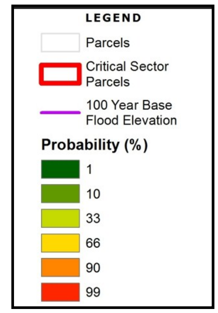
Downtown - Beach Street commercial plaza

Downtown - Central Street commercial area

Vulnerability and Risk Assessment

Downtown Businesses

Planning Period	Coastal Flood Hazard Sea Level Rise	Coastal Flood Hazard Storm Surge
2025		
2050		
2100		



The figures above depict the extent of flood hazard areas, including the current 100-year base flood elevation shown in purple and the future flooding hazards for storm surge and sea level rise. Exposure vulnerability for near, mid and long term climate change planning periods is represented based on probability of occurrence from 1% (very unlikely) to 99%, (extremely likely). The figures show that many of the businesses will likely not be impacted by sea level rise until 2100. However, many sites are at risk of flooding due to storm surge; probabilities greatly increase by 2100.

Vulnerability and Risk Assessment

Downtown Businesses

ADAPTATION GOALS:

- Provide tools to help educate downtown businesses about risks due to flooding.
- Provide incentives for implementing mitigation projects to improve economic resilience to flooding.

ADAPTATION PROJECTS:

1. Develop checklist to screen for and educate business owners about vulnerabilities.

   Recognizing that some but not all businesses in the downtown area may be vulnerable to flooding from sea level rise and storm surge for a 2050 planning horizon, the Town is encouraging business owners to proactively identify specific location vulnerabilities. The results of climate change flood modeling could be added to the Town GIS website as a starting point for business owners to compare their location to current FEMA 100-year flood maps. A self awareness checklist could be developed for business owners to do a preliminary vulnerability screening based on site conditions, architecture, structural systems, utilities (water, wastewater, mechanical, plumbing, gas, and electric), and emergency response (fire alarms and communications). The FEMA Checklist for Vulnerability of Flood-Prone Sites and Building provides an excellent starting point to develop the checklist (FEMA P-936, Floodproofing Non-Residential Buildings, FEMA 2013).

2. Provide incentives for business owners to improve resiliency.

   The Town should identify grant opportunities and/or other incentives to encourage implementing mitigation projects for Manchester-by-the-Sea business owners.

   Examples mitigation projects include:

   - Comprehensive vulnerability assessment and flood proofing evaluation.
   - Physical improvements such as elevating fuel tanks in basements and elevating electrical and mechanical systems, including generators, to 2 feet above the BFE.
   - Stockpiling emergency flood protection such as sand bags, sill or window well barriers.
   - Providing alternative emergency exits in the event of flooding.
   - Developing emergency operation plans to keep facility functional with limited or no power.

SHORT-TERM IMPLEMENTATION STEPS:

The Emergency Management Director, Town Planner, and the Downtown Improvement Committee should work together to provide business owners with education on opportunities and strategies for flood mitigation.

The Town should work with the Emergency Management Director, Town Planner, Grants Administrator, and Downtown Improvement Committee to identify grants or other incentives to improve economic resiliency.

Vulnerability and Risk Assessment

Sawmill Brook

Summary

Sawmill Brook is the longest watercourse that flows through Manchester-by-the-Sea and drains the majority of the Town. The main stem of Sawmill Brook drains a circuitous route. It begins just south of Route 128 and discharges through Central Pond near the downtown area to Manchester Harbor at the Central Street tide gate. Flooding has been documented along multiple sections of the Brook including areas with extensive wetlands, at the confluence of tributaries and locations where channelized stream bed and undersized culverts create hydraulic restrictions.

The overall VRA evaluation for this location is based on the following criteria:

Likelihood — 3 - High

Modeling results indicate that there is a high probability of flooding in all categories across all time periods: Sea Level Rise, Shallow Coastal Flooding, Storm Surge, and Upland Flooding.

The overall weighted score is 31 across all time periods, giving Sawmill Brook a high rating for likelihood of flooding in 2050.

Consequence — 2 - Medium

Because Sawmill Brook drains a majority of the Town, flooding of the Brook will have a large impact. Highest consequence will be in the downtown area, where numerous businesses, densely populated residential areas, and Police and Fire Departments are located.

Sensitivity — 2 - Medium

Numerous flooding events have been experienced in the past throughout the watershed, from Millets Creek at the headwaters to the Central Street tide gate at the mouth of Sawmill Brook. Flooding has also damaged municipal infrastructure and private property along the Brook.

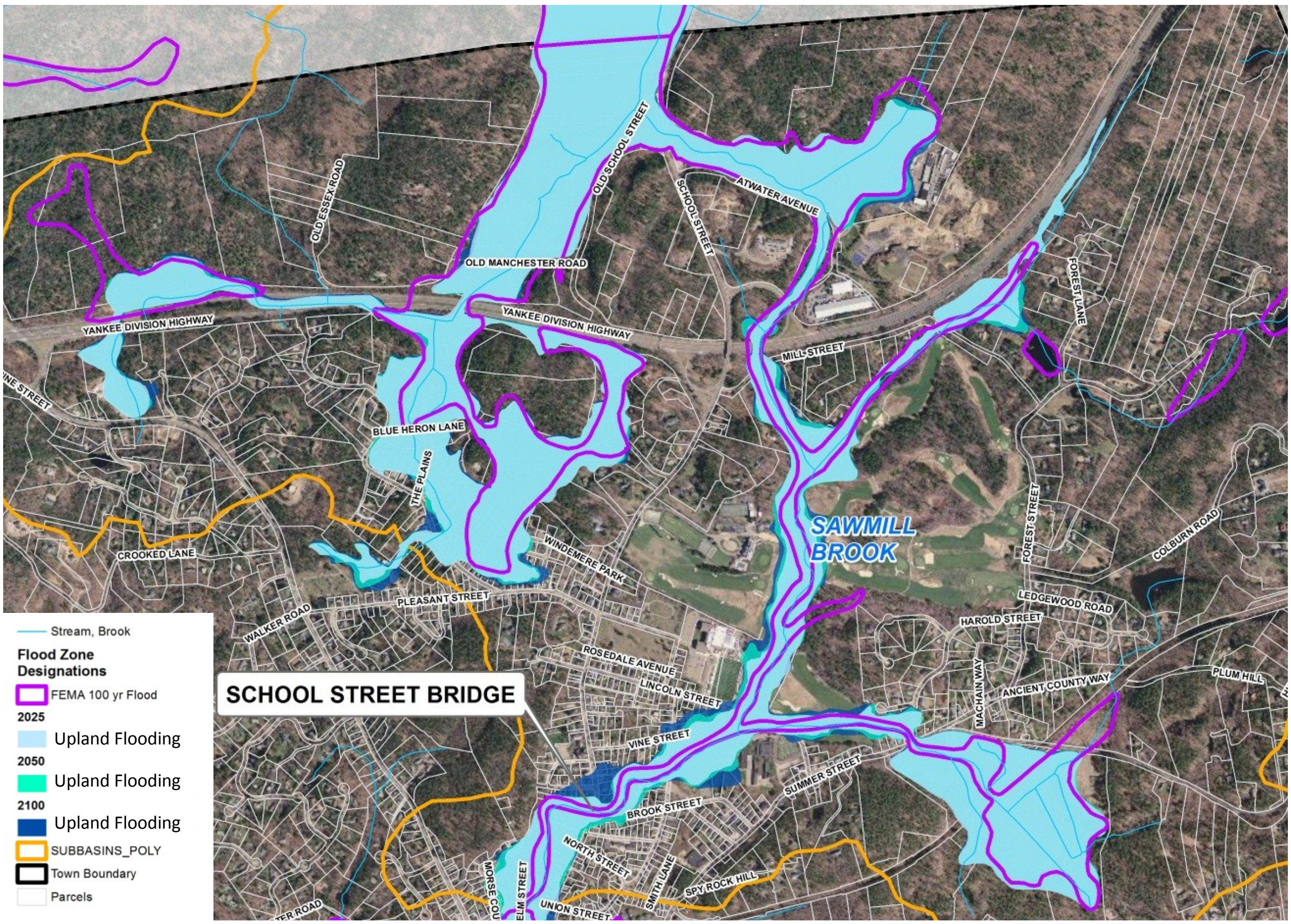
Adaptive Capacity — 3 - Low

A variety of funding sources may be available to improve culverts along the Brook in addition to flood storage and green infrastructure. Even with funding assistance, these improvements will be very costly and require complex permitting. Furthermore, these improvements will not mitigate all of the flooding.

Category	2050 Component	2050 Rating	2050 Category Total	2050 Overall Rating
Risk	Likelihood	High = 3	6	12
	Consequence	Medium = 2		
Vulnerability	Sensitivity	Medium = 2	6	
	Adaptive Capacity	Low = 3		

Vulnerability and Risk Assessment
Sawmill Brook

Sawmill Brook Upland Flooding Impacts 2025, 2050, 2100



This figure above depicts the extent of flood hazard areas, including the current 100-year FEMA flood elevation shown in purple and the future flooding hazards area for Upland Flooding based on the Sawmill Brook Watershed Model. The modeled area of inundation due to upland flooding is based on precipitation amounts generated under a balanced fossil fuel energy emission scenario and tail water conditions created with sea level rise at the Harbor. The modeled area of flooding is subject to change as culvert restrictions are addressed throughout the watershed.

Vulnerability and Risk Assessment

Sawmill Brook

ADAPTATION OBJECTIVES:

Refine and implement projects in the Sawmill Brook watershed that were identified through comprehensive watershed planning to improve flood storage, increase culvert capacity, and ultimately mitigate flooding within the watershed.

Coordinate required studies for priority projects to optimize the design and permitting process.

ADAPTATION PROJECTS:

Flood mitigation projects for Sawmill Brook were developed through a planning process that simultaneously considered inland and coastal climate change impacts, water quality, and habitat preservation. Initial projects identified were subject to a series of evaluations to narrow down and refine the list including a project benefit evaluation, iterative modeling to optimize flood reduction, and a cost/benefit analysis that considered health and safety, flood mitigation, utility conflicts, permitting needs, habitat impacts, water quality benefits, and maintenance needs. The top nine projects that were identified are listed below. The Central Street tide gate and culvert improvement alternatives are discussed under the Central Street VRA and the Hurricane Barrier is discussed under the VRA for Manchester Harbor.

Project	Primary Benefit	Description	Ranking
Central Street Tide Gate (Alt #2)	Improve hydraulic capacity and reduce upstream flooding	Remove tide gate, widen culvert, restore seawall and pond and brook	1
Central Street Tide Gate (Alt #1)	Improve hydraulic capacity and reduce upstream flooding	Remove tide gate, repair culvert, restore pond and brook	2
School Street Culvert	Improve hydraulic capacity and reduce downstream flooding	Widen culvert, widen channel, resort brook, restore stone walls	3
Norwood Avenue Culvert	Improve hydraulic capacity and reduce downstream flooding	Widen culvert, widen channel, resort brook, restore stone walls	4
Coach Field Parking Lot	Small storm flood reduction, water quality improvements	Install porous pavement to improve on-site drainage	5
Lincoln Street Culvert	Improve hydraulic capacity and reduce upstream flooding	Widen culvert	6
Hurricane Barrier	Limit impact of storm surge and backwater flooding	Install storm surge barrier	7
Golf Course	Flood attenuation, reduce downstream flooding	Grade existing channel, restore flood plain	8
Old School Street	Flood attenuation, reduce downstream flooding	Replace and culverts, raise roadway elevation	9

The Town is targeting implementation of the Sawmill Brook projects starting at the mouth of the Brook and working up the watershed. After the Central Street project the next phase for Sawmill Brook flood mitigation will likely be School Street and Norwood Avenue culvert improvements. The Coach Field parking lot retrofit project is already underway.

SHORT-TERM IMPLEMENTATION STEPS:

The Town should seek funding for required studies for School Street and Norwood Avenue culvert improvement projects to optimize the design and permitting process.

Vulnerability and Risk Assessment

Manchester Harbor

Summary

Manchester Harbor is one of the Town's greatest features. The Harbor is an important recreational, economic, scenic, environmental, and cultural asset of the Town. The main economic center of the Town surrounds the Harbor and the Harbor itself provides for economic activity through commercial fishing and tourism. There are numerous recreational activities available such as boating, kayaking, public and private piers, parks, and a sailing school. The Harbor is also home to many species of shorebirds, shellfish, finfish, and submerged and emergent vegetation including an abundance of eel grass. Both Sawmill Brook and Bennetts Brook flow directly to the Harbor. Other freshwater sources include stormwater outfalls. Flooding can have different impacts on the Harbor and its surroundings. For instance, flood waters entering the Harbor from land often carry extra sediment, silt, and debris. Flooding can also cause seawater to overtop the perimeter of the Harbor, which is surrounded by a variety of sea walls and natural landscape. Wave action associated with storm surge may have a deleterious impact on the eel grass beds, causing the grass to break or uproot emerging plants.

The overall VRA evaluation for this location is based on the following criteria:

Likelihood — 3 - High

Modeling results indicate that there is a high probability of flooding due to Sea Level Rise, Shallow Coastal Flooding, and Storm Surge across all time periods.

The overall weighted score is 28 in 2025, 2050, and 2100, giving the Harbor a high rating for likelihood of flooding.

Consequence — 2 - Medium

Likely ecological consequences due to negative impact of stormwater discharge on shellfish beds and wave action from storm surge on eel grass beds, which are vital to the Harbor.

Changes in the water level can also impact the grasses and natural shoreline surrounding the Harbor.

Sensitivity — 2 - Medium

Flood events in the past have caused a buildup of extra sediment on the Harbor floor. Flash flooding events have polluted the Harbor with debris and silt.

The Harbor overtops roadways and seawalls during extreme events.

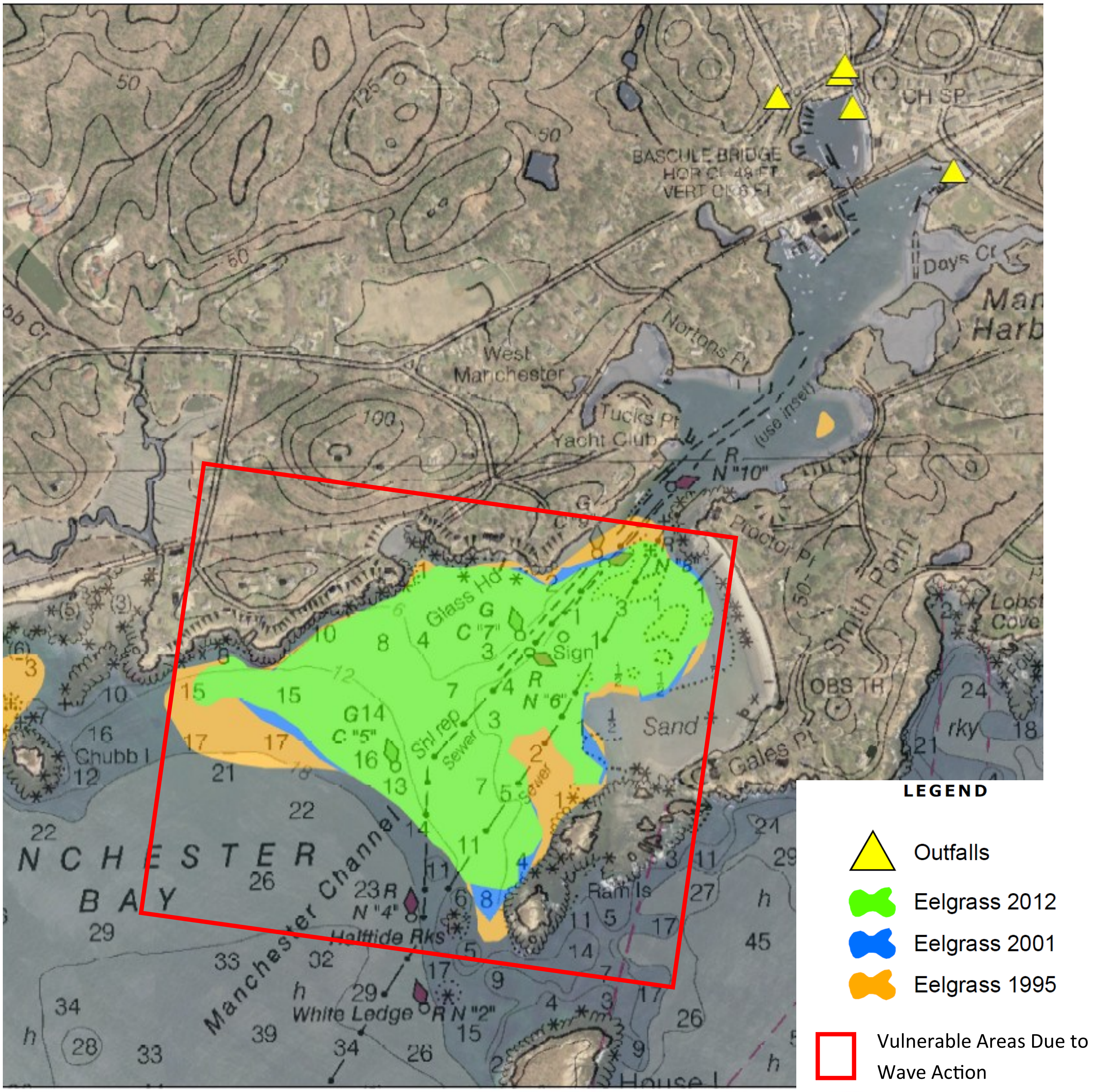
Adaptive Capacity — 3 - Low

Major upgrades and investments would be required to reduce runoff entering the Harbor and to increase the frequency of dredging if it is required.

Category	Component	2050 Rating	2050 Category Total	2050 Overall Rating
Risk	Likelihood	High = 3	6	12
	Consequence	Medium = 2		
Vulnerability	Sensitivity	Medium = 2	6	
	Adaptive Capacity	Low = 3		

Vulnerability and Risk Assessment

Manchester Harbor



The image above shows an NOAA nautical chart of Manchester Harbor and the extent of eel grass beds which have gotten smaller over time. Beds are vulnerable to wave action associated with storm surge that may increase with climate change. Areas most vulnerable are west of Rams Island where beds are more exposed to wave refraction. The stormwater outfalls in Manchester Inner Harbor are also located on the map.

Vulnerability and Risk Assessment

Manchester Harbor

ADAPTATION GOALS:

- Develop and maintain coastal zone and harbor management strategies to minimize wave impacts and erosion to Manchester Harbor coastline, maintain water quality, and limit conditions that contribute to the buildup of sediments within the Harbor.
- Maintain a safe mooring field during coastal storms, which may increase in intensity and duration with climate change.
- Maintain and improve biological habitat within the Harbor considering a changing climate.

ADAPTATION PROJECTS:

Storm Surge Barrier

Installation of a surge barrier will augment protection of Manchester Harbor in the event of a hurricane or tsunami by controlling storm surge entering the harbor. The barrier may assist in prevention of upland flooding by closing it at low tide, to control backwater hydraulic restrictions during periods of high stream discharge. The conceptual design of the surge barrier is a traditional stone armored dike/breakwater with a navigation opening aligned with the harbor entrance channel. A boat navigation opening at least 60 feet wide would be provided in the barrier, aligned with the channel, formed by side walls and a hinged steel gate, typically open, lying on the seabed.

Upgrade Seawalls

The entire coastline around Manchester Harbor is vulnerable to coastal erosion. Seawalls are critical to protect the shoreline, particularly in densely developed areas of the Inner Harbor. Many of the walls are in need of repair including Morss Pier at Masconomo Park. The concrete wall that supports the East side of the fishermen's pier and the road access to Masconomo Park is badly degraded. A large section of the wall beneath the shelter is completely gone and several sinkholes have developed in the parking area adjacent to the shelter on the pier. In addition, the wall from the pier to Beach St. and then Reed Park is showing signs of pushing out into the Harbor.

Implement Stormwater Outfall improvements to control water quality impairments in Manchester Harbor

Outfalls at several locations discharge stormwater directly to the Harbor with no treatment, contributing nutrients, metals, total suspended solids, and bacteria to the Harbor. The Town should evaluate stormwater retrofits to drainage discharging to Manchester Harbor that will improve stormwater quality and develop an implementation schedule.

SHORT-TERM IMPLEMENTATION STEPS:

- The Town should complete evaluation of seawalls, docks and piers in Manchester Harbor, prioritize funding for projects already identified, and complete repairs.
- The Town should develop a stormwater outfall retrofit implementation schedule.
- The Town should continue to discuss the benefits of designing and installing a surge barrier as an aggressive mitigation effort to protecting the Harbor and resolving flooding problems in downtown Manchester-by-the-Sea.

Vulnerability and Risk Assessment

Singing Beach

Summary

Singing Beach is located at the end of Beach Street close to the downtown area. The beach is a strong attraction for area residents and visiting tourists. Properties along the coast adjacent to the beach are protected by a 2,000 foot long armored bank of stone revetment. The beach has been flooded and badly damaged during multiple storm events as recently as the winter of 2013. Photos of this damage are shown on the following page.

The overall VRA evaluation was based on the following criteria and 2050 likelihood for this location:

Likelihood — 3 - High

Modeling results indicate that there is a high probability of flooding due to Sea Level Rise, Shallow Coastal Flooding, and Storm Surge across all time periods.

The overall weighted score is 28 in 2025, 2050, and 2100. Therefore, Singing Beach was assigned a high rating for likelihood.

Consequence — 2 - Medium

The Beach generates the majority of the revenue for the Parks and Recreation Department with beach users creating approximately $250,000 annually. Beach goers also produce additional income for local merchants estimated at a million dollars-worth of economic impact. Furthermore, the beach protects high value residential properties behind it, assessed at over $215 million dollars, or 10% of the towns total assessed value.

Sensitivity — 2 - Medium

History of storm events contributing to major coastal erosion, damage to roadways, infrastructure, structures and revetment.

Adaptive Capacity — 3 - Low

Beach re-nourishment and hardening is expensive and requires extensive permitting. This would require a major upgrade and investment.

Category	Component	2050 Rating	2050 Category Total	2050 Overall Rating
Risk	Likelihood	High = 3	6	12
	Consequence	Medium = 2		
Vulnerability	Sensitivity	Medium = 2	6	
	Adaptive Capacity	Low = 3		

Vulnerability and Risk Assessment

Singing Beach

Singing Beach, Manchester-by-the-Sea. The beach area, bath house and parking area shown have been fully sub-merged during a 100-year flood event.

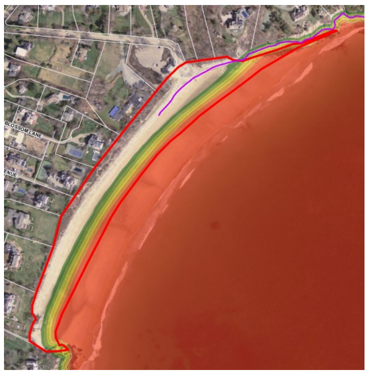
Singing Beach, Manchester-by-the-Sea. The roadway, structures and revetment have been damaged a number of times and repaired by the Town at significant cost. The damages shown above were from the winter of 2013.

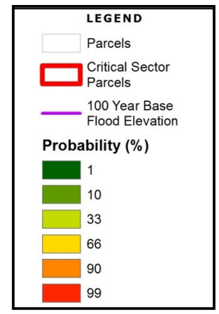
Vulnerability and Risk Assessment

Singing Beach

Planning Period | **Coastal Flood Hazard Sea Level Rise** | **Coastal Flood Hazard Storm Surge**

2025





2050

2100

This figures above depict the extent of flood hazard areas, including the current 100-year base flood elevation shown in purple and the future flooding hazards for storm surge and sea level rise. Exposure vulnerability for near, mid and long term climate change planning periods is represented based on probability of occurrence from 1% (very unlikely) to 99%, (extremely likely). The figures show that sea level rise will not significantly impact the site until 2100. Storm surge is likely to impact the site and may even breach the Singing Beach, impacting the homes behind it.

Vulnerability and Risk Assessment

Singing Beach

ADAPTATION OBJECTIVES:

- Prevent damage to Singing Beach, parking and amenities from storm surge and sea level rise.
- Maintain condition of seawall and other hard structures to prevent shoreline erosion.
- Protect utilities providing water and wastewater disposal to Singing Beach bath house.

ADAPTATION PROJECTS:

- Continue to support CZM efforts to track shoreline changes along Singing Beach, as shown in the figure below.
- If shoreline erosion becomes significant, evaluate shoreline restoration techniques such as beach nourishment or off shore breakwaters to reduce the wave energy impacting Singing Beach.
- Continue to monitor the seawall condition and if future repairs are needed include sea level rise in the design.
- Evaluate parking lot retrofits to improve stormwater drainage such as a porous pavement design . The retrofit evaluation should include opportunities to promote infiltration and improve water quality.

SHORT-TERM IMPLEMENTATION STEPS:

- Support CZM efforts to track shoreline changes as needed,.
- Seek funding for green infrastructure retrofits.