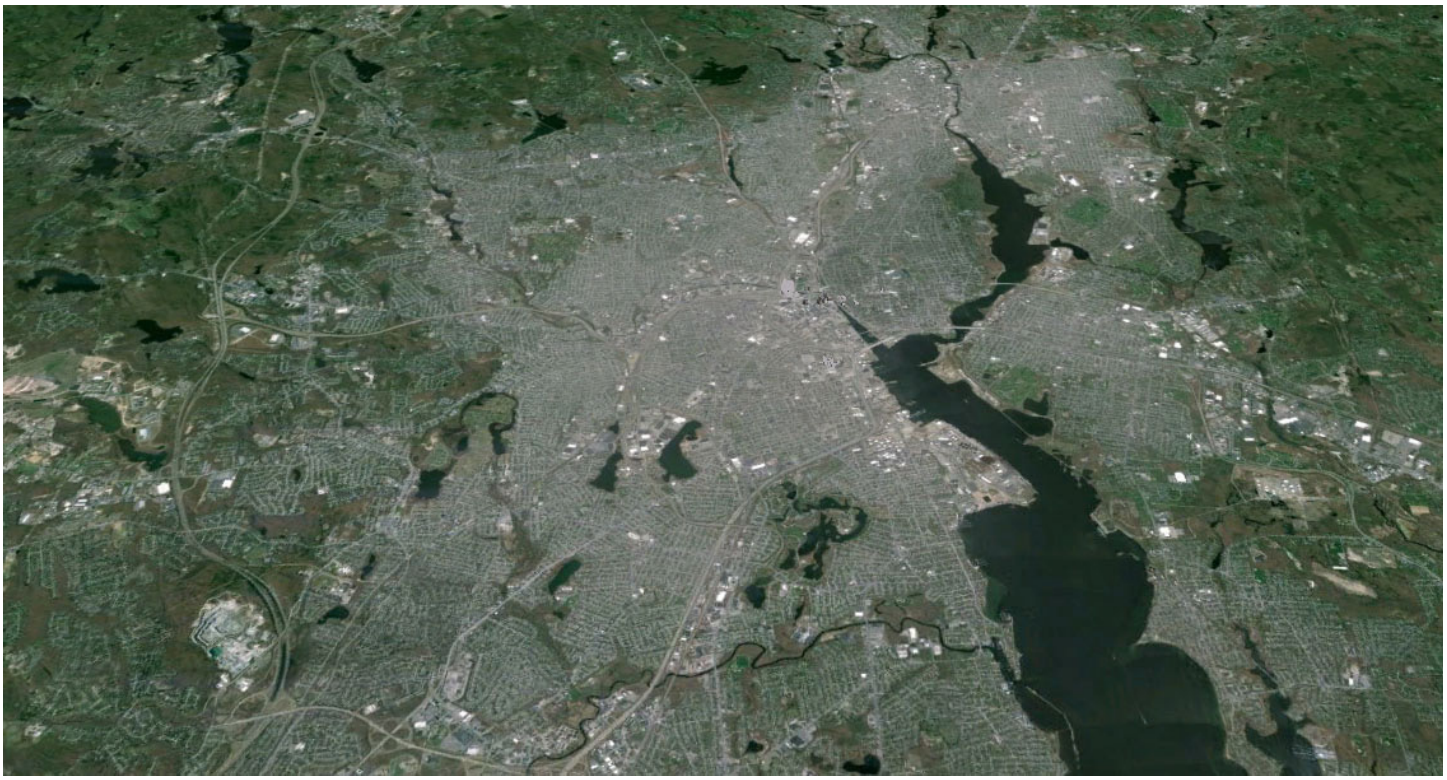
New England **Climate Adaptation** PROJECT



Summary Climate Change Risk Assessment
Cranston, Rhode Island

March 2014

PRODUCED BY:

Massachusetts Institute of Technology Science Impact Collaborative

Consensus Building Institute

National Estuarine Research Reserve System

University of New Hampshire

Acknowledgements

This Summary Risk Assessment was prepared by the Massachusetts Institute of Technology Science Impact Collaborative and the Consensus Building Institute, with the assistance of the Narragansett Bay National Estuarine Research Reserve, scientists from the University of New Hampshire, and partners in the City of Cranston. Toral Patel and Elisheva Yardeni provided GIS and mapping support. This assessment was produced as part of the New England Climate Adaptation Project, an effort funded by the National Estuarine Research Reserve System Science Collaborative.

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About the MIT Science Impact Collaborative

The Massachusetts Institute of Technology Science Impact Collaborative (MIT SIC) is a research group focused on developing and testing new ways of harmonizing science, politics and public policy in the management of natural resources and resolution of environmental disputes. MIT SIC's tools and approaches include collaborative adaptive management, joint fact-finding, scenario planning, collaborative decision-making and multi-stakeholder engagement, and the use of role-play simulation exercises.

MIT SIC was established in 2003 with initial support from the United States Geological Survey. Today, the research group has numerous partners and supporters, ranging from the U.S. National Estuarine Research Reserve System to the Dutch research organization TNO. By engaging in community-based action research projects, MIT SIC researchers—including doctoral students, masters students, and faculty from the MIT Department of Urban Studies and Planning—train emerging environmental professionals while simultaneously testing the latest environmental planning methods and providing assistance to communities and policy-makers who seek their help.

Visit the MIT Science Impact Collaborative website for more information:
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About the Consensus Building Institute

The Consensus Building Institute (CBI) is a not-for-profit organization founded in 1993 by leading practitioners and theory builders in the fields of negotiation and dispute resolution. CBI's experts bring decades of experience brokering agreements and building collaboration in complex, high-stakes environments — and possess the deep understanding required to tackle negotiation and collaboration challenges in their practice areas. CBI's founder, managing directors, and many of their board members are affiliated with the Program on Negotiation at Harvard Law School and the MIT-Harvard Public Disputes Program.

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About the Narragansett National Estuarine Research Reserve

The National Estuarine Research Reserve System (NERRS) is a network of 28 areas representing different biogeographic regions of the United States that are protected for long term research, water-quality monitoring, education, and coastal stewardship. The reserve system is a partnership program between the National Oceanic and Atmospheric Administration (NOAA) and the coastal states. Reserve staff work with local communities and regional groups to address natural resource management issues, such as climate change, non-point source pollution, habitat restoration, and invasive species. Through integrated research and education, the reserves help communities develop strategies to deal successfully with these coastal resource issues. Reserves provide adult audiences with training on coastal and estuarine issues of concern in their local communities. They offer educational programs for students, teachers, decision-makers, and community members. Reserves also provide long term weather, water quality, and biological monitoring as well as opportunities for scientists and graduate students to conduct research in a "living laboratory."

The Narragansett Bay National Estuarine Research Reserve is located on four islands in the Narragansett Bay and encompasses 4,400 acres of land and water. Habitats within the Reserve include salt marsh, eelgrass beds, rocky intertidal zone, forest, and meadow. The Reserve's Coastal Training Program serves decision-makers in the Narragansett Bay Watershed, which is comprised of 1,657 square miles in Massachusetts and Rhode Island.

Visit the Narragansett Bay National Estuarine Research Reserve website for more information: http://www.nbnerr.org

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Executive Summary

Cranston faces several climate-related risks, the most notable being the risk of increased inland and coastal flooding that stems from more intense precipitation events as well as sea level rise. Alongside flooding, heat waves, droughts, and ecosystem changes are expected to increase substantially in frequency and severity over the upcoming decades. These risks threaten Cranston's population, buildings, infrastructure, and ecosystem health. While Cranston has improved its physical infrastructure and services in response to related historical climate events, there is much more that can and needs to be done.

This risk assessment was developed by the New England Climate Adaptation Project with the primary objective of providing targeted content for a role-play exercise for Cranston residents. Nevertheless, the information gathered by this project may inform local officials and city residents about potential future climate risks and adaptation options. As such, this report aims to summarize how the climate could change in Cranston over the 21st century, as well as outline the city's key climate change risks and possible adaptation options to address those risks. Cranston could benefit from a more detailed risk assessment.

This report consists of two sections. Section 1 outlines the potential future climate of Cranston based on climate change projections downscaled to the nearest meteorological station, located in Kingston, Rhode Island. Historical and future trends for temperature, precipitation and sea level rise are considered. Climate change projections are presented for two scenarios, which are used to represent the uncertainty in future quantities of global greenhouse gas emissions. Projections are presented in terms of three time scales -– short term (2010-2039), medium term (2040-2069), and long term (2070-2099) -- to capture change over time. The historical baseline refers to the time period between 1980 and 2010. For a detailed discussion on downscaling see Appendix 1.

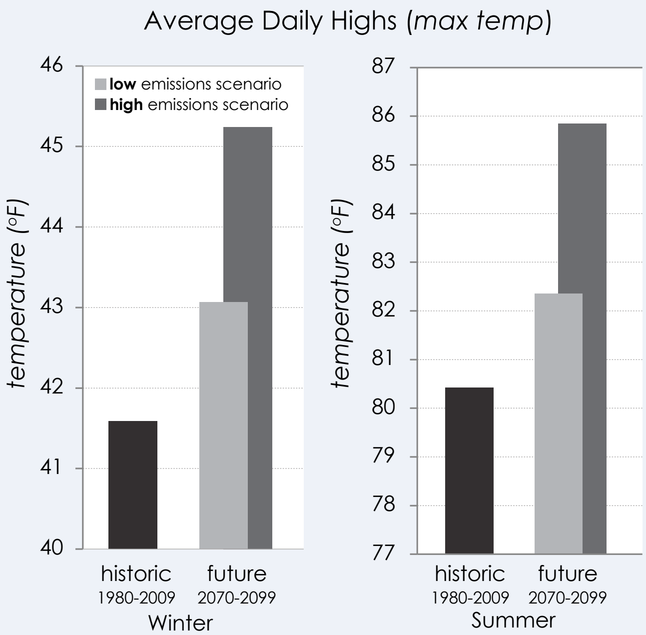
Section 2 discusses how future climatic changes (including those in temperature, precipitation, and sea level) combine with other factors (built environment, economics, demographics, and natural context) to create integrated risks and increased vulnerability for Cranston. This section pairs each risk with sample adaptation methods that prioritize reducing exposure and sensitivity, and increasing adaptive capacity. Vulnerabilities and adaptation options were developed based on input from city officials on the City's experience with past climate-related issues, as well as review of published documents, such as the Cranston Hazard Mitigation Study. Examples adaptation options include retreat, insurance, expanded wetlands, engineered approaches, retrofits, efficiency measures, and urban heat island reduction.

Even though some climate change impacts seem to be a long way off, many adaptation measures may take years of planning, coordination, and investment in order to come to fruition. Additionally, the choices and investments Cranston makes today will either increase or decrease the city's vulnerability to current and future climate-related risks. Cranston can increase its resilience in the face of a changing climate, but doing so will require that residents, business owners, and local and regional agencies work together and begin preparing for a changing climate now rather than waiting to confront the challenge after the damage has been done.

What do climate projections tell us about Cranston by the end of the century?

A hotter Cranston – all year round

Average daily maximum temperatures will rise by 2.1 to 5.5°F, while average daily minimum temperatures will rise by 3.2 to 7.2°F.



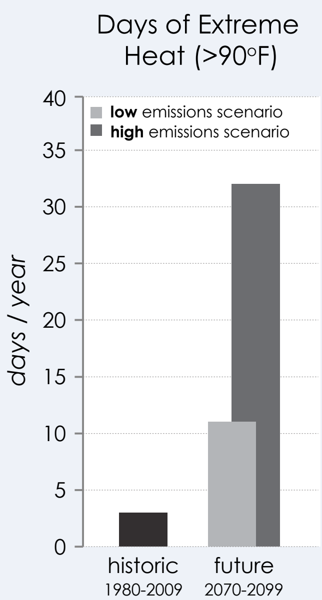
Hot nights

Summer nights will not cool down as much as they do now. Climate change will have a greater warming influence on nighttime minimum temperatures than daytime maximum temperatures, but both will increase.

Outdoor summer movies at Brown University.

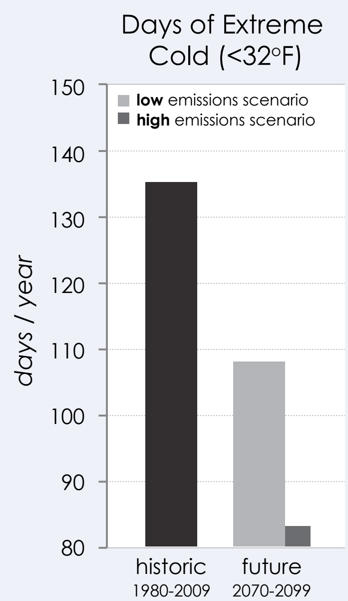
More extreme heat

Cranston will see more days where temperatures exceed 90°F, rising from a current average of 3 days per year to potentially as much as 30 or more days (a tenfold increase).



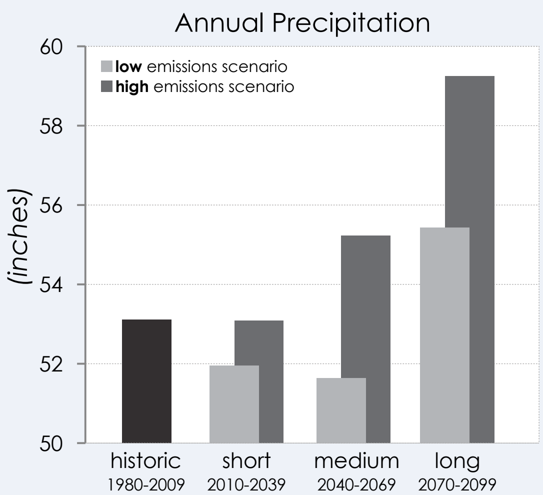
Less freezing

Cranston will see fewer days where temperatures drop below 32°F, from a current average of 129 to as few as 83 days (a 35% reduction).



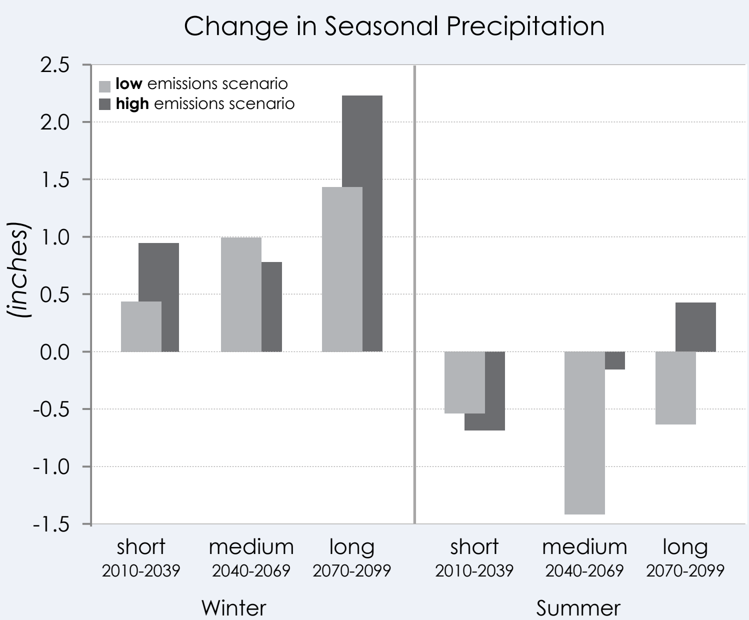
A wetter Cranston

Cranston will receive between 2.0 to 5.1 more inches of precipitation spread out across the year (as much as a 9.5% increase). This change is projected to surface later in the century.



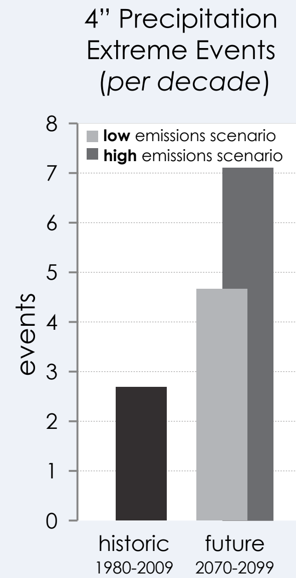
Wetter winters / drier summers

Projections show that Cranston will experience wetter winters and slightly drier summers as compared to historical precipitation averages.



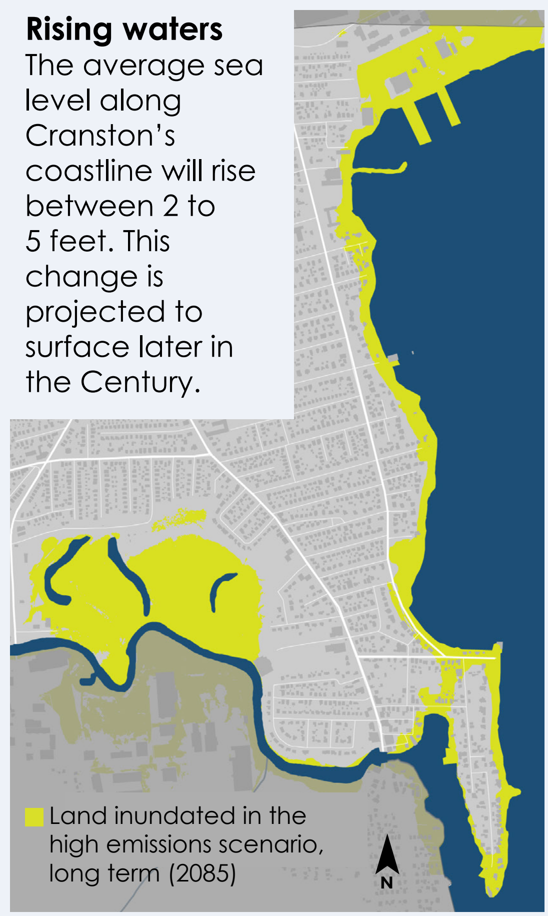
More extreme precipitation

Under a high emissions scenario, Cranston will double the number of events where more than 4" of precipitation falls in under 48 hours.



Rising waters

The average sea level along Cranston's coastline will rise between 2 to 5 feet. This change is projected to surface later in the Century.



What are the major risks for Cranston and what can be done?

FLOODING

Increased flooding is expected to be the primary climate change risk in Cranston. Riverine floodplains are at risk from extreme precipitation events. Over the next century, flooding along the Pawtuxet, Pocasset and Meshanticut Rivers will likely become more frequent and intense as a result of increased average annual precipitation and more extreme precipitation events. Further expansion of impervious surfaces resulting from future development may exacerbate flooding.

The coastal floodplain is narrow due to the coast's sharp incline, making sea level rise less of a direct influence on flood risks in Cranston. However, the coupling of sea level rise and increased river flooding may greatly increase inundation during storms, and development along the shoreline will therefore become more exposed.

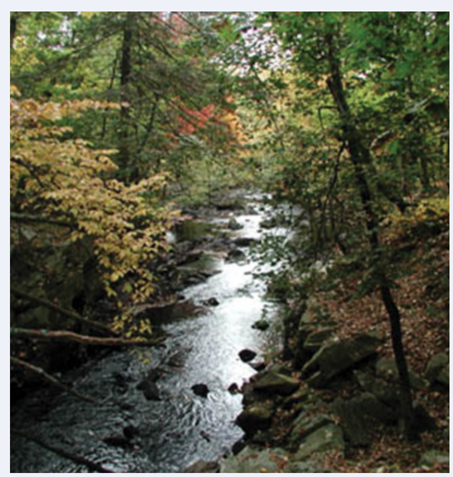
Coupling higher tidal levels from sea level rise with hurricanes and the removal of the Broad Street Dam means everything is magnified – in the future, a less intense storm is likely to inundate far greater areas than it does today.

Homes, businesses, and infrastructure located within the floodplain are at highest risk for flooding.

Examples of Adaptation Options

Floodwalls
ex: New Hampshire

Flood Resilient Building Design
ex: Providence, RI



Wetland Restoration
ex: Woonasquatucket,RI

HEAT WAVES

Cranston is at risk for more frequent and more extreme heat waves.

Sensitive populations such as the very young, very old, and presently sick are vulnerable to health impacts from heat waves. Families living in substandard housing with poor ventilation and/or no air conditioning may be more susceptible to suffering from heat extremes.

Electricity infrastructure may impacted from extreme heat. Electricity wires may come into contact with trees and structures as they sag under intense heat. Prolonged heat can damage equipment. Peak demands can lead to blackouts. One of the primary adaptations for protecting human health during heat waves is air conditioning, which relies upon the electricity grid.

DROUGHT

There is uncertainty around drought projections for Cranston. However, previous analysis has suggested that in the long term, much of New England will experience a significant increase in the frequency of drought, especially during the summer months.

Drought may impact residents relying on groundwater wells. Prolonged drought can impact the city's drinking water supply.

Crop failure due to drought and heat waves may impact the farming sector in western Cranston.

ECOSYSTEM CHANGES

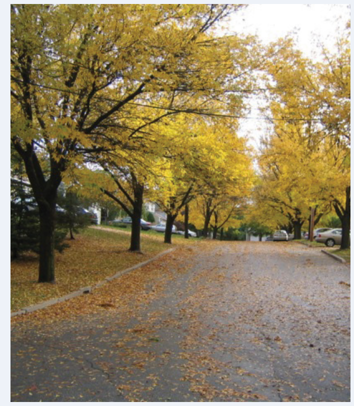
Unique and fragile ecosystems in the greater Narragansett Bay are vulnerable to multiple climatic and urbanization pressures.

Warmer atmospheric and water temperatures will almost certainly affect wildlife in streams and woodlands.

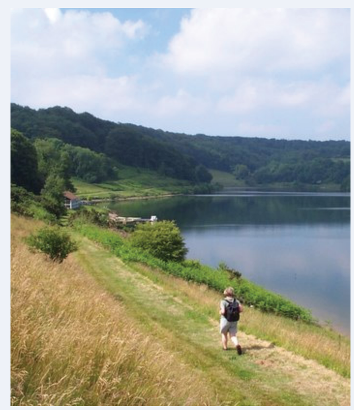
Pests such as ticks and mosquitos may thrive under hotter and wetter conditions.

Nearshore habitats may be altered by inundation due to sea level rise.

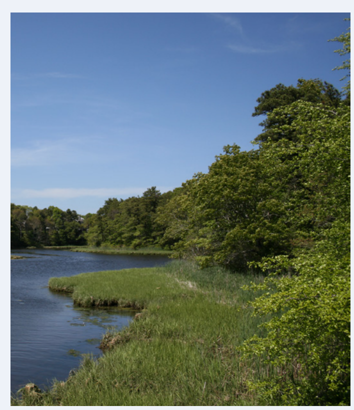
Examples of Adaptation Options



Tree Canopy
ex: *Providence, RI*



Additional Reservoir
ex: *West Hartford, CT*



Vegetated Waterways
ex: *Barnstable, MA*

Section 1: Future Climate in Cranston

This section highlights temperature and precipitation projections that have been downscaled for Cranston, RI. Statistical downscaling translates coarse global climate model projections to the spatial scale of local weather station observations (Stoner et al., 2012). This is done by quantifying historical relationships[1] between large-scale weather features and local patterns. Two irreducible uncertainties govern the use of multiple projections in estimating future change. The first is the sensitivity of the climate to increased atmospheric concentration of CO_2, which is addressed through the use of multiple computational models. The second is predicting how much CO_2 and other greenhouse gases will be emitted over the next century, which is captured in multiple emissions scenarios. In order to capture the full range of future climate changes that Cranston might experience during the 21st century, this project looks at the projections of four global climate models (GFDL, HdCM3, PCM and CCSM3) and two Intergovernmental Panel on Climate Change (IPCC) emissions scenarios (A1fi reflecting the highest projections of emissions and B1 reflecting the lowest projections of emissions) (Figure 1). Projections are presented in terms of three time scales – short term (2010-2039), medium term (2040-2069), and long term

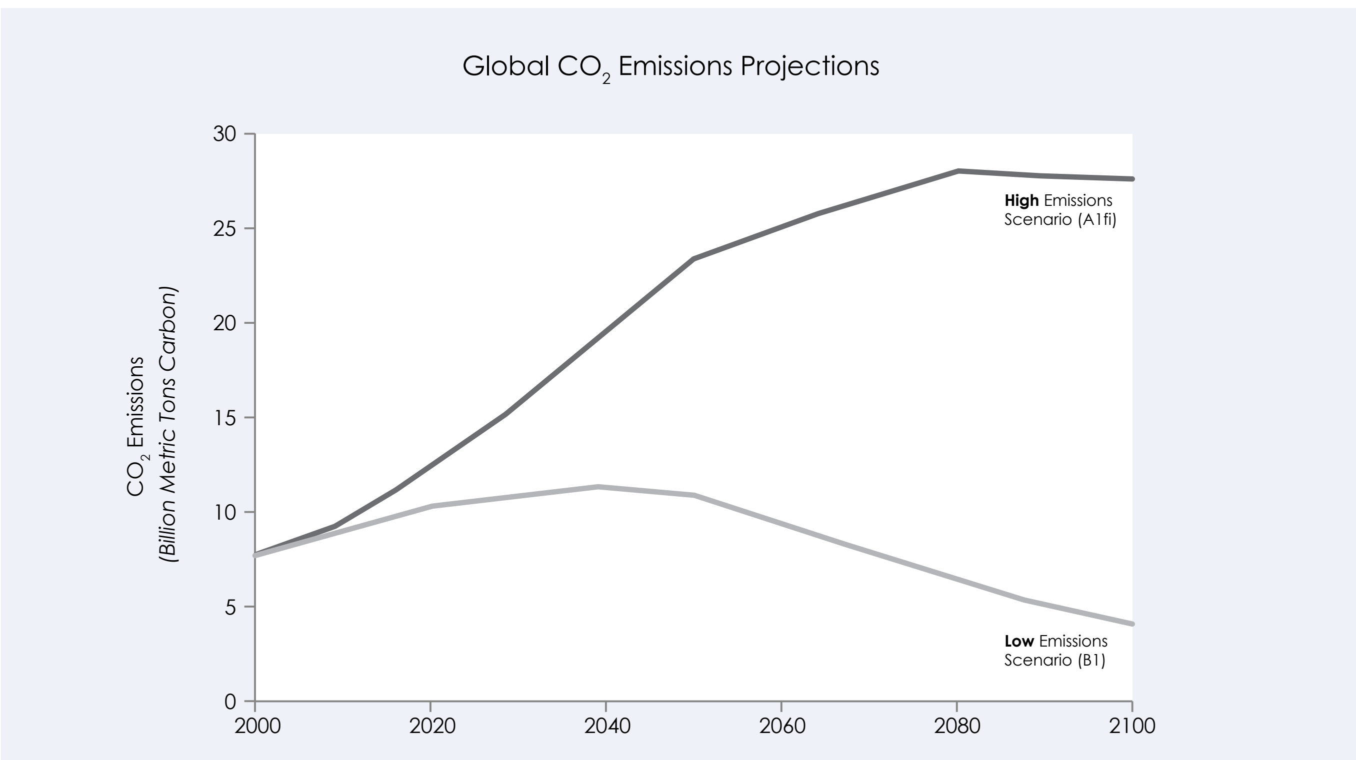


Figure 1: Global CO_2 Emissions Projected over a Century for High and Low IPCC Scenarios

1 It is worth noting that the historical period represents a relatively short and recent series of data relative to the period of anthropogenic greenhouse gas emissions – namely 1980-2009. That is, the historical period does not represent an era "pre-climate change," but is instead a baseline created due to available record-keeping. As an example, the New York Panel on Climate Change 2013 report states that for each decade between 1900 and 2011, the annual mean temperature rose by 0.4° Fahrenheit, precipitation increased by 0.7 inches, and sea level rose by 1.2 inches.

(2070-2099) - to capture change over time. A fuller description of the statistical downscaling methodology used for this report is provided in Appendix 1. Sea level projections are developed from a statistical analysis of the relationship between global temperatures and sea level rise.

Temperature

Average Daily Temperatures:

The average temperature in Cranston is projected to increase over the next century (Figure 2). This change is exhibited through increases in both the daily low temperatures (minimum) and daily high temperatures (maximum). The high emissions scenario (A1fi) corresponds with larger and faster temperature increases. By mid-century, the divergence between the low and high scenario temperature projections becomes pronounced. For example, average daily lows are expected to increase between 2.5-4.3°F by midcentury (2040-2069) based on the low and high emissions scenarios, respectively. By the end of the century (2070-2099), average daily lows are expected to increase between 3.2-7.2°F and average daily highs may increase between 2.1-5.5°F (Figure 3a).

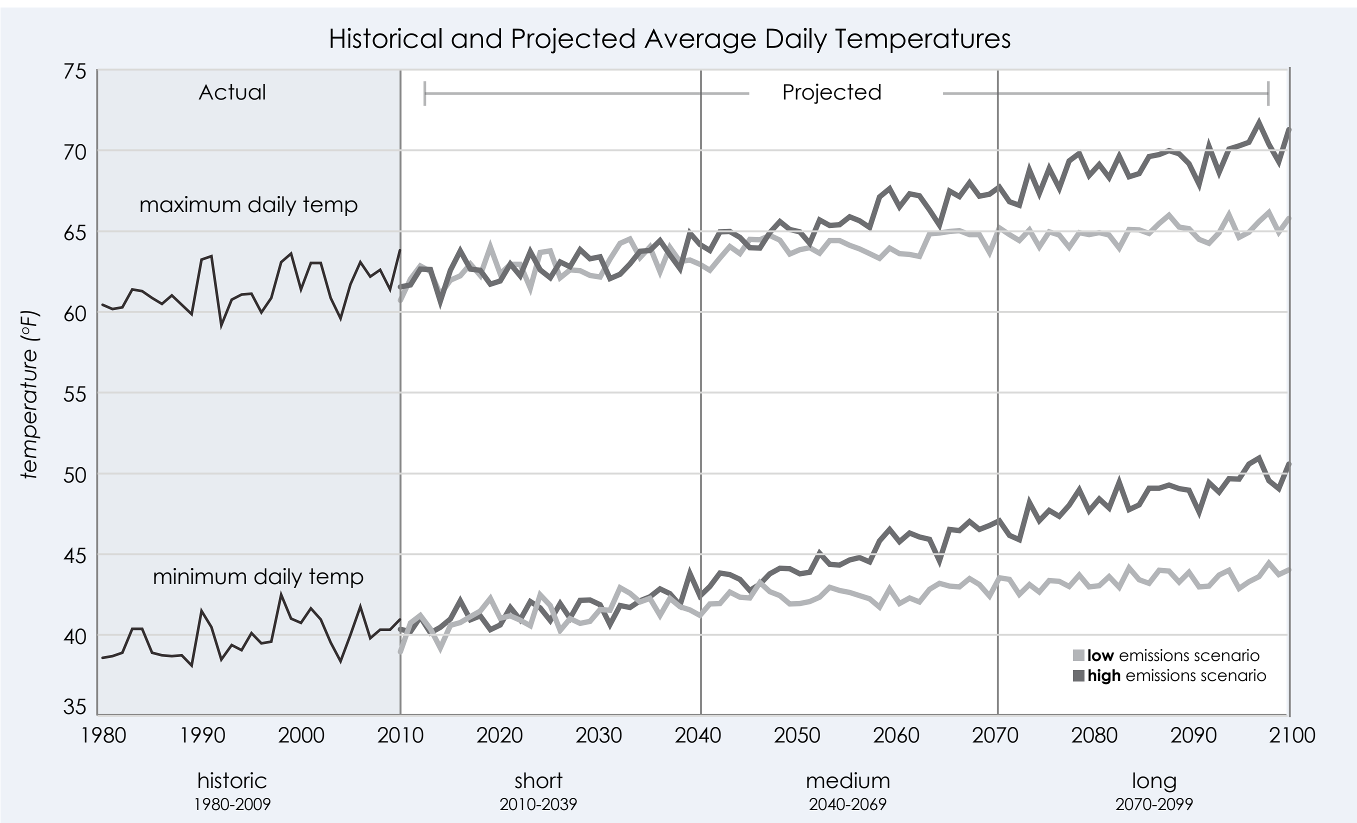


Figure 2: Historical (Actual) and Future (Projected) Daily Temperatures for Cranston Based on Different CO_2 Emissions Scenarios and Timeframes

Seasonal Highs and Lows:

Both summer and winter average daily temperatures are projected to increase over the next century. This includes both minimum and maximum temperatures. The projections indicate that climate change will have a greater influence on nighttime minimum temperatures than daytime maximum temperatures. This means that, especially in the long term, summer nights will not cool down as much as they did in the past. Also, wintertime minimum temperatures will not be as low, resulting in fewer very cold nights that eliminate pests, such as Hemlock Wooly Adelgid and ticks). By the end of the century (2070-2099), summer minimum daily averages in Cranston will potentially increase between 3.1-7.7°F. Summer maximum daily averages may increase between 1.9-5.4°F, raising the average daily high in the summertime to nearly 86°F under the high emissions scenario (Figure 3b). By the end of the century, minimum winter temperatures will very likely rise, bringing the average daily low from 21.9°F to between 25.1-28.3°F. Winter maximum temperatures will also rise, from 41.6°F to 43.1-45.12°F (Figure 3c). For both scenarios, but especially for the high emissions scenario, more winter days will experience temperatures above freezing (>32°F). As a result, more precipitation will arrive in the form of rain rather than snow, as compared to the past.

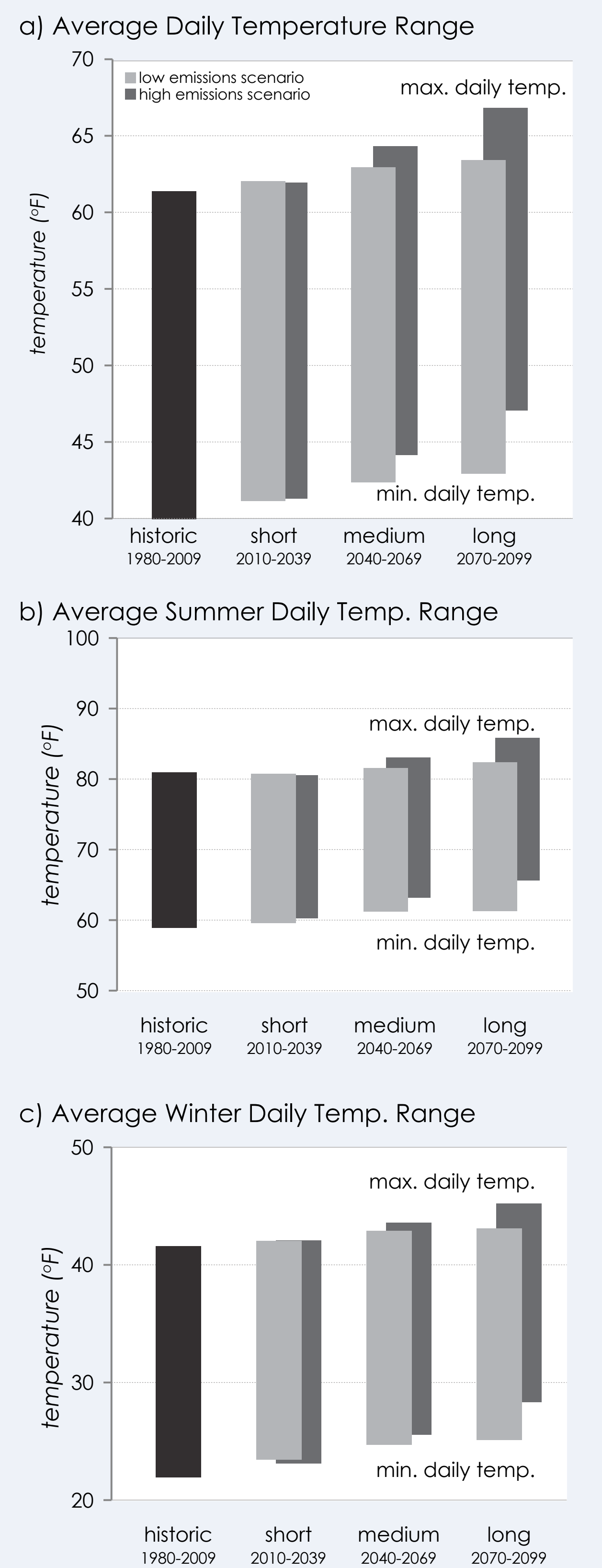


Figure 3: Future Average Daily Lows and Highs as Compared to Historical Baseline

Extreme Temperature:

As temperatures increase, Cranston is likely to experience more days of extreme heat and fewer days of extreme cold. In fact, in the long term, Cranston could experience over 10 times as many extreme heat days (with daily highs above 90°F) than have historically occurred, potentially increasing from 3 to 32 days per year (Figure 4a). With regard to extreme cold, Cranston has historically experienced, on average, temperatures below 32°F on 129 days every year. In the long term, under the low emissions scenario, the number of days Cranston experiences temperatures below 32°F could decrease to 105 days per year. Under the high emissions scenario, this could decrease to 83 days (Figure 4b).

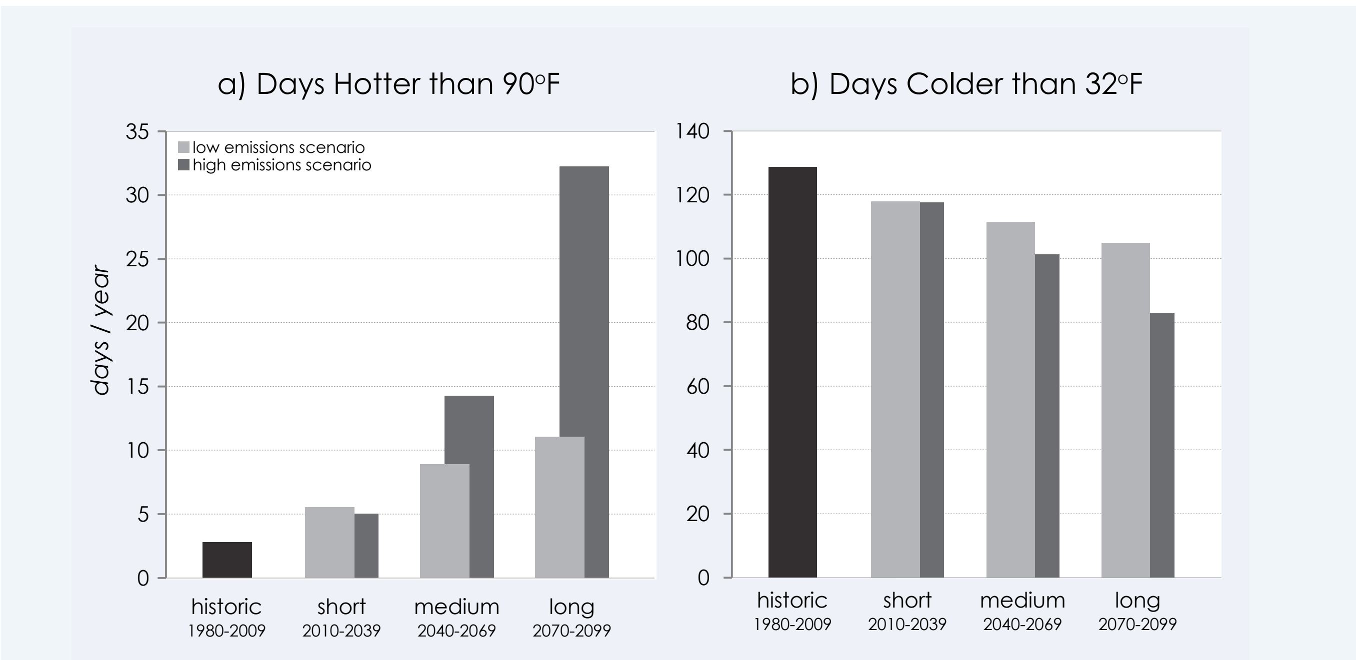


Figure 4: Extreme Temperature Events

Table 1: Potential Impacts of Higher Temperatures

Change	Potential Impacts of Higher Temperatures
↑	**Health impacts:** Extended and magnified heat events will increase risk of heat strokes, air pollution, and vector borne diseases.
↑	**Infrastructure damages:** Extreme heat and heat waves may damage roads and electricity transformers.
↓	**Water supply:** Higher temperatures will result in more precipitation falling as rain rather than snow. Snowpack functions as a natural reservoir to store water outside of manmade reservoirs for drinking water supply. The reduction of snowpack may reduce spring and early summer supplies. Higher average temperatures can also be associated with increased evaporation and transpiration which could further reduce water availability.
↓/↑	**Agriculture productivity:** Higher temperatures may cause a longer growing season, supporting agricultural benefits in crop production. Higher temperatures could also harm agricultural crops that are not suited for higher temperatures.
↑	**Ecosystem stress:** Higher temperatures can cause populations and habitats to migrate to lower temperature areas (high elevation or higher latitude), where possible. Ecosystems that cannot migrate or adapt to changing climatic conditions may degrade or collapse.
↓	**Snow removal costs:** Governments and property managers may be able to reduce their budgets for snow removal due to fewer extreme cold days.
↓/↑	**Heating and air conditioning bills:** People may save money if the warmer winter temperatures enable them to reduce the amount of energy needed to heat buildings. Conversely, higher summer temperatures may lead to higher air conditioning costs.

Precipitation

Average Daily Precipitation:

There is high variability in average annual precipitation, both historically and in future projections (Figure 5). Comparing an average historic baseline (1980-2009) to short term, medium and long term averages more clearly reflects trends (Figure 6). The projections show little change in average annual precipitation in the short and medium term (Figure 6). In the long term, however, both the low and high scenarios show an increase in precipitation (Figure 6). The long term high emissions projections indicate average annual rainfall could become 10% higher than the baseline, representing 5 more inches of rain annually.

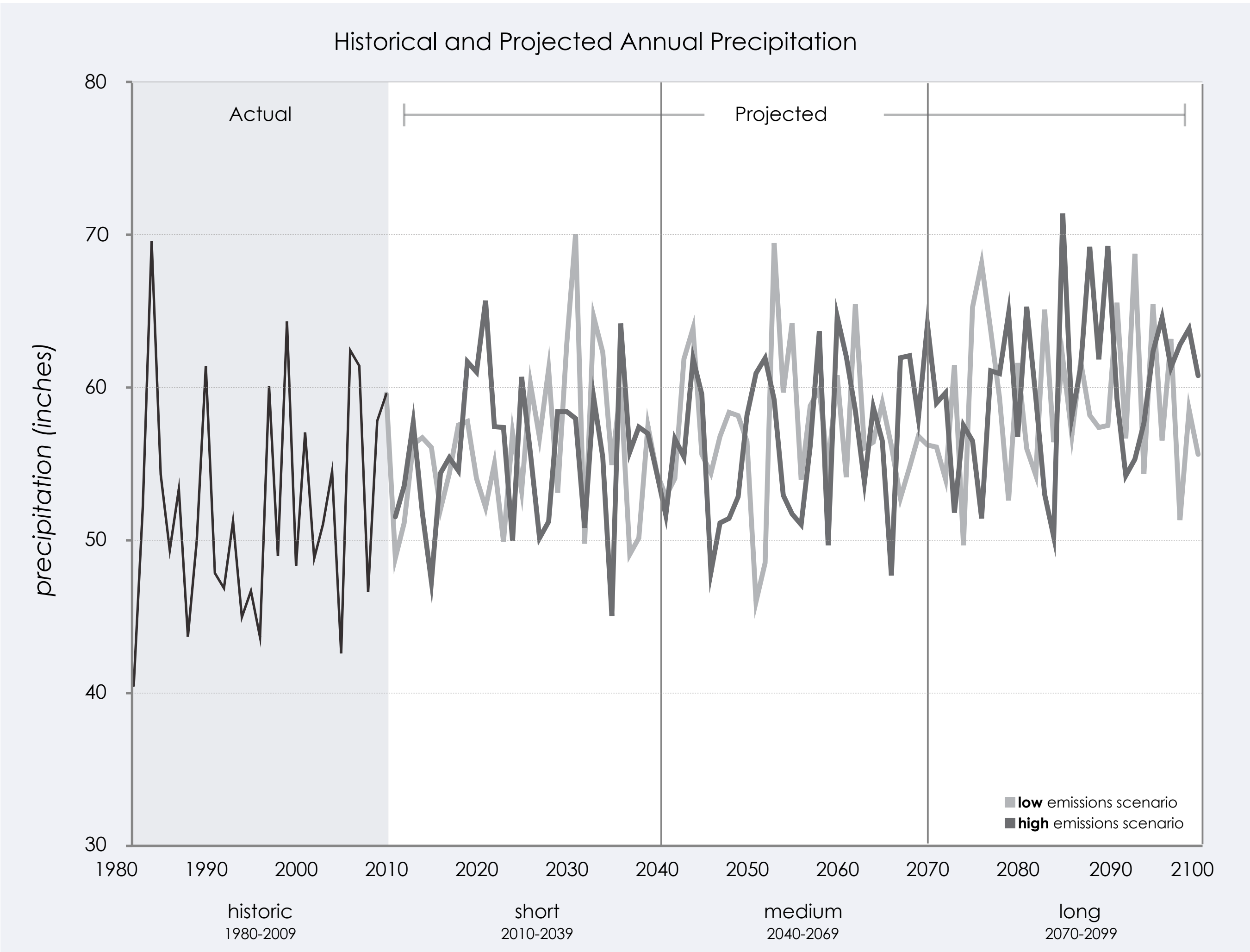


Figure 5: Historical and Future Average Annual Precipitation Trends

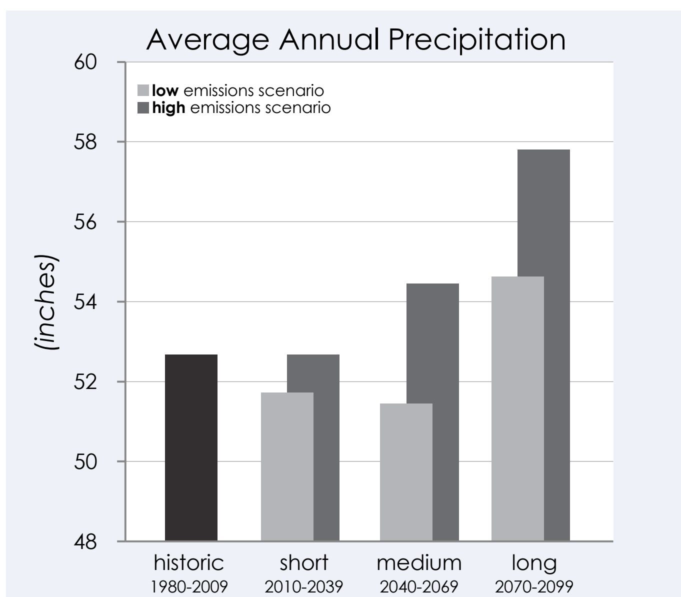


Figure 6: Comparison of Historical to Short, Medium, and Long Term Average Annual Precipitation Projections

Seasonal Precipitation:

Seasonal projections show a more nuanced picture of average rainfall totals. The projections indicate that Cranston could see wetter winters and potentially slightly drier summers compared to the historic baseline. Winter precipitation is predicted to increase by the end of the century between 12 to 18% under the low and high emissions scenarios, respectively (Figure 7a). Summer precipitation shows a decrease in the short and medium term (Figure 7b). Only the high emissions scenario projects a modest increase of 3% in the long term.

Extreme Precipitation Events:

Cranston can also expect to see more extreme precipitation events in the future. The most dramatic change is the increase in the number of precipitation events that result in 4 inches of rain in 48 hours. The historical average is 2.7 events per decade, and in the long term this could rise to 5 to 7 events under the low and high emissions scenarios, respectively (Figure 8c). This translates into the potential for more than doubling the number of 4 inches in 48 hours precipitation events per decade by the end of the century. Extreme precipitation events are a key driver of flooding in Cranston, so this projected increase could have significant impacts on flooding risk in the area.

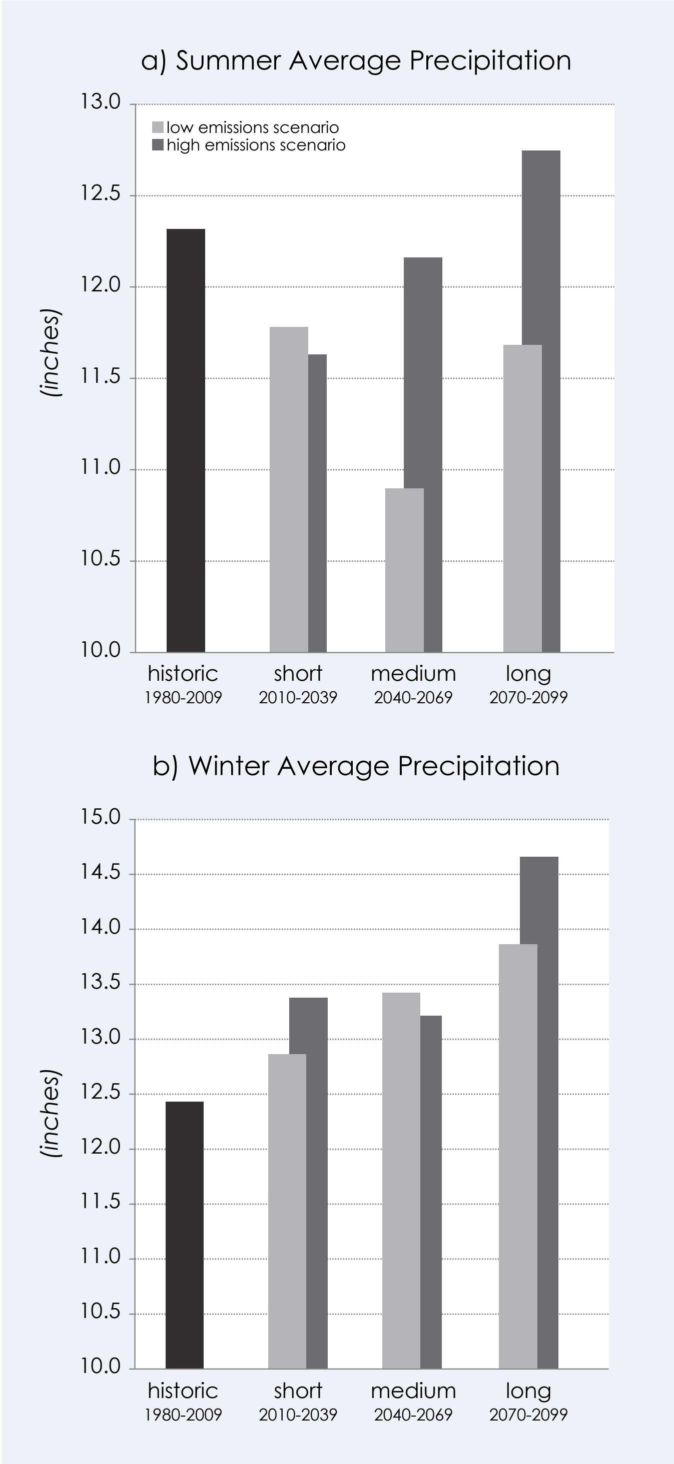


Figure 7: Seasonal Precipitation Pattern

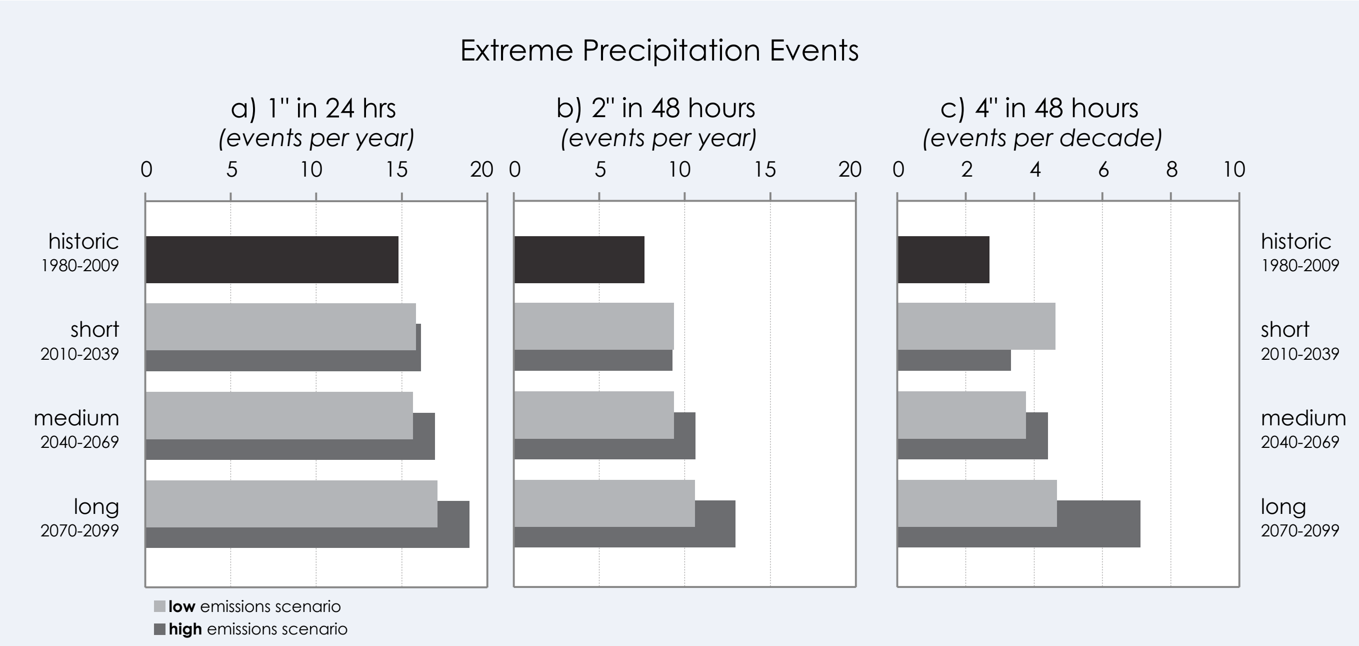


Figure 8: Extreme Precipitation Events

Table 2: Potential Impacts of Precipitation Changes

Change	Potential Impacts of Precipitation Changes
↑	**Flooding:** One of the key impacts associated with higher precipitation and more extreme precipitation events is increased flooding risk, which can potentially damage houses, businesses, and infrastructure and disrupt livelihoods.
↑	**Erosion:** Flash flooding and storm surges associated with extreme precipitation events may lead to increased erosion, especially along steep slopes and non-vegetated soil.
↓	**Water quality:** Increased stormwater runoff associated with precipitation events could increase the concentration of water-borne pollutants in urban streams.
↑	**Vector borne disease:** An increase in the amount and duration of standing water may lead to an increase in pests and vector borne diseases such as West Nile Virus.

Sea Level Rise

Both future emissions scenarios generate sea level rise. In the short term, sea level rise projections are similar under both the high and low emissions scenarios. But in the medium term, the trends diverge, predicting a sea level rise of 1.0 foot under the low scenario and 2 feet under the high scenario. In the long term, sea level rise under the high scenario has the potential to more than double that of the low scenario and rise as high as 5 feet from the historical baseline.

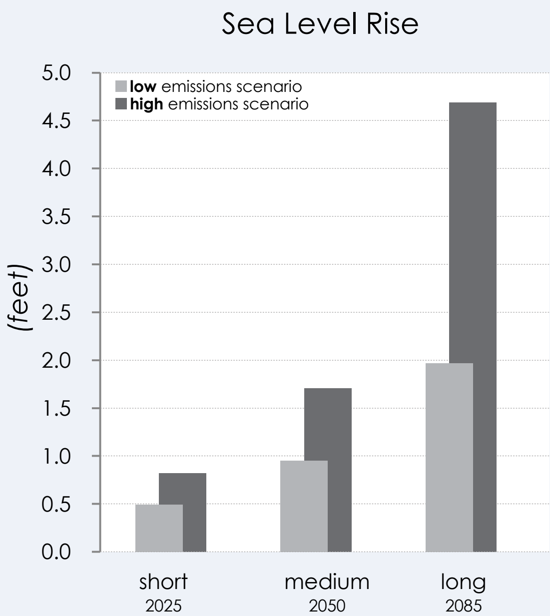


Figure 9: Sea Level Rise Projections

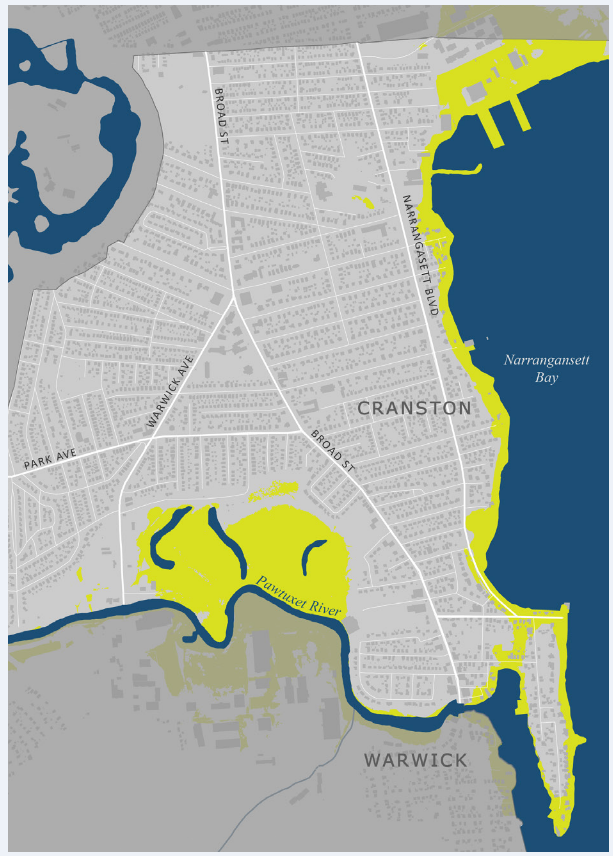


Figure 10: Coastal Sea Level Rise. Mean Sea Level Inundation

High emissions scenario
Long term *(2085)*

Table 3: Potential Impacts of Sea Level Rise

Change	Potential Impacts of Sea Level Rise
↑	**Daily tidal inundation:** Sea level rise will likely increase the extent of daily tidal inundation with social, economic, and ecological implications.
↑	**Coastal flooding:** While less significant than riverine flooding in Cranston, coastal flooding risk will increase due to sea level rise, especially when coupled with increases in extreme precipitation events and possible increases in hurricane intensity.
↑	**Groundwater levels:** Rising groundwater levels may damage infrastructure and property along the coast.

Section 2: Integrated Risks and Adaptation Options

This section of the report builds on the climate change projections and possible impacts from Section 1, and applies them to community systems and assets in Cranston to examine some of Cranston's key climate change risks, vulnerabilities, and adaptation options. Figure 11 represents the approach we used to understand and assess risk. This approach is based on the Intergovernmental Panel on Climate Change's (IPCC) Special Report on Extreme Events(2). Risk is the likelihood of impact resulting from the interaction of:

- a ***threat*** - an event caused by natural variability and/or anthropogenic climate change, and
- ***vulnerability*** - the sensitivity, exposure, and adaptive capacity of a place and its disposition to be adversely affected.

For example, the integrated risk of coastal flooding in Cranston is the result of both the threat from sea level rise and the vulnerability of the population and buildings in terms of their location along the coast (exposure), infrastructure design (sensitivity), and ability to respond to changing conditions (adaptive capacity). Adaptation options reflect alternative mechanisms that can be used to reduce Cranston's risk to a given climatic threat through minimizing the exposure (moving out of harm's way) and vulnerability (decreasing sensitivity and increasing resilience). Climate change *mitigation* practices that reduce global greenhouse gas emissions aim to lessen the speed and severity with which regional climates are changing and, as a result, minimize climate change risks globally and in the long term. Climate *adaptation* focuses on reducing local and regional vulnerability impacts that continue to manifest.

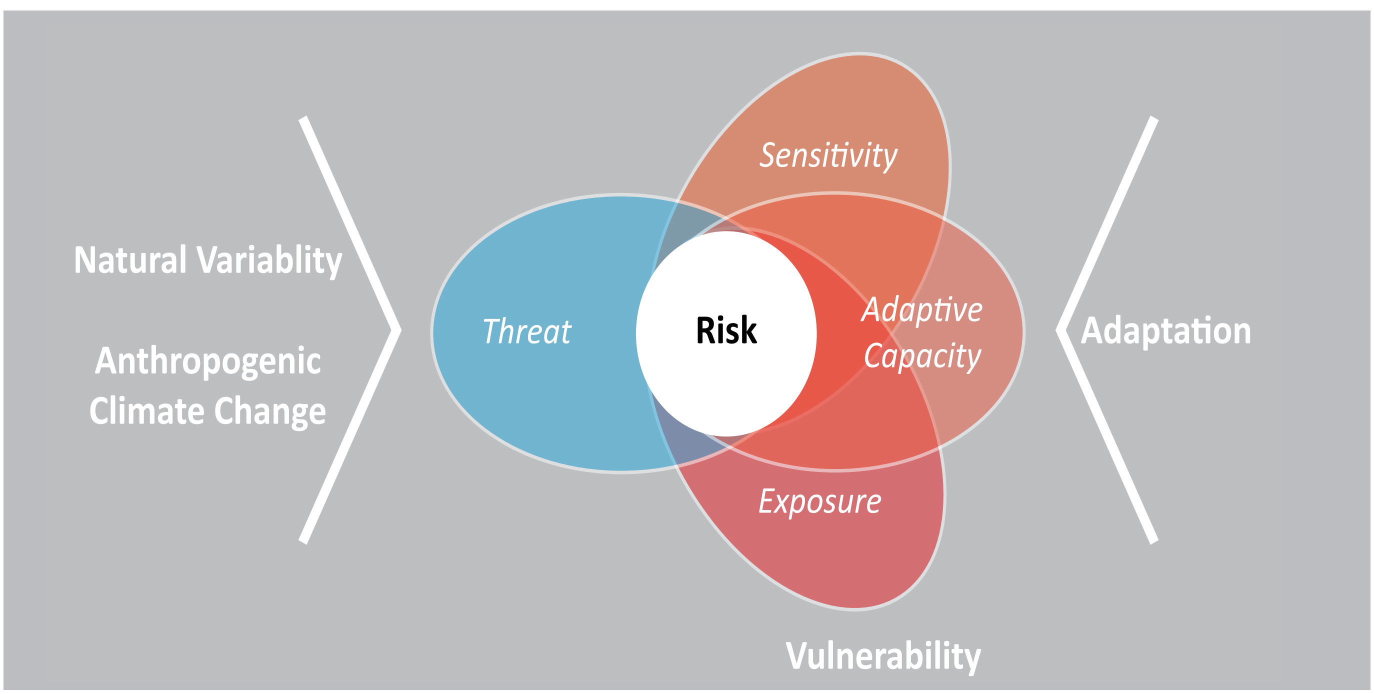


Figure 11: Integrated Risks (*Adapted from IPCC SREX Report)*

This section highlights four risks – ***flooding*** (both riverine and coastal), ***heat waves***, ***droughts,*** and ***ecosystem changes***. Specific vulnerabilities for Cranston were identified through a workshop with city officials where they discussed local climate projections and their experience with past climate-related vulnerabilities in the city. Additional vulnerabilities were also identified through reviewing published documents, such as the Cranston's Hazard Mitigation Study. Included adaptation options reflect broad examples of regional, national, and international best practices. See Appendix 2: Additional Resources for more in-depth narratives and diverse examples of adaptation options.

Flooding

Risks:

River Flooding. Cranston is at risk from increased flooding along both its river tributaries and along the coast. Flooding along the river constitutes Cranston's greatest climatic risk and is a result of the increased likelihood of extreme precipitation events. In addition, while it cannot be predicted without detailed analysis, it is possible that the combination of warmer winter temperatures and more winter precipitation could lead to increased spring flooding. Cranston's riverine flood risk is concentrated along the floodplains of the Pawtuxet, the Pocasset, and the Meshanticut Rivers. The floodplain is delineated based on the probability of flooding in a given year. Figure 12 reflects both the 100-year floodplain (area with a 1% chance of flooding in

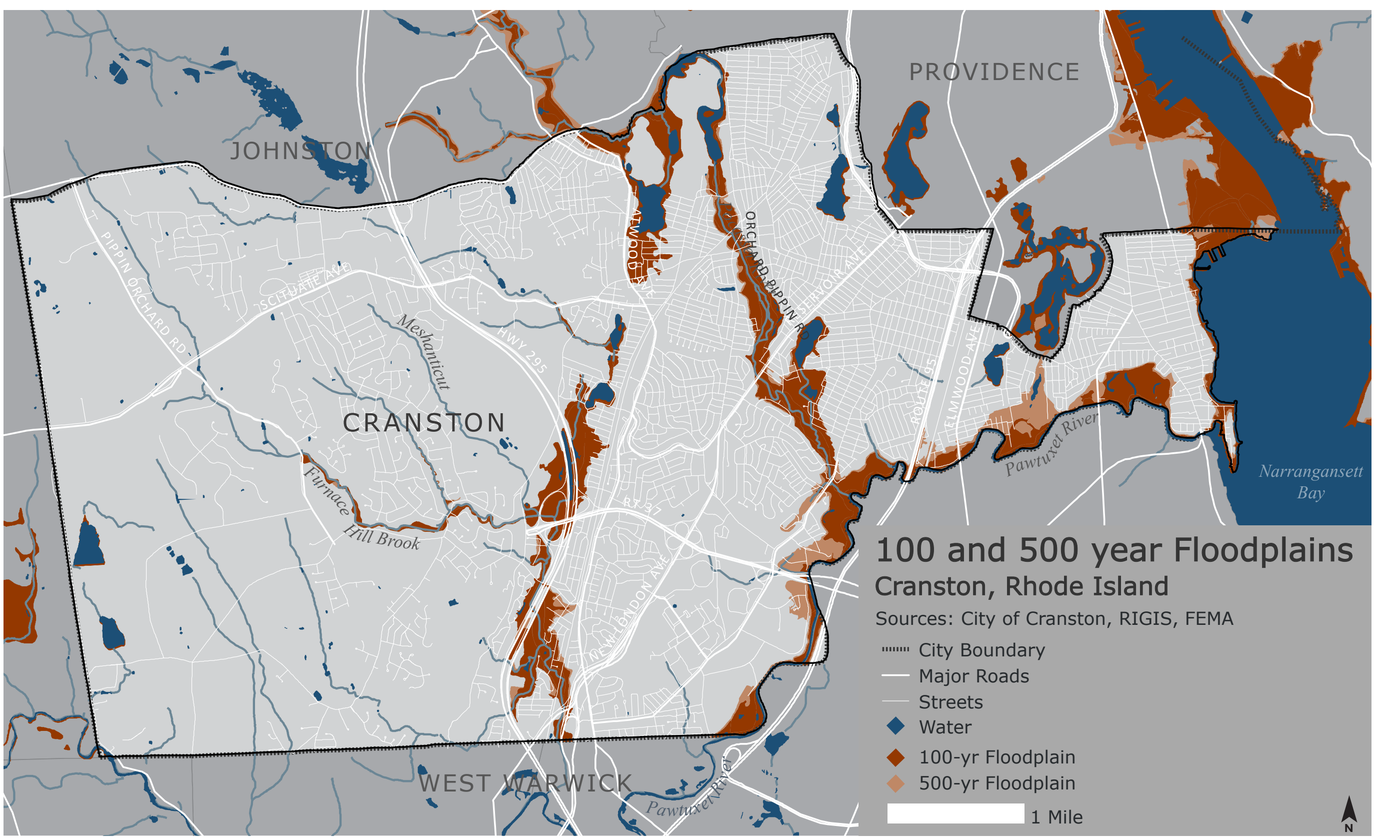


Figure 12: City of Cranston 100- and 500- Year River Floodplains

given year) and the 500-year floodplain (area with a 0.2% chance of flooding in a given year. However, it is important to note that between 1979 and 2010 the Pawtuxet River in Cranston exceeded the “flood stage” 47 times and exceeded the “major flood stage” seven times (National Weather Service)[2] . After three days of record-breaking rain in March 2010 , over 800 acres were directly flooded (with over 300 of those acres lying outside of the 100-year floodplain) and an additional 2,355 acres were flooded by rising ground waters outside of the floodplain (Figure 13).

Increased extreme precipitation events and warmer winters will increase the probability of flooding in a given year. The Federal Emergency Management Agency (FEMA) is currently updating the 100-year flood hazard maps to reflect changes based on recent trends. While the spatial extent of the new 100 and 500-year floodplains has not been updated, the new 100-year floodplain will likely fall somewhere between the current extents of the 100 and 500-year flood extents. In addition, depending on the type of development (i.e., conventional versus low impact development) the expansion of impervious surfaces could also contribute to enhanced flooding in the future(Rosen et al., 2010).

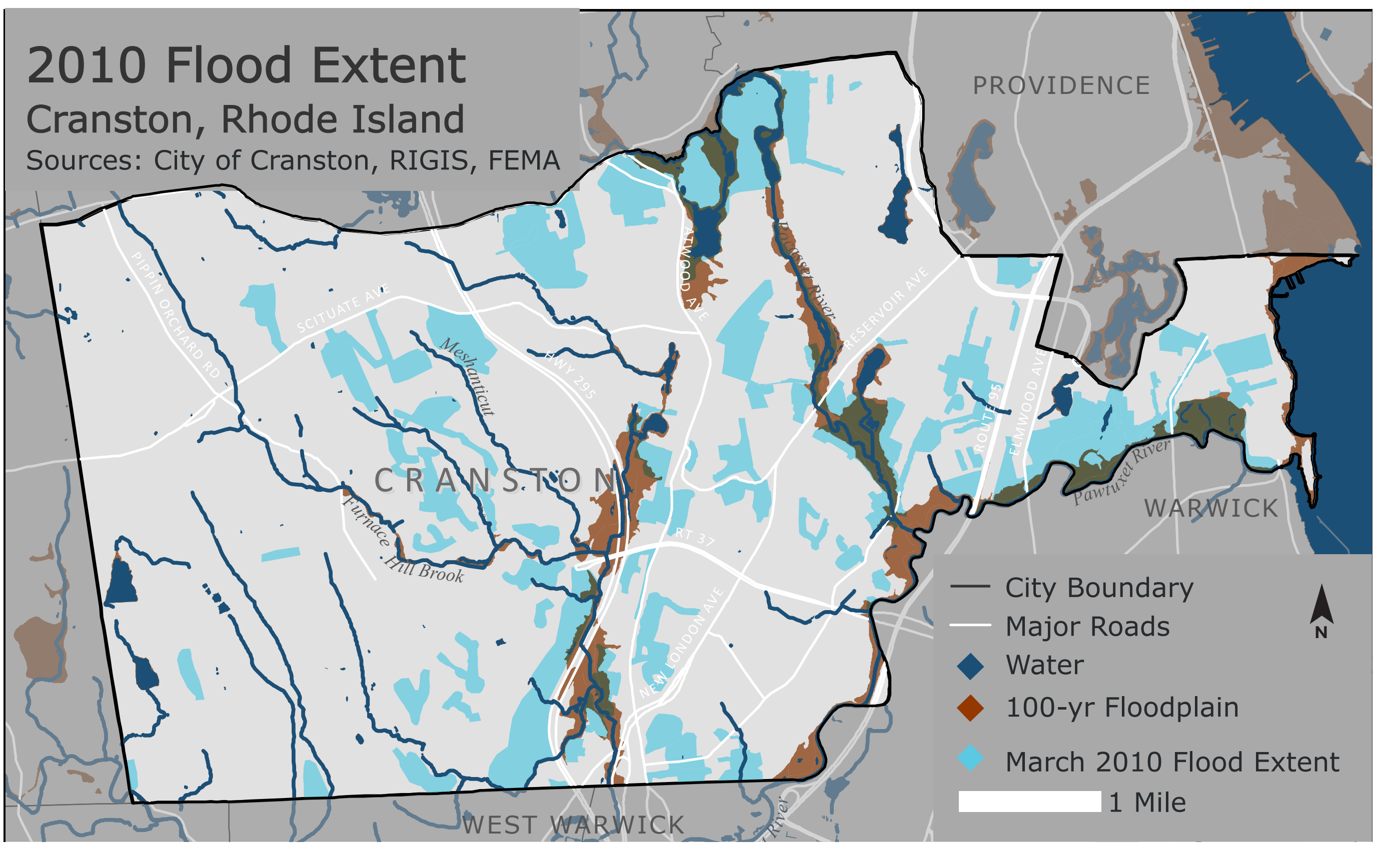


Figure 13: Extent of the March 2010 Flood Event (including flood waters, groundwater flooding and runoff flooding).

2 A flood stage is defined as the level at which a water body (e.g. river) will overflow its banks to inundate areas not normally covered by water. A major flood stage occurs when there is an extensive inundation of roads and structures (NOAA). These levels are generally measured at specific points along the river. There is a gauge along the Pawtuxet River in Cranston with a flood stage level of 9 feet and a major flood stage of 13 feet.

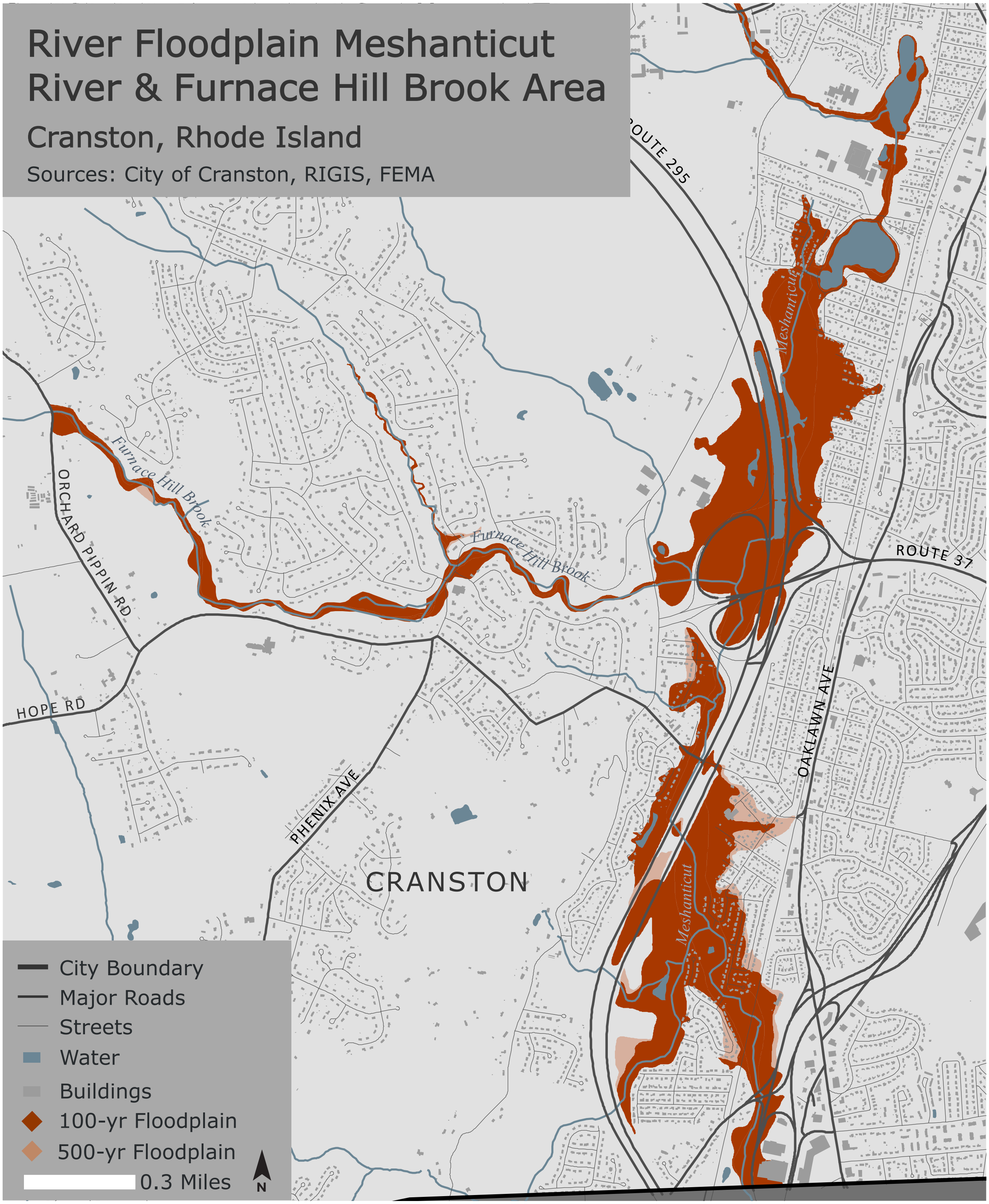


Figure 14a: Meschanticut River and Furnace Hill Brook Area Floodplain Inset

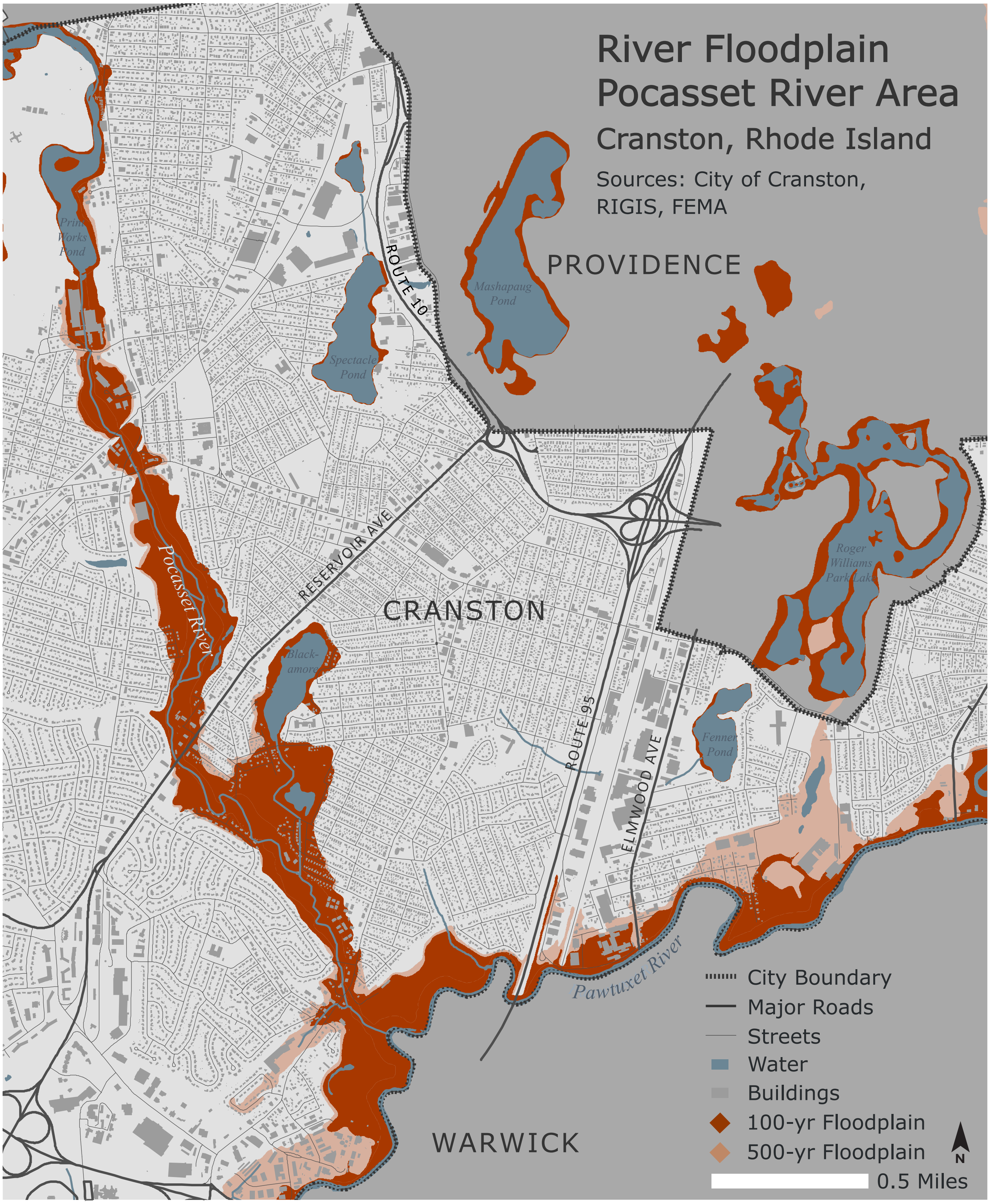


Figure 14b: Pocasset River Floodplain Inset

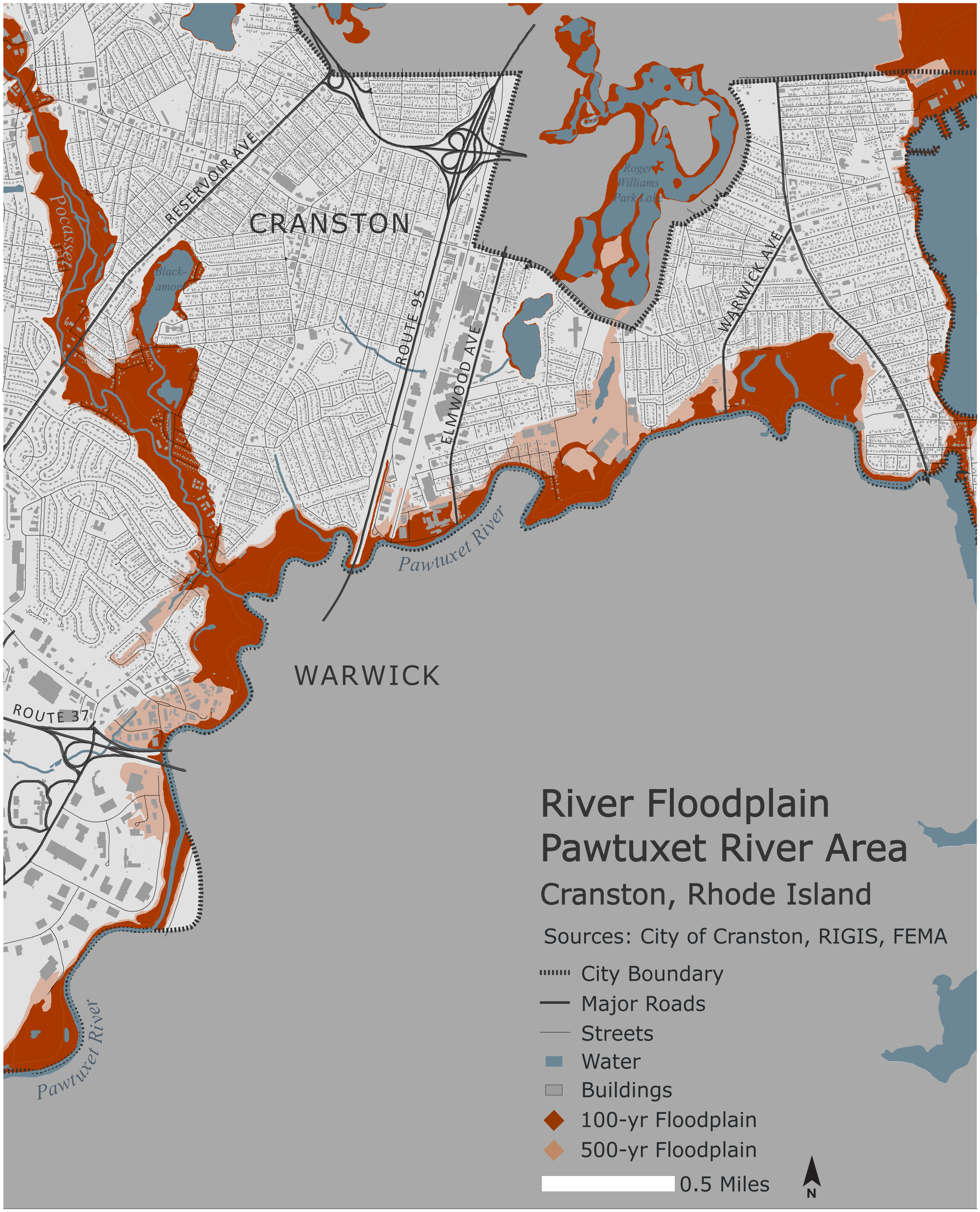


Figure 14c: Pawtuxet River Floodplain Inset

Coastal Flooding: Sea level rise is not as significant a driver of flood risks in Cranston, as Cranston has a small shoreline and it rises rather quickly from the Narragansett Bay. Thus, the coastal floodplain is not as large as the riverine floodplains. Figure 15a shows potential coastal inundation based on future mean sea level[3].

A major risk for Cranston stems from the intersection of both a rise in sea level and a flood event caused by extreme precipitation. Cranston currently sees more flooding when there is a rain event during high tide, as there is a lot less capacity in the channel due to the tide filling that volume. As the extent of inundation associated with sea level rise increases, the city will be in a constant state of high tide, increasing the frequency of flooding associated with precipitation events. The combination of extreme precipitation events and higher sea levels in the future will cause many homes, especially in the Pawtuxet Neck neighborhood, to be exposed to coastal flooding (Vallee, 2013). Figure 15b represents the enlarged coastal flooding zone associated with both a sea level rise and the current 100-year floodplain[4].

An additional threat stems from the combined effect of sea level rise and hurricanes. Currently, the Pawtuxet River up to Pontiac Mills dam becomes tidally influenced during a Category 3 hurricane, when the storm surge pushes water from the bay into the river. However, with 5 feet of sea level rise, the river could become tidally influenced during a Category 1 hurricane or even an astronomical high tide event, which occurs approximately twice a year (Vallee, 2013) (Figure 16).

Vulnerabilities:

Buildings and Neighborhoods. The previous maps demonstrate that in addition to the many buildings in the current flood hazard area, even more buildings and neighborhoods would be affected by sea level rise. A GIS analysis found that there are over 1,000 buildings in the current 100-year floodplain and an additional 700 in the 500-year floodplain. In the future, properties in the current flood hazard area will be at greater risk of flooding as the frequency of flooding is predicted to rise. Buildings can be severely damaged by floodwaters, causing displacement of residents and businesses. Basements can also become damaged from higher groundwater levels and leaks associated with flood events. Residences and businesses can also lose power, water service, and travel access due to road closures.

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3 This map was generated using publicly available spatial data from state and county GIS departments. Sea level rise is relative to NAVD88 at the nearest tide station (Providence, RI). This includes LiDAR data, administrative boundaries, and natural features. After conversion to the appropriate vertical datum (NAVD88), simple geoprocessing tools were used to reclass the elevation data and add sea level rise.

More sophisticated techniques – for instance the SLOSH model – require better quality data regarding storm surge heights and winds resulting from historical or predicted hurricanes, as well as engineering considerations such as infrastructure and unique bay and river configuration. As such, the maps in this assessment are intended for visualization purposes only.

4 This map was generating using the stillwater elevation reported at Cranston transects from the FEMA Flood Insurance Study. This number was converted to the correct datum, to which 4.7 feet of sea level rise were added. 4.7' represents the long term high emissions sea level rise scenario.

Figure 15a: Sea Level Rise along Cranston's Coast: High Emissions Scenario - Long Term

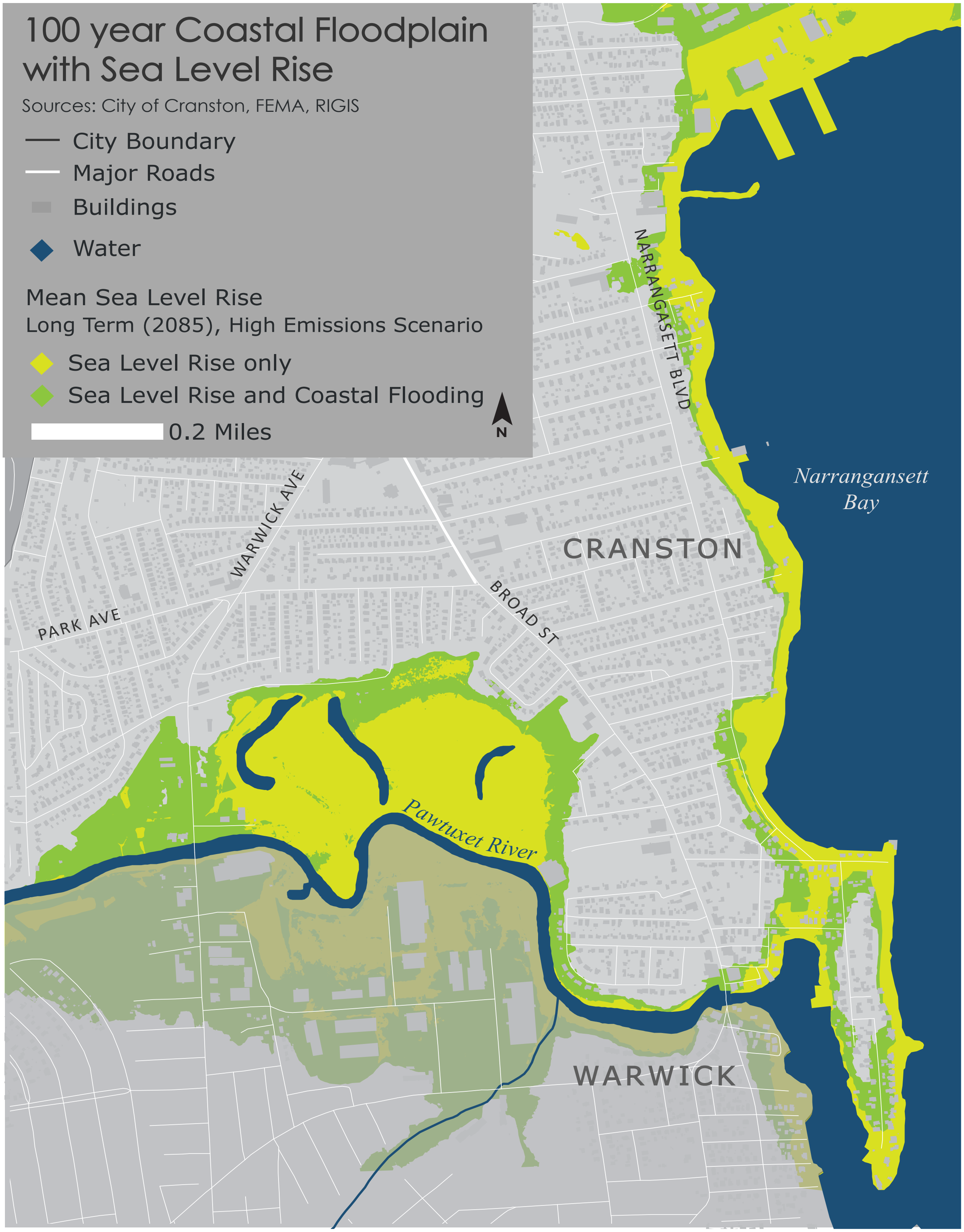


Figure 15b: Sea Level Rise on Top of 100- year Coastal Floodplain

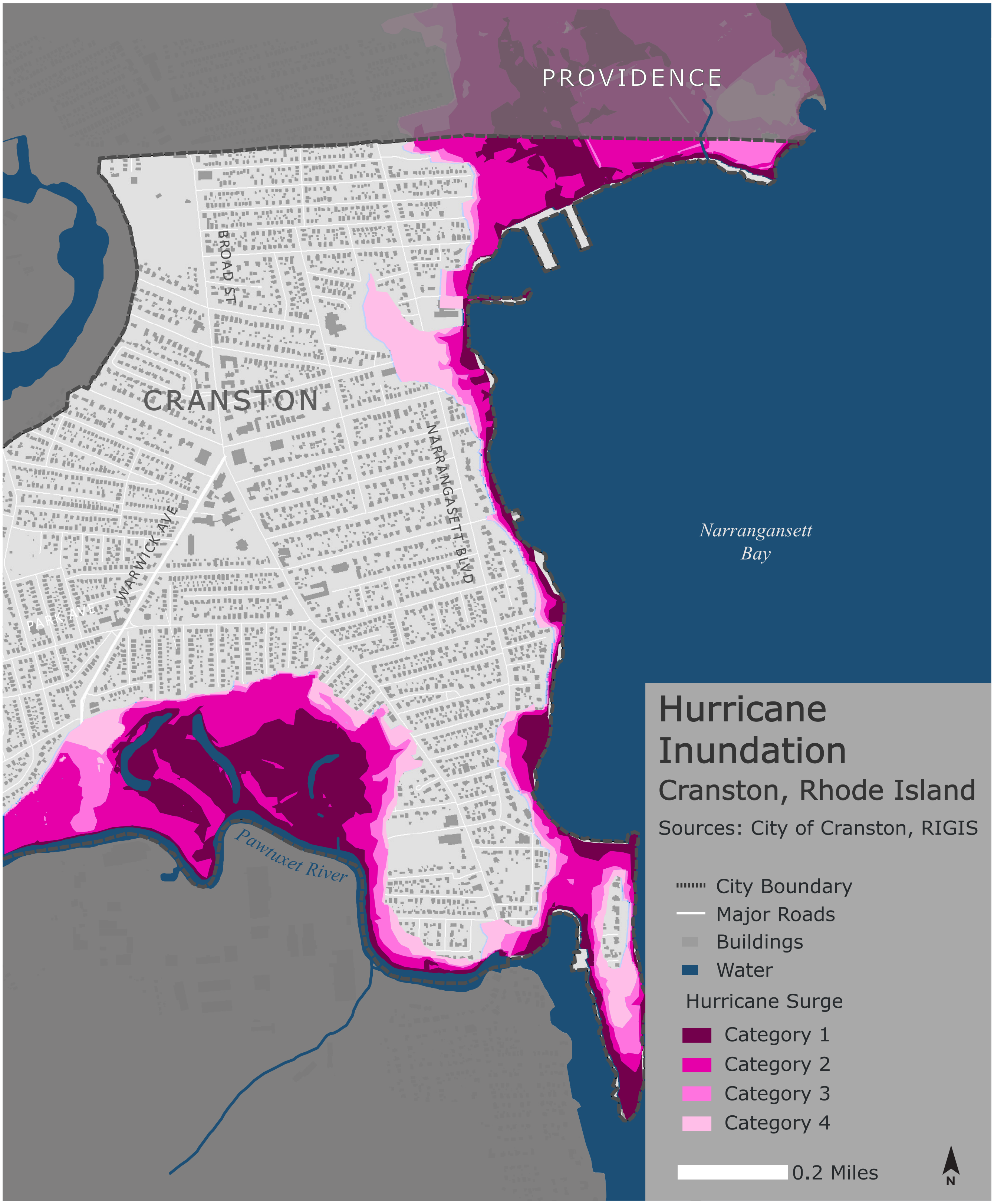


Figure 16: Current Hurricane Inundation

Transportation Network. Roads, highways, and bridges can be damaged and rendered inaccessible by floodwaters. Figure 17 illustrates roads currently at risk from flooding, including the 295 and 37 highways, which are major routes that cross the Pawtuxet. The Rhode Island Department of Transportation has made improvements to these highways to reduce their vulnerability to flooding (RI DOT, 2012). Smaller neighborhood streets are also at risk of inundation and damage from flooding along the Pawtuxet and Pocasset Rivers, including (RI DOT, 2012) Pontiac Ave, Wellington Ave, Perkins Ave, Amanda Court, Fletcher Ave, Randall Ave, Elmwood Ave, Sheldon Ave, and Ocean Ave. The neighborhood on the Pawtuxet Neck could lose transportation access if Sheldon or Ocean Ave are damaged or inundated (RI DOT, 2012). As illustrated in Figure 19, the Pawtuxet Neck neighborhood could become an island as a result of coastal flooding.

Wastewater Infrastructure. The wastewater treatment plant is located in the 500-year floodplain of the Pawtuxet River. Floodwaters could damage the plant and cause a sewage spill. There are also pumping stations located in low-lying areas near the rivers and the coastline (Figure 20). The pump stations could be damaged by floodwaters, potentially causing sewage to back-up into homes and businesses. For example, during a flood event in 2005, several homes experienced sewage backups due to flood-impaired pump stations (City of Cranston, 2012). The Cranston

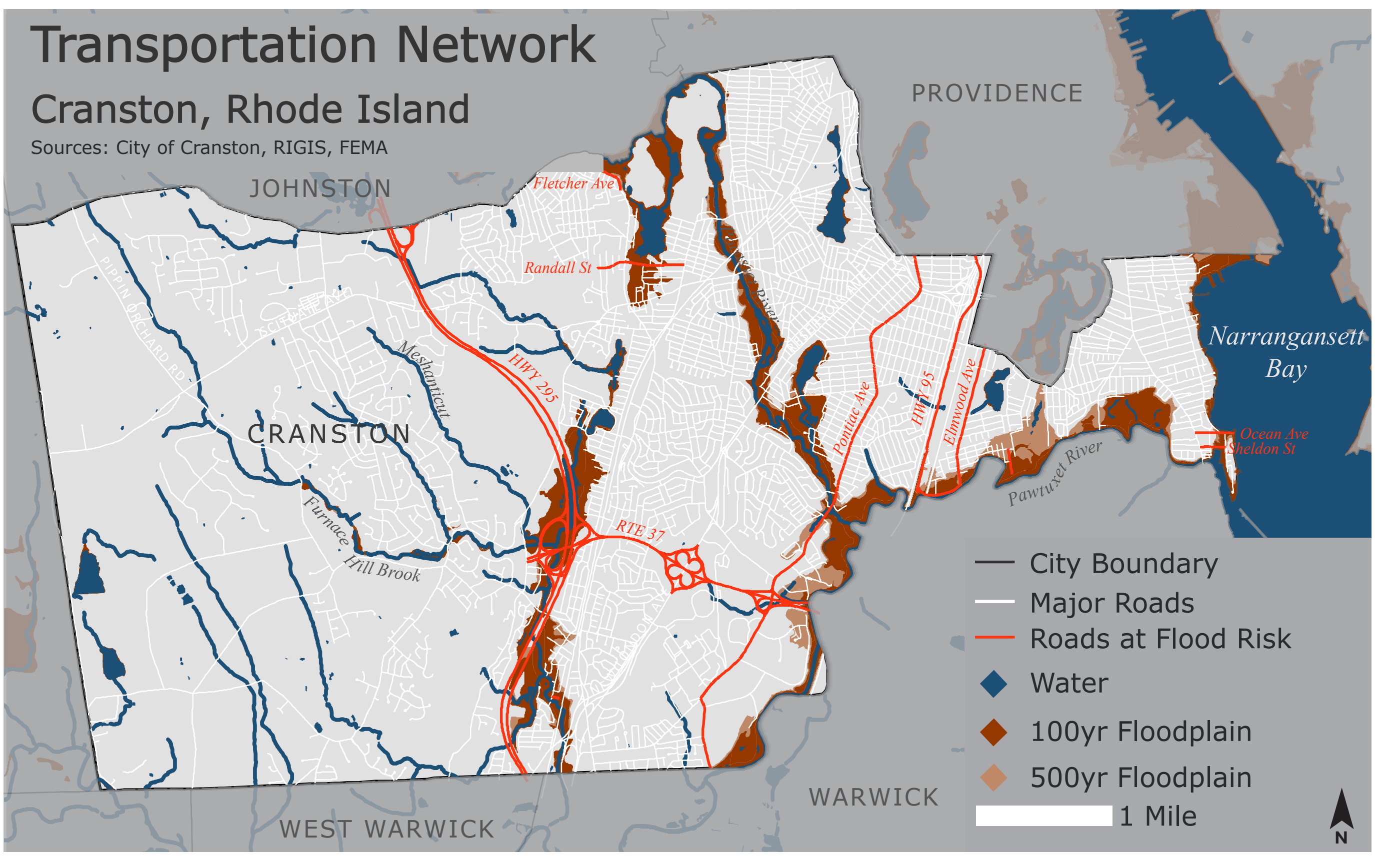


Figure 17: Transportation at Risk from Flooding

Figure 18: Warwick Ave Flooding in 2010 Flood

Public Works Department has been engaged in mitigating the risk of flood-damage to low-elevation pump stations (Cranston Planning Department, 2012).

Social Vulnerabilities. Displacement caused by flooding is a major social vulnerability. Lower-income households may have limited savings and can be especially hard hit by the disruption of work and expenses of recovery associated with flooding. Figure 22 reflects poverty rates of census tracts set against potential flood risk extents (100 and 500-year floodplains). Cranston is also home to a large incarcerated population because the Rhode Island Department of Correction Maximum Security Prison is located in Cranston. The prison is not in at risk for flooding, but the prisoners could be affected if essential services and infrastructure are disrupted because of flooding (City of Cranston, 2012).

Figure 19: Pawtuxet Neighborhood Flood Risks

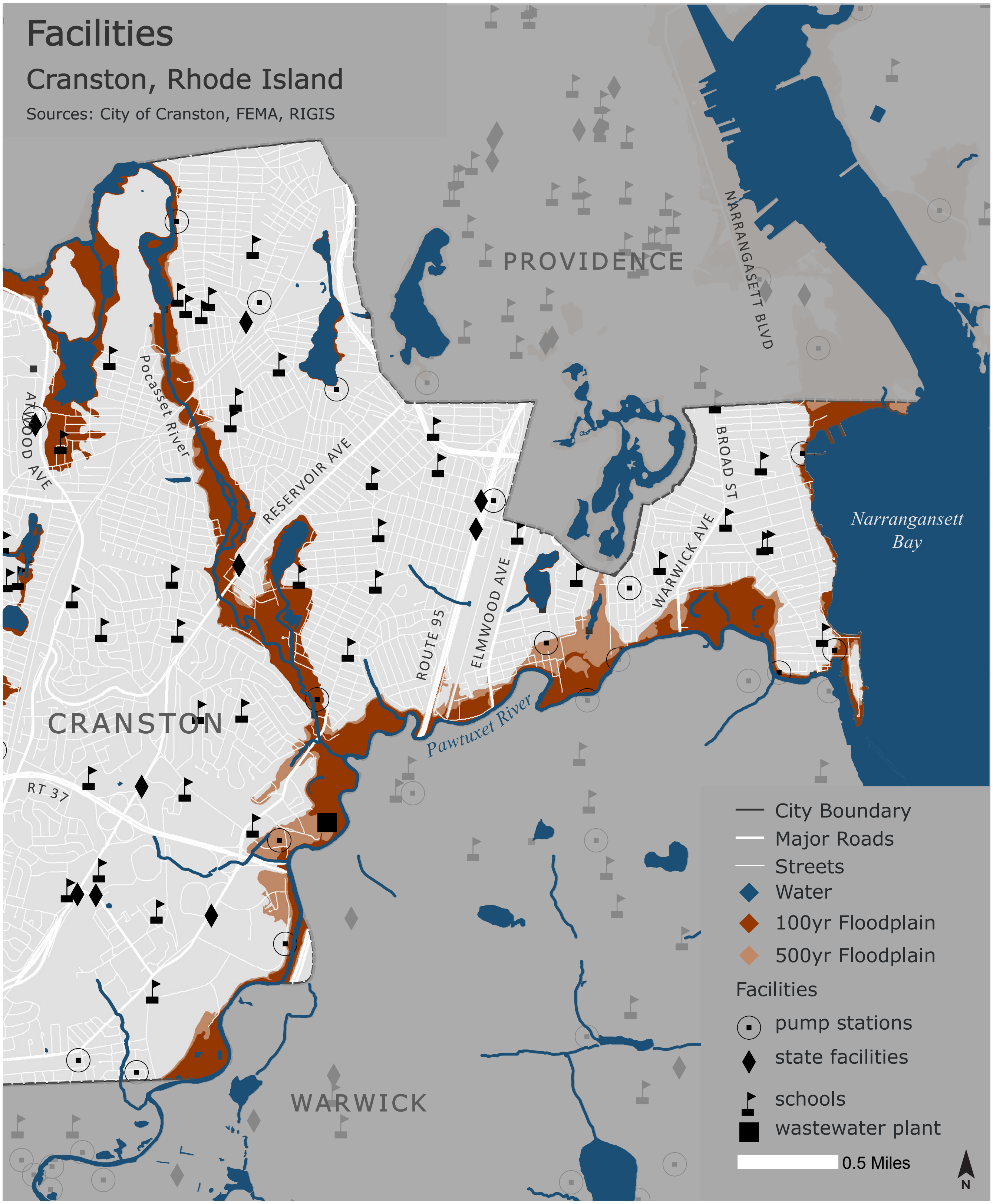


Figure 20: Facilities at Risk from Flooding

Figure 21: Elmwood and Wellington, 2013 Flood

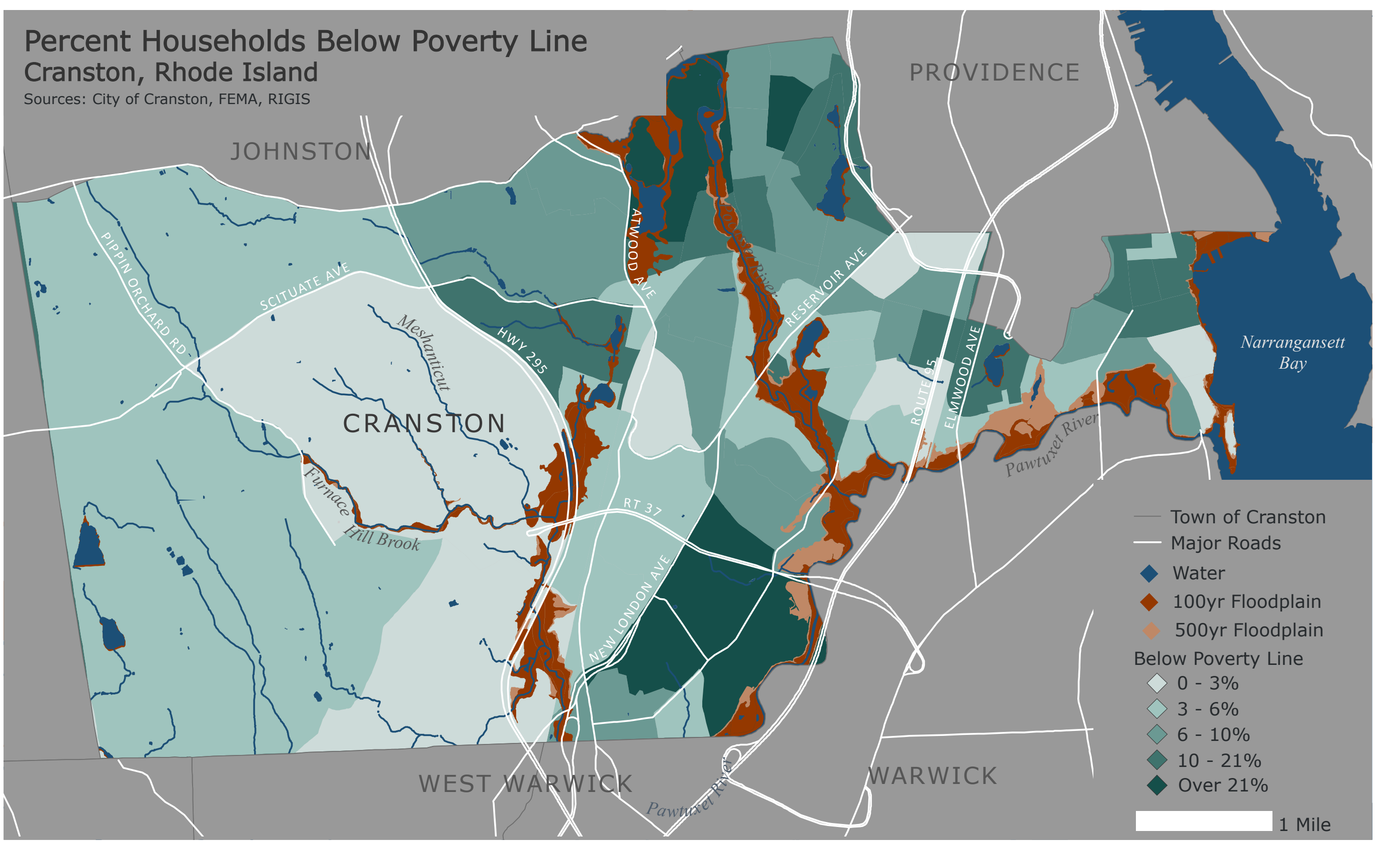


Figure 22: Percent of Populations Below Poverty Line, by 2010 Census Tracts

Adaptation Options:

Reducing Exposure. One way to reduce the risk of flooding is to reduce the exposure of people and community assets to flooding. One option, referred to as "managed retreat," strategically moves people and structures out of floodplains. Once structures have been removed from the floodplains, the land can be restored to provide flood mitigation, wildlife habitat, and open space. The City of Cranston is employing this strategy on a small scale with a program that purchases homes that have been repeatedly flooded using funding from FEMA(City of Cranston, 2012).

Another way to reduce exposure to river flooding is to use a "protect" strategy, which refers to using structural measures, such as floodwalls, to reduce the likelihood that the rivers will overflow their banks. For example, the City of Cranston has been engaged in a project to build floodwalls along the Pocasset River to protect the nearby neighborhoods from flooding (Cranston Planning Department, 2012). Another example of a protection strategy is the Fox Point Hurricane Barrier, which helps protect Providence from storm surges.

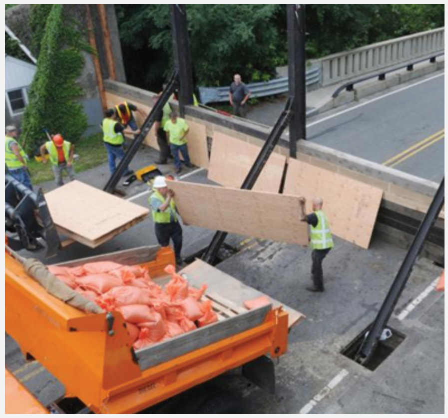
The downside to structural protection measures is that if they are breached by floodwaters, the economic losses tend to be very high in large part due to the "levee effect" – that is, the tendency of development to occur on the other side of a protective structure. In addition, these structural strategies tend to be less flexible than other options. They need to be designed to a certain specification in advance even though unexpected climate and environmental changes could occur.

Protection strategies do not always need to be based on infrastructure. Protection strategies can also employ ecosystem services. For example, a wetland can help store and slow down rising flood waters (Ramsar Convention of Wetland). Urban stormwater best management practices can slow down the flow of stormwater into rivers by storing water in retention ponds or increasing groundwater infiltration by replacing or removing impervious surfaces such as pavement.

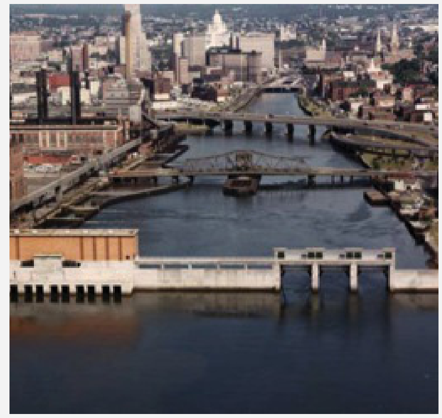
Reduce Sensitivity. Cranston can reduce its vulnerability to flooding by reducing the sensitivity of community assets to flooding impacts, so even if an asset is exposed to flooding, the damage is very limited. This is also known as an "accommodation" strategy. This can mean flood-resilient building design, such as homes that are elevated above the projected flood height, buildings that are dry or wet flood-proofed, or flood resistant infrastructure, such as electric transformers that are saltwater resistant.

Increase Adaptive Capacity. Building an adaptive capacity, or the ability for people and assets to bounce back from flooding, is an alternative way to reduce Cranston's vulnerability. Insurance and other forms of financial security can help people rebuild after a climate-related disaster. Community organizations and affiliations have also been shown to help people recover from disasters more quickly (Swim et al., 2011). Successful efforts employ various strategies that are coordinated in time and location.

a) Restored Wetland



b) Floodwall



c) Hurricane Barrier

d) Pervious Pavement

e) Flood Resilient Building

f) Low Impact Development

Figure 23: Adaptation Options for Flooding

Heat Waves

Risks:

Heat waves are driven by extreme heat events, which are expected to increase significantly in Cranston by the end of the century. Heat waves are particularly dangerous for human health and infrastructure when they last for long periods of time, when evenings do not cool down, and when heat is coupled with high humidity.

Vulnerabilities:

Social Vulnerabilities. The very young, very old, or presently ill are the most vulnerable populations to the health impacts of heat exposure. People who live in substandard housing without good ventilation and those unable to afford air conditioning are also susceptible to excessive heat exposure. Higher temperatures can also contribute to more air pollution, which disproportionately affects the health of the young and elderly.

Electricity Infrastructure. Extremely high temperatures can cause wires to sag and come into contact with trees or structures. Prolonged heatwaves can also damage other electricity distribution equipment, such as transformers, that are designed to cool down during the evenings. In addition, peak electricity demand tends to occur during hot summer afternoons and has the potential to cause reliability problems, such as brownouts or blackouts, if electricity demand outstrips supply.

Adaptation Options:

Reduce Exposure. An option for reducing the health impacts of heatwaves is to reduce the exposure of vulnerable populations. Strategies include providing cooling centers during heatwaves, retrofitting substandard housing, and providing assistance for people who cannot afford their electricity bills. Citywide strategies could also increase green space and tree canopy to mitigate the urban heat island effect.

Reduce Sensitivity. Options for reducing the vulnerability of electrical infrastructure to heat waves include improving the equipment and implementing energy efficiency measures that reduce stress on the electricity system during heat waves. Many electric utilities employ innovative demand management techniques, including programs that compensate customers who agree to have the electrical supply for certain devices (such as irrigation pumps or air conditioners) cycled on and off during periods of peak demand to reduce overall energy use. Some large industrial utility customers can even agree to run their operations at night, which reduces the load on the system during daytime peaks. General energy efficiency policies and practices also serve to lower average energy demand. Distributing and diversifying electricity sources is another way to improve electrical system reliability during extreme weather events. This could involve backup generation options, electricity storage options, and on-site energy options, such as rooftop solar power. Finally, maintaining and updating aging distribution infrastructure, such as transmission lines and transformers, is important for preventing system failures during heat waves (Vine, 2011).

a) Electrical Wires   b) Emergency Room during Heat Wave

Figure 24: Heat Wave Vulnerabilities

a) Building Retrofits   b) Cooling Center   c) Urban Canopy

Figure 25: Heat Wave Adaptation Options

Drought

Risks:

The threat of drought In Cranston is driven by lower-than-average and less consistent precipitation; high temperatures that result in more evaporation and transpiration; and potentially by warmer winters that result in less snow pack. Historically, between 1980 and 2009, Cranston experienced approximately 8 total months of drought conditions, where drought is defined as an event when the monthly precipitation is 20% below the long term monthly average. For this report, we have not included drought projections because of their high uncertainty. However, previous analysis has suggested that in the long term much of New England will experience a significant increase in drought. For example, short term drought (up to one month in duration) will likely increase by two to three-fold by the end of the century under the high emissions scenario. The projections show that the amount of summer precipitation will remain about the same, while significant increases in summertime temperatures will lead to heightened evaporation and transpiration and loss of soil moisture (Hayhoe et al., 2007).

Vulnerabilities:

Drinking Water Supply. The duration and frequency of drought will determine its impacts on water supply. Drought can particularly impact the potable water supply. People who rely on groundwater wells in western Cranston may be particularly vulnerable if a drought causes groundwater levels to fall, because they are not relying on water stored in reservoirs. Prolonged drought could potentially impact the city's drinking water supply, which comes from Providence Water, but the vulnerability of that water supply has not been thoroughly analyzed in this study.

Irrigation Water Supply. Drought can also cause crop failure and put a strain on the farming sector, which is prominent in western Cranston.

Adaptation Options:

Reduce Exposure. Communities can reduce their exposure to drought-induced water supply shortages by acquiring additional water supplies. This might involve digging deeper wells for those using well-water or building new or larger reservoirs for water utility districts like Providence Water.

Reduce Sensitivity. Farmers can reduce their sensitivity to drought by switching to drought-tolerant crops supplemented by more efficient irrigation systems. Decreasing municipal and industrial demands through water conservation also reduces sensitivity.

a) Additional Reservoirs

b) Water Efficiency

c) Irrigation Efficiency

Figure 26: Drought Adaptation Options

Ecosystems

Risks:

Cranston and the greater Narragansett Bay are home to unique and fragile ecosystems, such as the riverine ecosystems, the woods in western Cranston, and the marine ecosystems of the Bay. Warmer temperatures could affect the wildlife in the streams and wooded areas of Cranston. For example, streams and ponds could become too warm to support native fish species (University of Rhode Island Climate Change Collaborative, 2011). Increased ticks and mosquitoes due to warmer and wetter conditions could affect the health of woodland mammals and humans. Some of the unique coastal habitats in the Narragansett Bay could be drastically affected. For example, beaches could shrink and salt marshes could be inundated due to sea level rise (Union of Concerned Scientists, 2007).

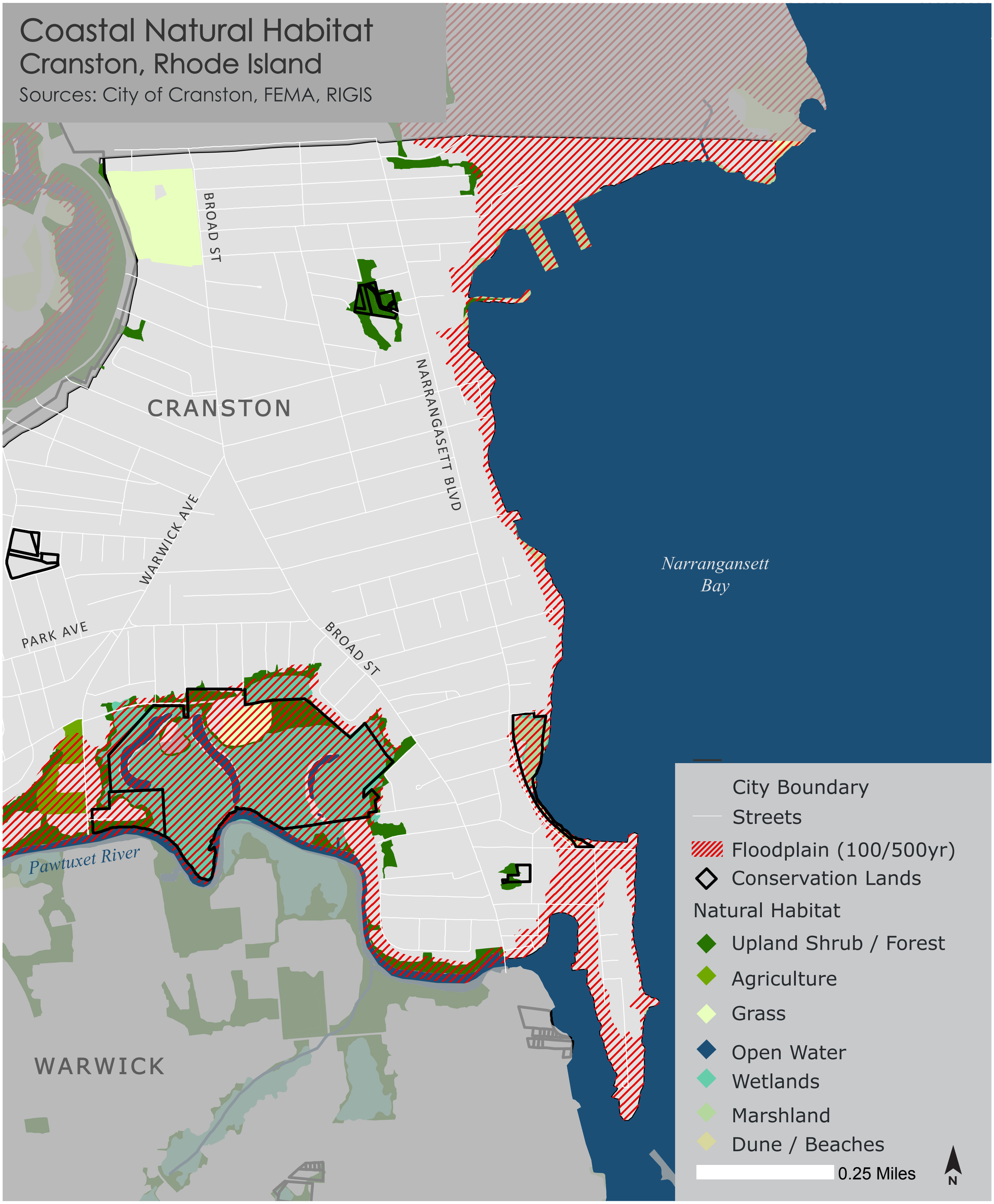
Vulnerabilities:

A vulnerability assessment of habitats and species within Cranston has not been completed. However, national studies have characterized the types of habitats and species that may be more vulnerable to climate changes (Bradley et al., 2012; Halpern et al., 2007; Kittel et al., 2011). Highly fragmented habitat is more vulnerable to pest outbreaks including vector borne diseases and invasive species (Jump et al., 2005). Already stressed species whose habitat and food sources have been reduced are more sensitive to additional stresses such as extreme heat, water loss, and diseases (Anderson Texeria et al., 2013). Aquatic species that cannot tolerate large fluctuations in temperature are threatened by increases in water temperature that can stem from stormwater surges associated with extreme precipitation events and heatwaves (Wainwright and Weitkamp, 2013). Nearshore habitats including deltas and estuaries are nurseries for juvenile fish. These habitats are sensitive to saltwater intrusion and extended periods of inundations (Rogers-Bwennett et al., 2001).

Adaptation Options:

Increase Adaptation Capacity. An important adaptation strategy is to increase the ability of ecosystems to bounce back and cope with disruptions, in other words their *resilience*. This means reducing some of the other human-induced stresses that they face, such as pollution and habitat fragmentation. Healthier populations and habitats will be more likely to adjust to a changing climate. Land behind wetlands can also be set aside to allow wetlands to migrate inland as the sea level rises.

Figure 27: Natural Habitats


Coastal Natural Habitat
Cranston, Rhode Island
Sources: City of Cranston, FEMA, RIGIS
BROAD ST
NARRANGANSETT BLVD
CRANSTON
WARWICK AVE
PARK AVE
BROAD ST
Narragansett Bay
Pawtuxet River
WARWICK
City Boundary
Streets
Floodplain (100/500yr)
Conservation Lands
Natural Habitat
Upland Shrub / Forest
Agriculture
Grass
Open Water
Wetlands
Marshland
Dune / Beaches
0.25 Miles
N

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Cover. Google maps

Executive Summary: Outdoor summer movies at Brown University; Floodwall. Reprinted with permission of the Daily Hampshire Gazette. All rights reserved; Flood Resilient Building. Photo by: Jeffrey Tortaro, Design firm: Tsoi/Kobus & Associates in Cambridge, MA; Wetland Restoration; Woonasquatucket Wetland Restoration http://www.dem.ri.gov/programs/benviron/water/wetlands/wetplan.htm. Tree Canopy, Courtesy of Douglas Still, City Forester, Providence, RI; Additional Reservoir. Wikicommons; Vegetated Waterways. Barnstable, MA

Figure 18 Warwick Ave Flooding in 2010 Flood. Photo credit: Town Planning Office

Figure 21 Elmwood and Wellington, 2013 Flood. Photo credit: Town Planning Office

Figure 23 Adaptation Options for Flooding: Restored Wetland. Three Bridges Foundation; Floodwall. Reprinted with permission of the Daily Hampshire Gazette. All rights reserved. Fox Point Hurricane Barrier. FEMA; Pervious Pavement. USDA; Flood Resilient Building. Photo by: Jeffrey Tortaro, Design firm: Tsoi/Kobus & Associates in Cambridge, MA; Low Impact Development, Southeast Michigan Council of Governments.

Figure 24 Heat Wave Vulnerabilities: Electrical Wires http://www.sbe124.org/newsletters/pdx0309/; Emergency Room during Heat Wave http://publichealth.yale.edu/news/slideshows/2012_internships/kumar.aspx.

Figure 25 Heat Wave Adaptation Options: Building Retrofits. RafterTales; Cooling Center. NYC Urbanlife Blogspot; Urban Canopy. Courtesy of Douglas Still, City Forester, Providence, RI; Additional Reservoir. Wikicommons; Vegetated Waterways. Barnstable, MA

Figure 26 Drought Adaptation Options: Additional Reservoirs. Wikicommons; Water Efficiency. Wikicommons; Irrigation Efficiency. Wikicommons.

Appendix 1: Methodology for Downscaled Projections and Sea Level Rise

The Cranston downscaled projections were generated as output from four different global circulation models (GCMs) that have been well-established and evaluated in the peer-reviewed scientific literature: 1) the US National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1; 2) the United Kingdom Meteorological Office's Hadley Centre Climate Model version 3 (HadCM3); 3) the National Center for Atmospheric Research's Parallel Climate Model (PCM) and 4) Community Climate System Model Version 3 (CCSM3) (Table A1). These models have different climate sensitivities, where sensitivity refers to the amount of temperature change resulting from a doubling of atmospheric CO_2 concentrations relative to pre-industrial times. GFDL, CCSM3, and HadCM3 have medium sensitivity, and PCM has a low sensitivity.

Each global model produces output in the form of geographic grid-based projections of daily, monthly, and annual temperatures, precipitation, and other climate variables. GCMs operate on the scale of hundreds of miles, which is too coarse a resolution to distinguish changes across different towns and cities in a given region, such as New England. However, scientists used state-of-the-art statistical downscaling models to capture historical relationships between large-scale weather features and local climate, and use these to translate future projections down to the scale of local weather station observations. In this project we used a relatively new statistical downscaling model, the Asynchronous Regional Regression Model[5]. This report uses the projections downscaled to the meteorological station in Kingston, RI, because it is the closest station to Cranston.

Two different IPCC climate change scenarios drove the projections from the GCMs: a high emissions scenario (A1fi) and a low emissions scenario (B1). The high emissions scenario assumes that the world will experience economic growth dependent primarily on fossil fuels and that atmospheric concentrations of CO_2 will reach 940 parts per million by 2100. The low emissions scenario assumes that economies will shift to cleaner, less fossil-fuel intensive technologies, and that atmospheric concentrations of CO_2 will reach 550 parts per million by 2100[6]. The purpose of choosing a high emissions and a low emissions scenario is to create a likely range of future climatic change that Cranston may experience during the 21st century.

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5 More information on the statistical downscaling method used is provided in: Stoner, AMK, K Hayhoe, X Yang and DJ Wuebbles (2012) An asynchronous regional regression model for statistical downscaling of daily climate variables. Int. J. Climatol. DOI: 10.1002/joc.3603.

6 The emissions scenarios and GCM simulations used in this report consist of models that contributed to phase 3 of the Coupled Model Intercomparison Project (CMIP3). These are the results presented in the Intergovernmental Panel on Climate Change (IPCC) Third (2001) and Fourth (2007) Assessment Reports. More recent scenarios combined with CMIP5 climate projections were recently released (September 2013) in the IPCC Fifth Assessment Report.

The projections are also presented in three time frames: short term, medium term, and long term. The short term refers to the time period between 2010 and 2039, the medium term refers to the time period between 2040 and 2069, and the long term refers to the time period between 2070 and 2099. The historical baseline refers to the time period between 1980 and 2009. We averaged the results of the historical baseline and climate projections over their respective 30-year timeframes. This period is long enough to filter out any inter-annual variation or anomalies and short enough to show longer climatic trends.

Table A1: Global Circulation Models

Origin	Model	Scenarios	Equilibrium Climate Sensitivity (°C)*
National Center for Atmospheric Research, USA	CCSM3	A1fi, B1	2.7
National Center for Atmospheric Research, USA	PCM	A1fi, B1	2.1
Geophysical Fluid Dynamics Laboratory, US	GFDL CM2.1	A1fi, B2	3.4
UK Meteorological Office Hadley Centre	HadCM3	A1fi, B3	3.3
* data from IPCC 2007 Fourth Assessment Report, Chapter 8.			

Table A2: Downscaled Projections for Cranston: Temperature Anomalies

Temperature Anomaly (°F)							
	Historical	Short Term (2010-2039)		Medium Term (2040-2069)		Long Term (2070-2099)	
	1980-2009	Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions
Annual TMIN	39.8	41.1	41.2	42.3	44.1	43.0	46.9
Annual TMAX	61.4	62.1	62.0	63.0	64.4	63.5	66.9
Winter TMIN	21.9	23.5	23.1	24.7	25.5	25.1	28.4
Winter TMAX	41.6	42.1	42.1	42.9	43.6	43.1	45.2
Summer TMIN	58.4	59.6	60.1	61.0	63.2	61.5	65.9
Summer TMAX	80.4	80.8	80.6	81.6	83.0	82.4	85.9

Table A3: Downscaled Projections for Cranston: Temperature Extremes

Temperature Extreme (days per year)							
	Historical	Short Term (2010-2039)		Medium Term (2040-2069)		Long Term (2070-2099)	
	1980-2009	Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions
<32°F	128.7	117.8	117.6	111.5	101.2	104.9	82.9
>90°F	2.8	5.5	5.0	8.9	14.3	11.0	32.2

Table A4: Downscaled Projections for Cranston: Precipitation

Precipitation (inches)							
	Historical	Short Term (2010-2039)		Medium Term (2040-2069)		Long Term (2070-2099)	
	1980-2009	Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions
Annual mean	52.7	51.7	52.7	51.5	54.4	54.6	57.8
Winter mean	12.4	12.9	13.4	13.4	13.2	13.9	14.7
Summer mean	12.3	11.8	11.6	10.9	12.2	11.7	12.8

Table A5: Downscaled Projections for Cranston: Extreme Precipitation Events

Extreme Precipitation (events per year)							
	Historical	Short Term (2010-2039)		Medium Term (2040-2069)		Long Term (2070-2099)	
	1980-2009	Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions
1" in 24 hrs	14.8	15.8	16.1	15.7	17.0	17.1	19.0
2" in 48 hours	7.6	9.4	9.3	9.4	10.6	10.6	13.0

Extreme Precipitation (events per decade)							
	Historical	Short Term (2010-2039)		Medium Term (2040-2069)		Long Term (2070-2099)	
	1980-2009	Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions
4" in 48 hrs	2.7	4.6	3.3	3.8	4.4	4.7	7.1

Relative sea level rise (SLR) at a site is considered to be the sum of global climate change and local subsidence. Other factors such as circulation changes are not considered. Based upon research done by NOAA (http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8454000), the historical relative rate of sea level rise is 1.95 mm/year. Following the method of Kirshen et al (2008), 1.6 mm/year global eustatic rate is subtracted from the relative rate to obtain the local rate, or 0.35 mm/year (0.01 inches), considered due to subsidence. This local rate is insignificant. Therefore, it is only necessary to use the global rate in Figure 1A.

Table 5: Downscaled Projections for Cranston: Sea Level Rise

Sea Level Rise (feet)						
	Short Term (2010-2039)		Medium Term (2040-2069)		Long Term (2070-2099)	
	Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions
Sea Level Rise	0.5	0.8	1.0	1.7	2.0	4.7

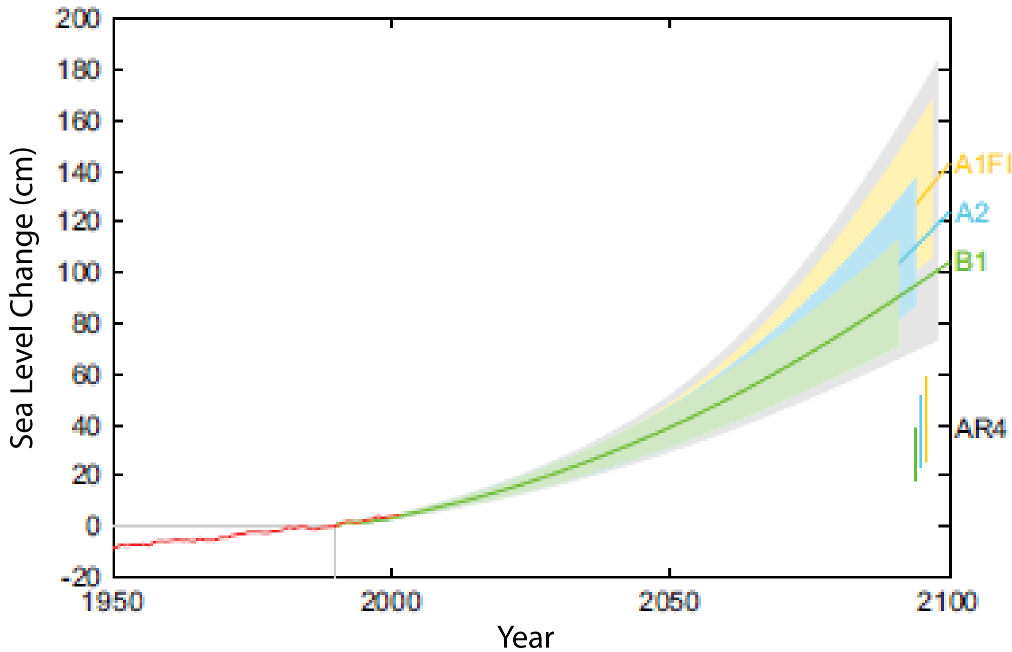

Figure A1: Global Sea Level Rise Projections *(Vermeer and Rahmstorf, 2009)*

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Appendix 2: Additional Resources

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