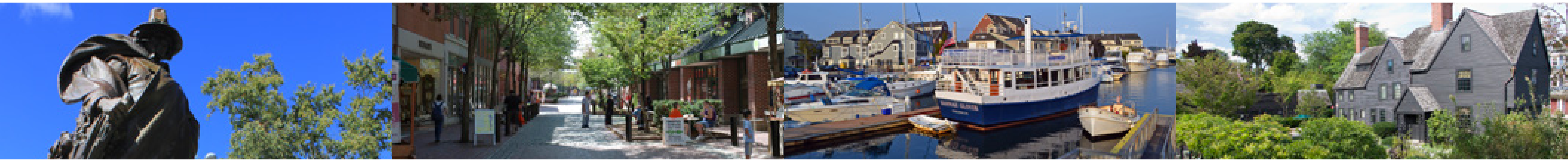
READY FOR TOMORROW



THE CITY OF SALEM CLIMATE CHANGE VULNERABILITY ASSESSMENT & ADAPTATION PLAN

December 2014

CDM Smith

Salem
Still making history.

READY FOR TOMORROW

THE CITY OF SALEM CLIMATE CHANGE VULNERABILITY ASSESSMENT AND ADAPTATION PLAN

PREPARED FOR:

City of Salem, Massachusetts

Kimberly Driscoll, Mayor

City of Salem
Department of Planning & Community Development

BY:

CDM Smith

December 2014

ACKNOWLEDGEMENTS

The City of Salem gratefully acknowledges the participation of the following individuals in providing valuable input to this Plan. Their involvement will aid in its implementation to make the City of Salem a more resilient community in the face of climate change.

The City of Salem also acknowledges our partners at CDM Smith, who partially sponsored this Plan through their Research and Development Program.

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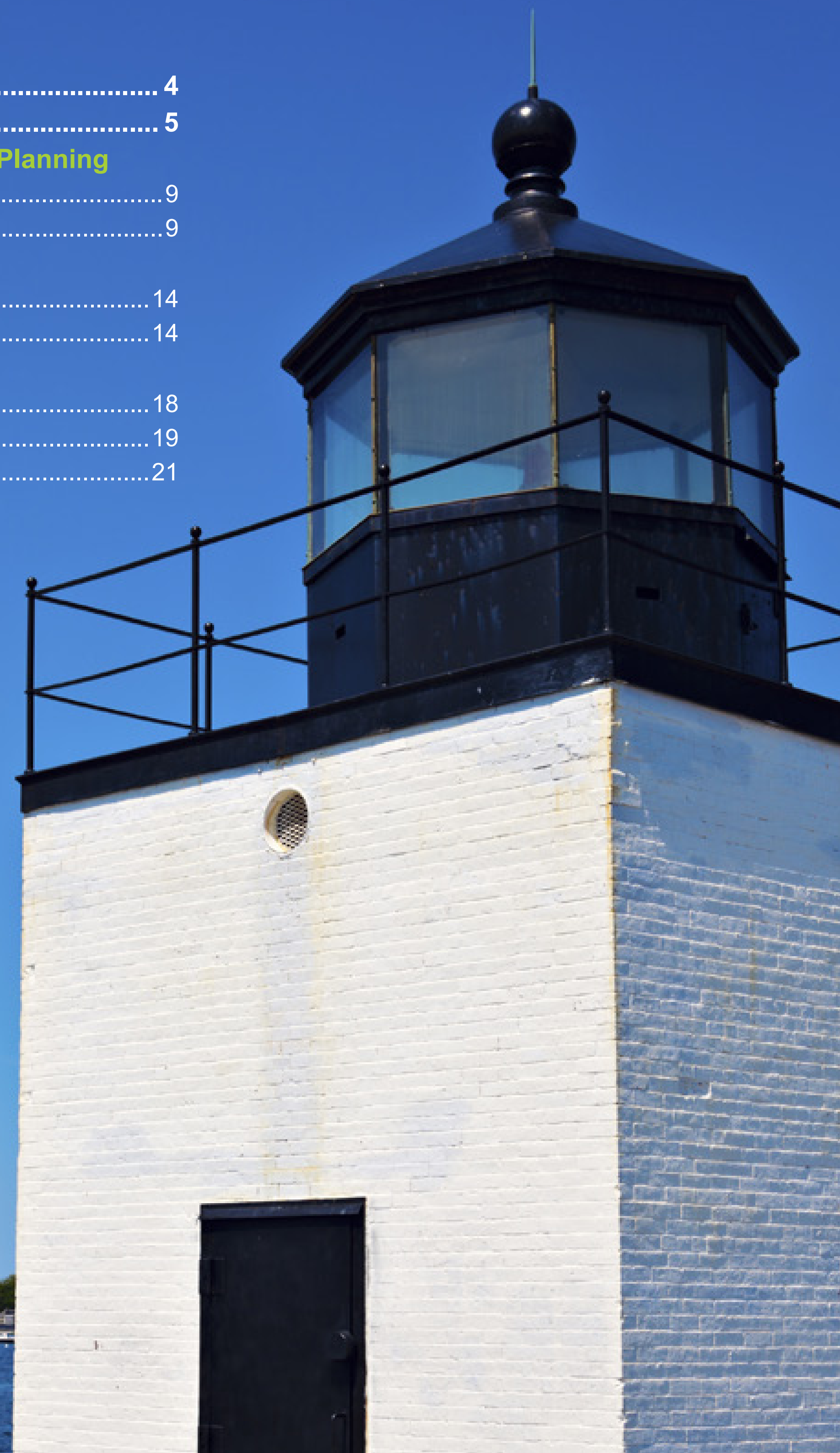


CITY OF SALEM, MASSACHUSETTS

December 15, 2014

Salem is a City rich with history, vibrant with economic activity, and enlivened by diverse populations of residents. As much as we known for being one of America's greatest historical communities, though, we are also forward-looking.

Critical to that is ensuring that we plan appropriately for the reality of life in a world with a changing climate. As a coastal city it is even more vital that we identify our most vulnerable assets and take appropriate actions to mitigate potential threats that will be caused or exacerbated by climate change.

Salem is a designated Green Community and we place a high value on policies and practices that are sustainable and environmentally sensitive.

Whether it is converting our City street lights to LED fixtures, advancing electricity aggregation for consumers, replacing our City fleet with more efficient vehicles and increasing the energy efficiency of public buildings, or pursuing solar opportunities for municipal and private property, Salem is focused on strategies that will reduce our overall carbon footprint and lessen our community's role in changing our planet's climate. Even small strategies like our free bike share program and curbside composting do their own part to help decrease our impact on the planet and our climate.

But the reality is that overall climate change is happening. And because it is happening, we must be ready for the consequences that it will ensue.

By planning well today, Salem will be ready for tomorrow.

Kimberley Driscoll
Mayor
City of Salem

DEFINITIONS

The following terms are used throughout this document:

- **Adaptation:** The Intergovernmental Panel on Climate Change (IPCC) definition is "the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities." In Salem, they are the actions the community may take to make living with climate change easier.
- **Adaptive Capacity:** The component's [see definition below] ability to accommodate the stresses resulting from climate change impacts. It also considers the ability of the component to return to normalcy after a disruption. Adaptive Capacity is closely related to resiliency.
- **Adaptation Plan:** The encompassing document that describes climate change impacts, an assessment and prioritization of vulnerabilities, and adaptation strategies to increase Adaptive Capacity of Salem.
- **Adaptation Strategies:** Projects to decrease the vulnerability of components to the stresses from climate change impacts.
- **Climate Change:** The IPCC definition is "a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use." [1]
- **Climate Change Consequence:** The known and estimated impact due to climate change. In Salem, economic, health and safety, cultural and historical, and ecological and environmental consequences were assessed as part of the risk assessment.
- **Climate Change Impact:** The response to natural systems due to climate change.
- **Climate Change Likelihood:** The probability of the climate change impact occurring based on the IPCC. They are based on the type, amount, quality, and consistency of evidence that a given climate change impact will occur. Climate change impacts are categorized with "Level of Confidence" rankings of virtually certain (99-100%), extremely likely (95-100%), very likely (90-100%), likely (66-100%), more likely than not (>50-100%), about as likely as not (33-66%), unlikely (0-33%), very unlikely (0-10%), extremely unlikely (0-5%), and exceptionally unlikely (0-1%).[1, 2]
- **Climate Change Risk:** A function of the consequences of climate change times the likelihood of climate change. This is used to prioritize the vulnerabilities.
- **Component:** An individual item in a sector [see definition below], including the infrastructure, policies, and programs that people in the City use and rely on. They may be owned and operated by the City, or they may be run by a third party - such as a state agency or private company.
- **Evaluation Criteria:** A method for prioritizing vulnerable, stressed components to incorporate Salem's particular opportunities and concerns based on alignment with existing plans, policies, or programs, funding availability, or the City's control over the implementation.
- **Resiliency:** The ability of sectors to accommodate climate change impacts and stresses with minimal potential damage or cost. It is the ability for human systems to survive and recover quickly from climate change impacts and risk factors. It is closely related to adaptive capacity.
- **Risk Assessment:** The determination of the risk of a climate change impact and stress to the component based on the economic, health and safety, cultural and historical, and ecological and environmental consequences to the component and the likelihood that the climate change impact will occur.

[1]International Panel on Climate Change (IPCC). Working Group III: Mitigation. Appendix II: Glossary. Accessed November 5, 2014 at http://www.ipcc.ch/ipccreports/tar/wg3/index.php?idp=456

[2]International Panel on Climate Change. 2014. Working Group II. Fifth Assessment Report -Impacts, Adaptation, and Vulnerability - Summary for Policymakers.

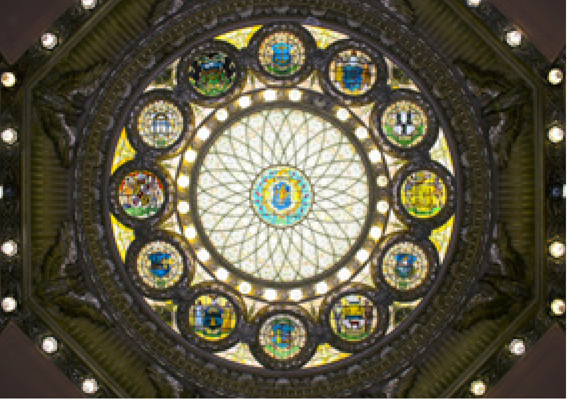
- **Sector:** A cohesive system within the City that may be impacted by climate change. It is made up of many components. In Salem, sectors included in this Plan are critical building infrastructure, water, energy, stormwater, transportation, and vulnerable populations.
- **Sensitivity:** The degree to which a component is directly or indirectly affected by the stresses resulting from climate change impacts. Sensitivity is composed of a component's exposure to the climate change impact and the known or predicted effects of the impact on the component.
- **Stress:** A problem arising to a sector or component due to one or more climate change impacts.
- **Vulnerability:** The susceptibility of a sector to harm from the stress of a climate change impact. It is a function of the sensitivity to climate change and the adaptive capacity to climate changes. A sector component with a high sensitivity and a low adaptive capacity has a high vulnerability.
- **Vulnerability Assessment:** The process to determine the sensitivity and adaptive capacity of components to the stresses of climate change impacts, and determine the overall vulnerability.

1 | Introduction to Climate Change Vulnerability Assessment and Adaption Planning

The City of Salem, Massachusetts is a coastal city with a rich and vibrant history. Founded in 1629, it is one of the oldest settlements in the United States. Throughout the City there are many unique cultural and historic resources that reflect Salem's maritime roots, literary importance, and the infamous witch trials of the late 17th century. Over Salem's nearly 400 year history, it has grown from a village to a city – filling in some coastal areas and wetlands to create more land area. Today, Salem is a diverse home to over 40,000 people, host to Salem State University, and proud of the many neighborhoods and businesses. Salem is a destination for tourists year round, but especially in October during the Haunted Happenings celebrations.

It is Salem's priority is to remain a vibrant, livable City that has a strong economy and continues to be a destination for visitors from around the world. For this reason, Salem recognizes the importance of being prepared for climate change and has produced this Climate Change Vulnerability Assessment and Adaptation Plan (Plan). The Plan investigates some of the most serious climate change impacts, the resulting stresses to different sectors in the City, and outlines project ideas to address some of the most critical issues. The goal for this plan is to identify immediate, actionable adaptation priorities, and incorporate these into existing and future projects and policies. This will make Salem a more resilient City and a great place to live, work, and visit for years to come.

Figure 1. Maps of Salem, Massachusetts: 1872 and today.



ROLE OF LOCAL GOVERNMENT IN CLIMATE CHANGE ADAPTATION PLANNING

Climate change adaptation efforts are effective at a regional and community scale. Impacts from climate change are place-based and typically affect the infrastructure and services that municipalities are responsible for providing. Local governments also have the tools to begin the adaptation processes as they are responsible for planning, codes, standards, and emergency responses. In addition, local governments invest in capital projects and programs that will serve the community over the long term. Incorporating climate change into these local government actions may also save money in the long term. An independent study found that for every $1 spent on hazard mitigation by the Federal Emergency Management Agency (FEMA), it saves $4 in future spending for disaster recovery.[3] These findings may reflect the magnitude of savings a local government could realize by proactively planning for climate change rather than reactively responding after an event.

CLIMATE CHANGE ADAPTATION PLANNING IN SALEM

Climate change adaptation planning is a relatively new field that pulls from the traditions of asset management, risk assessments, and scenario-based decision making. It is based on the latest climate science available. ICLEI - Local Governments for Sustainability have been on the forefront of climate change adaptation planning for governments of all sizes. This Plan is informed by the ICLEI approach in *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments.*[4] The general steps of Salem's Plan are the following:

1. **Determine Future Climate Change Impacts:** Based on the latest scientific information, identify potential future climate change scenarios, specific climate change impacts that are likely for Salem, and how far into the future the City will plan for each impact.
2. **Identify Affected Sectors:** Identify the sectors to include in the Plan and gather information on the existing conditions and operations.
3. **Conduct Vulnerability Assessment:** Determine the sensitivity and adaptive capacity of components to the stresses from climate change impacts, and determine the overall vulnerability.
4. **Prioritize Vulnerabilities:** The purpose is to prioritize the vulnerabilities to inform future actions. There are two steps to this process, 1) conduct a risk assessment and 2) prioritize based on evaluation criteria that incorporate the City's particular opportunities and concerns.
5. **Develop Adaptation Strategies:** Adaptation strategies are projects to decrease the vulnerability of components to the stresses from climate change impacts. They are designed to be incorporated within existing and future projects to decrease the vulnerability of Salem to climate change. They are created for priority vulnerabilities.
6. **Publish Adaptation Plan:** Publish the findings of the first five steps so it may be incorporated into existing and future projects and plans.

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[3] National Institute of Building Sciences. 2005. Natural Hazard Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities. Accessed November 10, 2014 at http://www.preventionweb.net/english/professional/publications/v.php?id=1087
[4] ICLEI: Local Governments for Sustainability. 2007. Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments. Accessed November 10, 2014 at: http://www.icleiusa.org/action-center/planning/adaptation-guidebook

Stakeholder engagement occurs at each step to create a strong Plan. More information on each of these steps is included throughout this Plan and in the attached Appendices.

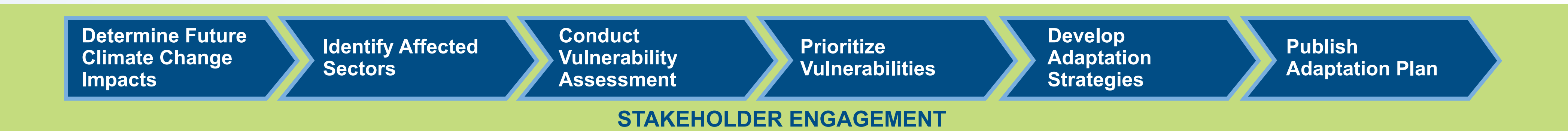
A COLLABORATIVE APPROACH

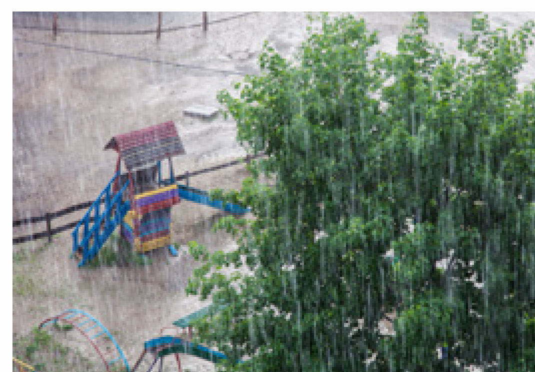
The Climate Change Vulnerability Assessment and Adaptation Plan was directed by the Department of Planning and Community Development and included an Advisory Working Group committee that was involved in the decision making process. The Working Group members represented some key organizations that are already involved in environmental efforts in Salem. In addition, a team of subject matter experts comprised of climate scientists, engineers, and planners executed the technical work involved in creating this Plan.

During each major step of the development of the Plan, representatives from different City departments were consulted. The input they provided was invaluable, especially for conducting the vulnerability assessment and prioritizing the vulnerabilities. These members of City staff will be crucial to implementing this Plan, with the support from the City Council and the Mayor.

This work was also presented to the public on December 15, 2014 at the Salem Five Community Room. The City welcomes input from its citizens and businesses as elements of this Plan are incorporated into existing and future projects and policies.

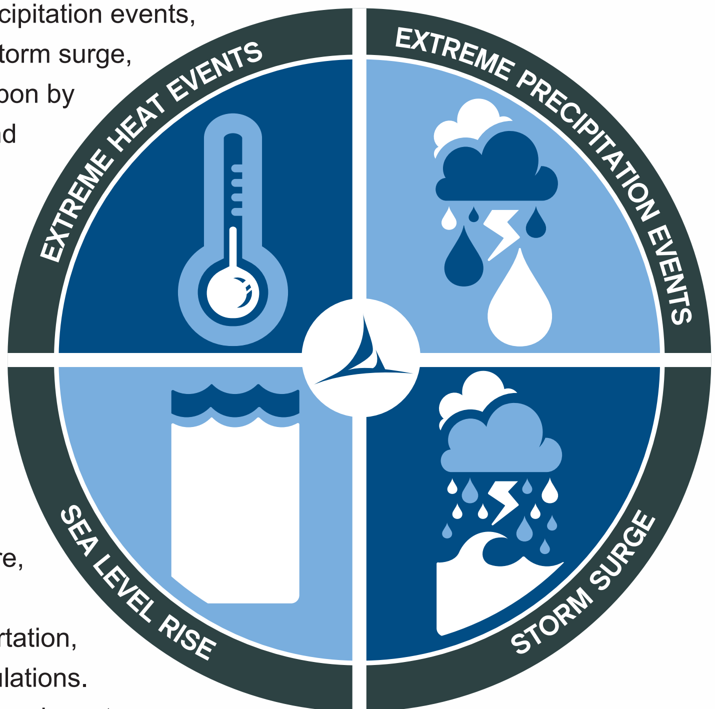
Figure 2. Flowchart of Salem's Climate Change Adaptation Plan Process.





A FOCUSED EFFORT

The scope of any climate change adaptation plan has the potential to be vast given the number of possible climate change impacts and their wide reaching effects throughout a city. This Plan is intentionally designed to focus on four of the most critical climate change impacts on six sectors in the City, and to prioritize the vulnerabilities to help inform which actions will give the greatest benefit for Salem. The four key climate change impacts are extreme heat events, extreme precipitation events, sea level rise, and storm surge, and were decided upon by the City of Salem and the Working Group. They are described further in the following sections of this Plan and in Appendix A.



The six sectors assessed in this Plan are critical building infrastructure, water, energy, stormwater, transportation, and vulnerable populations. The components of each sector are shown in more detail in Table 1.

Some of these components are outside of the control of the City and may require coordination and partnerships with other towns, utilities, state agencies, organizations, and the private sector. However, it is important to identify vulnerable, stressed components as part of this Plan because climate change will affect all aspects in these sectors, not only those the City has full control over. Practical coordination and partnerships are specifically noted in the vulnerability assessment (Appendix B) and the adaptation strategies (Appendix C), and are a key piece of any adaptation plan.

Table 1. Sectors Included in the Vulnerability Assessment and Adaptation Plan

SECTOR	COMPONENTS (ITEMS WITHIN A SECTOR)
Critical Building Infrastructure	• Critical City Facilities: Department of Public Works facility, South Essex Sewerage District, City Hall, recreational facilities • Emergency Facilities: Police, fire, hospitals, schools, • Historical and culturally significant buildings and areas • Salem State University • Seawalls • Tide gates
Water	• Plants, pumping stations, supply, distribution
Energy	• Electricity supply, transmission and distribution equipment, power lines, substations • Natural gas supply, transmission and distribution lines • Liquefied natural gas storage (LNG) • Renewable energy installations • Emergency back-up power • Streetlights
Stormwater	• Stormwater pipes, drainage areas, pump stations, discharge locations
Transportation	• Roadways, rail, bus lines, ferry service, sidewalks, bike paths
Vulnerable Populations	• Disproportionally impacted people within the City, including: elderly, children, low-income, homeless, disabled, non-native English speakers

2 | Climate Change Impacts in Salem, Massachusetts

INTRODUCTION TO CLIMATE CHANGE

Climate scientists around the world agree that the earth's climate system is warming at an unprecedented rate. Globally, this will result in warming air and water temperatures, rising sea levels, changes in precipitation patterns, changes in storm intensity and frequency. Climate change is a global issue, but the effects of it are experienced differently in each region[5].

As a consequence of climate change, planning for the future using historical observations may no longer be valid. Therefore, the approach presented here focuses on quantifying the future changes in climate, as projected by the best available science, to provide for more robust planning decision support.

In Massachusetts, the Executive Office of Energy and Environmental Affairs' Climate Change Adaptation Report (MA Report) summarizes the projected climate change impacts in the Commonwealth. These include increased annual and seasonal temperatures; changes in annual and seasonal precipitation; more frequent droughts; increases in intensity, duration, and frequency of extreme storms; sea level rise, and changes in the timing of peak stream flow.[6] The MA report is considered by policy-makers to be the current standard for planning-level climate change projections in the Commonwealth. It uses data from the International Panel on Climate Change (IPCC) and other peer-reviewed scientific climate change projections while employing the standard practice of comparing current conditions to a range of both mid-century conditions and end of century conditions[5]. The MA report serves as a benchmark for our Salem-specific analyses.

CLIMATE CHANGE IMPACTS IN SALEM, MASSACHUSETTS

The City focused on key climate change impacts that are considered most likely to have significant consequences for Salem. Today, many areas in Salem are prone to serious flooding and the City invests heavily in management of flood risks. There have been six major flooding events since 1996. However, only one of the City's flood hazard management initiatives to date has considered the impacts of climate change. When climate change is taken into account, flooding in the City is expected to get worse. For this reason, extreme precipitation events, sea level rise, and storm surge were chosen as key climate change impacts to incorporate into this Plan. In addition, extreme heat events were included as a key climate change impact because many areas in the Northeast are not currently equipped to handle frequent temperatures of this degree and scientists are confident that these events will occur more often.

The magnitude of these climate change impacts were determined using a technical approach that incorporates elements of the MA Report, the IPCC Fourth and Fifth Assessment Reports, and several other climate change reports, plans, and scientific papers. The methodology was designed to be consistent with the leading regional and international standards, while incorporating the latest scientific research. The detailed methodology may be found in Appendix A to this report.

Scientists present climate change impacts in ranges of low to high projections. They are reflective of the potential concentration of greenhouse gas (GHG) emissions in the atmosphere, based on different social, economic, and technical trends. This Plan focuses on the mid-range climate change projections; however the high and low projections are also included in Appendix A to provide context for users of this Plan. This is a practical approach for planning purposes. The details of the key climate change impacts for Salem, MA are below:

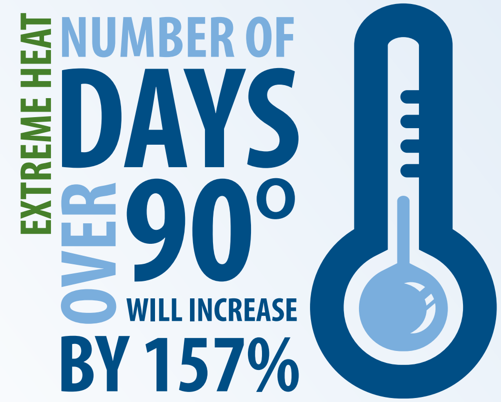
[5]International Panel on Climate Change (IPCC), 2013. Summary for Policymakers. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the International Panel on Climate Change.
[6]Massachusetts Executive Office of Energy and Environmental Affairs. 2011. *Massachusetts Climate Change Adaptation Report.*

MORE EVENTS LIKE THE MOTHER'S DAY STORM AND WINTER STORM NEMO

The Mother's Day Storm in 2006 dumped more than 10 inches of rain over three days in Salem and caused serious, localized flooding. This storm is considered a 3-day "100-year storm", which does not mean that it will occur once in 100 years, but rather, have a one percent chance of occurring in any given year.

In February of 2013, Winter Storm Nemo dropped over two feet of snow and produced hurricane-force winds. Nemo effectively shut down the Commonwealth, including Salem, for days.

By 2050, with climate change, Salem will likely experience rain or snowfall like these more often.



Extreme Heat Events: Extreme heat events are defined as days in which the daily maximum temperature is equal to or above 90˚F. The mid-range predictions from the climate models show that Salem may experience about 18 days per year by 2050, an increase of 11 days per year. These conditions will place a high demand on the electricity utilities, risking more frequent power outages. There are also air quality implications leading to health concerns for the people of Salem.

Extreme Precipitation Events: Today's 100-year 24-hour storm – a storm has a one percent chance of occurring in any given year – is a storm that produces 8.76 inches of precipitation over a 24-hour period in Salem. It is known to cause flooding in the City today. With climate change, the mid-range predictions show that this magnitude of storm is expected to occur more frequently, making it a 77-year storm by 2050. While this magnitude of storm has been selected to represent extreme precipitation events for this Plan, precipitation events in general will increase in the City.

Sea Level Rise: Sea level rise is caused by local coastal subsidence (sinking of the land) coupled with the expansion of ocean water caused by increased temperatures and the melting of land ice in places such as Greenland and Antarctica. The National Oceanic and Atmospheric Administration (NOAA) currently reports Mean Higher High Water (MHHW) for the Boston[7] station as 4.76 feet NAVD88. With the mid-range climate change, MHHW is expected to be 9.03 feet NAVD88 by 2100. This is an increase of 4.23 feet NAVD88 from the 1998 baseline.

Storm Surge: Storm surge is the rise of water above tide levels that occurs during storms. Higher sea levels can increase the severity of coastal inundation on a regular basis and during storms. To evaluate the potential risk to Salem under storm conditions, the return period stillwater elevations from a 100-year storm event (one percent annual chance event) were considered. These are today's storm surge events, but coupled with the predicted mid-range sea level rise scenario, storm surge is expected to be 13.03 feet NAVD88 by 2100.

Extreme precipitation events and extreme heat events estimates were determined for the year 2050, consistent with the MA Report, and reflecting the City of Salem's desire for this Plan to identify immediate, actionable adaptation priorities. However, it was found that climate model projections for sea level rise and storm surge are more useful for a 2100 planning year. This is because the models show very similar projections in the nearer term and show more pronounced ranges further out in time.

WHAT IS "SEA LEVEL"?

The level of the ocean changes daily as the tide comes in and goes out. Everyone is familiar with the twice daily high-tides and low-tides. The height of these tides changes throughout year with moon cycles and can become higher than normal during a storm. Salem already experiences some tidal flooding, so how can we measure how high the ocean will be in 2100 in Salem after sea level rise and during a storm event?

In this Plan, Mean Higher High Water (MHHW) and storm surge are adjusted to future sea level rise in 2100. MHHW is the average of the higher of the two high water levels of each tidal day over a 19-year period as established by the NOAA. When sea level rise is added to the current MHHW, it means that Salem could expect to see a high tide of over nine feet NAVD88 once per day. During a storm event at high tide, the ocean level could be over 13 feet NAVD88[8]. This is an increase in sea levels of four feet NAVD88 from what is seen today in Salem.

[8]NAVD88 is the North American Vertical Datum of 1988. It is a fixed vertical reference elevation determined by the U.S. Geological Survey to establish a common base point for measuring the height. It is used for many measurements, including sea levels and mountain heights. The sea level rise and storm surge maps in Appendix D show the MHHW based on NAVD88 expected in 2100.

[7]The City of Salem lacks established tidal datums - or recording stations - by NOAA, and the closest established tidal datums are for Boston (Station 8443970)

3 | Vulnerability Assessment and Prioritization Methodology

VULNERABILITY ASSESSMENT

The purpose of the vulnerability assessment and prioritization is to determine the top vulnerabilities for the City and to inform decision making around priority adaptation strategies for implementation. Once the sectors and the climate change impacts were established by the City and the Working Group, the next step was to determine what the vulnerable, stressed components are within each sector. There are two main sources that informed the vulnerability assessment: 1) interviews with City staff to gather institutional knowledge and 2) maps of the components and the climate change impacts.

INSTITUTIONAL KNOWLEDGE

The City staff have a wealth of institutional knowledge and work every day to ensure the components in each of the sectors they are responsible for work as they should to keep the City functioning effectively. As such, City staff are the logical starting point to understand how different sectors may be impacted by climate change. City staff from multiple departments participated in a workshop to discuss stresses they are already observing on City components, the seasonal variability of the stresses, and how the future climate change impacts may change those stresses. Staff were also asked about how well the components responded to current stresses and how capable they may be to respond to future climate change impacts.

MAPPING THE SECTOR COMPONENTS AND THE FUTURE FLOODING LEVELS

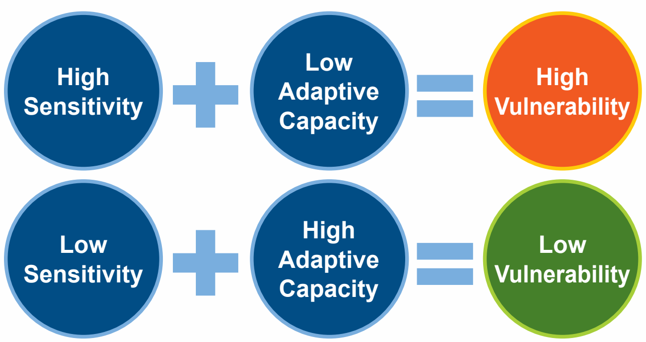
The second step is to show geographically where future flooding levels may be within Salem. There are three separate types of maps to show future flooding

levels due to 1) extreme precipitation events, 2) sea level rise, and 3) storm surge (including sea level rise). A map for each of these climate change impacts overlaid onto the components of each sector located in Salem – with the exception of vulnerable populations – who may be found throughout the City.

DETERMINING THE VULNERABILITY

Technical experts in each sector from CDM Smith used the information from City staff interviews and the maps to conduct the vulnerability assessment. “Vulnerability” is the susceptibility of the sector being studied to harm from the stress of a climate change impact. It is a function of the sensitivity to climate change and the adaptive capacity to climate changes. For Salem, the sensitivity and adaptive capacity of each component is ranked on a five point scale from low (1) to high (5). A “high” sensitivity score indicates that the component is very susceptible a climate change impact. Conversely, a “high” adaptive capacity score indicates that the component is not susceptible, but is resilient, to a climate change impact. This concept is shown in Figure 3 below.

Figure 3. Representation of the Vulnerability Determination

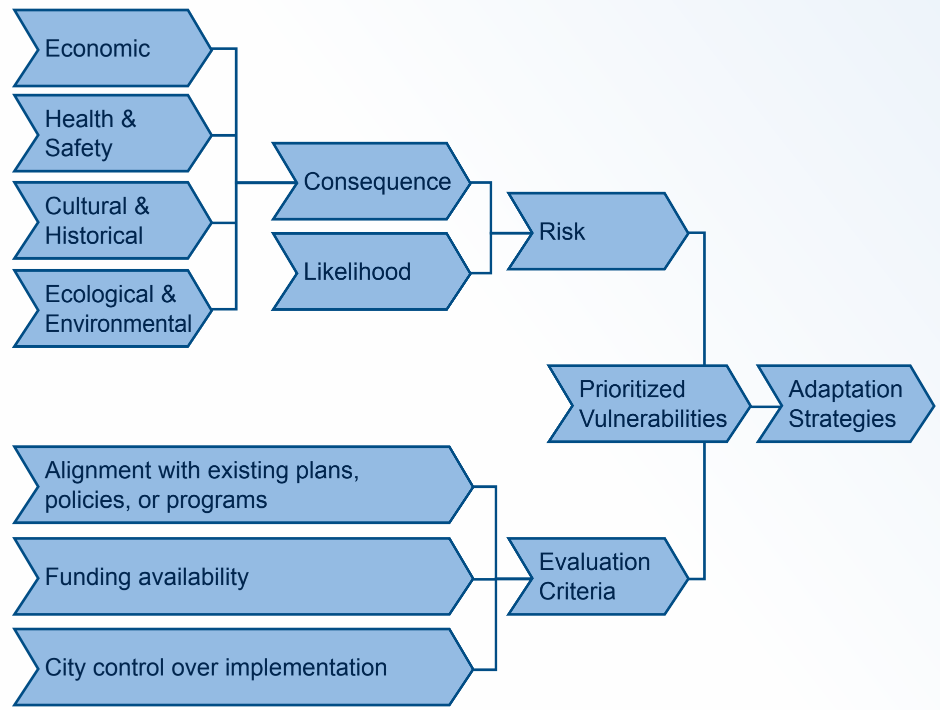


The results of the vulnerability assessment show that there are 104 vulnerable, stressed components in the City of Salem. One third of these have a high or medium-high vulnerability to the climate change impact. There are a number of common themes throughout the sectors and impacts, most notably flooding. As a result, there is much overlap because two or more different climate change impacts often yield the same types of stresses impacting the same component. For example, extreme precipitation and storm surge both can cause flooding that stresses the stormwater drainage system. The full vulnerability assessment is available in Appendix B.

PRIORITIZING VULNERABILITIES

Multiple adaptation strategies may be developed for any given vulnerability to increase the adaptive capacity. For this reason, the City chose to prioritize which vulnerabilities to develop adaptation strategies for in order to keep this Plan focused and meaningful. There two ways that a vulnerable, stressed component may become prioritized: 1) based on the results of a risk assessment, it has a high risk and high vulnerability to the climate change impact or 2) it is aligned with specific evaluation criteria that incorporates the City’s particular opportunities and concerns. The prioritization process is graphically represented below in Figure 4.

Figure 4. Representation of the Priority Vulnerability Determination



RISK ASSESSMENT

The risk of a climate change impact and stress to the component is based on the economic, health and safety, cultural and historical, and ecological and environmental consequences as well as the likelihood that the climate change impact will occur.

CONSEQUENCE

Each of the four types of consequences is ranked on a five point scale from low (1) to high (5) using the following definitions to provide a general scope of the consequences:

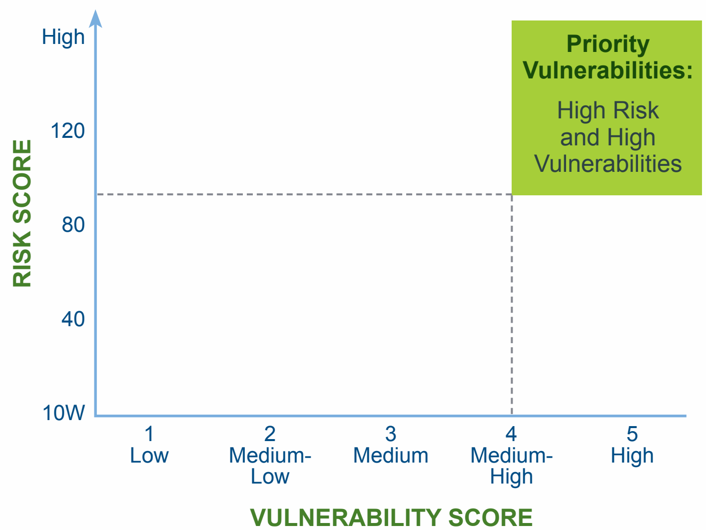
- **Economic:** the known and estimated consequences both to the City government's finances and city-wide economic consequences. On the City government side, they include changes to city-owned property, tax base/income, and costs for capital and maintenance projects. City-wide economic consequences include change in business revenues, private property capital and maintenance projects, and changes in tourism spending.
- **Health and Safety:** the known and estimated impacts to the well-being of the people who live, work, and visit Salem in both day-to-day public health and emergency situations.
- **Cultural and Historical:** the known and estimated impacts to buildings and areas that hold cultural or historical significance; these are the areas that define Salem's identity.
- **Ecological and Environmental:** the known and estimated consequences that cause alterations to natural resources, habitats, organisms, and open spaces.

LIKELIHOOD

The likelihood is the probability of the climate change impact occurring, based on the latest IPCC report[2]. It includes the type, amount, quality, and consistency of evidence that a given climate change impact will occur. There are ten IPCC "Level of Confidence" rankings that a given climate change impact will occur, so for the purposes of the risk assessment, each of the four climate change impact occurrence probabilities are scored on a ten point scale from extremely unlikely to occur (1) to virtually certain to occur (10).

If the stress to the component has both a high vulnerability score and a high risk score, it is considered a priority vulnerability. This concept is show in Figure 5 below. A highly vulnerable and high risk situation indicates that addressing that particular issue may be critical to increasing the resiliency of the City. The full risk assessment is available in Appendix B.

Figure 5. Representation of High Vulnerability and High Risk to Climate Change



EVALUATION CRITERIA

The second method for prioritizing vulnerabilities is applying the City's particular opportunities and concerns – also known as the evaluation criteria. If a particular vulnerability is not ranked as high risk and high vulnerability, but instead meets the evaluation criteria below, it is considered priority vulnerability. The evaluation criteria for Salem are:

- Alignment with existing plans, policies, or programs: the City has current plans, policies, or programs related to the vulnerable component, and a related adaptation strategy would further existing City goals.
- Funding availability: known outside funding is available (especially through grants) at the time of the evaluation.
- City control over implementation: the City has a high level (if not total control) over the component, and therefore can implement an adaptation strategy with fewer institutional barriers.

THE PRIORITIZED VULNERABILITIES

The results of the risk assessment and the application of the evaluation criteria show there are 17 priority vulnerabilities. These vulnerable, stressed components are considered the most critical for Salem to address to increase the City's resiliency to climate change. Adaptation strategies for these 17 are included in this Plan or are currently underway.

Table 2. List of the Prioritized Vulnerabilities

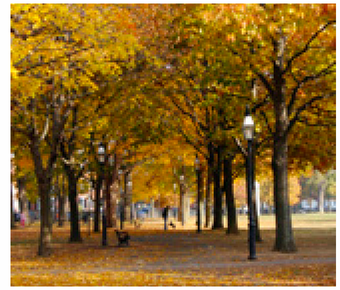
Critical Building Infrastructure · Transportation · Water · Stormwater · Vulnerable Populations · Energy

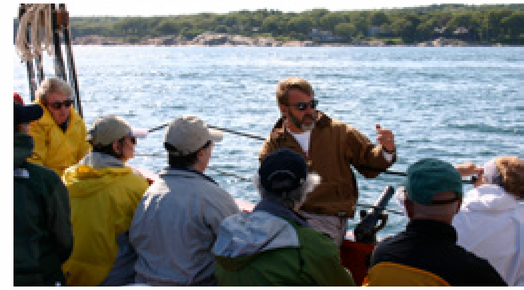
VULNERABLE, STRESSED COMPONENTS	CLIMATE CHANGE IMPACTS				SECTOR IMPACTED
A: Ineffective seawalls			✓	✓	Critical Building Infrastructure
B: Ineffective tide gates, inadequate tide gates at Lafayette Street		✓	✓	✓	Critical Building Infrastructure, Stormwater
C: Insufficient capacity and drainage in the stormwater system to remove water from streets and neighborhoods		✓	✓	✓	Stormwater
D: Flooding and disrupted operation of pump stations		✓	✓	✓	Stormwater
E: Flooding of the transportation network infrastructure from storm drain overflow and overwhelmed seawalls		✓		✓	Transportation
F: Flooding of evacuation routes		✓	✓	✓	Vulnerable Populations
G: Loss of power at critical City buildings	✓				Energy
H: Backup (emergency) power failure at critical City facilities		✓	✓	✓	Critical Building Infrastructure
I: Downed power lines		✓			Energy
J: Critical emergency preparedness communication	✓	✓		✓	Vulnerable Populations
K: Poor air quality	✓				Vulnerable Populations
L: Property damage or loss of emergency and critical City facilities		✓	✓	✓	Critical Building Infrastructure
M: Property damage or loss at Salem State University				✓	Critical Building Infrastructure
N: Flooding of emergency response facilities		✓		✓	Critical Building Infrastructure
O: Property damage or loss of historic properties		✓	✓	✓	Critical Building Infrastructure
P: Flooding of residential areas			✓	✓	Vulnerable Populations
Q: Overtopping of Rosie's Pond[9]		✓		✓	Stormwater

The details of this methodology and the results of the risk assessment and evaluation criteria may be found in Appendix B.

[9] Salem has begun a climate change adaptation project to address the flooding issues at Rosie's Pond. See the Case Study on page 24.

4 | Adaptation Strategies to Address the Priority Vulnerabilities





As with the vulnerability assessment, there is much overlap in the adaptation strategies because one strategy may address several of the vulnerable, stressed components within the City. For this plan, 43 strategies were developed to address 16 of the prioritized vulnerabilities[9]. They are designed to be incorporated within existing and future projects to decrease the vulnerability of Salem to climate change. The following sections summarize each of the prioritized vulnerabilities from Table 2 and outlines the adaptation strategies that may help alleviate the vulnerable, stressed components.

The full details for the 43 adaptation strategies are included in Appendix C. They give a description of the adaptation strategy and show the Primary City Department(s) or Staff that may be responsible for planning and implementing these strategies within existing and future projects. Each strategy will require the support from the Mayor's Office and City Council to move forward. In addition, these adaptation strategies may be most effectively implemented with additional partnerships. These partnerships are identified for each strategy, but may include: hospitals, the fire department, the police department, FEMA, MEMA, neighboring cities, EPA, DEP, DOER, MAPC, MBTA, CZM, National Grid, Salem Sound Coastwatch, North Shore Community Development Coalition, Salem Alliance for the Environment, private property owners, the Conservation Commission, and others.

CLIMATE CHANGE ADAPTATION IN ACTION AT ROSIE'S POND

The City of Salem was awarded $200,000 in grant funding from the MA Office of Coastal Zone Management for the design and permitting of a flood control project for the Rosie's Pond neighborhood. The redesign will account for the climate change impact projections to increase the neighborhood's ability to endure stresses associated flooding from extreme precipitation events, sea level rise, and storm surge. The project is expected to provide protection to 12.5 acres of residential property, 40 residential structures, and four roads. Salem Sound Coastwatch is a partner for this project, and will be providing public outreach, including StormSmart workshop presentations.

Table 3. Adaptation Strategies and the Prioritized Vulnerabilities they Address

	ADAPTATION STRATEGIES \ PRIORITY VULNERABILITIES	Ineffective seawalls	Ineffective tide gates, Inadequate tide gates at Lafayette Street	Insufficient capacity and drainage in the stormwater system to remove water from streets and neighborhoods	Flooding and disrupted operation of pump stations	Flooding of the transportation network infrastructure from storm drain overflow and overwhelmed seawalls	Flooding of evacuation routes	Loss of power at critical city buildings	Backup power failure at critical city facilities	Downed power lines	Critical emergency preparedness communication	Poor air quality	Property damage or loss of emergency and critical city facilities	Property damage or loss at Salem State University	Flooding of emergency response facilities	Property damage or loss of historic properties	Flooding of residential areas	Overtopping of Rosie's Pond*
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Seawall Repair: Installation of Drainage Features	✓																
2	Seawall Repair: Increase Crest/Top of Structure Height	✓																
3	Seawall Repair: Installation of Structural Toe Protection	✓																
4	Seawall Repair: Installation of Recurved Cap Systems	✓																
5	Seawall Repair: Bulkhead Materials	✓																
6	Seawall Repair: Living Shorelines	✓																
7	Seawall Repair: Beach Nourishment	✓																
8	Installation/Upgrades of Tide Gates		✓	✓	✓													
9	Tide Gate Alternative: Duckbill/Tide Flex		✓	✓	✓													
10	Tide Gate Alternative: Buoyant or Self-Regulating Structures		✓	✓	✓													
11	Water Level Monitoring and Alert System		✓															
12	Conduct a Drainage Study			✓	✓	✓												
13	Enlarging and Supplementing the Drainage System			✓		✓												
14	Installation of Above Ground or Subsurface Stormwater Storage Systems			✓	✓	✓												
15	Installation/Upgrade of Pump Stations			✓	✓	✓												
16	Installation of Deployable Floodwalls			✓	✓	✓												
17	Green Infrastructure - Bioretention/Street Planters			✓		✓												
18	Green Infrastructure - Green Roofs			✓		✓												
19	Green Infrastructure - Permeable Pavements			✓		✓												
20	Infrastructure Design and Materials in the Transportation Network			✓		✓	✓											
21	Elevate or Relocate Transportation Infrastructure			✓		✓	✓											

✓ Indicates that the adaptation strategy addresses the prioritized vulnerability

* Salem is already undertaking climate change adaptation measures at Rosie's Pond

Table 3. Adaptation Strategies and the Prioritized Vulnerabilities they Address (contined)

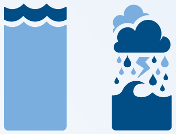
	PRIORITY VULNERABILITIES	Ineffective seawalls	Ineffective tide gates, Inadequate tide gates at Lafayette Street	Insufficient capacity and drainage in the stormwater system to remove water from streets and neighborhoods	Flooding and disrupted operation of pump stations	Flooding of the transportation network infrastructure from storm drain overflow and overwhelmed seawalls	Flooding of evacuation routes	Loss of power at critical city buildings	Backup power failure at critical city facilities	Downed power lines	Critical emergency preparedness communication	Poor air quality	Property damage or loss of emergency and critical city facilities	Property damage or loss at Salem State University	Flooding of emergency response facilities	Property damage or loss of historic properties	Flooding of residential areas	Overtopping of Rosie's Pond*
	ADAPTATION STRATEGIES	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**
22	Increase Energy Efficiency in Critical City Buildings							✓										
23	Install and Elevate Backup Power Sources							✓	✓									
24	Install Renewable Energy Backup Power Sources								✓									
25	Bury the Electrical Distribution System									✓								
26	Maintain Overhead Distribution System									✓								
27	Improve Utility and City Communication							✓		✓								
28	Increase Awareness of Climate Change Risks and Safety										✓							
29	Assist Vulnerable Populations										✓							
30	Community Health Impact Assessment and Public Outreach during Poor Air Quality Events											✓						
31	Redundancy of Evacuation Routes						✓											
32	Review Local Public Health Care Sectors Readiness											✓						
33	Promote and Expand Urban Forestry											✓						
34	Evaluation of Buildings for Flood Proofing Opportunities												✓	✓	✓	✓	✓	
35	Development of New Critical Use Facilities Outside Future Flooding Levels												✓	✓	✓	✓		
36	Re-Development Existing Facilities Outside Future Flooding Levels												✓	✓	✓	✓	✓	
37	Elevate the Building												✓	✓	✓	✓		
38	Elevate a Building's Critical Uses												✓	✓	✓	✓	✓	
39	Adopt and Enforce Updated Building Codes												✓	✓	✓	✓		
40	Limit or Restrict Development in Future Flooding Areas												✓	✓	✓	✓		
41	Improve Land Use Planning and Regulations												✓	✓	✓	✓		
42	Flood Proof Buildings												✓	✓	✓	✓	✓	
43	Perform Wharf Area Water Study												✓					

✓ Indicates that the adaptation strategy addresses the prioritized vulnerability

* Salem is already undertaking climate change adaptation measures at Rosie's Pond

The seawalls that protect the coast of Salem are aging and some have significant damage. They currently overtop at some locations in the City. Sea level rise and storm surge will only further the damage and the seawalls will become inadequate in the future. Improvements to the seawalls are necessary to prevent flooding in the surrounding areas.

CLIMATE IMPACT(S)



APPLICABLE ADAPTATION STRATEGIES

1 | **Installation of drainage features** to prevent structural damage to seawalls from stormwater. If the area is subject to ponding caused by stormwater runoff and/or soil erosion at the top of the structure, consider improving drainage systems to alleviate hydrostatic pressure landward of the structure.

2 | **Increase the crest or top of the structure height** if the seawalls or revetment systems are “ineffective” because the crest elevation (or top) of the coastal structure is too low to resist storm surge inundation to upland areas. A variable crest height along the seawall system may make areas with lower crest heights vulnerable to flooding.

3 | **Installation of structural toe protection** to stabilize the seawall where there is wave action or erosion. The stabilization depends on its total weight in cross-section, location seaward of the shoreline, cap elevation, underlying geology, and the degree to which it is used to retain the upland bluff or bank. Adding a robust toe stone and/or stone aprons to prevent sliding and sediment removal at the bottom of the structure.

4 | **Installation of recurved cap systems** for seawalls and the revetments in coastal areas to minimize overtopping. Potential waves impacting the structure may cause an upward force on the structure and proper design of the foundation and footing is equally important.

5 | **Use bulkhead materials** to repair seawalls. Deteriorating and corroding bulkheads may be replaced with marine-grade fiber-reinforced polymer sheeting for steel bulkheads. The appropriate design should be considered for mooring piles, capping, patching, coating, or other protective measures of the bulkhead to prevent any degradation of the structure.

Seawall protecting a coastal highway (Florida Highway A1A, Flagler Beach)

Recurved seawall and toe scour protection at Deer Island WWTP, Winthrop, MA.

6 | **Living Shoreline** installation to increase the resilience of seawalls to undermining and failure after episodes of storm surge and long-term effects of sea level rise. They are alternatives or in some cases, an enhancement, to bulkheads, seawalls, or revetments that provide for a stable shoreline resistant to erosion. As a “hybrid” or “blended” approach, living shorelines may be hardened structures that are rehabilitated to introduce a naturalized edge. Living shorelines use plants, sand/soil, and the limited use of hard structures to provide shoreline protection. They preserve, create, or enhance coastal habitats and improve water quality, and reduce sedimentation.

7 | **Beach nourishment** and rehabilitation as a replacement for failing seawalls, where applicable. It could be used to maintain a range of beach widths to prevent overtopping of seawalls and near shore beach erosion.

Fish Pier, City of Newburyport, 2014.

ENHANCING SALEM'S NATURAL RESOURCES

On December 1st, 2014, the City was awarded by the Office of Coastal Zone Management a $75,000 grant to conduct a site assessment and an engineering study for coastal green infrastructure implementation in Salem. The project will explore and research green infrastructure implementation as a whole in Salem. This effort will further identify key areas that experience flooding or degradation to vulnerable property and infrastructure. Salem Sound Coastwatch and an engineering firm will assist with the project.

Potential green infrastructure strategies that will be assessed for feasibility include: 1) fringing tidal marsh restoration, 2) natural oyster or mussel reef creation, enhancement, or restoration; 3) engineering with coir rolls, natural fiber blankets, and other organic, biodegradable materials combined with planting/re-vegetation; and 4) natural enhancement of existing coastal structures.

Winthrop Beach, MA after beach nourishment.

CLIMATE IMPACT(S)

The tide gates at the South and Forrest Rivers and Lafayette Street are structures that prevent backflow of tidal water or storm surge into creeks, rivers, and drainage systems. Tide gates close during incoming tides to prevent water from traveling into low-lying areas, but they also keep flood water from draining into the harbor or ocean. The tide gates are aging and in need of repair; they are generally ineffective at preventing flooding. Today at Lafayette Street, high tides coupled with significant precipitation events results in flooding, so the tide gate is closed prior to storms. The Forest River tide gate is operated manually and long-term reliability of the tide gates is in question. With climate change, the tide gates will need to be used more frequently, resulting in more maintenance and damage.

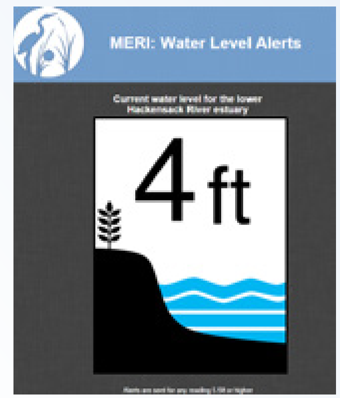
APPLICABLE ADAPTATION STRATEGIES

8 | **Installation or updates of tide gates** to seal a pipe at the end of the gate and prevent water from flowing backwards through the drainage system, while still allowing water to drain. Tide gates may be added to outfalls to prevent high tides, sea level rise and storm surges from entering the drainage system.

9 | **Duckbill/tide flex** design as a tide gate alternative. The duck bill technology, or tide flex, operates automatically based on the flow or water level. Duckbill tide gates are self-cleaning when debris is caught in the opening. This design is considered to be reliable and low maintenance.

10 | **Buoyant or self-regulation structures** as a tide gate alternative. The buoyant front flap tide gate operates automatically based on the flow or water level. These tide gate solutions allow for self-regulation of flow in and out of low-lying areas. The floats at the top of the self-regulating tide gate may be adjusted in height to fit site-specific conditions, which could be closed during daily tides, during extreme events, or as a managed adaptation to sea level rise.

11 | **Water level monitoring and alert system** are tide-gate sensors that enable real-time operations and field adjustments as needed. The tide gate sensors and tide gages provide real-time data, in the form of an early warning system for flood prediction and alert facilities, municipalities, and the public if water levels reach a certain elevation. This measure is also effective in alerting engineers or the public works department to target certain areas for flood proofing measures (sand bags, etc.).



NJ Meadowlands Research Institute water level alert website.

C | Insufficient Capacity and Drainage in the Stormwater System to Remove Water from Streets and Neighborhoods

The existing drainage system cannot accommodate extreme precipitation events coupled with a storm surge. It could result in flooding in several of the neighborhoods along the coast and the rivers. In the future, the storm surge will extend further into neighborhoods and commercial areas in the City. When coupled with an extreme precipitation event, even more localized flooding is possible because the stormwater cannot be conveyed to the ocean.

CLIMATE IMPACT(S)

APPLICABLE ADAPTATION STRATEGIES

8 | **Installation or updates of tide gates** to seal a pipe at the end of the gate and prevent water from flowing backwards through the drainage system, while still allowing water to drain. Tide gates may be added to outfalls to prevent high tides, sea level rise and storm surges from entering the drainage system.

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11 | **Conduct a drainage study** to assess existing and future conditions and to determine which drainage mitigation measure may work best to reduce flooding in the City. The model for existing drainage system would determine the current capacity of the stormwater system for extreme precipitation events, sea level rise, and storm surge conditions and identify the extent and degree of flooding in the City.

13 | **Enlarging and supplementing the drainage system.** Replacing undersized pipes with those that have more capacity allows better flow of water to discharge points. Another option is to add additional pipes parallel to the existing drainage system to provide additional capacity in the system. The appropriate size of these pipes is best determined from future conditions modeling performed in a drainage study.

14 | **Installation of above ground or subsurface stormwater storage systems** for the excess water flows that undersized pipes cannot handle. Water is stored and then released at a later point in time, when the precipitation event has passed.

15 | **Installation or upgrade of pump stations** to pump stormwater from areas where it may not be conveyed to the outfalls by gravity flow (generally low-lying areas).

An enlarged stormwater drainage system.

Rendering of subsurface storage in Worcester, MA.

16 | **Installation of deployable floodwalls**, which are temporary floodwalls that may quickly be erected at the sign of an impending storm. They consist of moveable posts and panels which are attached to permanent, in-ground foundations during storms for which flooding is a concern.

17 | **Install bioretention areas or street planters**, especially in highly impervious areas. A bioretention area is a shallow, vegetated basin that collects and absorbs runoff from rooftops, sidewalks, and streets, and may be installed in any unpaved space. A street planter box is a bioretention area with vertical walls and open or closed bottoms that collect and absorb runoff from sidewalks, parking lots, and streets. This is a “green infrastructure” option that is designed to mimic natural systems by absorbing and storing water; they are designed to manage the first inch of rainfall.

18 | **Convert to green roofs**, which are roofs that are covered with vegetation. They enable rainfall infiltration and evapotranspiration of stored water. Thus, they reduce the amount of runoff that a conventional stormwater system would be required to handle. This is a “green infrastructure” option that is designed to mimic natural systems by absorbing and storing water; they are designed to manage the first inch of rainfall.

19 | **Use permeable pavements** rather than traditional pavements. Permeable pavements are paved surfaces that infiltrate, treat, and/or store rainwater where it falls. Permeable pavements include pervious concrete, porous asphalt, and permeable interlocking pavers. This is a “green infrastructure” option that is designed to mimic natural systems by absorbing and storing water and to manage the first inch of rainfall.

20 | **Improve infrastructure design and materials in the transportation network** and use nonerodible and permeable base materials to prevent failure or collapse. Using these types of materials may protect the structural integrity of the roadways, bridges, and railbed support structures. Nonerodible materials include lean concrete base and cement treated base. Permeable materials include porous asphalt, pervious concrete, impermeable interlocking concrete pavement, grass and gravel pavers and may naturally treat stormwater

21 | **Elevate or relocate transportation infrastructure** to protect it from flooding. Elevating the infrastructure to avoid flooding may extend its service life. Relocating it out of flooding areas may maintain the structural integrity of the roadways, bridges, and railbed support structures. This may be particularly important for evacuation routes.

A green infrastructure containing a bioretention area.

A green roof in Ipswich, Massachusetts.

D | Flooding and Disrupted Operation of Pump Stations

Pump stations along the North River frequently flood and cause disruption. This is expected to increase with more extreme precipitation events, sea level rise, and storm surge. An increased frequency of flooding will require more maintenance and repair. Localized flooding will be exacerbated. Pump stations need to be "hardened" to minimize the risk of their flooding.

CLIMATE IMPACT(S)

APPLICABLE ADAPTATION STRATEGIES

8 | **Installation or updates of tide gates** to seal a pipe at the end of the gate and prevent water from flowing backwards through the drainage system, while still allowing water to drain. Tide gates may be added to outfalls to prevent high tides, sea level rise and storm surges from entering the drainage system.

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Twin tide gates Galilee Salt Marsh Restoration, Narragansett, RI.

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14 | **Installation of above ground or subsurface stormwater storage systems** for the excess water flows that undersized pipes cannot handle. Water is stored and then released at a later point in time, when the precipitation event has passed.

15 | **Installation or upgrade of pump stations** to pump stormwater from areas where it may not be conveyed to the outfalls by gravity flow (generally low-lying areas).

16 | **Installation of deployable floodwalls**, which are temporary floodwalls that may quickly be erected at the sign of an impending storm. They consist of moveable posts and panels which are attached to permanent, in-ground foundations during storms for which flooding is a concern.

E | Flooding of the Transportation Network Infrastructure from Storm Drain Overflow and Overwhelmed Seawalls

CLIMATE IMPACT(S)

Flooding from storm drain overflow and overwhelmed seawalls currently undermines the transportation network infrastructure. In the past, extreme snow and rain events have led to flooding of City streets and tunnels and the commuter rail. More frequent extreme precipitation events and storm surge exacerbate flooding in these areas and overwhelm the pumping capacity for tunnels. Access to Route 128 will be limited more frequently.

APPLICABLE ADAPTATION STRATEGIES

12 | **Conduct a drainage study** to assess existing and future conditions and to determine which drainage mitigation measure may work best to reduce flooding in the City. The model for existing drainage system would determine the current capacity of the stormwater system for extreme precipitation events, sea level rise, and storm surge conditions and identify the extent and degree of flooding in the City.

13 | **Enlarging and supplementing the drainage system.** Replacing undersized pipes with those that have more capacity allows better conveys the flow of water to discharge points. Another option is to add additional pipes parallel to the existing drainage system to provide additional capacity in the system. The appropriate size of these pipes is best determined from future conditions modeling performed in a drainage study.

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15 | **Installation or upgrade of pump stations** to pump stormwater from areas where it may not be conveyed to the outfalls by gravity flow (generally low-lying areas).

A view from the McCormack POCH's green roof.

16 | **Installation of deployable floodwalls** which are temporary floodwalls that may quickly be erected at the sign of an impending storm. They consist of moveable posts and panels which are attached to permanent, in-ground foundations during storms for which flooding is a concern.

17 | **Install bioretention areas or street planters**, especially in highly impervious areas. A bioretention area is a shallow, vegetated basin that collects and absorbs runoff from rooftops, sidewalks, and streets, and may be installed in any unpaved space. A street planter box is a bioretention area with vertical walls and open or closed bottoms that collect and absorb runoff from sidewalks, parking lots, and streets. This is a “green infrastructure” option that is designed to mimic natural systems by absorbing and storing water; they are designed to manage the first inch of rainfall.

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19 | **Use permeable pavements** rather than traditional pavement. Permeable pavements are paved surfaces that infiltrate, treat, and/or store rainwater where it falls. Permeable pavements include pervious concrete, porous asphalt, and permeable interlocking pavers. This is a "green infrastructure" option that is designed to mimic natural systems by absorbing and storing water and to manage the first inch of rainfall.

20 | **Improve infrastructure design and materials in the transportation network** and use nonerodible and permeable base materials to prevent failure or collapse. Using these types of materials may protect the structural integrity of the roadways, bridges, and railbed support structures. Nonerodible materials include lean concrete base and cement treated base. Permeable materials include porous asphalt, pervious concrete, impermeable interlocking concrete pavement, grass and gravel pavers and may naturally treat stormwater.

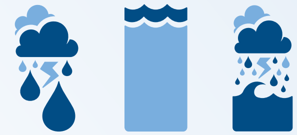
21 | **Elevate or relocate transportation infrastructure** to protect it from flooding. Elevating the infrastructure to avoid flooding may extend its service life. Relocating it out of flooding areas may maintain the structural integrity of the roadways, bridges, and railbed support structures. This may be particularly important for evacuation routes.

Permeable pavement and porous concrete sidewalks at the capital building in Harford CT.

King Tide at Juniper Cove, October 2011

Several major streets out of Salem experience flooding during major storm events, including Route 1A, Lafayette Street, and Kernwood Street. These areas may expect an increase in flooding due to climate change. While some evacuation routes are not expected flood, they may experience increased congestion, causing evacuation delays.

CLIMATE IMPACT(S)



APPLICABLE ADAPTATION STRATEGIES

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31 | **Increase the redundancy of evacuation routes** within the transportation network in and around Salem. Redundancy allows the transportation network to compensate for losses by ensuring the functionality remains even when network segments are damaged or destroyed. Identifying and addressing transportation bottlenecks within the system is critical.

Ross Sterling Avenue was raised to protect the MSB to the level of the base flood.

G | Loss of Power at Critical City Buildings

CLIMATE IMPACT(S)

Extreme heat events will increase the frequency of brown-outs and black-outs in the City, resulting in the inability to operate critical City buildings and facilities. It will also result in more frequent and lengthy power losses for residents and businesses. If a brown-outs or black-outs if coincides with a storm event, public health may be even more at risk.

APPLICABLE ADAPTATION STRATEGIES

22 | **Increase energy efficiency in critical buildings** to reduce the risk of power outages during events that cause grid power failure. This may also reduce the energy demand on the grid to begin to reduce the risk of power failure in the first place.

23 | **Install and elevate backup power sources** to maintain some level of power during events that could cause grid power failure at critical City facilities. A backup generator with properly rated distribution equipment and installed above future flooding elevation is recommended to maintain power at critical facilities. One possible location is to install the equipment, such as generators, above future flooding elevation is on the roof of these buildings. Fuel pumps could be installed to allow for easy refilling of the generators and all equipment could be properly rated for use outdoors.

24 | **Install renewable energy backup power sources** to maintain some level of power during events that could cause grid power failure at critical City facilities. The use of renewable energy sources may be evaluated for both feasibility and practicality. In order for a renewable energy source to be a viable option as a means for back up generation, a large battery room would need to be built to store the energy from the renewable source. This strategy may increase the overall reliability of the facilities as well eliminate their reliance on outside power sources.

27 | **Improve utility and City communication** during a power outage event. The City and National Grid could benefit from having a designated individual handle all utility issues during power outage events. Outages are stressful times for both the City and National Grid. By having a specific point person that handles and delegates all of Salem's needs on National Grid's end, efficiency would improve by reducing the need to re-explain the City's needs to multiple people and avoid confusion.

Diesel-fired emergency generators are located at two of the fire stations, the Department of Public Works, and at the schools. Those located at the fire stations and schools are at street-level or in basements, which are the most vulnerable to flooding. The Department of Public Works generator is raised on a pad above ground level. If emergency power is flooded, it presents a public safety risk and may make emergency shelters inoperable.

CLIMATE IMPACT(S)

APPLICABLE ADAPTATION STRATEGIES

23 | **Install and elevate backup power sources** to maintain some level of power during events that could cause grid power failure at critical City facilities. A backup generator with properly rated distribution equipment and installed above future flooding elevation is recommended to maintain power at critical facilities. One possible location is to install the equipment, such as generators, above future flooding elevation is on the roof of these buildings. Fuel pumps could be installed to allow for easy refilling of the generators and all equipment could be properly rated for use outdoors.

24 | **Install renewable energy backup power sources** to maintain some level of power during events that could cause grid power failure at critical City facilities. The use of renewable energy sources may be evaluated for both feasibility and practicality. In order for a renewable energy source to be a viable option as a means for back up generation, a large battery room would need to be built to store the energy from the renewable source. This strategy may increase the overall reliability of the facilities as well eliminate their reliance on outside power sources.

Emergency generator elevated above flood levels.

Installation of photovoltaic panels.

CLIMATE IMPACT(S)

Currently, there is infrequent power loss due to downed power lines with the exception of some areas in North Salem. The frequency of downed power lines and outages is expected to increase due to high winds from extreme precipitation events. This is expected to result in more frequent and lengthy power losses for residents and businesses.

APPLICABLE ADAPTATION STRATEGIES

25 | **Bury the electrical distribution system** to reduce the risk of power outages during events that could cause grid power failure. Underground distribution may solve many of the problems that extreme precipitation events cause. New electrical distribution equipment rated to be submerged in water for extended periods of time have been developed and makes this type of distribution even more reliable. The underground lines are protected from high winds and downed trees, increasing the grids reliability.

26 | **Maintain the overhead distribution system** to prevent outages from high winds during extreme precipitation events. Upgrades and more preventative maintenance to the existing overhead distribution may increase the reliability of existing distribution. Replacing existing overhead wires with more durable cable and replacing poles that do not pass inspection are examples of upgrades that could help reliability.

27 | **Improve utility and City communication** during a power outage event. The City and National Grid could benefit from having a designated individual handle all utility issues during power outage events. Outages are stressful times for both the City and National Grid. By having a specific point person that handles and delegates all of Salem's needs on National Grid's end, efficiency would improve by reducing the need to re-explain the City's needs to multiple people and avoid confusion.

Electrical crew repairs damaged electrical distribution system after a storm.

More extreme heat events, extreme precipitation events, and storm surges will result in the need to communicate with and protect vulnerable populations more frequently. Current systems for communication are in place, but may need to be augmented. The City is already taking some alternative communication measures such as developing picture-based signage for emergency response.

CLIMATE IMPACT(S)

APPLICABLE ADAPTATION STRATEGIES

28 | **Increase awareness of climate change risks** and safety to protect public health. The impacts of climate change on public health may be lessened if citizens know how to prepare and protect themselves. This may be done through educational campaigns, producing and distribution emergency preparedness information, and outreach programs.

29 | **Assist vulnerable populations** to ensure they are prepared for climate change and remain safe during a climate change event. This may be done through outreach programs, identifying where the vulnerable individuals are located, and creating social media and neighborhood campaigns to check on or assist their neighbors.

CLIMATE IMPACT(S)

Air pollutant concentrations increase during more extreme hot and humid days, resulting in poor air quality. Poor air quality may adversely affect the health of many people, with a disproportionate disease burden among vulnerable populations. The most common ailments are respiratory issues. With more extreme heat events, there is an increased public health risk for people with respiratory illness, especially among vulnerable populations.

APPLICABLE ADAPTATION STRATEGIES

30 | Conduct a community health impact assessment and public outreach during poor air quality events. A community health impact assessment may be designed to specifically understand the relationship between the health risk and poor air quality with a focus on the extent of the health risk specifically to the vulnerable populations. The public outreach program may be used to educate the vulnerable groups and their caregivers to detect these signs and symptoms of respiratory illness during an event. To alert the populations of the air quality risks during extreme heat events, the health department may integrate EPA's pre-existing air quality alert program (EnviroFlash). This may enable vulnerable population to take appropriate measures to protect themselves.

32 | Review local public health care sector readiness to understand the capacity and available resources of local health care providers to handle poor air quality-related diseases and aliments. The goal is to ensure there are sufficient clinics or hospitals available to care for people during poor air quality events and that the people have the ability to access them. It is also possible to integrate the emergency medical response mechanism with EPA's pre-existing air quality alert program (EnviroFlash) to provide a timely response to high risk groups.

33 | Promote and expand urban forestry. Urban forestry helps improve air quality. Trees have the ability to absorb air pollutants to improve local air quality. In addition, urban forests provide economic benefits, aesthetic value, sequester carbon dioxide, improve water quality, provide health benefits, and wildlife habitats. The City may increase tree planning activities and consider partnership with local or regional agencies to coordinate tree planting in areas with populations sensitive to poor air quality.

L | Property Damage or Loss of Emergency and Critical City Facilities

The emergency and critical facilities in Salem continue to provide services during flooding events. Flooding may become more severe at these critical facilities due to extreme precipitation events, sea level rise, and storm surge. Additional facilities may flood or be damaged by erosion. Providing the needed level of service to the community will become impaired, putting public safety at risk.

CLIMATE IMPACT(S)

APPLICABLE ADAPTATION STRATEGIES

34 | **Evaluation of buildings for flood proofing opportunities.** Evaluating the utilities and critical operations in the building is key to determining if they are at risk for flooding. An evaluation may include: assessing the building strength to determine if it may withstand flooding-forces; Understanding the likely flooding characteristics, such as the length of time a building is expected to flood; Determining the building location within established or future flooding areas; Operational and maintenance initiatives that would to ensure flood proofing options are kept in working order.

35 | **Development of new critical use facilities outside future flooding levels.** Critical use buildings are those essential to a community's resiliency and sustainability. In some cases, relocating a critical public service or use into an area that is not expected to flood in the future, could be more cost effective than to design or modify such a facility located in flood prone area.

36 | **Re-development of existing facilities outside future flooding levels**, especially small structures or historic properties. By relocating properties into future non-flood areas, the City may avoid the extreme alterations required to protect the structure, risking loss of significant historic character. This strategy is to be considered for smaller structures due to the significant constraints and engineering considerations necessary to move a structure.

37 | **Elevate the building** so it is raised and out of risk of flooding. Modifications may be made to resist all flood-related loads and conditions, including hydrostatic loads, break wave action debris impact, and rapid rise and drawdown of water. Foundation systems for consideration include open foundations, fill, pilings, columns, stem wall or slabs.

38 | **Elevate a building's critical uses** within the building. In existing buildings, utility equipment that is critical for functionality may be relocated to higher floors or elevated additions. Most building systems may be divided into two components: 1) main equipment and 2) distribution. One strategy is to strap or bolt equipment so it is designed to withstand wind and other forces. Elevating supporting distribution systems (ducts, supply lines, and piping) within the facilities may also help prevent flooding.

39 | **Adopt and enforce updated building codes.** Stricter building codes for new construction and existing facilities may help the City protect its building stock from flooding as well as wind, and prolonged power outages. Targeted strategies include building code legislation changes, adjustments to zoning regulations, incentive programs, and best practices guides.

40 | **Limit or restrict development in future flooding areas.** The first step is to review the existing regulations and zoning ordinance, review historical flood events and insurance claims, review future flooding levels, and determine implications to tax base and private property rights. Coastal erosion setbacks, sea level rise, increased coastal flood and surge elevations, and building elevations are examples of what may be considered in flood-related ordinances.

41 | **Improve land use planning and regulations** to prevent or manage flooding. Land uses may be planned and regulated to minimize the impact of storm surge and mitigate future losses resulting from extreme precipitation events and sea level rise.

42 | **Flood proof buildings** to protect the existing buildings, critical systems and equipment. There are two techniques for flood proofing a building: "dry flood proofing" and "wet flood proofing". "Dry flood proofing" is applied to building entrances, windows and surrounding equipment rooms located within the flood prone area to ensure the area remains watertight. "Wet flood proofing" is another method were water is allowed to enter into the structure intentionally, but remains structurally sound and repairs are relatively easy to make.

43 | **Perform wharf area water study** and field investigation. This will include the review of public and private water piping systems in the wharf area to update the GIS data and mapping. The benefit of creating more accurate mapping will allow staff to more quickly locate and operate key valves in the system during a storm surge event or emergency. The study will allow staff to evaluate the wharf area piping systems and recommend the most appropriate location for any new emergency shutdown gate valves, protecting against a wider water distribution system failure or potential contamination, in the event of a wharf water piping failure.

M | Property Damage or Loss at Salem State University

CLIMATE IMPACT(S)

The Central Campus and O'Keefe Center at Salem State University may experience severe flooding damage from storm surge flooding. Flooding may also occur at the North and South campuses. This may impact emergency shelters for students and staff and result in lost school days if the buildings are sufficiently damaged.

APPLICABLE ADAPTATION STRATEGIES

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Flooding of police and fire station headquarters may occur more frequently and become more intense. Emergency response may be impaired during and immediately after storms. Emergency vehicles are capable of movement in extreme conditions, but operations may be affected as the level of flood waters rise. Some emergency response centers may experience flooding during storms, limiting their ability to respond to the needs of the community.

CLIMATE IMPACT(S)

APPLICABLE ADAPTATION STRATEGIES

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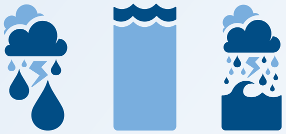
CLIMATE IMPACT(S)



Flooding currently occurs in the historic areas of Willows near Fort Lee, Emerton and Forester Streets, Derby Wharf/ Maritime Historic Site, and Bridge Street. Flooding from storm surge may flood these areas more severely and frequently and may flood additional historically or culturally significant properties in the future. These are important assets for economic development and tourism.

APPLICABLE ADAPTATION STRATEGIES

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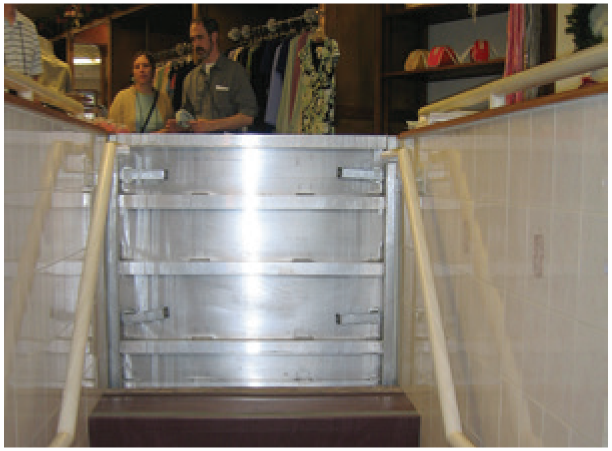

Commercial structure mitigated using a combination of wet and dry floodproofing techniques.

Non-residential structure retrofitted with flood openings.

Today, high tide flooding occurs anywhere between the canals and the ocean. Sea level rise and storm surge will result in greater flooding in these at-risk areas. Residents may be at greater risk for loss of property and safety during storms.

CLIMATE IMPACT(S)

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Three sets of stairs that provide building egress during the design flood event, but still allow normal use of the building.

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Equipment room with watertight door.

Rear of retrofit dry floodproofed building with permanently installed flood shield.

5 | Getting Involved

GETTING INVOLVED

This Plan investigated some of the most serious climate change impacts, the resulting stresses to different sectors in the City, and outlines project ideas to address some of the most serious issues. City staff now have guidance on how to approach climate change and how to incorporate it into existing and future projects and policies that may serve the City for decades to come. As the City implements this Plan, it will be continuously reevaluated to see if the climate change impacts have become more or less severe, if the vulnerabilities have changed, or if there are additional adaptation strategies that should be included.

If you are interested in providing comments or developing a partnership please contact: Jeffrey Elie, Energy and Sustainability Manager, City of Salem Department of Planning and Community Development, at (978) 619-5693 or jelie@salem.com.

The City has released this Plan with the hope that others who have a stake in the future of Salem are called to action. There are opportunities to create or strengthen alliances to work together – from neighboring towns, utilities, state agencies, non-profit organizations, businesses, and neighbors. Implementing this Plan and working collaboratively together will make Salem a more resilient City and a great place to live, work, and visit for years to come.

Flooding at Derby Wharf Light Station after Winter Storm Nemo, February 2013

Photos provided by the City of Salem:

Susan Plutsky: Front Cover, Page 14, Appendix Covers

Jared Charney: Pages 10, 21

Cristina Muraca: Page 13

Stanley J. Slysz: Page 20

Peabody Essex Museum: Page 21

Linda J. Orlomoski: Page 23

Lori Costa: Page 24

Kate Fox: Page 24

S. Jean Johnson: Page 24

Destination Salem: Page 48

Dorthy Moerlein: Page 48

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City of Newburyport, MA: Page 28

Massachusetts Coastal Zone Management: Page 28

New Jersey Meadowlands Commission: Page 29

U.S. Environmental Protection Agency: Pages 31, 33

U.S. Army Corps of Engineers: Page 32

U.S. Federal Emergency Management Agency: Pages 35, 37, 44, 45, 46

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