TOWARDS A RESILIENT PROVIDENCE

ISSUES | IMPACTS | INITIATIVES | INFORMATION

FEBRUARY 2021 | PROVIDENCE RESILIENCE PARTNERSHIP

Towards a Resilient Providence: Issues, Impacts, Initiatives, Information
A report by Pam Rubinoff, Megan Elwell, Sue Kennedy and Noah Hallisey. Edited by Lesley Squillante.
February 2021

Cover photograph © Nicole Capobianco

Acknowledgements

We thank the researchers, practitioners, and stakeholders who have contributed to this effort to strengthen resilience in Providence and throughout Rhode Island. Their time, expertise, and varied perspectives have been invaluable in shaping this report and leading the work of the Providence Resilience Partnership.

Contributors

Curt Spalding, Brown University
Horsley Witten Group

Funding and Guidance

Providence Resilience Partnership

Personal Communications, Reviews, Information

Monica Allard Cox, Rhode Island Sea Grant
Leah Bamburger, City of Providence
Austin Becker, URI
David Bowen, Narragansett Bay Commission
Rachel Calabro, RIDOH
Al Dahlberg, Brown University
Clara Decerbo, City of Providence
David DosReis, City of Providence
Barnaby Evans, WaterFire
David Everett, City of Providence
Janet Freedman, CRMC
Tom Giordano, Partnership for Rhode Island
Lichen Grewer, Brown University
o Lee, Brown University, PopUp Rhody
Alicia Lehrer, Woonasquatucket River Watershed Council
Isaac Ginis, URI
Dan Goulet, CRMC
Meg Goulet, Narragansett Bay Commission
Jon McPherson, USACE
Bonnie Nickerson, City of Providence
Shaun O'Rourke, RI Infrastructure Bank
Bill Patenaude, RIDEM
Carolyn Skuncik, I-195 Commission
Elizabeth Stone, RIDEM
Tom Uva, Narragansett Bay Commission
Chris Waterson, ProvPort

PROVIDENCE RESILIENCE PARTNERSHIP
Sea Grant Rhode Island
THE UNIVERSITY OF RHODE ISLAND GRADUATE SCHOOL OF OCEANOGRAPHY
CRC COASTAL RESOURCES CENTER

Foreword

A Comprehensive Look at Providence's Vulnerability

Dear Fellow Rhode Islanders:

We have both good news and difficult realities to present.

First, the good news is we can address the current and future impacts from climate change in Providence if we come together, mobilize and adapt.

Second, there are real and measurable threats stemming from climate change. Efforts to decarbonize economies across the world will not mitigate the threats facing us over the next decade. Increases in storm activity, extreme rain events and sea level rise will cause unmanageable damage without substantial upgrades and repairs to our current infrastructure. Without action, there will likely be significant flooding in our city causing catastrophic damage to our economy.

There is no avoiding the fact that Providence must prepare for the impending risks by creating and implementing the necessary adaptation and resiliency strategies. These efforts must begin now.

The Providence Resilience Partnership (PRP) was formed with the goal of supporting a citywide mobilization effort to address Providence's vulnerabilities. We thought it was critical to identify these key vulnerabilities in one comprehensive report.

We are grateful to Pam Rubinoff and her team at the University of Rhode Island's Coastal Resources Center (URI-CRC) who built a baseline from dozens of previous studies, compiling what we already know as well as what needs to be further studied regarding Providence's risk profile. The study area focused on the floodplain from the Save the Bay Center on Fields Point extending north along the Port area, through the Hurricane Barrier and downtown under the Providence Place Mall and up through neighborhoods along the Woonasquatucket River.

Finally, this report underlines the urgency for the larger community to join together to address Providence's vulnerability to climate change. PRP will continue its efforts to expand our community's awareness on this subject. We will also convene and encourage further dialogue among our civic, institutional and government leaders so they may efficiently suggest and support next steps in both protecting our city's residents and our economy.

Sound actions will emerge from informed, inclusive dialogue and a shared commitment to create a thriving future for Providence. We thank all our partners who have stepped in to work to protect our city and The Providence Foundation for serving as our affiliate and fiscal agent.

Here is our call to action for you: Please visit our website at providenceresilience.org, sign up to join the PRP network and give us your ideas, time and resources to make this a reality. We appreciate your interest and hope you will support positive action ensuring Providence's future.

Respectfully submitted.

Arnold B. Chace Jr and Curt Spalding

on behalf of the PRP Partnership Members

Table of Contents

Executive Summary

As the rate of rising water in Narragansett Bay accelerates, as the intensity of storms becomes more damaging, and as the amount of water that falls with major rain events grows, no home, no business, no neighborhood will escape the impact of accelerating climate change that science tells us is already certain to affect Providence.

Building resilience means learning to manage the risks climate change will bring. It means learning to act rather than react to what we know is coming. It starts with assessing vulnerability and proceeds with taking action to limit the risks.

Climate change has long been acknowledged as a "wicked problem" for planners and policy makers.

– Richard Lazarus, "Super Wicked Problems and Climate Change: Restraining the Present to Liberate the Future", 2008

Rhode Island's First Nations thrived for thousands of years by embracing their relationship to Narragansett Bay. Through storytelling, from elders to youth, history was always present. Tribal communities understood how natural assets like forests, floodplains, and wetlands protected their communities. This understanding was their great strength and the cornerstone of their resilience.

Colonial settlement and industrial development generally exploited natural resources rather than heeding the tribal knowledge of the Narragansetts and Wampanoags among others. For much of the

19th and 20th centuries, Providence's expansive growth meant eliminating the natural assets that protected the city and building extensive infrastructure on what were salt marshes and floodplains. Consequently, storm events repeatedly and catastrophically flooded—and impacted—Providence. Because of several mid-century hurricanes, the U.S. Army Corps of Engineers built the Fox Point Hurricane Barrier—the highest in the country. The multiple-layered threats associated with climate will defy expensive but relatively simple solutions like the hurricane barrier.

Over several decades, the Rhode Island state agencies and the city of Providence pursued numerous studies and plans addressing largely infrastructure vulnerability from multiple hazards. More recently, city planning and climate justice initiatives are giving greater attention to issues of equity and social vulnerability and have expanded the scope of work being undertaken that addresses issues of vulnerability associated with climate threats. This work shows that adapting to climate change is a complex endeavor. The first step in understanding this complexity is to review this work and broadly assess what we know and do not know about Providence's vulnerability to climate change threats. With this clear objective in mind, the Providence Resilience Partnership (PRP), a group of civic and business leaders deeply concerned about the flooding threats of climate change asked the University of Rhode Island Coastal Resources Center to research what we know about the current situation, the climate challenges, efforts underway, and a host of recommendations that have been put forward to enhance resilience policy and practice to move Toward a Resilient Providence.

Key Findings

Overarching

Understand that increasing risk and vulnerability of changing climate affects different places and people throughout the city. Providence is threatened by flooding, with climate change increasing that risk. This plays out differently in various parts of the city. The port area, at the head of the bay and south of the hurricane barrier, is extremely vulnerable to storm surge and rising seas. Downtown, while protected by the hurricane barrier for extreme storm surges, is vulnerable to extreme and rising tides affecting this low-lying area. In the Woonasquatucket River Corridor, the river floods meet coastal tides in addition to upland flooding throughout the watershed. Frontline communities, some of which are in low tree canopy neighborhoods, are disproportionately affected by heat and flooding.

Develop comprehensive strategies with citywide stakeholder engagement. Preparation for increased flooding in Providence (and at the state level) cuts across many agencies, many sets of regulations, and many core infrastructure elements. While all of these entities have initiatives related to resilience, the efforts to predict, design, and respond to future inundation (from both sea level rise and storms) are often fragmented. Across Providence, there are numerous studies, plans, policies, and actions at the neighborhood/sector scale that address vulnerability concerns. This is important and positive work and essential to short- and long-term resilience building. These efforts underscore the need for an integrated vision, framework, and strategy for resilience in Providence, much of which must be coordinated with the state and other public, private, and nonprofit entities.

Assess larger scale infrastructure, economic, and social systems. Partnerships with public, private, and nonprofit organizations, together with community stakeholders have implemented substantial initiatives with multiple benefits that support building resilience to natural hazards. However, this work does not cumulatively or consistently address larger scale infrastructure, or economic or social systems at risk from changing climate conditions.

Continuously assess (or re-assess) risk and plan accordingly. Infrastructure planning and projects for building resilience are an important focus for the Fox Point Hurricane Barrier and the wastewater treatment facilities owned and managed by the Narragansett Bay Commission. Also assessed was the vulnerability of the state transportation system, including transportation assets for Providence. The study identified bridge improvements and stormwater management improvements as priorities. Despite the substantial flooding risk associated with stormwater management, the full scope of vulnerability issues for the stormwater infrastructure network is unknown. With the understanding that projects addressing significant vulnerabilities can takes years from design to completion, accelerating climate change requires establishing policies and actions for more frequent assessment, planning, investment for all major infrastructure that sustains community well-being.

Improve communication, and coordination of priority issues regarding how water infrastructure systems are affected by intensifying climate change impacts. Drinking water, wastewater, and stormwater systems are managed, regulated, and overseen by different organizations and regulatory frameworks. Greater coordination towards better decision making on strategic actions for these separately managed but connected systems is necessary.

Develop a single predictive flood model that is used and agreed upon by multiple entities. Multiple models and tools are used in Rhode Island to assess vulnerability, define risk, and drive regulatory actions. The lack of a *single* predictive flooding model that incorporates future climate conditions—e.g., increased precipitation, coastal and riverine flooding, and rising seas—is an impediment to data-driven investment and decisions for municipalities like Providence; here, the hurricane barrier and the confluence of riverine and coastal systems provides additional complexity to modeling. Consequently, flooding vulnerability is likely underestimated—leading to what may be insufficient adaptation planning, priority setting, and action. Currently there is no process to resolve inconsistent projections of exposure nor are there efforts underway to rework the regulatory framework associated with inconsistent vulnerability assessments.

Hazards of Focus and Modeling Tools

Providence is experiencing the impacts and implications of a changing climate, and these are only expected to increase in the future.

Hurricanes, high winds, and riverine flooding are identified as the top wind- and flood-related threats (over 50% threat) to Providence over the short term. Close behind are threats from severe thunderstorms, flash flooding, sea level rise, and extreme heat.

Actions underway to mitigate the impacts of climate change—elevating buildings, incorporating green space buffers along the waterfront, or reducing greenhouse gas emissions—are critical to reducing the implications of a changing climate. Many impacts, however, will be long lasting or irreversible given the elevated temperatures of atmosphere and oceans today.

Flood models used by the state and city are applied to regulatory requirements, planning, assessment and design. Yet these modeling tools differ in attributes, accuracy, and results. Rhode Island would benefit from the development of an agreement upon one risk model that incorporates future-looking combined river and coastal flooding, precipitation, and sea level rise. In the case of Providence, this model also would need to incorporate hurricane barrier dynamics.

Economy and Society

The impacts and consequences of changing climate challenge the effective functioning of the Providence (and state) economies and its residents/business owners—although these impacts and consequences disproportionately affect vulnerable populations and small businesses.

The full scope of economic and social vulnerability associated with accelerating climate change is not understood, assessed at scale, or quantitatively evaluated.

Using predictive social and economic modeling to assess vulnerability is essential to effective planning, determination of actions, and priorities that will reduce risk.

Infrastructure and Environment

There are essential infrastructure assets that are highly vulnerable to accelerating climate change, and yet there is an inconsistent level of attention given to these vulnerabilities. This presents significant risk to affected communities' well-being and public health and has consequences for the larger statewide/Northeast Region. This research did not include a study of the resilience of the heating supply, and the communications and electricity networks (including a backup to the hurricane barrier).

Linking infrastructure and environment issues and opportunities engages highly capable community initiatives that leverage multiple partnerships to effectively address infrastructure vulnerability. An example is the efforts linking "green infrastructure" approaches to local job growth and community development work.

Available to the public are studies that assess the vulnerability of transportation assets, the hurricane barrier, and wastewater treatment facilities. Either unavailable to the public, or not yet undertaken or completed, are studies that fully assess how accelerating climate change will impact energy, communications, water, and stormwater utility infrastructure.

Health and Well-being

There are large disparities in vulnerability tied to levels of income and racial inequities. These have not been comprehensively assessed, or are not fully understood, and are not communicated to diverse stakeholders connected to climate adaptation and resilience building efforts.

There is a lack of solid research, assessment, and measurement of public health vulnerabilities to chronic and catastrophic environmental hazards, including those that could be exacerbated (or accentuated) by natural hazards in the short and long term. As a consequence, there is limited understanding of risk to the community from storms that result in chemical spills, wastewater releases, and other hazards.

Several ongoing initiatives, including Resilience Hubs in frontline communities, tree planting, green infrastructure installations, and the expansion of Riverwalk parks increase community health and well-being and resilience by mitigating heat and flooding.

Fox Point Hurricane Barrier

The transfer of the Fox Point Hurricane Barrier to the U.S. Army Corps of Engineers secured effective maintenance and operation through the design life of the barrier. Its conservative, mid-19th century design provides protection for all but today's most extreme storm surge scenarios; but its design did not consider increased tidal flooding associated with sea level rise. Using the barrier frequently for this purpose, i.e., to address increased tidal flooding, would likely compromise its long-term efficacy for protection.

Given the above, the Providence Multi-Hazard Mitigation Plan (informed by a 2016 economic analysis on alternatives) recommends evaluating climate change projections and the likely impacts on the barrier every five years—with a commitment to make a decision about any future barrier no later than 2050. Discussions related to mitigation in low-lying waterfront areas should take place with decisions implemented in the 2040-2050 timeframe to prevent increased tidal flooding.

A thorough evaluation is needed to assess the barrier's integrity and ability to protect the areas behind it from the combined impacts of changing and accelerating climate conditions. This includes the likelihood of increased storm/hurricane intensity accompanied by higher surge and precipitation, higher sea levels, and an increased frequency of tidal flooding.

Wastewater Treatment

The wastewater infrastructure system in Greater Providence is highly threatened and therefore vulnerable to increased storm surge, precipitation, urban flooding, and rising tidal water levels.

The Narragansett Bay Commission (NBC) is proactively taking action, building its own capability and capacity to address increasing vulnerabilities, and it is prepared to consider all actions necessary to sustain service in the long term. Building resilience requires balancing the impact that action(s) will have on rate payers against the ability to recover from an inundation event. There is no policy guidance from the Public Utilities Commission or the Rhode Island Department of Environmental Management (RIDEM) for addressing this challenge.

Addressing expected threats through the next few decades, NBC uses the Federal Emergency Management Agency (FEMA) model with added freeboard to accommodate

increased flooding potential—consistent with RIDEM guidance—to guide their planning and designs. Other models, including Rhode Island-based STORMTOOLS, incorporate future storm and inundation scenarios with accurate available methodology. Results from these models project greater exposure.

Stormwater Systems

The collective expertise within the state and city is perhaps our greatest resource. However, the number and diversity of stormwater stakeholders makes coordination challenging.

The lack of a single, accepted statewide predictive flooding model that incorporates future climate conditions—increased precipitation, coastal and inland flooding, and rising seas—is an impediment to data-driven investment in more resilient infrastructure.

Fragmented jurisdiction over stormwater systems and the absence of a long-term funding/financing solution for stormwater management is a major challenge to proper maintenance, upgrades, and expansion. Studies led by different agencies and organizations should be coordinated to ensure valuable data are shared across jurisdictions, leading to consistency in design criteria to mitigate future flooding.

Providence Port Area

Several studies using predictive models effectively define the threat of coastal storms and sea level rise for the port area. Much less is known about how the threat of coastal storms and sea level rise will physically, economically, and socially impact the port area, the state, and the Northeast Region that it serves.

An understanding of and attention to threats—and taking action to build resilience—is uneven across port area stakeholders and decision makers.

The lack of a unifying agency, such as a Port Authority, may increase the difficulty of making decisions on investments in infrastructure that affect the port as a whole.

Ongoing Port/Community Working Group discussions are an opportunity to understand stakeholder concerns, assess vulnerability, and define actions that will advance all aspects of social and physical resilience.

Downtown

Downtown, a hub for the city and state alike, is currently designated by FEMA as an ‘area of minimal risk flooding’ from the .2% annual chance (500-year) flood. The Fox Point Hurricane Barrier, reconditioned over the last decade and operated by the federal government in partnership with the city, affords protection to ‘design’ floods from hurricanes and other coastal storms that will likely threaten Providence over the next several decades.

The low-lying areas that characterize much of Downtown are vulnerable to more frequent, higher, chronic tidal flooding with increasing sea levels. The majority of the city’s infrastructure that is at risk from sea level rise—its roads, bridges, and buildings—are located Downtown. Used intermittently to reduce tidal flooding, the hurricane barrier is not designed to operate on a regular basis for this purpose.

Developing a predictive modeling capability for combined future risk (and its implications for infrastructure, business, and society) from sea level rise, storm surge, precipitation, and riverine flooding from hurricanes and other storms is complicated but necessary. Two complicating factors, the presence of the barrier and the city’s coast/river geography, are key

components of effective modeling and assessment for Downtown and Providence as a whole.

Woonasquatucket Corridor

Chronic flooding associated with regular rain events is impacting the well-being of near-river neighborhoods as well as those throughout the watershed.

The federal stormwater Consent Decree agreement with Rhode Island Department of Transportation (RIDOT) together with the RIDOT partnership with the Woonasquatucket River Council and the Rhode Island Infrastructure Bank is facilitating the most ambitious green infrastructure stormwater remediation program in Rhode Island.

Woonasquatucket River Corridor initiatives, including its vision plan and the current watershed-wide flood resilience study, is a model approach to build community resilience by integrating stormwater improvements, brownfield remediation, economic development, and citizen engagement through local place-based partnerships, planning, and implementation.

Next Steps

With the initial research complete for the PRP's *Towards a Resilient Providence* synthesis, the question of what to do next becomes critical. What is clear from the research performed for this first step (not surprisingly) is the inherent complexity related to many of these issues. In some cases, the complexity is technical in nature. In other cases, it is administrative.

For example, it is worth noting that there is no new umbrella agency (either at the city or State level) designated to address resilience as its primary, overarching focus. Instead, each existing state agency, regional organization, and local government is left to view its standard duties through the lens of resilience and adjust policies and expenditures as best they can. While this approach is not unique to Rhode Island, it nonetheless lends itself to a fragmented and inefficient system. The creation of the state's Executive Climate Change Coordinating Committee (EC4) is an attempt to mitigate this fragmentation with periodic discussion and coordination across agencies and other key stakeholders to support the state and its 39 municipalities. Limited resources are allocated to support integrated resilience planning and implementation, unlike other states in the Northeast. Regardless of the complexity, research performed for this project showed that, while all entities believe resilience planning is critically important, how these organizations understand and address their focal challenges is different.

To address the growing threat of increased flooding from climate change, this situation must change. An inclusive engagement with a full range of agencies/organizations that are connected to vulnerability concerns is necessary. Because many organizations view the issues differently, it will be helpful to better understand whether important groups or agencies understand the scope of the emerging threats and share a sense of urgency to address major vulnerabilities. A sufficiently funded and appropriately scoped process that develops a shared understanding and a commitment to strategic thinking and action must take place for Providence to manage the risks and build the resilience necessary to thrive in the 21st century. Priority questions that should be explored include:

- Is benchmarking and planning occurring in ways that are consistent and accurate? Is Rhode Island's modeling currently adequate for predicting inundation for the purposes of resilience planning in Providence?
- Are agencies incorporating modeled predictions into policy and regulation to the full reasonable extent? What opportunities are we missing (if any)?
- Is there a firm commitment to evaluate how long the hurricane barrier will provide adequate protection? Can this be done with the analytical tools and modeling we have in place?
- Do stakeholder agencies and other stakeholders understand the full scope of stormwater system vulnerability issues, and is there a commitment to revisit the discussion of steady, reliable funding for the continued maintenance and upgrade of stormwater facilities?
- Are there ways to leverage, accelerate, and/or scale up implementation of resilience measures that are already underway throughout the city?
- Can community, business, and government stakeholders align to develop—and implement—a vision to transform the port area, considering its extreme exposure to flooding risks and the trend to move to renewable energy sources.?
- Where are the opportunities to leverage adaptation and greenhouse gas mitigation strategies to enhance resilience with multiple social, economic, and environmental benefits?

These questions and opportunities for discussion and collaborative thinking and action are a starting place for learning how to manage risks associated with the threats from climate change. The Providence Resilience Partnership came together to engage, listen, learn, and catalyze strategic action. By fully assessing the situation on vulnerability work in Providence, a plan to fill information gaps and make investments can come together and advance a long-term commitment *Towards a Resilient Providence*.

Building a Resilient Future for Providence: Business and Civic Leaders Forum, January 2019. Sharing experiences from Resilient Cities and the Boston Green Ribbon Commission with Providence leaders inspires the creation of the Providence Resilience Partnership (RI Sea Grant).

Introduction

Providence is an important urban hub, serving city residents and the people of Rhode Island with a diversity of economic, educational, and recreational opportunities offered—often in collaboration—by government, private sector, academic, and community efforts. Its proximity to water has shaped how people of varied cultures, from Native Americans to 19th century industrialists to today's diversity of ethnicities, have lived and worked in the region. Yet its coastal and riverine position—it is located both on Narragansett Bay, via the Providence River, and within the basin of the region's watershed, alongside the Woonasquatucket River — makes Providence susceptible to flooding tied to strong storms, tides, and rising seas. With accelerating trends of increased temperature and sea level rise, these risks facing the city are also increasing. In addition, paving or impervious surfaces placed together with areas lacking trees puts Providence at risk for compounding issues of heat intensification—another impact of a warming climate.

> *"Resilience" means the capacity of individuals, institutions, businesses, and natural systems within Rhode Island to survive, adapt and grow no matter what chronic stresses and weather events they experience.*
>
> *- Resilient Rhody, 2020*

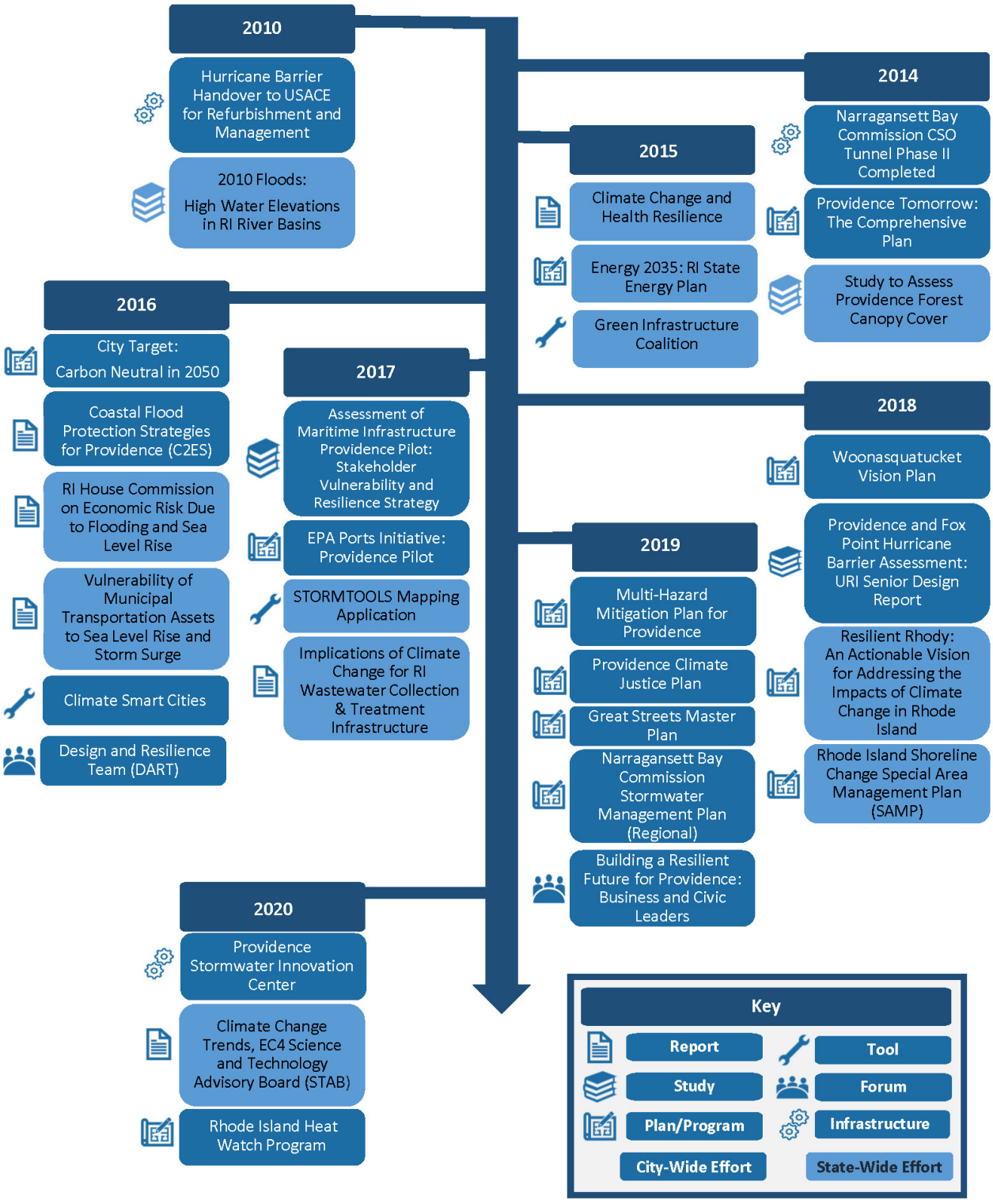
Already, the public, private, academic, and community sectors have begun efforts to both understand and answer climate change challenges for Providence. These efforts provide the city with forward momentum to address the spectrum of climate change issues—whether they are tied to water, heat, emissions, or health—to expand initiatives and join with, learn from, and contribute to larger citywide, statewide and regional initiatives.

Recognizing this, the Providence Resilience Partnership (PRP) worked with the University of Rhode Island Coastal Resources Center to develop this synthesis report on key climate change vulnerabilities facing Providence. This report: 1) Culls and synthesizes existing information and data about climate change issues, impacts, and risks to Providence; 2) Identifies key data and information gaps; and 3) Identifies options to address informational and procedural gaps.

Context

The PRP opted to develop this synthesis upon reviewing a wide variety of resources containing useful resiliency information pertaining to Providence. All the material—from plans and programs to strategies and databases—provide critical and valuable information; this synthesis report represents a curating of that information so it can serve as a supportive tool for the decision-making process. It is worth noting that the project team used external input from the PRP, stakeholders, and literature research to select the geographic locations, infrastructure and facilities, and overarching themes that are part of this study and report.

A Decade of Building Blocks for Informing Resilience Plans, Policy and Programs (Summary of efforts, not fully inclusive)



Methods

The natural hazards—and associated tools used for modeling—identified and prioritized for the study area of Providence were those related to inland, riverine, tidal and sea level rise nuisance flooding; increasing air temperature combined with flooding was viewed as a compounding risk. Three themes were investigated on a citywide level: Economy and Society; Infrastructure and Environment; and Health and Wellbeing. Further, the team took a deep dive into three geographical subset areas: the Port Area, Downtown, and the Woonasquatucket River Corridor. Additionally, the study team examined three critical infrastructure assets: the Fox Point Hurricane Barrier, Wastewater Systems, and Stormwater Systems.

Approximately 100 plans, policies, studies, reports, and assorted information sources were reviewed and culled for this synthesis report. For each of the nine thematic sections, the vast array of information was summarized into situation, climate challenges, and opportunities for resilience highlights.

The Executive Summary provides highlights from the entire report, presenting key findings for each theme. Overarching findings that capture a cross-cutting view of the whole situation, which is critical, were summarized throughout and also presented in the Executive Summary.

Hazards of Focus and Modeling Tools

Overview

Natural hazards—intense hurricanes, heavy rainfalls, rising seas—have heavily impacted Rhode Island and Providence and shaped the evolving shoreline of the Ocean State. Climate change, with global air and water temperatures increasing at unprecedented rates, is affecting these changes with increasing relevance to coastal cities worldwide.

2020 Tied for Warmest Year on Record. "The last seven years have been the warmest seven years on record, typifying the ongoing and dramatic warming trend."

- NASA press release, January 14, 2021

Key Findings

Providence is experiencing the impacts and implications of a changing climate, and these are only expected to increase in the future.

Hurricanes, high winds, and riverine flooding are identified as the top wind- and flood-related threats (over 50% threat) to Providence over the short term. Close behind are severe thunderstorms, flash flooding, sea level rise, and extreme heat.

Actions underway to mitigate the impacts of climate change—elevating buildings, incorporating green space buffers along the waterfront, or reducing greenhouse gas emissions—are critical to reducing the implications of a changing climate. Many impacts, however, will be long lasting or irreversible given the elevated temperatures of atmosphere and oceans today.

Flood models used by the state and city are applied to regulatory requirements, planning, assessment and design. Yet these modeling tools differ in attributes, accuracy, and results. Rhode Island would benefit from the development of an agreement upon one risk model that incorporates future-looking, combined river and coastal flooding, precipitation, and sea level rise. In the case of Providence, this model also would need to incorporate hurricane barrier dynamics.

Sea level rise is causing high tide flooding, which is increasingly visible along the Riverwalk. Heavy rainfall causes street flooding citywide. The 2010 river floods broke records. Though hurricanes are infrequent in Rhode Island, they are tending to come with increased rainfall rates, and consensus is their intensity will increase as well. Coastal surge impacts are minimized behind the Fox Point Hurricane Barrier. However, the port and the Seekonk River are still at risk. Meanwhile, increasingly warmer air temperatures further stress vulnerable populations, outdoor workers, and energy systems.

Modeling, using the best available science, provides projections and associated tools for decision makers responsible for public and private entities who assess, plan, design, and regulate. This includes agencies who use the information to inform their models and associated tools regularly. The challenge of our times is that evidence is changing rapidly.

Various models, including the Federal Emergency Management Agency (FEMA) floodplain maps and STORMTOOLS interactive tools, are based on different methods and used for different purposes in Rhode Island—i.e., for assessment, planning, and regulations.

Various agencies support national level research and monitoring that, in turn, supports efforts in Rhode Island. Some of these mentioned throughout the report include:

- National Oceanic and Atmospheric Administration (NOAA) maintains the tide stations.
- Federal Emergency Management Agency (FEMA) administers the National Flood Insurance Program and the floodplain mapping.
- US Army Corps of Engineers (USACE) assesses flooding and rising seas, as well as designs and implements projects.

The Rhode Island Coastal Resource Management Council (CRMC) assesses/monitors coastal storm hazards and their impacts to inform their plans, policies, and regulations. At the city level, the Providence Emergency Management Agency (PEMA) develops and implements the city's Multi-hazard Mitigation Plan, the blueprint for hazard mitigation.

This section summarizes the hazards that are likely to affect Providence. This includes hurricanes, sea level rise, riverine flooding, and others hazards. Models used for planning, assessment, and regulation are summarized as well. Reference to these hazards, impacts, and assessment are included throughout this document.

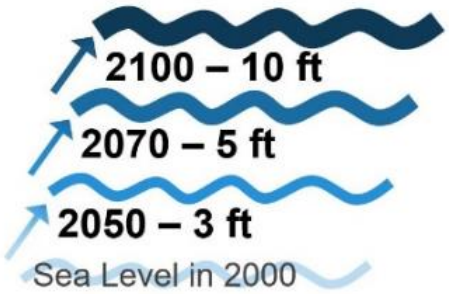
Natural Hazard *	Likelihood to Occur	Average Severity of Impact			Pre-planning Preparedness Level	Relative Threat (2019) (*Scale: 0-100%*)
		Human	Property	Business		
Hurricane	High	High	High	High	Moderate	69%
Riverine Flooding	Highly Likely	N/A	High	High	Moderate	67%
High Winds	Highly Likely	Low	Moderate	Low	Moderate	50%
Dam Inundation	High	Moderate	Moderate	Moderate	Moderate	50%
Sea Level Rise	Highly likely	Low	Low	Low	Moderate	42%
Extreme Heat	Highly likely	Low	Low	Low	Moderate	42%
Severe Thunderstorm	Highly Likely	N/A	Low	Low	Low	42%
Flash Flooding	Highly Likely	N/A	Low	Moderate	Moderate	42%
Heavy Rain, Inland/ Urban Flooding	High	N/A	Moderate	Moderate	Moderate	38%
Drought	Moderate	Low	Low	Low	Moderate	21%
Coastal Flooding	Moderate	N/A	Low	Low	Moderate	17%

* Selected hazards assessed over a five-year planning horizon do not account for medium- and long-term threats.

Figure H-1. Relative Threat from Wind, Flood, and Drought-related Hazards in Providence over a Five-year Planning Horizon. Sea level rise was assessed for the short term and, therefore, may not fully reflect change in decades to come (adapted from PEMA, 2019).

Sea Level Rise

Sea level rise, resulting from thermal expansion of the oceans and melting of ice on land, contributes to increasing frequency of coastal flooding from extreme high tides and coastal storm surges (STAB, 2020). Measurements at the NOAA's Providence tide station indicate that sea levels have risen almost eight inches since 1938 and over nine inches in Newport.



RI Sea Level Rise Projections (NOAA High Curve, 2017)

The CRMC has adopted for the sea level rise projections of NOAA's 2017 High Curve for Newport, which is the longest continuous station in the state. The current planning scenarios (using the 83% confidence level) are estimated at 3 feet by 2050, 5 feet by 2070, and almost 10 feet by 2100 (USACE, 2019).

As discussed in the 2019 Multi-Hazard Mitigation Plan, while sea level rise is 'highly likely' to affect Providence, the overall threat over the plan's five-year horizon is 42%. With increased sea level rise, chronic inundation will affect low-lying areas adjacent to Providence's tidal shorelines experiencing two tides a day every day. With three feet of sea level rise, an estimated quarter mile of roads is projected to flood, and some buildings in Providence will be inundated twice daily from tidal cycles alone, making them completely unusable if precautions are not taken. There reaches a tipping point after 5 feet of rise, where the projection is for a more substantial, permanent impact to 1.4 miles of roads (RISP, 2016). There are 26 buildings damaged at a projected 5 feet of rise, increasing to 184 buildings permanently impacted at 7 feet of rise (URI, 2018a), causing cascading impacts throughout the city that continued to increase beyond that time (see Economy/Society and Infrastructure/Environment sections for more information).

Nuisance Flooding. Today, the city intermittently experiences 'nuisance' or high tide flooding that impacts low-lying areas along tidal waterfronts in places that include Downtown Riverwalk and Waterplace Park. Additionally, extreme tide heights prompt a precautionary closing of the Fox Point Hurricane Barrier about 10 times a year. Future projections indicate the barrier might need to be closed more than weekly by 2050 and twice daily by 2100. This increased frequency of closing may be a challenge, as questions remain about whether the barrier can withstand near-constant use (PEMA, 2019). Recent projections indicate the number of high tide flood days (i.e., when the flood threshold is 1.8 feet above mean higher high water/MHHW) will increasingly impact Providence for five to 10 days in 2020, 15-30 days in 2030, and 40-105 days in 2050 (NOAA, 2020).


Extreme high tides Fgood Providence increasingly with accelerating sea level rise (MyCoast.org).

Hurricanes

Hurricanes and the accompanying storm surges have impacted Rhode Island throughout history, with those most notable over the last century being The Great Hurricane of 1938 (Category 3—with its record water level of 12.7 feet above MHHW in Providence); Hurricane Carol (1954, Category 3); Hurricane Diane (1955, with nearly 20 inches of rainfall over a two-day period in New England); and Hurricane Bob (1991, Category 2). Superstorm Sandy in 2012, no longer a hurricane when it hit Rhode Island, impacted Westerly and other coastal shorelines significantly, with less impacts to the bay and Providence area (PEMA, 2019). Hurricanes, with their high likelihood of affecting Providence and a relative threat of 69%, are the greatest natural hazard threat for the city.

Hurricane categories reflect wind strength, not storm surge elevation. The Saffir-Simpson Hurricane Wind Scale is a 1 to 5 rating based on a hurricane's sustained wind speed. This scale estimates potential property damage. Hurricanes reaching Category 3 and higher are considered major hurricanes because of their potential for significant loss of life and damage.

-National Hurricane Center, NOAA

Warming air and ocean waters affect the dynamics of hurricanes, increasing the impacts on communities. Projections show that hurricanes in this region will have increased rainfall rates. There is strong consensus that tropical cyclones will continue to become more intense (i.e., a larger percentage of Category 4 and 5 storms). It should be noted that there remains uncertainty on how climate change will impact the frequency of storms (STAB, 2020).

This is of particular concern to Providence, where rivers converge with the coast; increased rainfall and wind intensity will combine with tidal surge to increase the impact of flooding. Over the past five years, the number of hurricanes has been above the average, with the 2020 Atlantic hurricane season making the record for the most active and the fifth costliest on record. The trend is also showing intense precipitation, where, for example, the 2017 Texas Hurricane Harvey recorded 60 inches of rain in five days as the storm stalled over the state.[1] In efforts to see how such hurricanes would impact Rhode Island, the University of Rhode Island (URI) has recently modeled feasible and plausible scenarios in which a hypothetical Hurricane Ram was modeled for Providence with over 18” of rain over 24-36 hours, causing massive river flooding and a 15-foot coastal surge. The scenarios included a worst case, in which the hurricane barrier is closed and pumps do not operate, which resulted in a “bathtub” response with 14 to 15 feet of water within 24 hours (I. Ginis and D. Ulman, personal communication, August 31, 2020). Modeling of these up-to-date scenarios of precipitation, storm surge, and barrier pump operation are currently not available. However, they would be useful for the city, state, and the federal government in planning and response.

[1] https://www.weather.gov/media/publications/assessments/harvey6-18.pdf

Coastal Flooding and Storms

Coastal storm surge flooding, caused by the wind and pressure forces of storms, can significantly impact property and public safety during hurricanes, Nor'easters, and other coastal storms. Storm surge with added sea level rise will intensify coastal flooding, leading to more frequent flooding of buildings, structures, critical facilities, public space and greenways, roads, and bridges.

The term "100-year flood" is used to describe the recurrence interval of floods. The 100-year recurrence interval means that a flood of that magnitude has a 1% chance of occurring in any given year. In other words, the chances that a river will flow as high as the 100-year flood stage this year is 1 in 100.

Coastal flooding, identified with a moderate likelihood of occurrence, has a relative threat to the city of 17% (PEMA, 2019). This lower threat is in part due to the hurricane barrier, which is designed to protect much of the city from storm surge. However, the port area and the Seekonk River are still vulnerable to coastal storm surge flooding.

Sea level rise will increase the threat of flooding from coastal storms. A future 20-year storm on top of two feet of rise in sea level will have the same water level and depth as today's 100-year storm. (PEMA, 2019). STORMTOOLS, which CRMC uses for planning and assessment purposes, provides interactive maps to show inundation under different storm and sea level rise combined scenarios; these maps do not consider the presence of the hurricane barrier.

Flood Standards Behind the Hurricane Barrier

The Fox Point Hurricane Barrier is considered an "accredited levee" by FEMA standards. Based on its design, it is expected to provide sufficient protection of the 'shaded-X' areas on the map during a flood with a 1% chance of being equaled or exceeded in any given year (also referred to as the 100-year flood). The accreditation distinction is important, as flood insurance is not required in a shaded-X zone, while flood insurance would be required for those areas if the barrier was not an "accredited levee". Additionally, X-zones (.2% annual chance or '500-year' flood areas), including shaded X zones, are not considered part of the regulatory Special Flood Hazard Area (SFHA). This means properties within a shaded-X zone are not required to meet FEMA's minimum regulatory standards for the National Flood Insurance Program (NFIP). Refer to FEMA's Living with Levees for more information on accredited levees and shaded-X zones and insurance requirements for shaded-X zones.

- Joe Dwyer, RIEMA

FEMA maps, which are used to regulate building codes and assess flood insurance rates, are based on the flood risk of different zones. These maps include: 1) Special Flood Hazard Areas comprising V-zones, i.e., those areas at risk from a 1% storm (100-year storm), where wave heights can reach three feet or more; and A-zones, i.e., areas with waves below three feet; and 2) Areas of Minimal Risk, which incorporate X-zones, which are areas at risk from the .2% storm (500-year storm), including those

areas behind the hurricane barrier, which are considered shaded X-zones. It is important to note that FEMA maps do not currently include sea level rise considerations in their zones or height designations.

Riverine Flooding

Riverine flooding occurs after heavy rain from longer-lasting rainstorms, particularly in areas with high water tables, along low-lying riverfront areas. Flash flooding is characterized by a rapid onset and high velocity waters and is caused by intense runoff occurring after heavy precipitation events or associated with spring snowmelt (PEMA, 2019).

Both river and flash flooding are highly likely to threaten Providence—with a 67% chance for riverine flooding and 42% chance for flash flooding (PEMA, 2019). For example, several factors caused the conditions that lead to the 2010 floods, where extreme precipitation over 38 days (over 20 inches) lead to the Woonasquatucket River overflowing its banks and flooding areas of Providence and elsewhere in the region.

Precipitation and Flooding

"Continued increases in greenhouse gas affecting the climate patterns is expected to contribute to more intense and wetter precipitation events, now and into the future. Over the past 80 years, Rhode Island has experienced a significant increase in both flood frequency and flood severity, including a doubling of the frequency of flooding and an increase in the magnitude of flood events. Intense rainfall events (heaviest 1% of all daily events from 1901 to 2012 in New England) have increased 71% since 1958."

"Recent research suggests an increase in rainfall volume from future thunderstorms across the U.S. More frequent and intense Nor'easters and "bomb cyclones" riding on top of rising seas is contributing to coastal flooding as damaging as that associated with hurricanes. Trends of increasing precipitation in the 20th century may mask risks related to episodic and severe drought, such as the 1960s drought."

- Resilient Rhody, 2018

Based on the increasing frequency and severity of riverine flooding events due to increased storm intensity (12 events since 2013), which caused significant urban flooding, the projected increase in both storm intensity and precipitation is likely to only further exacerbate riverine flooding. It is also important to note that riverine flooding and coastal flooding due to sea level rise can have a coupling effect. Rising seas can set a new flood stage in riverine systems, thus increasing flood risk in inland areas adjacent to rivers (PEMA, 2019).

View of Merino Park from the Sheridan Street Footbridge during the 2010 Floods (A. Lehrer).

Inland and Upland Flooding

As new development and urbanization continues, the amount of impervious surface and associated stormwater drainage increases. This, in turn, reduces the carrying capacity of the land to absorb stormwater and increases the chances that interior flooding and stormwater runoff events will occur on a more frequent basis. Considering the continuation of urbanization and increasing intensity of rain events (and the timing of those events relative to saturated ground

levels), it is expected that Providence will continue to experience flood events on an annual basis (PEMA, 2019).

Extreme Heat

With increasing warmth associated with climate change, Providence is experiencing more warm days (Resilient Rhody, 2018). The impacts of these increased temperatures are exacerbated in cities and urban areas, where less greenery and more impervious hardtop translate to a greater amount of heat—the urban "heat island" effect (RIDOH, 2015). Extreme heat is highly likely to occur, with a relative threat of 42% (PEMA, 2019).

More intense and prolonged heat waves are predicted with climate change. The frequency of days with high temperatures at or above 90°F has already increased (Vallee and Giuliano, 2014). The average number of days expected to be above 90°F in 1950 was about seven, while the new normal is 12 days. (PEMA, 2019)

As a result of climate change, Rhode Island anticipates more days of extreme heat each year, which will likely have inequitable impacts on Providence neighborhoods that are at risk as a result of climate change and varying susceptibilities to the effects of heat waves (STAB, 2020). Some of these neighborhoods are also vulnerable to flooding, increasing the cascading impacts to the most vulnerable populations of the city (PEMA, 2019).

Looking at the combined impacts of extreme heat and flooding will exacerbate health inequities (City of Providence, 2019).

Modeling Tools

Different Models for Different Purposes: Rhode Island's state and municipal agencies apply different tools and models to assess exposure and impacts of flooding used for assessment, regulation, design, and planning today and into the future. For example, storm return periods included in the RI Shoreline Change SAMP and STORMTOOLS characterize future conditions for planning purposes, whereas floodplains defined by FEMA are mapped based on past conditions and are used for regulatory purposes.

FEMA Maps: Flood Insurance Rate Maps (FIRMs) are official community maps that show special flood hazard areas and the risk-premium zones for the National Flood Insurance Program (NFIP); the maps provide this data to help guide mitigation actions. As a regulatory tool, FIRMS are the basis for the state building codes, implemented by the municipalities as well as the state, to inform about the risk and extent of inundation (both coastal and riverine); this, in turn, stipulates the minimum Base Flood Elevation (BFE) to be applied in the design of

Inundation Projections Differ with Model Input

STORMTOOLS uses the 95% confidence interval, meaning there is a 95% chance the flood level and associated inundation depth will not reach higher than that level and a 5% chance it will be worse.

FIRM and FEMA maps use the 50% confidence interval, or the average. This would mean that there is a 50% chance that the flood will be as high as the estimated water level and a 50% chance it could be worse.

This indicates that at a given point, the FEMA map would commonly indicate less inundation than STORMTOOLS.

- CRMC, 2018

structures in the floodplain. Also, property owners use these maps for understanding risk, and NFIP uses them in assessing flood insurance premiums.

These maps show the 1% (100-year) and .2% (500-year) floods; the maps used in Rhode Island do not incorporate sea level rise considerations. The RI Floodplain Mapping Tool helps users visualize regulatory FIRMs. (For official FEMA flood maps, see https://msc.fema.gov/portal/home; to view the RI Mapping Tool, see http://www.riema.ri.gov/resources/citizens/mitigation/mapping.php).

Rhode Island STORMTOOLS: The Rhode Island Shoreline Change Special Area Management Plan (Beach SAMP), using the best available science and data from researchers at URI and the federal agencies, developed the STORMTOOLS suite of decision-support tools for property owners and decision makers to illustrate exposure from storm surge and projected sea level rise (CRMC, 2018). CRMC uses STORMTOOLS for assessment, planning, and their required permit application purposes; local and state agencies use it for assessment and planning purposes as well. Project designers for structures in the coastal zone also are encouraged to use the tools. STORMTOOLS are high resolution, interactive maps available on-line.

STORMTOOLS' sea level rise projections for the state depict property level inundation of 1, 2, 3, 5, 7, 10, and 12-foot sea level rise scenarios (based on the NOAA high curve 2017 from the USACE sea level change calculator). CRMC expects to update their projections, planning tools, and analyses on an ongoing basis, using NOAA's most recent scenarios, as resources allow (CRMC, 2018).

The STORMTOOLS Coastal Environment Risk Index (CERI) is a single exposure index incorporating coastal erosion, storm surge, waves, and sea level rise associated with different storm intensities—developed to better plan for future conditions (CRMC, 2018). STORMTOOLS Design Elevations (SDE) provide a recommended base flood elevation that accounts for sea level rise, given that the current FEMA BFE does not incorporate considerations of rising sea levels.

All STORMTOOLS interactive maps are available online. CERI is also a downloadable phone app that provides access to flood and wind risk and associated damages for a user-selected structure. (For more information about STORMTOOLS suite of tools, see https://www.beachsamp.org/stormtools/).

Storm Model Simulations: Models refined and enhanced by URI for the Northeast and piloted in Providence—i.e., Hurricane Ram and Hurricane Rhody—are hypothetical, yet plausible, hurricane scenarios created to simulate the effect of high-impact storms in Rhode Island. These scenarios will allow state and local agencies to better understand the consequences of combined coastal and inland hazards associated with extreme high impact hurricanes and to better prepare the Rhode Island communities for future risks. These scenarios reflect a trend with hurricanes that have made landfall over the U.S. (storms slowing down, increased intensity of rainfall), which are plausible for Rhode Island. The Hurricane Rhody model incorporated two landfalls, while the Hurricane Ram model includes the impacts of over 18" of rain over 36-48 hours (similar to 1955 Hurricane Diane) with storm surge up to 16 feet above mean sea level. While these scenarios have not explicitly modeled a functioning hurricane barrier, they include assessment of the worst-case damning of the river flows that cause the waters upstream of the barrier to rise in the absence of operable pumps. (For more information, see https://www.richamp.org/).

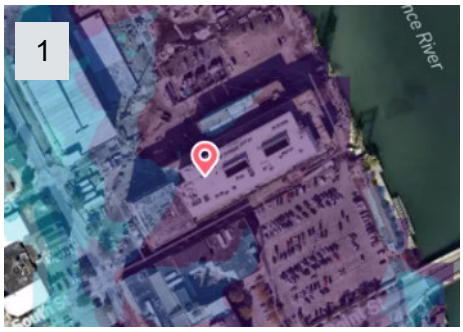
Other National-based Tools: Online inundation applications, including those from NOAA's Sea Level Viewer and Climate Central's Surging Seas Risk Finder, provide tools for citizens, communities, and policy makers to better understand their risks to sea level rise and storms. These are screening level tools and are not used for regulation. Inundation risk may include different factors for property, socio-economic, and demographic elements. These are commonly used national-based data, which may not have the specificity of Rhode Island-based information. (For more information, see NOAA https://coast.noaa.gov/slr/ and Climate Central https://riskfinder.climatecentral.org/).

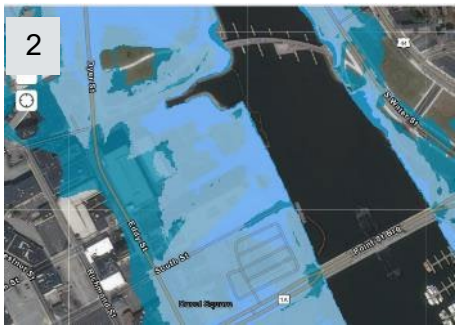
First Street Foundation: Flood Factor™ provides high resolution, publicly available information for individual property owners regarding the likelihood of flooding potential today and in the future with climate change. The climate-adjusted model uses past hurricanes, tropical storms, Nor'easters, and major inland flooding events to inform the model. It calculates the current probability of tidal, storm surge, rainfall, and riverine flooding for individual homes and properties. The model then adds in future risk factors including sea level rise, changing precipitation patterns, and warming sea surface and atmospheric temperatures. The high-quality, probabilistic flood risk information available to the public was also summarized in a state report for Rhode Island, which summarizes First Street Foundation flood risk, adaptation, and changing environmental factors as they relate to flood risk. (For more information, see https://firststreet.org/).

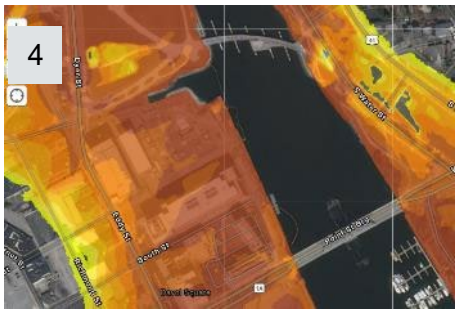
A Picture is Worth a Thousand Words: Interpreting the Mapping Tools: Illustrating the differences among mapping tools available

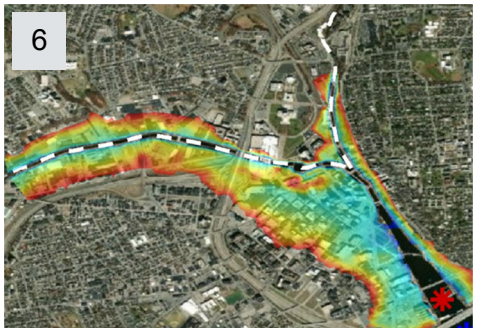
Rhode Island Nursing Center – 350 Eddy Street, Providence (North of the hurricane barrier)

1. ***Flood Factor, First Street Foundation:*** "This property has an Extreme Flood Factor™ with a 99% chance of flooding at least once by mid-century. In 2021, it is 0.2% likely that 3.6-4.3 feet of water will reach this property. In 2051, it is 0.2% likely that 6.5-7.4 feet of water will reach the largest building on this property" (https://floodfactor.com/). This combines the flood risk from high intensity rainfall, overflowing rivers and streams, and high tides; it considers protection provided by the hurricane barrier.
2. ***STORMTOOLS Sea Level Rise (SLR):*** Looking to the future, water depth projected is .13 feet (3 feet SLR) and 2.2 feet (7 feet SLR), impacting the property during two tides a day every day.
3. ***FEMA 1% (100-year flood):*** Areas behind the barrier indicate this as a 'shaded-X zone' with "reduced flood risk due to levee", where provisions for floodplain building standards are not required, but encouraged.
4. ***STORMTOOLS 1% (100-year flood):*** Estimates 11 feet of inundation. STORMTOOLS does not consider the hurricane barrier in place.
5. ***STORMTOOLS Design Elevation (SDE):*** Identifies the SDE as 19 feet NAVD88. STORMTOOLS does not consider the hurricane barrier in place.
6. ***Hurricane Ram Hypothetical Storm Model:*** A worst-case scenario—i.e., with intense rainfall, barrier closed, and pumps disabled— shows over 15 feet of water (blue) will inundate much of the waterfront behind the barrier over the two days of rainfall, reducing inland.



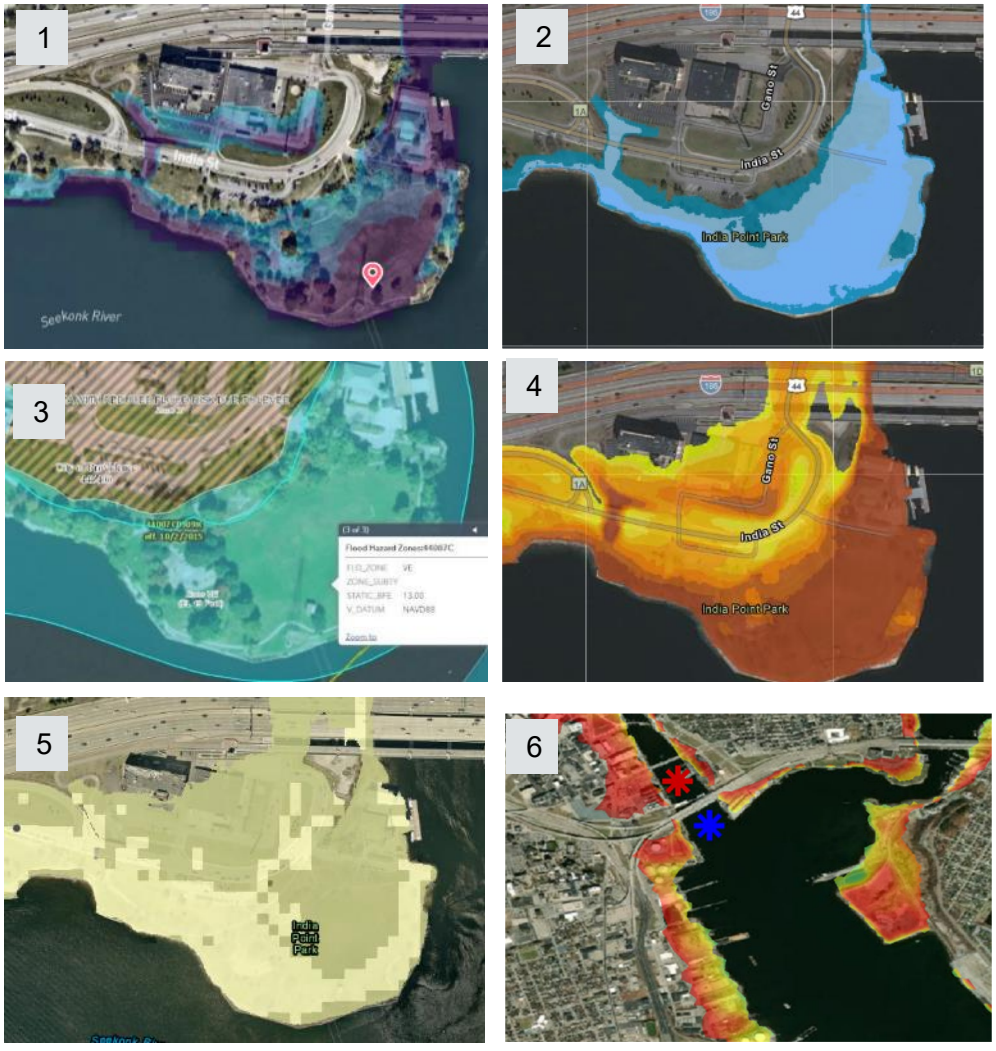






India Point Park, 253 India Street, Providence (South of the hurricane barrier)

1. ***Flood Factor, First Street Foundation:*** **"**This property has an Extreme Flood Factor™ (9 out of 10) with a 99% chance of flooding at least once by mid-century. Today, it is 1% likely that 2.4 - 2.9 feet of water will reach this property. In 2051, it is 1% likely that 4.2 - 7.7 feet of water will reach this property". This combines the flood risk from high intensity rainfall, overflowing rivers and streams, and high tides (https://floodfactor.com/).
2. ***STORMTOOLS Sea Level Rise (SLR):*** Looking to the future with 5 feet SLR, at high tide there will be around 2 feet of water near the shoreline, and with a 7-foot rise, it would vary from 3 - 6 feet of water in the Park, occurring during two tides a day every day.
3. ***FEMA 1% (100-year flood):***Flooding from coastal storm surge with a velocity zone designation of VE 13 feet (NAVD) Base Flood Elevation (BFE) covers much of the area; areas inland indicate shaded-X zone, an area of minimal risk of flooding.
4. ***STORMTOOLS 1% (100-year flood):*** Estimates vary from greater than 10 feet (dark orange) inundation along the shore, reducing flood depths (lighter shades) as it moves inland to 1 foot (light yellow) of inundation.
5. ***STORMTOOLS Design Elevation (SDE):*** SDE varies with 22 feet at the shoreline (lighter shade) to a SDE of 18 feet inland (darker shade).
6. ***Hurricane Ram Hypothetical Storm Model:*** At India Point Park (light blue star), maximum inundation is 2-3 feet (yellow-orange) of water when the surge was up to 16 feet above mean sea level.



Economy and Society

Overview

Key Findings

- The impacts and consequences of changing climate challenge the effective functioning of the Providence (and state) economies and its residents/business owners—although these impacts and consequences disproportionately affect vulnerable populations and small businesses.
- The full scope of economic and social vulnerability associated with accelerating climate change is not understood, assessed at scale, or quantitatively evaluated.
- Using predictive social and economic modeling to assess vulnerability is essential to effective planning, determination of actions, and priorities that will reduce risk.

Having suffered historic flooding from strong 20th century hurricanes, the downtown area of Providence has since benefited from the protection of the Fox Point Hurricane Barrier. Downtown—a center, and crossroads of activity for all Providence residents—continues to serve as Rhode Island's primary urban hub for government, transportation, financial and educational institutions, and cultural and social activity; it also provides significant tax revenue for the city. While built to keep strong storms from flooding Downtown, the barrier may not be equipped to manage inundation heightened by projected sea level rise. Providence, in concert with state and federal partners, is increasingly considering how best to support barrier infrastructure, while promoting community education and other initiatives to reduce the risk of the Providence waterfront flooding due to climate change. Downtown, along with its port and areas of Fox Point, are the most vulnerable to future daily projected inundation from rising sea levels. Acknowledging that climate change and sea level rise are real and critical threats—with lasting impacts to the built and cultural heritage of the city—the Providence Preservation Society has included the entire city of Providence in their 2021 List of Endangered Places, a designation that should raise the bar for action.

Situation

Multiple Contexts: The city of Providence, working in concert with public, private, academic, and community partners, has taken steps toward resilience planning. That planning reflects the need to not only consider the environmental context, but the social and economic contexts as well (City of Providence, 2014; City of Providence, 2019).

"Providence's population is ethnically and culturally diverse and varied, which creates a unique cultural and educational environment. The city is also home to numerous top hospitals, colleges and universities, a key part of its economy. The city is alive with new development designed to complement existing scale, and along with the ongoing preservation and renovation activities, is helping to continue the tradition that is Providence."

-Providence Tomorrow, 2014

Social Perspective: From a social perspective, efforts have begun to consider resilience building in terms of how best to protect residents, neighborhoods, and their assets—such as buildings deemed culturally or historically valuable—from flooding and heat linked to climate change. Already, the nexus of environmental, economic, and social issues—in terms of climate change—has provided an opportunity to consider

practical obstacles to resilience implementation. For example, how can continuity for resilience planning be implemented in neighborhoods if a significant portion of homes are rented (City of Providence, 2019) and/or subject to frequent turnover? One possible solution could be engaging with local churches and service clubs to encourage residents—whether they be short- or long-term, or present at the property or not—to participate in neighborhood resilience activities (Resilient Rhody, 2018). As a strategy for frontline communities, the Green Justice Zones in the Olneyville and Washington Park neighborhoods seek to improve quality of life and climate resilience through investments in sustainability and equity (City of Providence, 2019).

Economic Standpoint: From an economic standpoint, examination of Providence's vulnerability to climate change impacts increasingly considers not only the value of businesses and buildings—the city hosts Fortune 500 companies Textron, Inc. and Citizens Financial Group headquarters, as well as 7,000 smaller firms and numerous hospitals, medical centers, and colleges (City of Providence, 2014)—but the cost to workers and customers related to closures; labor productivity (Rhode Island House Commission, 2016); loss of vital services, such as transportation and communication; and "emotional strain from financial and physical losses" (City of Providence, 2019).

Economic Hub for City and State: Downtown, which includes the Capital Center, the Jewelry District, and the Innovation & Design District (aka Jewelry District) is the economic hub for the city and the state, with its government, private sector, academic, cultural, historical, and community assets.

The effects of rising sea levels will affect the city's social and economic fabric in the future (RI Sea Grant).

Measuring more than 150 acres, these areas are slated for growth (City of Providence, 2014), with the emerging Innovation & Design District a hallmark of the Interstate 195 relocation project and host to significant new developments.

Moving Forward: Moving forward, resilience planning for Providence is approaching the issue of protection in terms of the benefits that can be drawn collectively from environmental, economic, and social perspectives. For instance, to what degree can green infrastructure—an environmental solution—be applied at the site of emerging coastal developments, such as Providence's "Innovation and Design District," to address flooding and reduced urban heat and greenhouse gases, while encouraging neighborhood use of cultural and social assets? Examples of this integration are seen in the designs of the Downtown Riverwalk and the Woonasquatucket Greenway.

"We are a river city in the Ocean State, and the impacts of climate change and sea level rise will affect Providence's built and cultural heritage in both incremental and profound ways."

- '2021 Most Endangered Properties List', Providence Preservation Society

Climate Challenges

Flood-prone Economic and Social Assets: Providence faces flooding risks tied to both coastal and riverine flooding; while the hurricane barrier reduces the risk from coastal storm surge to the downtown area, other business and residential areas remain vulnerable. As of 2018, 590 National Flood Insurance Program insurance policies protected $163 million in Providence property (PEMA, 2019); this relatively low number of flood-insured structures in part reflects the relative protection the barrier provides. Also, the U.S. Federal Emergency Management Agency (FEMA) reports repetitive flood losses along the Woonasquatucket Corridor in the Olneyville and Valley neighborhoods, particularly around Eagle Square, the Atwells Avenue Bridge, and Tuxedo Avenue (City of Providence, 2014a)

Figure ES-1. Parcels at Risk of Being Impacted by Different Flood Intensity Storms. While residential land use has the most parcels exposed, the value of the commercial properties is greatest (adapted from PEMA, 2018).

Scenario	Special Flood Hazard Area (A+V Zone) (1% Annual Chance Flood)		Area of Minimal Flood Hazard (X Zone) (0.2% Annual Chance)		Hurricane Category 3	
Land Use	**Parcels Impacted**	**Total Value ($ million)**	**Parcels Impacted**	**Value ($ million)**	**Parcels Impacted**	**Total Value ($ million)**
Residential	622	$ 160.5	133	$ 45.5	845	$ 251.1
Commercial	335	$ 644.9	84	$ 67.2	437	$ 1,503.1
Industrial / Port	143	$ 241	60	$ 133.9	176	$ 522.1
Public	122	$ 1,272	114	$ 473.1	132	$ 1,142.3
Energy / Utility	16	$ 320.9	7	$ 686.3	19	$ 346.3
Total	1238	$ 2,639.3	398	$ 1,406	1609	$ 3,764.9

	Total Population (2010 Census)	1% Annual Chance Event	1% Event with 3 Feet Sea Level Rise
Population Exposed to 1% Flood Event	182,911	4,321 2.4%	4,485 2.5%
Elderly Over 65 Years	19,249	233 1.2%	249 1.3%
Economically Disadvantaged (annual Income $20K or less)	24,779	591 2.4%	628 2.5%
Population Under 18 Years	46,450	907 2.0%	921 2.0%
Disabled (sensory, physical, mental, self-care)	182,911	32,680 17%	

Figure ES-2. Percent Population Exposed to Flood Hazard.

At-risk populations constitute a sizable share of population located in the future floodplains with the economically

Critical Facilities Impacted by Various Flooding Scenarios	STORMTOOLS Sea Level Rise (SLR)			Hurricane Category				FEMA 1% Chance (100-year) Flood		FEMA X Zone .2% Chance (500-year) Flood
	MHHW (Mean Higher High Water)	MHHW + 1' SLR	MHHW + 7' SLR	Cat 1	Cat 2	Cat 3	Cat 4	FEMA VE Velocity Zone > 2.9' wave	FEMA AE Zone <2.9' wave	
Land Use										
College / University	2	3	17	6	9	11	28	3	7	22
Dams							3		7	10
Energy/Utility	3	3	4	1	2	5	6	1	7	7
Emergency Response							4		1	2
Federal							5			4
Hazardous Materials	1	1	1	1	1	1	2	1	3	4
Healthcare / Hospitals	3	3	4	3	4	73	84	3	6	7
Ports	16	16	20	22	27	30	30	14	27	29
Public Assembly		1	4				8		1	1
Schools						1	4		8	10
Shelters									1	1
State							8			7
Transportation		1	1				22		24	25
Water Infrastructure										1
Wastewater Infrastructure	1	1	2	1	6	8	17	1	4	7
Total	26	29	61	34	49	129	221	23	96	137

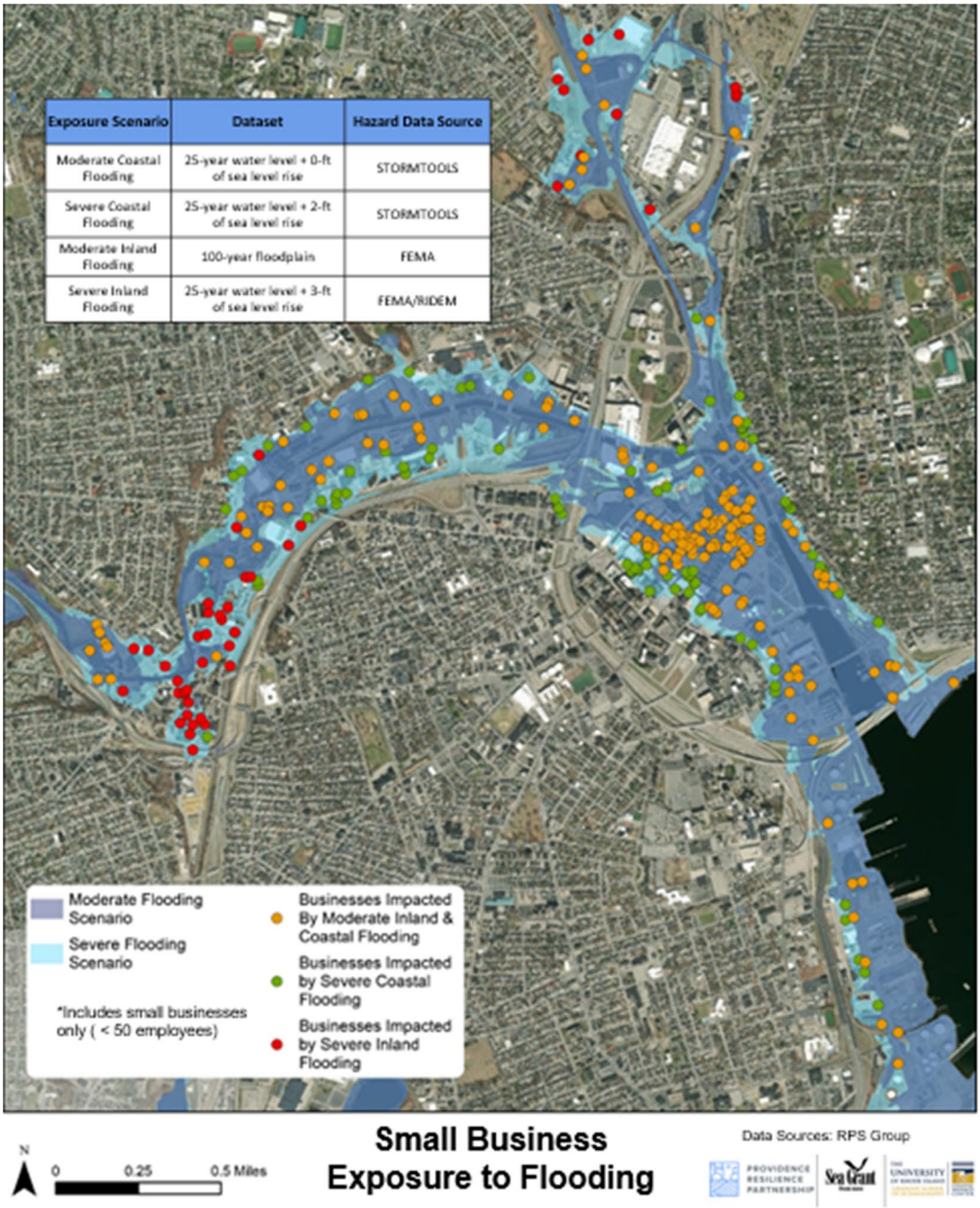
Figure ES-3. Critical Facilities Impacted by Storms and Rising Seas.

The city has many critical facility assets that are vulnerable to hurricanes, coastal and inland flooding, and rising seas. While numbers may seem low, the facilities are critical for social and economic safety and

Critical Facilities at Risk: The potential losses to critical components of the community include the closure of institutions, loss of vital services (communication, transportation, and utility systems), disruption in the movement of goods and services, and emotional strain from financial and physical losses (PEMA, 2019).

ES-4. Small Business Exposed to Moderate and Severe Coastal and Riverine Flooding. Small businesses are economic drivers for communities, create local jobs, and increase the tax base.

Downtown and the Woonasquatucket River area are especially at risk to both Nor'easter type storms and severe storms.



Small Business Vulnerability to Flooding: Providence small businesses (approximately 7,000 businesses with fewer than 50 employees) are especially vulnerable to flooding from inland and coastal storms. When looking at combined inland and coastal flooding, over 15% are impacted in moderate storms, while over 22% are impacted in severe storms in the city (RPS, 2018). For any disaster, experience in the U.S. shows that 40% of affected small businesses never reopen; another 25% that do reopen, fail within a year.

Work and School Buildings, Cultural and Historical Assets in the Floodplain: Government buildings and academic institutions—including portions of Brown University, Johnson & Wales University, and the Rhode Island School of Design—are in low-lying areas and are vulnerable to flooding from river and/or surge flooding, as well as from projected sea level rise. Also, as of 2015, 40 assets—buildings or landmarks—listed or eligible for listing on the National Register were located in Providence's federally recognized flood zone, with a majority in the downtown area (Youngken, 2015). Overall, the assets do not meet floodplain standards, although the city is making efforts to adapt and reuse cultural and historical buildings and structures in economic redevelopment plans for low-lying coastal areas (City of Providence, 2014a), which may provide an opportunity to reduce their vulnerability.

Heat and Power Outages Impact Economy and Society: Increasing air temperatures is a result of climate change. Providence, like most heavily paved urban places, is prone to collecting the sun's heat on its surfaces, and heat waves can cause problems for both people and the functioning of the infrastructure. From a health standpoint, people—especially seniors, outdoor workers, economically disadvantaged, and anyone without access to cool air and water (R. Calabro, personal communication, January 18, 2021)—can get sick from the stress of heat waves. This, in turn, becomes an economic issue if it translates into reduced productivity at school or work. In addition, in both the social and economic veins, heat waves prompt an increase in air conditioning and water use, which can stress energy systems, potentially causing power outages that hamper residential and business activity, including transportation and communications (City of Providence, 2019); longer-term heat impacts could lead to declines in labor productivity, while worsening social and economic inequities. While overuse can impact energy systems, natural hazards in general—especially hurricanes, strong winds, or snowstorms—can cause power outages. Cascading impacts of these storms are tied to social and economic losses, including property damage, impacts to school and business operations, reduced revenues to proprietors, lost wages for employees, and reduced tax revenues to the city (PEMA, 2019).

> *"Power outages and limited accessibility may force businesses to temporarily shut down. These unexpected closures can result in large financial losses. Since businesses operate within an inter-connected system, the closure of one may have large impacts on other businesses in the area. Smaller businesses may not be able to recover from the loss of business or damages caused by a hurricane or tropical storm."*
>
> *- PEMA, 2019*

The Double Impact of Water and Heat: When two impacts happen at once, such as flooding accompanied by the extreme heat, problems can worsen within the social and economic spheres. For example, mold, a potential health issue, can result from these conditions, and this can pose

interruptions to both school and business operations or increase health issues in residences. School buildings may also represent an additional concern as they generally serve as Providence's emergency shelters (Resilient Rhody, 2018; PEMA, 2019).

Efforts to Increase Resilience

Embracing Strengths and Cultivating Leadership: The Providence Resilience Project (PRP) provided a forum in 2019 to identify how local leaders can shape the city's resilience efforts; the proceedings from the event reflected the group's interest in several focus areas, including: 1) cultivating resilience leaders in the city from varied economic, environmental, and social arenas; and 2) harnessing Rhode Island's "small state" identity as a unique means of building resilience awareness (IBES & URI, 2019).

Application of STORMTOOLS to Assess Flooding Issues: Localized Rhode Island tools are available for use by the city, private sector, academic, and community partners. The Coastal Resources Management Council (CRMC) STORMTOOLS mapping, and the Coastal Environmental Risk Index (CERI) applications—developed by CRMC and the University of Rhode Island—are used for assessment, design, and planning purposes. Users can view current and projected flooding scenarios and assess structural risk and damage to inform tailored, science-based solutions to address each scenario.

Plans and Initiatives Support Socio-economic Resilience*

- Multi-Hazard Mitigation Plan
- Providence Tomorrow and Neighborhood Plans
- Great Streets Initiative
- Climate Justice Plan
- Sustainable Providence
- Woonasquatucket Vision Plan
- Providence Neighborhood Planting Program

** Hyperlinks are provided here and are summarized throughout this document.*

Preparing Health Efforts for Emergencies: The city works with public and private health partners (Healthcare Coalition of Rhode Island, co-led by Rhode Island Department of Health and the Hospital Association of Rhode Island) to build emergency management efforts focused on preparedness, response, recovery, and mitigation (PEMA, 2019).

Rhode Island Alliance for Business Resilience (RIABR): The Alliance—a self-governed public-private partnership—focuses on improving the resilience of Rhode Island businesses and local communities. In 2016, RIABR formed around a shared vision for collaboration in emergency preparation, response, and recovery. RIABR membership is available to companies that employ 50 or more people, as well as trade associations and chambers of commerce with more than 50 members. Current members in Providence include the Greater Providence Chamber of Commerce, Lifespan, and Unified Natural Foods, Inc., among others.

Risk Reduction for Small Business Resilience: The State offers a series of guides on Rhode Island Natural Hazard and Extreme Weather Risk Reduction for Small Business. The guides target different sectors (e.g., restaurants, service providers, and construction industry) that can be used to increase that sector's awareness of techniques and best practices for reducing risk. Field interviews with small businesses in different regions of the state, including Providence, informed these guides. See more at: http://climatechange.ri.gov/businesses/small-biz.php.

Recommendations

Communication and Collaboration

Encourage Cross-Sector Collaboration on Pre-event Planning: Leverage opportunities for government, private sector, and community participation in developing and implementing pre-event planning and adaptation and continuity efforts. A specific activity, for example, could engage public and private sector partners on reevaluating building codes and regulations (IBES & URI, 2019; C2ES, 2016; Becker & Caldwell, 2015).

Develop Business and Property Flood Audit Program: Create a flood audit program for property owners and businesses, similar to the RISE Energy Audit program, to incentivize property fortification and adaptation (RI House of Representatives, 2016; Resilient Rhody, 2018).

Increase Outreach to Current and Prospective Homeowners and Renter: Increase outreach about property-related climate risks and how to reduce them and incorporate climate resilience opportunities into existing social services outreach programs. Opportunities include strengthening real estate disclosure requirements with information on climate risks and increasing outreach through homebuyer education programs, which are mandatory for Rhode Island housing loans (Resilient Rhody, 2018).

Enhance Understanding of Social Assets: More study is needed to move beyond property values and gain a more comprehensive understanding of the economic value of the city's social assets, and the degree to which the quality of life stands to be enhanced by resilience building.

Assessment, Planning, and Funding

Pursue Grants Collaboratively: Encourage opportunities between public (City and State), private sector, and community partners to pursue resilience planning and/or grants, including city-based efforts to secure a variety of adaptation funds (C2ES, 2016).

Encourage Uniformity and Enforcement in Zoning and Land-Use Regulations: Foster interest in the public, private sector, and community sectors for land-use design standards that allow development with appropriate mixed uses and ensure that the design adds value to the surrounding neighborhoods and local character. Encourage development to consider natural and man-made environmental constraints and preserve social, cultural, and historical assets as possible (C2ES, 2016, City of Providence, 2014a).

Identify Data Needs to Address Information Gaps: Dialogue and study is needed to move beyond property values and gain a more comprehensive understanding of the economic value of the city's economic and social assets and the degree to which the quality of life stands to be enhanced by resilience building. In addition, more information is needed about climate change impacts (e.g., flooding caused by strong storms and sea level rise, and intensifying heat) as well as about city-specific scenarios, such as a port "shutdown".

Businesses and Jobs

Emphasize Clean Energy within Workforce Development Programs: Focus on programs that prepare frontline communities for meaningful work in a local, carbon-free economy, including training and education initiatives in industries such as construction, energy efficiency, clean energy, electrical trades, and engineering (City of Providence, 2019, City of Providence, 2016).

Engage with the Rhode Island Alliance for Business Resilience: This network provides updates, resources, and access to an active network of businesses to support business resilience. Membership is open to businesses with more than 50 employees.

Ensure Available Resources for Post-disasters are Widely and Equitably Accessible for Small Business: Identify and promote the variety of post-event resources already available to the private sector; partner with organizations such as the Greater Providence Chamber of Commerce to offer reopening training and distribution of resources available from the state, including the Risk Reduction for Small Business in Rhode Island guides or those of the Rhode Island Alliance for Business Resilience (RPS, 2018; RI House of Representatives, 2016).

Social and Cultural Aspects

Consider Historical Property Guidance: Support historic preservation of areas at risk to flooding. Newport, Rhode Island, provides an excellent local example of using standards to help protect historic neighborhoods from threats posed from sea level rise. Its Design Guidelines for Elevating Historic Buildings and flood maps are available through the Historic District Commission (See City of Newport Historical Preservation for more information).

Continue Development of Place-based Resilience Plans: Work to develop long-term climate resilience and adaptation plans in targeted areas. Focus on frontline communities, partnering with the city's Racial and Environmental Justice Committee (REJC) on efforts tailored for neighborhoods on the Woonasquatucket River, in the port area, and near the Fox Point Hurricane Barrier (City of Providence, 2019).

Infrastructure and Environment

Overview

In large part, the natural environment provided the shape and support that enabled Providence to thrive as an industrial and commercial hub for the Northeast Region into the 21st century. The city's location in the basin of the Narragansett Bay watershed area allowed it to both benefit from river downflows that powered 18th century mills and from coastal access that fostered maritime industry and international trade. Eventually, modern-day development would significantly alter the environment of Providence, as the Providence River area has been urbanized, with parts of the waterway dredged for navigation and other portions relocated and paved. As the state's capital, coordinated management amongst federal, state, city and local partners is necessary to ensure that this heavily manmade system, with several forms of infrastructure, responds to a wide array of issues, including navigation, transportation, and stormwater and pollution mitigation, and the need to expand the urban forest.

Key Findings

There are essential infrastructure assets that are highly vulnerable to accelerating climate change, and yet there is an inconsistent level of attention given to these vulnerabilities. This presents significant risk to affected communities' well-being and public health and has consequences for the larger statewide/Northeast Region. This research did not include a study of the resilience of the heating supply, and the communications and electricity networks (including a backup to the hurricane barrier).

Linking infrastructure and environment issues and opportunities engages highly capable community initiatives that leverage multiple partnerships to effectively address infrastructure vulnerability. An example is the efforts linking "green infrastructure" approaches to local job growth and community development work.

Available to the public are studies that assess the vulnerability of transportation assets, the hurricane barrier, and wastewater treatment facilities. Either unavailable to the public, or not yet undertaken or completed, are studies that fully assess how accelerating climate change will impact energy, communications, water, and stormwater utility infrastructure.

This management effort is complicated today by the aging of Providence area infrastructure, such as roads and bridges, port facilities, wastewater and drainage systems—some of it a century old—and the impacts of climate change, including acute flooding from storms and extreme high tides and the more gradual effects of sea level rise and temperature increases. The Providence Fox Point Hurricane Barrier provides significant protection from coastal storm surge to the downtown area, but the older structure needs consistent maintenance, isn't designed to address mid-to-end century projected flood heights, and does not protect other low-lying parts of the city, with some neighborhoods (e.g., the Woonasquatucket River Corridor) and economic interests (e.g., the port) remaining exposed. In addition, urban paving exacerbates flooding and temperature conditions; impervious surface both prevents water from being absorbed by the ground and collects and radiates heat into the surrounding city, a double issue that often affects those least able to address it.

Planning efforts are underway to address these problems that highlight the interdependence between Providence's urban landscape and its environment. Guiding documents, such as the city's comprehensive plan (Providence Tomorrow) and the more recent 2019 hazard mitigation plan (Strategy for Reducing Risks from Natural, Human-Caused and Technologic Hazards: A Multi-Hazard Mitigation Plan), speak to the need to incorporate resilience approaches, including flood mitigation and green

infrastructure, into community planning and development activities. Among the projects and programs are those focused on the Woonasquatucket River Greenway, the Providence Combined Sewer Overflow Facilities project, the Providence Great Streets Initiative, in addition to transportation improvements with state and city funding. The city is in the 2020 Cohort of the state's Municipal Resilience Program (MRP) with the goal of highlighting key projects, with a focus on infrastructure; the implementation has been delayed by the city due to COVID. With a list of priorities identified, the state and the city can more effectively access funding, in the form of grants, loans, and partnerships that support adaptation actions for resilience improvement and construction projects.

Resilience initiatives can leverage opportunities for sometimes-competing issues of infrastructure and environment (RI Sea Grant).

Recognizing the growing need to incorporate resilience into urban infrastructure, partners from government, the private sector, academia, and the community are increasingly collaborating to consider the value of infrastructure to human life, as well as the realistic costs of supporting its upkeep. To this point, the city reviewed seven lifeline sectors critical to daily life—Electricity, Communications, Emergency Services, Energy, Information Technology, Transportation Systems, and Water and Wastewater Systems—identifying that infrastructure management, maintenance, and enhancement are primary means of ensuring the safety of people and property when addressing natural hazards (PEMA, 2019).

> *"Critical infrastructure/utility facilities or 'lifeline sectors' are important to the safety, security, and economic well-being of the city. Infrastructure failure is considered any disruption to critical infrastructure that could have cascading effects that negatively impact a community's security, public health and safety, and economic vitality"*
>
> *- PEMA, 2019*

Communications
Communications systems are especially vulnerable to wind-related events that impact power lines.
Energy
Climate change and projected increases in warmer temperatures are likely to both increase electricity demand for cooling in the summer and decrease electricity, natural gas, heating oil, and wood demand for heating in the winter. Sea level rise projections and increases in the frequency and intensity of storm events could disrupt energy production and delivery by damaging electricity infrastructure, fuel delivery infrastructure and equipment, power plants, and/or storage facilities.
Information Technology
Natural hazard events can often indirectly contribute to information technology threats through long-term loss of power or extreme heat. Projected increases in the frequency and severity of natural hazards, particularly wind-related events such as downed power lines, will likely impact the provision for and security of information technology.
Transportation Systems
The quality of the city's transportation systems (roads and highways) significantly affect the response to a disaster. Poor quality systems and structures can hinder access or limit ability to evacuate if necessary. Bridges, many of which are on the RIDOT list of capital projects, are also a component of the critical infrastructure within Providence. Flooding from sea level rise has a potential to increase nuisance flooding, resulting in impacts to roads, bridges, rail, and port transportation. Projected increases in the frequency and severity of natural hazard events for wind-, flood- and snow-related events could impact the movement of goods and services within the port, as well as disrupt public transportation in, out, and throughout the city.
Wastewater
Although operations have not been severely impacted in the past, the facilities face increasing risks from flood water from stronger storms and accelerated sea level rise; and inland pump stations face potential increased flooding from riverine and localized sources. Varied studies project different impacts for operational and structural components, where actions are being evaluated (and implemented) to maintain resilience for the near future (see Wastewater section for more information).
Water
SafeWater RI provides an overall ranking for vulnerability to five hazards. Rankings identified for the Providence water system indicate high risk from sea level rise, riverine flooding **and** hurricane hazards and project a low to moderate risk **from** coastal flooding.

Figure IE-1. Critical Risks to Lifeline Sectors Impacted by Flooding. These services are critical to the everyday activities throughout the city (PEMA 2019).

Situation, Climate Challenges, and Efforts to Increase Resilience

Collaborative planning for the effective and efficient maintenance and enhancement of infrastructure that is important for protecting people and property from climate change impacts involves identifying and understanding each structure's history and management context, along with resilience opportunities and challenges. Basic information, summarized from many different resources, is

provided here and in other areas of the report, as indicated, for these infrastructure components: the hurricane barrier, the port area, the wastewater treatment facility, the stormwater management system, the transportation (roads/bridges) system, electricity (energy) utilities, and green space.

Hurricane Barrier (see Hurricane Barrier section for more information)

Situation: The Fox Point Hurricane Barrier represented a state-of-the-art infrastructure project when it was constructed by the U.S. Army Corps of Engineers (USACE), in concert with state and municipal management partners, more than 60 years ago. After the destruction wrought upon Downtown Providence by the Hurricane of 1938 and other strong storms in succeeding decades, the barrier was designed to protect the city's inner commercial district from storm flooding. It has proved useful in several major weather events and is managed in partnership today by the City, USACE, and other critical service providers—who are confronted by the costs of maintaining the aging structure.

Climate Challenges: The barrier was not designed to accommodate today's projections for future storm surge, intense storm precipitation, and sea level rise; nor does it protect the surrounding and now significantly developed low-lying neighborhoods and commercial areas of Providence.

Efforts to Increase Resilience: Government, private sector, academic, and community interests have done cursory reviews to examine impacts and weigh options for retrofitting barrier components to accommodate greater flooding and increased usage, although it is recognized there is only so much that can be done to increase the infrastructure's efficacy. The question of how to protect the rest of the Providence waterfront areas remains (see Hurricane Barrier section for more information).

Port Area (see Port Area section for more information)

Situation: The port area has functioned as an industrial and commercial hub for centuries, with its Providence River maritime entities enduring flooding and wind damages from past hurricanes and strong storms.

Climate Challenges: Some infrastructure and equipment for loading and unloading, storing, and moving materials, cargo, and product are in low-lying areas directly adjacent to the coast, as are various utilities and fuel facilities. Impervious surface is common in port areas and could exacerbate flooding and temperature increases. In addition, as no single entity oversees the entire port area, leadership for a concerted private sector, government, and community partnership is either complicated or lacking.

Efforts to Increase Resilience: Today, various projects are underway within the port community. For example, port manager, ProvPort, has assumed a leadership role for the private sector in implementing planning to address the management of stormwater and sea level rise. However, additional effort is needed to create a resilience initiative that encompasses all spheres of the port area community (see Port Area section for more information). Several efforts are also coordinated with the adjacent communities to address broader environmental concerns for air and water, in addition to safety and resilience.

Wastewater Treatment (see Wastewater Treatment section for more information)

Situation: As with the majority of Rhode Island's wastewater treatment plants, Providence's facilities, which are managed by the Narragansett Bay Commission, are located on the coast at the bottom of the Narragansett Bay watershed; using gravity as a key design element, it made sense to place such facilities at the receiving end of downward-streaming water sources and systems. The facility is a state-of-the-art treatment center and has been recognized for its efforts in aiding wastewater research and education efforts.

Climate Challenges: Although operations have not been severely impacted in the past, some of the facilities' components face increasing risks of flooding from stronger storms and accelerated sea level rise. This is true, as well, for pumping stations located both along the coast and inland.

Efforts to Increase Resilience: Different studies have evaluated impacts, based on different model scenarios. Acknowledging that it is not always feasible (or cost effective) to have a resilience goal of 'keep all the water out', the commission has implemented a plan to address resilience building for their treatment facilities and has put measures in place to reduce operational and structural impacts to critical components. It participates in community dialogue along with government, private sector, academic, and other interests on issues such as climate change (see Wastewater section for more information).

Stormwater (see Stormwater Systems section for more information)

Situation: The majority of stormwater in Providence is handled through combined sewer overflow (CSO) infrastructure, managed by the Narragansett Bay Commission. Large-scale, phased improvements to the CSO system will allow it to accommodate flood water from rain and storm events and process it for pollution and debris. A significant portion of the stormwater system is not connected to the CSO system. This includes some discharges south of the hurricane barrier and direct discharges to the Woonasquatucket and Moshassuck Rivers.

Climate Challenges: Projected increases in floodwater tied to strong storms and sea level rise point to the need to ensure that the overflow system is maintained to withstand increased use. Outside of the overflow system, a substantial portion of the infrastructure related to stormwater removal in Providence is aging and vulnerable to flooding and inundation. Maintaining these systems is a joint effort of the state and municipality.

Efforts to Increase Resilience: The state, municipality, and the commission continue to engage in planning efforts to bolster stormwater management systems in Providence. The CSO separation project includes $40 million for green infrastructure design and installation. Green infrastructure projects throughout the city represent an opportunity to enhance resilience by managing stormwater, while increasing greenspace and habitats and associated quality of life (see Stormwater section for more information). Organizations like the Woonasquatucket River Watershed Council, the Green Infrastructure Coalition, the Rhode Island Department of Transportation, and the Rhode Island

Infrastructure Bank (RIIB) will play critical roles in advancing the implementation of more resilient stormwater practices.

Transportation

Situation: In Providence, as with all Rhode Island municipalities, the transportation system is, in part, comprised of roadways and bridges identified as assets of either the state or local government, with federal funds made available via concerted allocation programs. While transportation infrastructure is generally considered a priority need and expenditure for government, implementing improvements has traditionally been complicated by ongoing development pressures and the rising costs associated with maintaining aging components. Providence currently experiences upland urban flooding from heavy rainfall, affecting stormwater drainage in many areas throughout the city. However, there are no current assessments that look at this issue citywide (see Stormwater section for more detail).

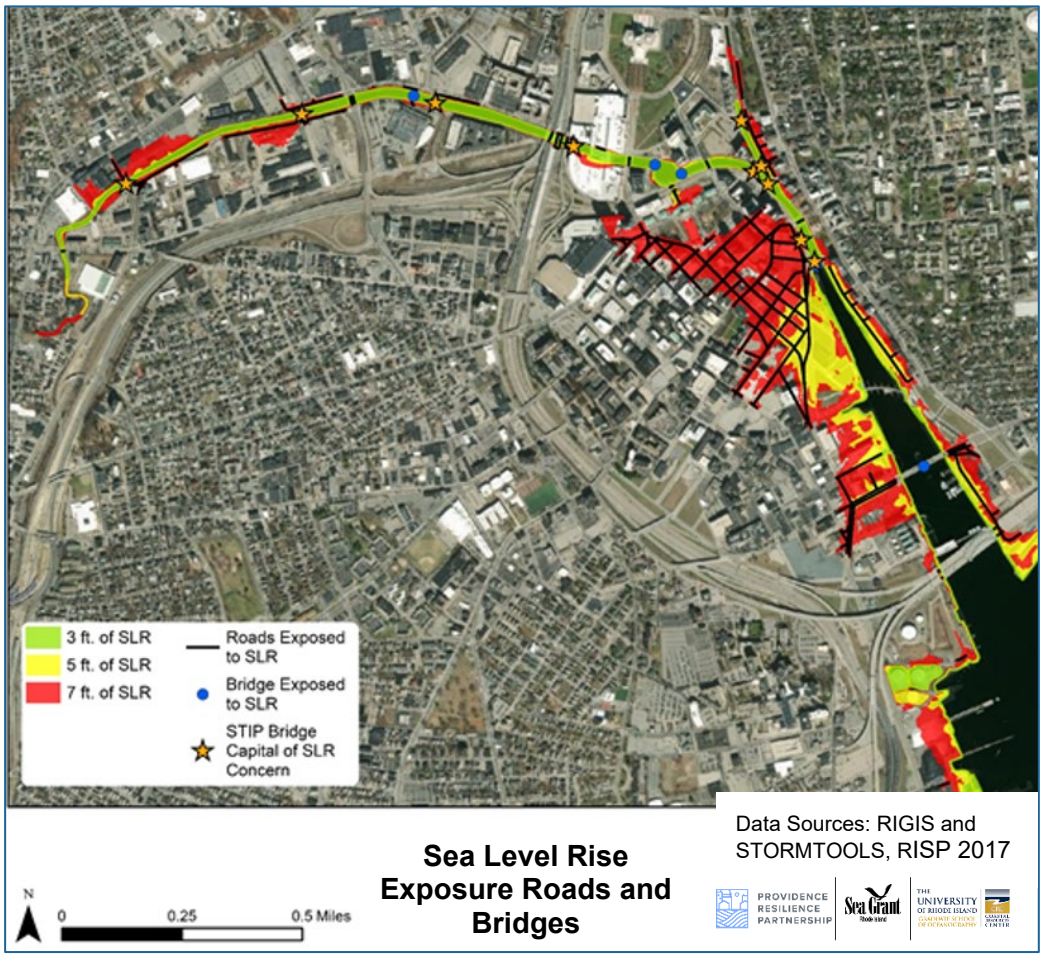


Figure IE-2. Sea Level Rise affects Roads and Bridges in Low-Lying Areas particularly Downtown and to a Lesser Degree in the Woonasquatucket River Corridor.

Climate Challenges: Today, further complexity is introduced into transportation planning as climate change impacts, especially flooding from strong storms with heavy rainfall and sea level rise, pose a threat to coastal roads and bridges. Some Providence roadways, such as Eagle Square and Rising Sun Mills, periodically flood from intense rains and poor stormwater drainage (City of Providence, 2009; PEMA, 2019) so increasing attention is being paid by transportation planners and other decision makers to identify which infrastructure is most at-risk and how it can be either protected from, or adapted to, the changing coastal environmental.

Figure IE-2. Potential Impacts to Transportation Assets from Sea Level Rise and Storm Surge* (RISP, 2015; RISP, 2016; RISP 2016b; PEMA, 2019).

Roads
Sea Level Rise
1 foot = .4 mile local; 3 feet = 1.8 miles local; 5 feet = 4.7 miles local Given seven feet of sea level rise, nine miles of roadway inundation can be expected. Of this, 39% (3.56 miles) are local. Providence's roads (state and local) are the fifth most vulnerable in the state of Rhode Island to sea level rise.
100-Year Storm + 7 Feet of Sea Level Rise
The expectation is that outside the hurricane barrier, 12 miles of roadway will be inundated; 45% (~6 miles) is municipally owned/managed.
Bridges
Sea Level Rise
Given seven feet of sea level rise, in Providence there are 21 bridges of concern, five of which carry non-motorized facilities. Providence's bridge infrastructure is the most vulnerable in the state of Rhode Island to sea level rise.
100-Year Storm
Providence's bridge infrastructure is the third most vulnerable to storm surge in Rhode Island.
100-Year Storm + 7 feet of Sea Level Rise
There are 19 bridges of concern, including Eagle and Park, both over the tidal portion of the Woonasquatucket River, which are among the state's top 10 most vulnerable bridges.
Rail
Sea Level Rise
Impacts to Amtrak could increase significantly at 3 feet of sea level rise (120 LF) and 5 feet of rise (277 LF). In the port area, a small segment of rail line at South Harbor near Terminal Road is projected to be flooded at 5 feet sea level rise. The study recommends further investigation in these two areas due to the elevations of the rail and the proximity to tidal waters.
Commercial and Industrial Port Facilities
Sea Level Rise
1 foot - 4.3 acres; 3 feet - 8.6 acres; 5 feet - 24 acres Impacts may include piers and/or upland facilities, where those most affected include liquid cargo and ship building and repair facilities, and to a lesser extent dry bulk cargo, electric power generation, and general berthing.

* The 100-year storm (1% chance of occurring in any given year) can be considered similar to Hurricane Carol in 1954.

Efforts to Increase Resilience

Both the Rhode Island and Providence governments have undertaken efforts to examine their transportation assets and either prioritize or initiate activities to protect infrastructure from flooding and sea level rise impacts through infrastructure improvement funding (RISP, 2015; RISP, 2016; STIP 2020). Online mappers provide an overview of some of these efforts: RIDOT Stormwater Program, RI Sea Level Rise Impacts on Transportation Assets, State Transportation Improvement Program. As it the case for other coastal municipalities, Providence recognizes that today's periodic flooding events are projected to be more numerous—perhaps twice daily in some cases—and more damaging, with 5 to 9 foot increases possible by mid-to-end century. As such, government entities and their consultants have begun to incorporate these changing conditions into infrastructure design over the useful life of that infrastructure.

Mun. Rank	Road Name	1 ft SLR	3 ft SLR	5 ft SLR	7 ft SLR	Total Linear Ft	Intermodal Facility	Functional Classification	Vuln. Score	State Rank
1	I-95 N	85	17	20	41	163	Yes	Interstate	6.54	19
2	I-95 S	85	20	31	40	176	Yes	Interstate	6.47	20
3	Canal St	0	0	0	1,244	1,244	Yes	Principal Art.	6.43	21
4	Steeple St	120	11		179	306	Yes	Principal Art.	6.27	24
5	On ramp I-95 N	166	20	30	50	265	Yes	Interstate	6.25	25
6	Dorrance St	0	0	660	1,640	2,300	Yes	Minor Art.	6.22	26
7	Dean St	186	14	9	15	224	No	Minor Art.	6.22	27
8	Kinsley Ave	0	0	0	2,795	2,795	Yes	Major Coll.	6.17	31
9	Point St	0	0	4	1,495	1,499	No	Principal Art.	5.89	40
10	Exit 22	85	5	11	28	129	No	Interstate	5.81	43

Figure IE-3. Top Ten Road Assets Vulnerable to Sea Level Rise. Providence's top ten roads vulnerable to sea level rise are ranked within the top 50 of the state's vulnerable roads. It should be noted that none of these are within evacuation routes (RISP, 2016a, 2016b; 2020).

State and City Focus on Roadway Resilience: Both Rhode Island and the City of Providence have taken steps to start addressing how they'll prepare for a future where roads are compromised by water more often. A major effort carried out by the Rhode Island Division of Statewide Planning (RISP) Program during 2015-2016 provided mapping detail on state roads and bridges at-risk for inundation from flooding caused by strong storms, sea level rise and related tide events. It led to the state's collaboration with municipalities on solutions moving forward (see the RI Sea Level Rise Impacts on Transportation Assets mapper). This study revealed that Providence bridges were the most vulnerable in the state. Providence also ranked 5th in the state in terms of road vulnerability to long-term sea level rise. While not a chronic risk today, planning should consider these two issues for the future. On the City side, guidance drafted in 2019—although not yet passed—focuses on contributing to a low-carbon

and climate resilient future through capital improvements. Providence is also looking to its Great Streets Initiative as a platform for implementing transportation improvements with multiple benefits. This includes green infrastructure to reduce flood-prone areas, such as South Water Street and the Woonasquatucket River Greenway. The City's Michael S. Van Leesten Pedestrian Bridge, completed in 2019, is an example of planning for the future. As a result of its design, which includes increased elevation and materials that can withstand immersion, the structure can accommodate three feet of sea level rise.

State Improvements Implemented: The most recent Statewide Transportation Improvement Program (STIP) (2018-2027), which is continually updated, includes a number of improvements for the City of Providence, including bridge improvements for those that have been designated "sea level rise concern". The Rhode Island Department of Transportation (RIDOT) Stormwater Program, funded by a consent decree, has ongoing programs to retrofit, and, in some cases, rehabilitate stormwater infrastructure to help address upland flooding risks.

"Through RhodeWorks, (the) Rhode Island Department of Transportation (RIDOT) initiated work on the reconstruction of structurally deficient bridges as well as preventative approaches to prevent others from also becoming deficient. A number of these structures are in Providence, scheduled for rehabilitation or preservation through the STIP projected through 2027."

- City of Providence, 2019

Options and Issues*:* Adaptation options for Providence to weigh include protecting at-risk flood areas via armoring or employing green infrastructure, accommodating in-place or through realignment, and retreating (RISP, 2015; RISP, 2016). Throughout Rhode Island, conversations about how to move forward with roadway resilience are somewhat complicated by the stark division of responsibility for transportation infrastructure; the state manages specific roads and bridges, while the municipalities are tasked with managing others—increasingly, efforts are being made between the government levels, in coordination with other private sector and community partners, to communicate on these separate responsibilities and leverage effectiveness and efficiency where possible.

A Funding Quilt: Funding opportunities for resilience roadwork are provided via state and municipal programming. For example, Rhode Island funnels federal allocations and state resources to cities and towns via the comprehensive STIP. On the city side, Providence funds and has developed a five-year capital improvement plan to address a wide range of infrastructure, construction, and enhancement projects, including resilience roadwork. Capital improvements are usually funded by borrowing dollars through municipal bonds and approved by the City Council.

Electric Power (Energy)

Situation: The electric grid is an important essential for the people and economic viability of Providence and is critical for operating other infrastructure, including the hurricane barrier. Electric power is identified by the state as a critical lifeline sector, and efforts are underway to diversify the sector towards renewable energy, which increases resilience from storm-affected outages at the same

time it decreases reliance on fossil fuels. Government commitment to carbon-free electricity includes the state goal per the 2020 Governor's declaration to reach 100% renewable electricity by decade end and the city's goal per 2016 executive order to reach100% carbon-free electricity by 2050). These stated goals, along with other progressive goals and programs, have increased the opportunities to access renewable energy, while also implementing programs to increase energy efficiency within the current, traditional energy supply sources. Electricity in the New England power grid today relies primarily on natural gas and nuclear. Increasing resilience of the electric grid provides an opportunity to adapt to climate change impacts, while mitigating or reducing greenhouse gas emissions.

Climate Challenges: Most impact arises from storm events that can occur year-round, as the citywide grid—with its primarily above-ground distribution lines—are vulnerable to damage from wind and snow loads, affecting transmission/distribution infrastructure. Indirect impacts of extreme weather can affect a broad array of infrastructure, from traffic lights to the hurricane barrier to wastewater treatment facilities, which have contingency options. Impacts from changing climate are seen citywide, especially regarding air conditioning and heating—the lack of which disproportionately affect vulnerable populations and frontline communities. Other issues include the need for trimming trees adjacent to above-ground transmission lines and the need for snow removal, both of which are exacerbated by wind and which effect residents, businesses, and municipal operations.

"The increasing frequency of extreme weather events and the ongoing possibility of future natural or manmade disasters also pose serious energy security risks to Rhode Island, particularly the state's dependence on natural gas"

- Resilient Rhody, 2018

Efforts to Increase Resilience*:* Beyond the noted state and city commitments to clean energy, other efforts include the Sustainable Providence Plan of 2014, which established goals for energy; and the voluntary RePowerPVD program of 2018, which encourages property owners to commit to reducing energy consumption by 20% by 2025. As of January 2021, there is also a proposed city ordinance that would require owners of large buildings to track usage and report it annually to the city. In addition, the Providence Climate Justice Plan, with a focus on frontline communities, identifies a full spectrum of actions, from a shift towards zero carbon energy in municipal operations to access to renewable energy for frontline communities—all of which take a collaborative governance approach. Government, private sector and community interests continue to explore solutions, such as solar and wind, to diversify the grid to make it more resilient and reduce greenhouse gas emissions.

"One of the most direct energy security impacts of major storm events is power outages. The increasing need for electricity restoration following storms is directly contributing to the rising cost of storm response."

- Resilient Rhody, 2018

***Looking for Long-Term Energy Resilience*:** Rhode Island has laid the foundation for a long-term energy resilience strategy via the State Energy Plan, which recommends the formation of a working group charged with developing short- and long-term strategies for mitigating critical infrastructure energy security risks and investing in power

resilience solutions (Resilient Rhody, 2018). Also, the Rhode Island Office of Energy Resources (RIOER), Division of Public Utilities and Carriers (DPUC), and Public Utilities Commission (PUC) play key roles in overseeing energy assurance and resilience in Rhode Island.

The Microgrid Option: The state, via RIOER, is examining the potential for this option, as smaller infrastructure could be placed above flood levels, enable grid-independent terminal operation during external power outages, strengthen grid resilience, and provide mitigation against grid disturbances (RIOER, 2017).

Solar Siting Starting Point: The RIOER identified in a 2020 report the potential for solar facilities being placed on rooftops, landfills, gravel pits, brownfields, carports, and other commercial and industrial locales. The report findings are initial estimates or provide a starting point for assessing opportunities. For instance, Providence, more than any other municipality, offers the potential for parking lot solar installations (RIOER, 2020).

Renewable Energy Transformation: The Partnership for Rhode Island is an executive roundtable comprised of 13 of the largest employers in the state, represented by their CEOs/presidents. Founded in 2017 to help advance priority goals statewide, and most recently, in collaboration with National Grid and Ørsted, this partnership founded ETHOS (The Energy Transformation Hub of the Ocean State). ETHOS is helping achieve the state's 2030 energy goals by convening experts and securing financing to face challenges in moving toward a more sustainable, renewable Rhode Island (T. Giordano, personal communication, August 24, 2020). ETHOS also is designing a partnership with the Amazon Web Services (AWS) Cloud Innovation Centers (CIC) Program to provide an opportunity for nonprofits, education institutions, and government agencies to collaborate on their most pressing challenges, test new ideas with Amazon's innovation process, and access the technology expertise of AWS (A. Dahlberg, personal communication, January 3, 2021).

Green Space in the Urban Environment

"Sea level rise is an increasing issue that will continue to rise with climate change and global warming. An adaptive landscape that enables and allows for change to occur throughout the day due to various tidal sequences and water levels from sea level rise and nuisance flooding is one way of solving the issue of increased coastal flooding

- URI, 2018a

Situation: Investing in urban forest throughout the city and in green spaces, whether traditional natural landscapes or the more managed or engineered vegetated areas supported in today's cities, is increasingly an opportunity to multiply social, environment, and economic benefits to increase resilience. Many of the Providence green spaces, such as the Woonasquatucket River Greenway, Roger Williams Park, India Point Park, the Downtown Parks Conservancy projects, and Roger Williams Park, have included green infrastructure to reduce street flooding. Community planning recognizes that beyond serving as critical plant and animal habitat, green space

matters because it is sought by residents, businesses, and schools—our social underpinnings. In the Providence region, major projects to restore urban river areas and walkways and to clean Narragansett Bay and expand public access to it has enhanced waterfront and greenway appreciation for all community sectors. And the city, via its Great Streets Initiative, emphasizes its commitment to fostering the development and upkeep of parks, open space, and greenways. Both science and practice prove that in terms of resilience, green space—via plants, soil, and rock materials—has the ability to absorb both water and heat, often at a price substantially lower than the costs associated with more traditional construction or mitigation methods. Furthermore, while impact reduction is often considered exclusively from either an adaptation (e.g., reducing flooding damage) or mitigation lens (e.g., reducing greenhouse gas emissions), green space is increasingly seen as an opportunity to achieve both aims.

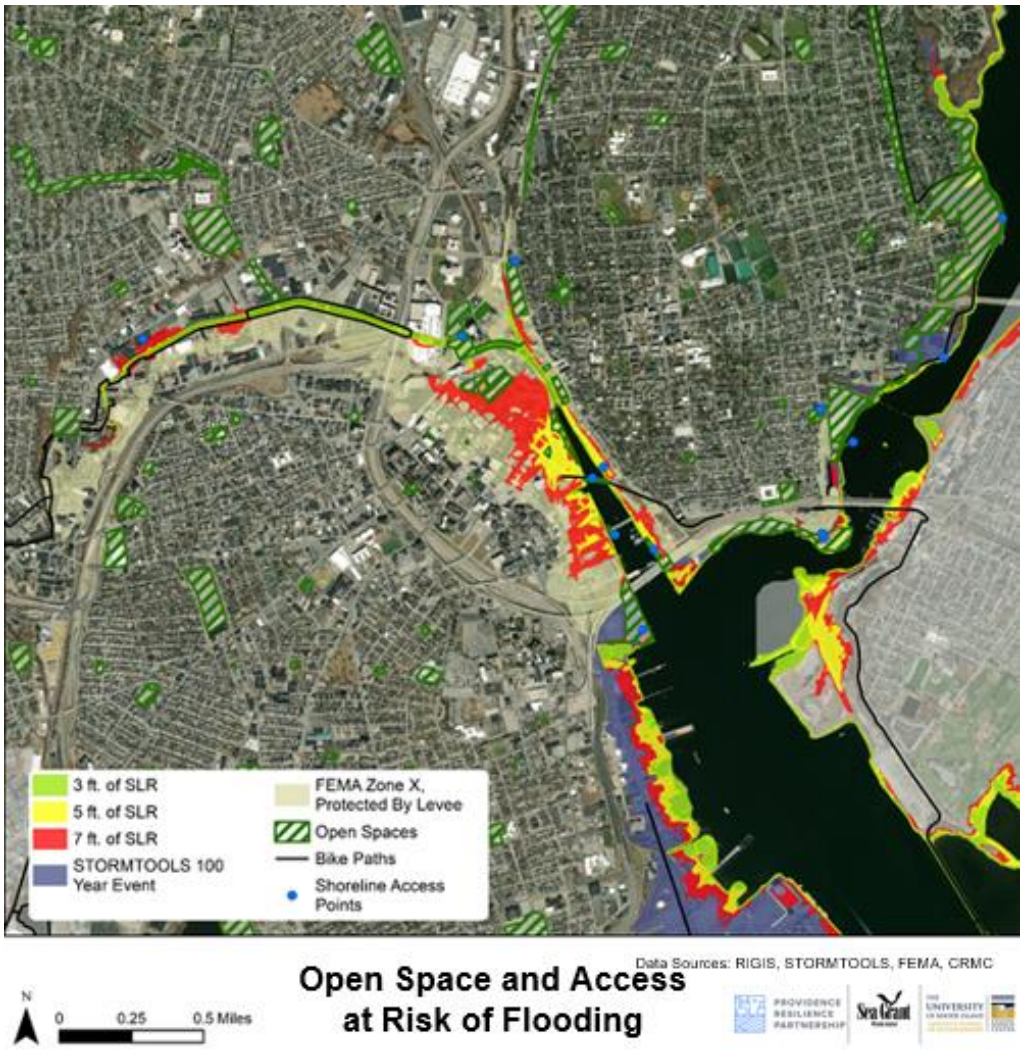


Figure IE-4. Open Spaces at Risk of Flooding. Given current sea level rise and storm projections, the already limited amount of open space may continue to shrink due to more frequent and intense flooding events.

Climate Challenges: Increased rainfall trends with warming temperatures provide an opportunity for increased use of green infrastructure to support flood mitigation actions. Green spaces and projects require consistent management in order to ensure that features, such as trees, stay healthy and are not likely to be downed in storm conditions—as this can endanger people and damage power lines and property. Accelerating sea level rise will continue to impact the dwindling wetland habitat present in the urban shoreline.

Efforts to Increase Resilience: Substantial government interest in implementing green space projects as a means to both increase community value and decrease climate change impacts tied to flooding and heat is reflected in several of the city's guiding documents, including the 2014 Providence

Tomorrow comprehensive plan, which speaks to the need to: 1) Protect and preserve the natural environment and strive to make Providence a "green" sustainable city; 2) Protect, preserve and promote a high quality built environment; and 3) Create a sustainable, high-quality parks and recreation system that reflects the unique identity of Providence. Providence area green space or infrastructure initiatives include the following:

Providence Metro Area Projects and Programs: The Providence Metro area has been a focus of the Rhode Island Green Infrastructure Coalition since 2015. This network of partners (i.e., City of Providence, Groundwork Rhode Island, Woonasquatucket River Watershed Association, The Nature Conservancy) has been actively learning and advancing green infrastructure installations in Providence. While efforts to develop an Upper Narragansett Bay Regional Stormwater Management District as a sustainable funding mechanism for stormwater management did not come to fruition in 2014-2016, there has been substantial progress in enhanced green infrastructure. Partnerships with government and nongovernment entities have resulted in green infrastructure projects that have reduced street flooding, increased green space, and in many instances enhanced local skill-building programs in frontline communities. Most recently, in 2019, the Providence Stormwater Innovation Center was established at Roger Williams Park, a collaboration of the City of Providence Parks Department, Audubon Society of Rhode Island, The Nature Conservancy, the University of Rhode Island (URI) Cooperative Extension, and the University of New Hampshire Stormwater Center. This demonstration center features green infrastructure installations to reduce stormwater contamination, while providing hands-on training for practitioners to learn about best management practices in green infrastructure design, implementation, and maintenance. Climate Smart Cities Metro Providence, a project completed with the Trust for Public Lands together with municipalities and community members, provides decision support tools, including a mapping portal, for the Providence Metro area to develop science-based prioritization for green infrastructure development. The strategy is to connect places, cool spaces, absorb water, and protect infrastructure and neighborhoods from flooding.

Climate Smart Cities Strategies Help Increase Resilience to Climate Change (web.tplgis.org/metroprovidence_csc)

State Transportation, Stormwater Management, and Greenway Planning: Green infrastructure has been incorporated into transportation projects and continues through Rhode Island Department of Transportation (RIDOT) efforts in the Providence area of the Woonasquatucket River, among other city locations. Green infrastructure is also central to state, municipal, private and nonprofit implementation of stormwater management efforts throughout the city. In addition, the Rhode Island Coastal Resources

Management Council (CRMC) administers an Urban Greenway Policy and guidebook and works with municipalities, including Providence, on implementing Urban Coastal Greenway projects. Besides using low-impact development techniques, like green walkways and roofs, to enhance the quality of urban coastal waters and access to them, the projects offer the resilience-building benefits of minimized flooding and erosion (CRMC, 2007).

The PVD Tree Plan will be a comprehensive and strategic roadmap to guide the City and other key urban forest stewards and the public in proactively managing the resource of Providence's tree canopy in order to maximize its many environmental, social and public health benefits, as well as to ensure that these benefits are equitable shared throughout the city.

- Providence Neighborhood Planting Program.

Providence's Urban Forest Efforts: In recognition of the desire, need, and benefits of a more robust and resilient urban forest in the city, the Providence Neighborhood Planting Program (PNPP) has initiated the PVDTreePlan, a collaborative community effort that aims to ensure that the public health and climate resilience benefits that are the product of the urban forest are equitably distributed across the city (PNPP, 2020). The city actively manages its urban forest, via a Forestry Division Block Pruning Program, to systematically maintain all street trees. With a 10-year cycle, the program prunes

Program partnerships plant trees throughout the city, with a particular focus in Providence's lowest-canopy neighborhoods (PNPP).

approximately 10% of city trees annually. Also, the PNPP, in partnership with residents, installs approximately 500 trees per year. In addition, the Rhode Island Urban Forests for Climate and Health Initiative addresses heat impacts as the number one public health threat from extreme weather. Providence is an area of focus in this statewide environmental justice effort to employ trees to cool

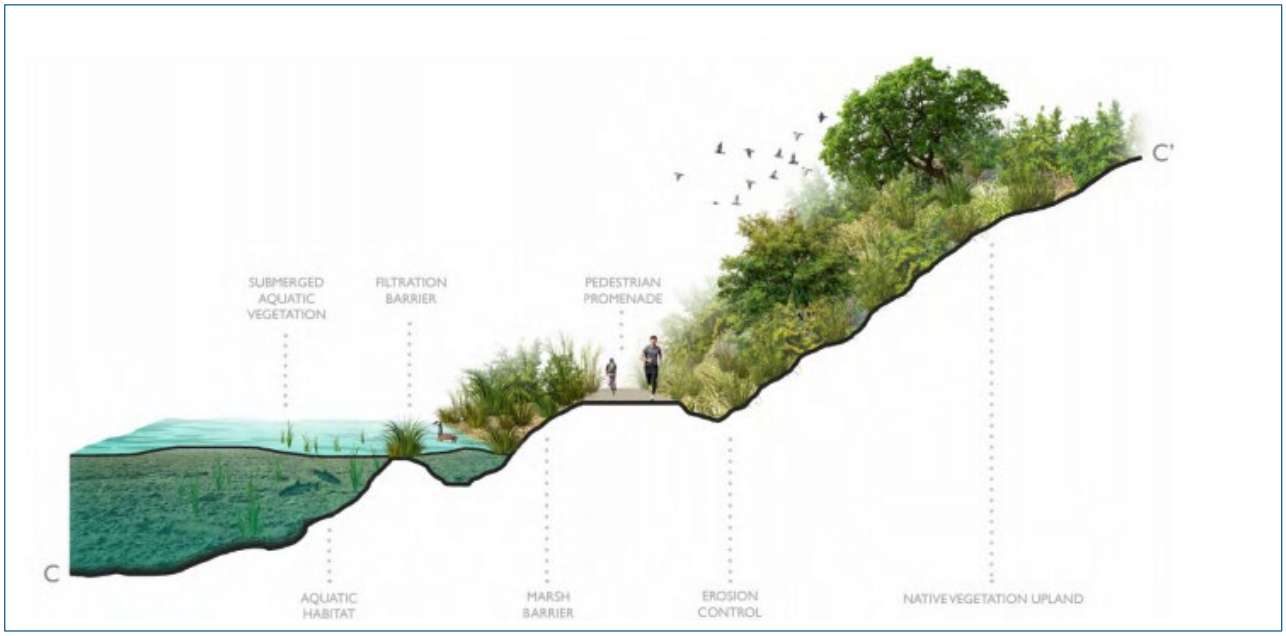
neighborhoods and reduce energy costs (RIDOH, 2019) through community-based tools that determine priority areas to plant trees.

Adaptive Landscapes and Public Spaces: Landscape design can effectively support community resilience by incorporating flood mitigation, green infrastructure, and public access. The design spaces aim to transform the waterfront into a lively and accessible asset that draws people to its banks, connects neighboring cities, and restores the environment, while accounting for the uncertainties of climate change. This is seen throughout the city, with active implementation partnerships in areas including the Woonasquatucket River Corridor and the Downtown Riverwalk. Landscape architecture practicums of the Rhode Island School of Design and the University of Rhode Island Landscape Architecture Program provide students with real-life scenarios in areas including Downtown, the Woonasquatucket Riverway, and the Seekonk River Corridor. These designs incorporate green infrastructure techniques to address economic, social, and environmental issues that include adaptation to and mitigation of climate change impacts like flooding and excessive heat. In facilitated discussions, stakeholders brought these ideas together, resulting in a vision of enhanced water quality, public access, and resilience that became part of the Seekonk River Design Book and led to a collaboration focused on A Vision for a Post-Industrial Seekonk River Corridor.

The Woonasquatucket River Greenway could be considered one giant GI practice, and we are connecting as many GI practices along the Greenway as possible! You can already visit green roofs, rain gardens, community food gardens, a bioswale, meadow buffers and more on your next trip up the Greenway.

- Woonasquatucket River Watershed Council

Figure IE-5. Living Shoreline Envisioned for the Seekonk River (web.uri.edu/lar/outreach-projects).



Funding Opportunities to Increase Resilience

There are several opportunities for funding projects through municipal, state, and federal sources to increase resilience to floods, heat, and other stressors. As can be seen in recent stormwater infrastructure improvements and bikeway enhancements, financial tools often can be leveraged and combined to achieve multiple benefits, create enhanced partnerships, and secure increased community buy-in. While there are many barriers for funding, there are also new and emerging mechanisms that may be appropriate for the city. These include environment impact bonds, stormwater utilities, resilience bonds, and resilience zones as summarized in Resilient Rhody (Resilient Rhody, 2018). The RIIB has taken a leadership role in supporting communities in expanding programs to increase climate resilience.

Critical Infrastructure and Utilities			
Finance Tool	**Water**	**Power**	**Transportation**
Clean Water State Revolving Fund	X	X	
Drinking Water State Revolving Fund	X	X	
USDA Rural Development Loan Program	X	X	
Bonds	X	X	X
RIIB Stormwater Accelerator	X		
Efficient Buildings Fund		X	
Water Infrastructure Finance and Innovation Fund	X		
Electric/Gas Ratepayer Funds		X	
Energy Savings Performance Contracts		X	
Power Purchase Agreements		X	
Property Assessed Clean Energy	X	X	
Municipal Road and Bridge Revolving Fund			X
Tax Increment Financing	x	X	X

Natural Systems		
Finance Tool	**Coastal**	**Inland**
Mitigation Banking	X	X
Land Trust	X	X
Clean Water State Revolving Fund	X	X
Drinking Water State Revolving Fund		X
Bonds	X	X

Emergency Preparedness		
Efficient Buildings Fund	X	X
Property Assessed Clean Energy	X	X
Municipal Road and Bridge Revolving Fund	X	
Bonds	X	X

Figure IE-5. Existing Climate Finance Mechanisms (Resilient Rhody, 2018).

Recommendations

Recommendations for the hurricane barrier, port, wastewater treatment, and stormwater are included in the sections of this document specifically dedicated to those topics.

Planning

Create Checklist for Resilience Standards for Capital Investments: Doing so would provide a useful tool for city government officials and the private sector to implement efficiently. A long-term resilience and adaptation plan should include collaboration with the city's Racial and Environmental Justice Committee and frontline communities to ensure those most impacted by climate change are involved in the design and implementation of the plan (C2ES, 2016, City of Providence, 2019).

Support the development and implementation of the Municipal Resilience Plan (MRP): This state-municipal partnership is a 'municipal-driven' process to identify and prioritize actions to improve infrastructure, environment, and social resilience. Providence is targeted for the 2021 cohort. The MRP engages a Community Resilience Building process, which is not an in-depth assessment. It does, however, result in designation as a Resilient Rhody Municipality, which allows the city to apply for dedicated action grants to implement identified projects.

Engage with the RIIB: Build upon successful partnerships with the RIIB, such as that in the Woonasquatucket River Corridor, to leverage grants, loans, and opportunities to build resilience as a component of infrastructure improvements (e.g., clean water, transportation, wastewater).

Research

Examine Opportunity for Infrastructure Resilience Plan: A plan specifically to build resilience within Providence infrastructure could highlight how improvements to all systems could yield day-to-day benefits, protect the city long term, and increase understanding of interactions and interdependencies between the systems (C2ES, 2016; City of Providence, 2014a).

Flood Mitigation

Consider Infrastructure Risk Assessment: Conduct a risk assessment to identify at-risk structures subject to frequent flooding (PEMA, 2019, Resilient Rhody, 2018).

Evaluate Alternatives for Vulnerable Fire Station: Weigh options to determine the best long-term solution to protect the city's fire station on Atwells Avenue at Valley Street as it is in a floodplain and periodically floods (PEMA, 2019).

Examine Greening Options: Pursue pavement reduction strategies and implement green infrastructure projects to improve water quality and reduce flooding (City of Providence, 2014b).

Energy

This study and its synthesis report did not include an extensive review of energy systems at risk or evaluate the programs related to greenhouse gas reduction.

***Assess and Prioritize Strategies to Build the Resilience of Energy Infrastructure for Risk to Natural Hazards in a Changing Climate*:** Fully understand the risks and identify alternatives, such as microgrids, that could help support energy security today and into the future.

***Incentivize Microgrid Implementation*:** Examine market barriers to implementing microgrids at critical facilities, ensuring that the state can prioritize petroleum marine terminals and storage facilities for microgrid support (e.g., preferential scoring and/or including microgrids in a Unique Asset Track) (RIOER, 2017).

Address Local Impacts of Regional Power Operations: Identify opportunities to assist state agencies, including the RIOER and the Rhode Island Department of Environmental Management (RIDEM), as they work to enhance, in terms of the regional power grid, how air quality is monitored and improved; this can complement the larger state effort to develop a comprehensive energy strategy focused on resilient, renewable, and affordable energy generation, transmission, distribution, and consumption (City of Providence, 2019, Resilient Rhody, 2018).

***Expand Business Access to State Energy Program*:** Promote the RIIB's commercial property assessed clean energy (PACE) program that allows businesses to pay for long-term building investments over time as a potential step toward helping small businesses embrace resilience measures (C2ES, 2016).

Transportation

Identify and Address Key Transportation Issues: Among the issues are resolving heavy reliance on the main highway bridge connecting the city without a readily identifiable alternative (C2ES, 2016); modifying traffic patterns to reduce emissions in frontline communities; reducing air pollution; identifying opportunities to reroute truck traffic to reduce diesel emissions in neighborhoods; and engaging frontline community members in future corridor planning, especially for work related to on-ramps and other major highway projects (City of Providence, 2019).

***Review Priorities and Coordination between State and City Programs*:** Maintain ongoing communication and collaboration in planning, assessment, and implementation planning in partnership with the Rhode Island Department of Transportation (RIDOT) to support designs that incorporate resilience elements in the Capital Improvement Plan and the State Transportation Improvement Plan.

Water Supplies

Address Supply Vulnerability: Assist water suppliers in developing local emergency interconnection programs to address supply vulnerability among small systems throughout the state. Emergency water system interconnections provide redundancy of supply and the ability to address water emergencies rapidly and efficiently across water supply districts (Resilient Rhody, 2018).

Take Stock of Drinking Water Reservoirs: Assess the vulnerability of near-coastal drinking water reservoirs to storm surge and sea level rise, and advance common goal setting and communication between water suppliers to manage reservoirs and downstream municipalities. Potential practices include ensuring downstream flood mitigation via proactive spillway management without adverse impacts on safe yield and evaluating whether suppliers have current contingency contracts for the purchase of emergency supplies, as well as emergency interconnection/distribution processes (Resilient Rhody, 2018).

Health and Well-being

Overview

A healthy community is resilient to a multitude of risks, be it economic, as with unemployment; or social, as with the COVID-19 pandemic and chronic heart, lung, and related illnesses. From an environmental standpoint, Providence neighborhoods face climate change impacts; these coastal and riverine communities are challenged by flooding tied to strong storms and sea level rise and by the "heat island" effect, caused in part by the large amount of impervious surface typical of urban areas. While Providence, as a whole, can ultimately benefit from science-informed, public efforts focused on comprehensive resilience, targeted programming has already been initiated in several at-risk, or frontline, communities—South Providence and Olneyville, for example—to fortify opportunities for economic, social, and environmental health and well-being as they are interconnected issues.

Key Findings

There are large disparities in vulnerability that are tied to levels of income and racial inequities. These have not been comprehensively assessed, or are not fully understood, and are not communicated to diverse stakeholders connected to climate adaptation and resilience-building efforts.

There is a lack of solid research, assessment, and measurement of public health vulnerabilities to chronic and catastrophic environmental hazards, including those that could be exacerbated (or accentuated) by natural hazards in the short and long term. As a consequence, there is limited understanding of risk to the community from storms that result in chemical spills, wastewater releases, and other hazards.

Several ongoing initiatives, including Resilience Hubs in frontline communities, tree planting, green infrastructure installations, and the expansion of Riverwalk parks increase community health and well-being and resilience by mitigating heat and flooding.

Situation

Defining Well-Being: Economic prosperity of an urban hub like Providence is closely tied to the quality of life experienced by the people who live, work, and recreate within its neighborhoods and communities. Health and well-being are critical aspects of this quality. Besides physical, mental, and emotional health, well-being can be defined, for example, by equitable living conditions, ample access to healthcare, and a clean environment (CDC, 2018). Gauging health and well-being is a complex process, with many factors at play, including issues of demographics and environmental justice.

Need for Building Citywide Resilience: As with many cities, Providence's health and well-being reflects, in part, the extent to which government, private sector, community, and academic partners work together to understand the collective urban context—barriers embracing positive economic and societal contributions, while addressing/mitigating negative impacts. Resilience building encompasses the needs of the entire city, while recognizing that certain populations—the elderly, youth, and those with special needs or compromised health—require a targeted approach. The elderly and children are more vulnerable to the impacts of dangerous weather events. Elderly people, particularly those with limited mobility, may be unable to relocate before or recover after a storm, while children are necessarily dependent on guardians for evacuation and may be more sensitive to the stress of a disaster and its aftermath (RIDOH, 2015).

Targeted Resilience Building for Frontline Communities: Frontline communities, with increased vulnerabilities based on geographic and socio-economic conditions, must be prioritized and be partners in this work in order to avoid further harm and marginalization. The U.S. Environmental Protection Agency (U.S. EPA) identifies frontline communities as those most impacted by "the crises of ecology, economy, and democracy" (City of Providence, 2019). In Providence, this includes communities of Indigenous, African American, Black, Latinx, and Southeast Asian people as well as those with criminal records, those who speak languages other than English, and LGBTQIA+ individuals. Parts of South Providence, Washington Park, Olneyville, Manton, Silver Lake, Wanskuck, and the West End are designated as frontline communities (City of Providence, 2019). By definition, these are communities adjacent to industrial areas or major highways where emissions, pollutants, and chemical hazards can have an impact on the health and safety of the residents (City of Providence, 2019; Resilient Rhody, 2018).

Planning with Frontline Communities: Under the umbrella of environmental justice, recent planning efforts in the city have yielded community leadership; guiding documents, such as the city of Providence's Climate Justice Plan (City of Providence, 2019); planning tools and approaches, such as Green Justice Zones and Health Equity Zones; and commitments for infrastructure improvements. These reflect the participation of a wide spectrum of stakeholders, including the City of Providence Office of Sustainability, the Racial and Environmental Justice Committee of Providence (REJC), the Providence Department of Planning and Development, the Providence Department of Public Works, and frontline community organizations representing a variety of urban residents' economic, social and environmental concerns and interests. This network of stakeholders is imperative for the collaborative governance approach to improving the health and well-being across the City of Providence. Frontline communities must have the resources to

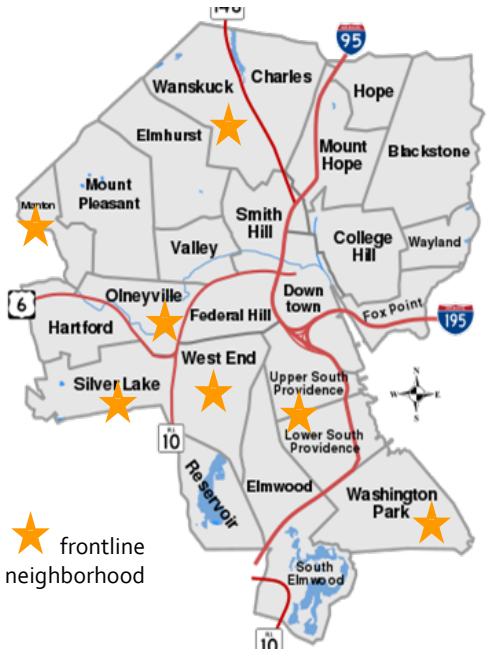


Figure HW-1. Frontline Neighborhoods are Disproportionally Impacted by Changing Climate (City of Providence).

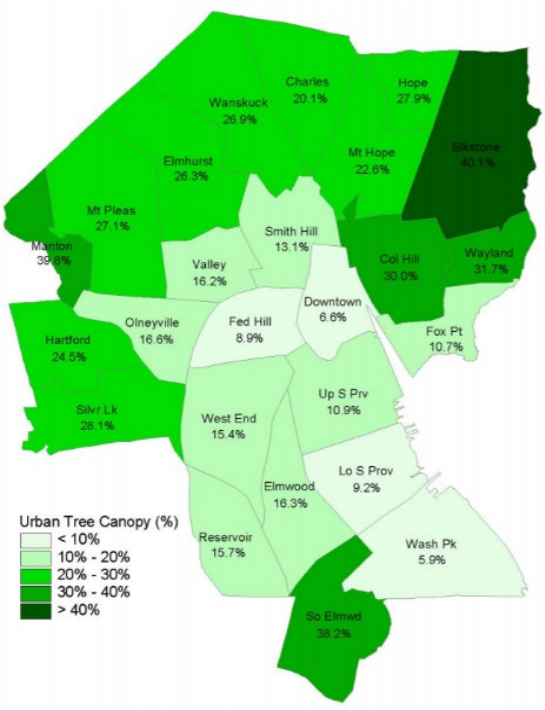


Figure HW-2. Urban Tree Canopy Affects the Impacts Caused by Extreme Temperatures. Less tree canopy (lighter green shading) results in increased urban heat affects at extreme temperatures (RIDOH).

participate in the decision-making process with shared power—allowing these communities the final say in programs and policies designed to address their needs and priorities.

Climate Change Impacts and the Urban Environment: Urban communities have an increased vulnerability to the impacts of a changing climate, including the increasing potential for a warmer and wetter coastal environment. For example, cities are generally dense and feature more hardtop and impervious surfaces and less tree cover or canopy than suburban and rural areas; as a result, they attract and retain heat. This can exacerbate illness and disease and prompt increased hospitalizations due to heat (RIDOH, 2015). Increasing potential for flooding from strong storms and sea level rise is also a problem for these communities as many are located in the city's floodplain (PEMA, 2019). Storm impacts raise the potential for people in frontline communities to be displaced from their homes and go without important resources, including food, fuel, and medicine (RIDOH, 2015). The impacts of climate change such as extreme heat and flooding will only exacerbate existing health inequities (City of Providence, 2019).

Climate Challenges

Flooding Impacts: Providence, located both on the Providence River and within a watershed basin, is subject to flooding tied to strong storms and sea level rise. Flooding can cause drowning; form stagnant pools that breed disease; impede stormwater and sanitation systems; and ruin homes and business properties, resulting in displaced residents and workers (RIDOH, 2015; City of Providence, 2014a). Also, water damage in homes or other facilities can cause the development of mold, resulting in health complications and illnesses (RIDOH, 2015). In terms of causes of death related to flood events, 90% of hurricane-related deaths are due to drowning. Other causes of casualties in flood events are hypothermia or trauma. Hurricanes can also result in collapsed structures and debris that injure people (RIDOH, 2015).

Heat Impacts: The increasing warmth associated with climate change is exacerbated in cities and urban areas where less greenery and more impervious hardtop translate to a greater amount of heat—the urban "heat island" effect (RIDOH, 2015). As Providence is experiencing more warm days (Resilient Rhody, 2018) and as housing in depressed neighborhoods is often ill-equipped to provide adequate temperature control (RIDOH, 2015), the result can be more people in need of healthcare and hospitalizations (Resilient Rhody, 2018). Populations at highest risk of heat-related illnesses or death are frontline community residents and/or neighborhoods with a high percentage of elderly, children, and communities of color (Resilient Rhody, 2018). Outdoor workers and athletes are also at risk of heat-related illness. Rhode Island data show that most emergency department visits for heat-related causes are among younger adults, while more hospitalizations are among older adults who have underlying medical conditions (R. Calabro, personal communications, January 18, 2021).

Combined Impacts: Heat and water impacts related to climate change can take place at the same time and cause significant harm to people and property (RIDOH, 2015). "Impervious surfaces such as roads, sidewalks, parking lots, and driveways, have two main impacts on climate risk. First, they prevent rain from being absorbed into the ground, increasing the pooling of water at the surface and stressing sewer systems, which can lead to sewer overflows. Second, they absorb and slowly release

the sun's heat back into the neighborhood. Communities with more impervious surfaces can be several degrees hotter than neighborhoods with less pavement" (Groundwork Rhode Island, 2020).

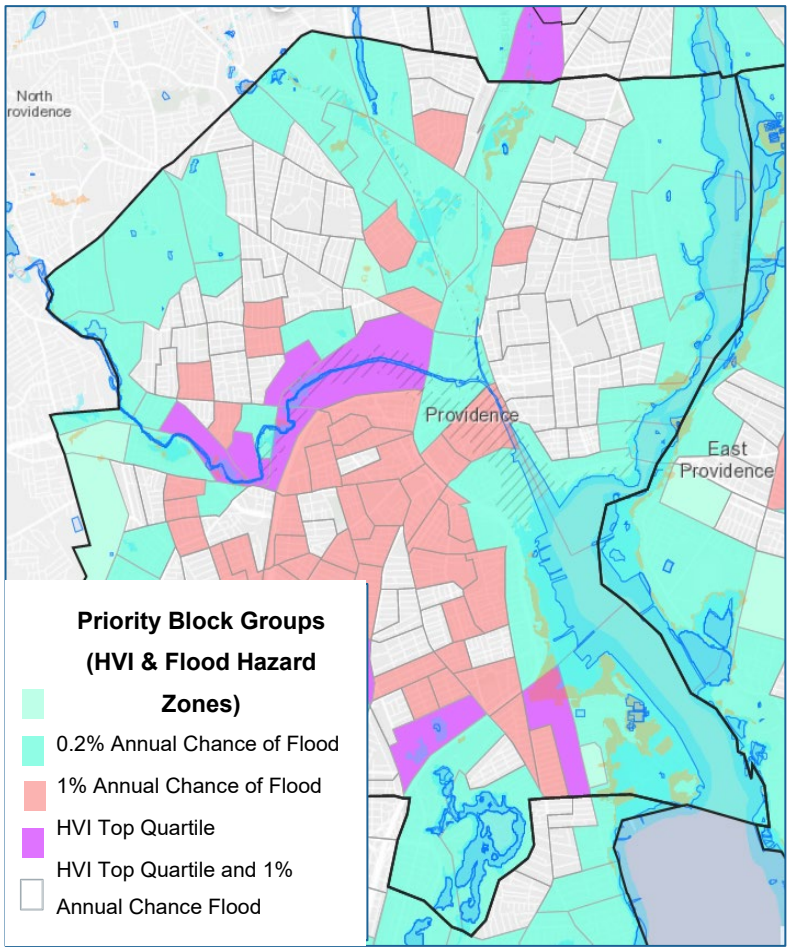


Figure HW-3. Neighborhood Vulnerability to Combined Heat and Flood Hazards in Providence.

The dark blue shaded regions of the map are FEMA flood zones, with the light blue identifying neighborhoods vulnerable to the impacts of flooding. Pink shaded regions are in the top 25% of the Heat Vulnerability Index (HVI). Purple areas are most vulnerable to combined heat and flood impacts, falling within the top 25% of the HVI as well as the FEMA flood zones. When vulnerability maps are overlaid with redlining maps, a relationship between redlined areas and low-income areas with high heat and flood vulnerability can be seen (Groundwork RI, 2020).

The Public Health Context: Coastal surge or storm flooding has the potential to compromise physical access to healthcare facilities and hospitals, including major institutions like Hasbro Children's Hospital, Rhode Island Hospital, and Women and Infants Hospital. These and several other healthcare facilities are located south of the barrier, near the port areas. The Providence Multi-Hazard Mitigation Plan (PEMA, 2019) shows that three hospitals/healthcare facilities would be impacted by the storm surge of a Category 1 hurricane, while 84 facilities would be impacted by a Category 4 hurricane storm surge. Also, even one additional foot of sea level rise would impact several facilities, with many more at risk as the level increases. According to FEMA, 21 hospitals or healthcare facilities are within the Special Flood Hazard Area, with an estimated total value of over $700 million (PEMA, 2019). Damage to roadways caused by wind events can also impact access to such facilities

The Housing Context: Providence, like other cities, is experiencing a housing crisis. On one hand, it lacks housing stock for both low- and middle-income people, with fewer options available for those at the lower end of the socio-economic spectrum. At the same time, opportunities to improve or enhance

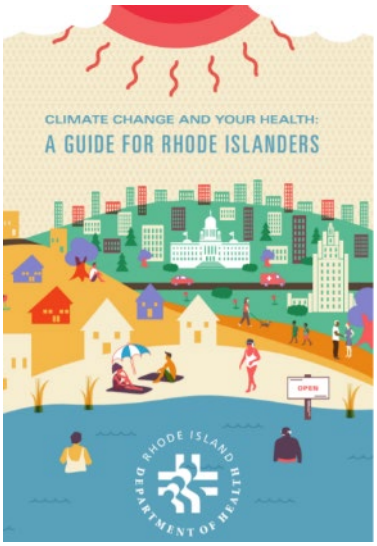
debilitated areas to serve these income levels are lost as developer-driven gentrification efforts rapidly convert urban areas into enclaves for luxury homebuyers (City of Providence, 2019). When natural disasters, such as hurricanes, compromise housing and displace residents, the potential for this gentrification and permanent displacement of lower income neighborhoods increases. It is imperative to ensure that post-disaster rebuilt housing still supports those living in the community. The Providence Comprehensive Housing Strategy, released in late 2020, establishes “a clear plan to create and preserve dedicated affordable housing units, promote affordability by increasing the overall housing supply by lowering barriers and costs ... and reduce displacement of existing residents at all income levels. The strategy [builds] upon and unifies affordable housing conversations and initiatives recently completed by partner organizations and other local groups ... recommend[s] updates to the city’s regulatory and permitting processes and establish[es] specific housing production targets for Providence” (Anti-Displacement and Comprehensive Housing Strategy, 2020).

Affordable, Safe, and Equitable Housing Provides a Foundation for Resilient Communities (City of Providence, 2020).

Toxic Pollution Context: Toxic and hazardous substances can have the potential for pollution in the event of sea level rise or a storm event, putting surrounding communities at risk (Resilient Rhody, 2018). “Many brownfield and superfund sites are located next to water bodies where they are susceptible to climate impacts. Active industrial facilities that store, process, or use hazardous and/or flammable substances may be sited in locations susceptible to climate impacts" (Resilient Rhody, 2018). Agricultural and chemical repositories pose risks as pollutants after a flood event and can contaminate water bodies, soil, and the air (RIDOH, 2015). Also, air pollution is considered a cause of the high rates of asthma in the South Providence and Washington Park neighborhoods. Asthma and lead poisoning are both exacerbated by sustained high temperatures (City of Providence, 2019).

The Energy Context: Loss of heat, air conditioning, and/or ventilation can result in community and individual health impacts or potential loss of life, as well as lost business revenue and associated macroeconomic impacts (Resilient Rhody, 2018). Outages can cause issues with food refrigeration, threatening food stores and increasing the risk of potential food-borne illness. Additionally, lack of adequate heating and/or cooling in homes due to outages can increase people’s risk of hypothermia or hyperthermia, especially that of the elderly (RIDOH, 2015). In addition, Providence has a high residential energy burden (the percentage of income a household spends on energy). Many families are caught in an “eat or heat” battle and need enhanced supports for weatherization, efficiency, and heating or cooling assistance (R. Calabro, personal communications, January 18, 2021).

Efforts to Increase Resilience



Public outreach guides, available in multiple languages, provide valuable tips for reducing health impacts from climate change (RIDOH).

Climate Change and Health: The RIDOH Climate Change and Health Program aims to "prepare for the human health effects related to climate change and create a healthy, sustainable, and resilient future for all Rhode Islanders." Their programs address public education, adaptation planning, policy changes, holistic solutions, and reducing health impacts among vulnerable populations. The Community Resilience Program supports efforts with Health Equity Zones, Urban Forests for Climate and Health initiative, and the Senior Resilience Project, among others. (For more information, see https://health.ri.gov/healthrisks/climatechange/).

Centering Racial Justice in Climate Resilience Work: The REJC was established in 2016 with the focus of bringing a racial equity lens to the city's sustainability work, including work related to climate resilience. The Just Providence Framework, created in 2017, was adopted by the city as a tool to incorporate racial equity and collaborative governance, into the city's Office of Sustainability work.

The Climate Justice Plan, co-developed with the city and the REJC, establishes a place-based approach to engaging frontline communities in designing and implementing a plan to prepare the city for the impacts of climate change. Topics include the impacts of heat, riverine flooding, coastal storms, sea-level rise, and other related effects of climate change. Areas of interest include communities adjacent to the Woonasquatucket River, the Port of Providence, and the hurricane barrier (City of Providence, 2019).

Trees planted throughout the city provide social, environmental, and public health benefits (PNPP).

Greening Urban Neighborhoods: Human interaction with green space and safe public access to resources can greatly improve the health and well-being of a community. Adaptation projects incorporating green infrastructure, stormwater management, trees and green spaces, and health initiatives can help to mitigate and counteract the impacts of both flood and heat (Groundwork Rhode Island, 2020). Public, private sector, and community efforts to introduce green infrastructure—vegetation, sediments, and rock material—to absorb or redirect floodwater have reduced impervious cover and enhanced stormwater management across Providence. Partners include the city, the Rhode Island Department of

Transportation (RIDOT), the Rhode Island Green Infrastructure Coalition, Groundwork Rhode Island, and the Woonasquatucket River Watershed Council (Green Infrastructure Coalition, 2020).

The Rhode Island Urban Forests for Climate and Health Initiative focuses on heat as the number one public health threat from extreme weather (RIDOH, 2019). The program is a partnership with American Forests, RIDEM, the Rhode Island Infrastructure Bank, RIDOH, and other national partners and seeks to use equity in tree canopy to measure how well communities are using trees to protect community health. The program has developed a Tree Equity Score Analyzer (TESA) online mapping tool to help cities measure their efforts. A climate and health action guide also helps communities optimize urban forestry programs. In addition to these state-wide efforts, the city of Providence is embarking on the development of an urban forestry plan, the PVD Tree Plan, with a coalition of core stakeholders.

Low tree canopy cover and high impervious surface can lead to increased heat. Neighborhoods with denser tree canopies are cooler than neighborhoods with less dense tree canopies. Neighborhoods with more trees also have lower risk of flooding since water seeps into the surrounding soil and is absorbed by plant roots. In this way, tree canopy reduces risk of both heat and flooding."

- Groundwork Rhode Island

Health Equity Zones (HEZ): Two of the state's nine HEZ programs are in Providence, with emphasis on communities with health disparities. The HEZ programs, funded through the RIDOH, are led by a local backbone agency with the help of a collaborative of supporting groups. Backbone agencies for the two Providence HEZs are ONE Neighborhood Builders in Olneyville; and the West Elmwood Housing Development Corporation, which represents the ZIP code 02907. Efforts within the programs are tailored to the needs of the local neighborhoods. For example, as Olneyville is subject to flooding from the Woonasquatucket River, the Central Providence HEZ engaged residents and businesses in the creation of a video on community emergency preparation and resilience building, with local flooding issues as a focus.

Two youth members tending a community garden with the Southside Community Land Trust, a partner of HEZ programs. Food security is a key component of resilient communities (RIDOH).

Programs for Specific Populations: A Special Needs Registry was created by RIDOT and the Rhode Island Emergency Management Agency (RIEMA) as a registry for Rhode Islanders with disabilities, chronic conditions, and other special healthcare needs so they can be prioritized for assistance during emergencies. Enrollment in the registry does not guarantee assistance, but allows first responders to appropriately plan for, and respond to, community needs (RIDOH, 2015). Also, through the RIDOH Senior Resiliency Project, a series of tools and guides were made available for long-term care facilities, senior housing complexes, and older adults to prepare for weather-related emergencies, such as extreme heat and power outages (RIDOH, 2015).

Recommendations

Community Networks

Leverage Connections and Learning: Rhode Island's small size, growing number of involved and active climate leaders, existing networks, and quality data on climate-related risks and vulnerabilities should be capitalized on as key platforms for furthering resilience activities in a social justice context (IBES & URI, 2019).

Tie Resilience Building to Key Social Issues: Examine opportunities to interweave the building blocks of resilience building within public programming, including efforts targeted at improving health, education, food security, and transportation in Providence communities. Funding opportunities may become available for socially linked issues (IBES & URI, 2019).

Creation of 'Resiliency Hubs': Establish community-serving facilities that support residents and coordinate resource distribution and services before, during, or after a natural hazard event. A community-defined vision of resilience, combined with a neighborhood specific plan and assessment, increases long-term preparedness (IBES & URI, 2019; City of Providence, 2016; City of Providence, 2019).

Equitable Resilience Planning and Implementation

Collaborative Governance Approach: Establish a community advisory committee that is lead by people of color, implement a race and social justice screen, develop an equitable engagement checklist, and fund community members and organizations to lead engagement processes to ensure climate resilience efforts are moving toward collaborative governance. Ensure frontline communities have the resources to participate in the decision-making process and build their capacity to have ownership of programs and policies that are designed to address their needs and priorities (City of Providence, 2016, City of Providence, 2019).

Continue to Advance Green Justice Zones: Green Justice Zones seek to achieve health equity, improve quality of life, and increase climate resilience in frontline communities. Development of these zones should continue in frontline communities via public-private partnership to enhance and interlace neighborhoods' environmental, economic, and social assets (City of Providence, 2019).

Continue addressing water quality and flooding issues: Support the continued creation of public-private partnerships to expand green spaces and parks in frontline communities—with climate

resilience as the priority investment. Green spaces and tree plantings in low-canopy areas where heat island index is high offer benefits for cooling, electricity savings, air pollution, and water filtration (City of Providence, 2019).

Expand Green Infrastructure Implementation: Increasing the number of greening and resilience efforts speaks to Goal 1 of the Sustainability and Environment section of the city's 2014 Providence Tomorrow Comprehensive Plan. The goal is to increase tree canopy coverage throughout the city, leading to cleaner air, lower summer temperatures, and better stormwater retention. As of early 2021, parts of the Comprehensive Plan, including the Sustainability section are being reevaluated and updated to better incorporate these and other climate impacts (City of Providence, 2014a).

Continue Implementation of the Great Streets Plan: Further the Great Streets Initiative to improve bike lanes, street lighting, and traffic-calming measures in frontline communities; and to support efforts to connect neighborhoods (City of Providence, 2019).

The Fox Point Hurricane Barrier

Overview

The Fox Point Hurricane Barrier is directly south of the South Street Station (the former Narragansett Electric Company plant) in Providence and spans the Providence River between the Fox Point and downtown neighborhoods. Its functions are to manage high tides from potential storm surges in Narragansett Bay and to maintain river flow, so water levels do not rise too high behind it (PEMA, 2016).

Authorized in 1958 after the devastating hurricanes of 1938 and 1954, the barrier, built by the U.S. Army Corps of Engineers (USACE), was "the first hurricane protection structure in the U.S." (Kuffner, 2019) and was put into service in 1966. While the barrier mostly protects large areas of the city from coastal flooding, areas such as the Fox Point shoreline as well as the port stand to be impacted by surges from any coastal storms and hurricanes.

The infrastructure has played an important role in flood management for the city. As recently as 2012, the barrier prevented more than $600,000 in flood damages from "Superstorm" or Tropical Storm Sandy (USACE, 2012), and today "The stakes are high for Providence. The barrier protects 280 acres of Downtown, property that the city estimates is worth $2 billion and includes South Street Landing, the Wexford Innovation Center, and other new projects that have been built near the water" (Kuffner, 2019). To keep the barrier functional, the infrastructure is jointly managed by the USACE and the city of Providence and each is responsible for specific tasks, with overall coordination provided by the Providence Emergency Management Agency (PEMA). The USACE estimates that more than $20 million has been invested in improvements since 2010.

While the barrier has prevented over $3 million in damages (USACE, 2017) that could have proved disastrous to the downtown commercial district, transportation facilities, government offices, and residential areas, its protection has limits. First, while the downtown areas behind the barrier are

Key Findings

The transfer of the Fox Point Hurricane Barrier to the U.S. Army Corps of Engineers secured effective maintenance and operation through the design life of the barrier. Its conservative, mid-19th century design provides protection for all but today's most extreme storm surge scenarios; but its design did not consider increased tidal flooding associated with sea level rise. Using the barrier frequently for this purpose, i.e., to address increased tidal flooding, would likely compromise its long-term efficacy for protection.

Given the above, the Providence Multi-Hazard Mitigation Plan (informed by a 2016 economic analysis on alternatives) recommends evaluating climate change projections and the likely impacts on the barrier every five years—with a commitment to make a decision about any future barrier no later than 2050. Discussions related to mitigation in low-lying waterfront areas should take place with decisions implemented in the 2040-2050 timeframe to prevent increased tidal flooding.

A thorough evaluation is needed to assess the barrier's integrity and ability to protect the areas behind it from the combined impacts of changing and accelerating climate conditions. This includes the likelihood of increased storm/hurricane intensity accompanied by higher surge and precipitation, higher sea levels, and an increased frequency of tidal flooding.

Fox Point Hurricane Barrier Gates and Providence River Bridge (Wikimedia Commons)

technically out of the flood zone for a 1% annual chance storm (100-year storm), other areas to the south and east, such as the Port of Providence and India Point, are without protection, so structures are required to be built to higher standards to reduce impact. Second, while the barrier design was based on the devasting hurricanes in the mid-1990s, projected sea level rise could eventually compromise the effectiveness of the barrier in the latter part of the century (URI, 2018a). In addition to increased and accelerating sea levels, recent trends indicate that hurricanes are moving slower, thus bringing higher rainfall levels. These concerns, raised by managers, researchers, and legislators, have resulted in recommendations for a comprehensive study to address how effective the barrier will be with changing conditions in the future. The study would also examine options for augmenting the infrastructure to accommodate rising water, for evaluating protection measures for areas outside of the barrier boundary, and options for building a new barrier.

"It was designed to withstand a surge of up to 20.5 feet from a 500-year storm, or one with a 0.2 percent chance of happening in any year — a conservative design at the time." – Malcolm Spaulding, emeritus professor of ocean engineering at the University of Rhode Island.

-Alex Kuffner, Providence Journal, 2019

Situation

Barrier Design

A First: The Fox Point Hurricane Barrier was the "first structure of its type in the United States to be approved for construction," with its location chosen as the best of three options, its benefits for reducing storm impacts around Narragansett Bay outweighing costs two to one (Morang, 2016).

Designed for a Category 3: The barrier design was based on the September 1944 hurricane (Morang, 2016). Based on this storm, the surge would be 17.4 feet. The barrier can likely withstand a surge associated with a Category 3 Hurricane (PEMA, 2019 corrected; URI, 2018a).

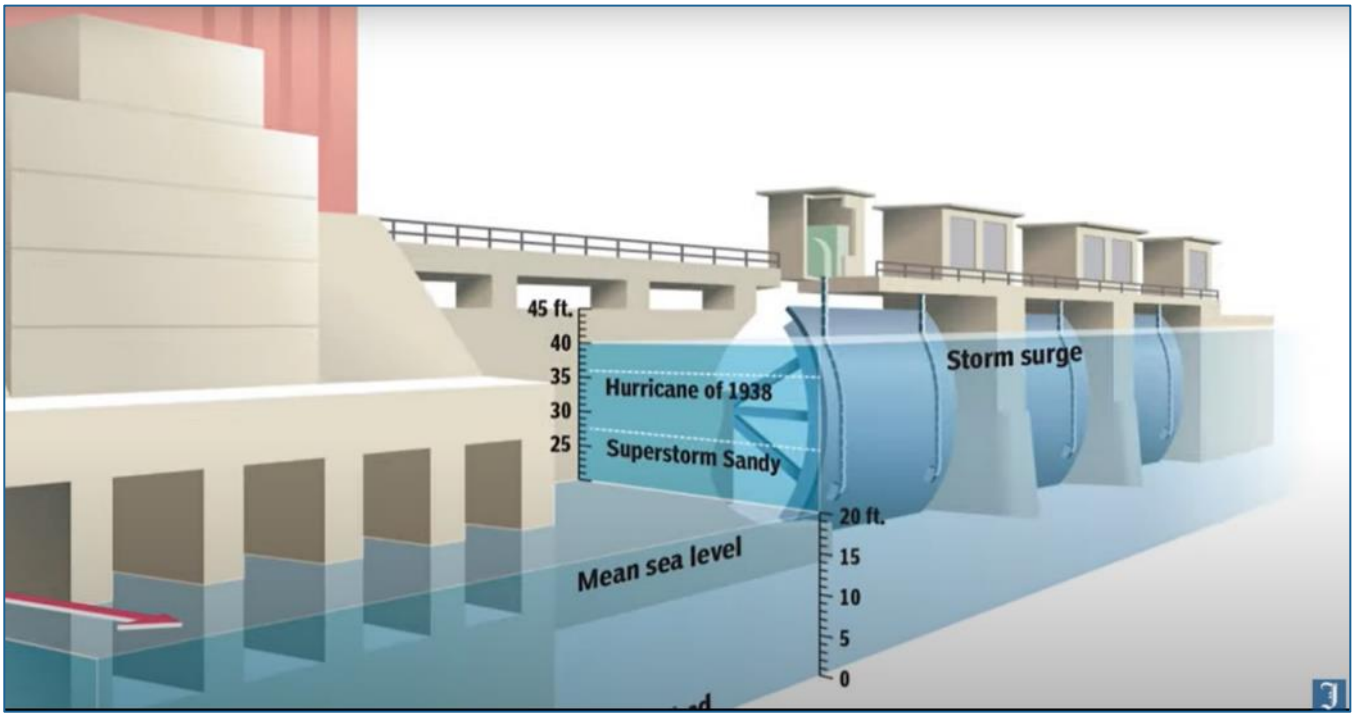


Figure HB-1: Historical Storms' Impact on the Hurricane Barrier. The top of the barrier is approximately 9 feet above the elevation of Hurricane of 1938, which is the highest water elevation recorded in Providence (Kuffner, 2019).

Little Room for Rise: The barrier's ability to manage rising sea levels may be limited as the water level for Providence is about five inches higher than it was during barrier construction. The structure was designed to accommodate a water level of about 22 feet above mean lower low water (MLLW). For comparison, the Hurricane of 1938—which resulted in the highest flood on record in Providence at nearly 18 feet above MLLW—left just nine feet before reaching the top of the barrier, which is 27 feet above MLLW (PEMA, 2019).

Protection Means Savings: Evidence of the barrier's value is captured within U.S. Federal Emergency Management Agency (FEMA) flood insurance rate maps showing that properties protected by the structure, or those areas "with reduced flood risk due to levee" are not required to build to higher floodplain standards, like those in designated high hazard flood zones (FEMA, 2020) in the port area and Fox Point shoreline that lie outside of the barrier's protection. Likewise, a compromised barrier could mean increased costs, as "Overtopping or failure of any levee system is possible," as stated on the FEMA maps (FEMA, 2020).

Damage Is Significantly Reduced with the Barrier: The value of the Fox Point Hurricane Barrier perhaps is best seen in looking at a hypothetical scenario without the barrier in place today. URI's 2018 Senior Engineering Capstone concluded if a 100-year coastal storm hit today, modeling shows that storm surge could cause damage to over 650 structures, with over a third of them suffering a greater than 50% structural damage. This number increases substantially with three feet of sea level rise, where over 1,000 structures are projected to be inundated, with half damaged over 50%. Looking at an extreme riverine flood event with extreme rainfall, over 200 structures would be damaged even with the barrier's pumps functioning, while almost four times that amount—864 structures—would be damaged with pumps disabled (URI, 2018a).

Figure HB-2. Flood impacts behind the barrier.

(Top) 633 buildings are affected in the event of a 100-year storm today without the barrier in place.

(Middle) 234 buildings are affected by river flooding with the pumps functioning as normal.

(Bottom) 864 buildings are affected when the river floods and the pumps are off and not functioning.

Barrier Structure

Five Key Parts: The barrier consists of five main components: 1) three river gates; 2) dikes of rock and earth along each shore; 3) five vehicular gates allowing roads to pass through the dikes and along each shore; 4) two canal gates at the west end of the barrier associated with cooling water for the nearby electric power station; and 5) one pumping station with five pumps to control the flow of water when the hurricane barrier is closed (PEMA, 2016).

Sewer Protection: Five underground sewer gates and associated facilities prevent high tides from backing up through the sewer lines (USACE, 2020).

"The barrier was designed for a storm that had the highest energy offshore, and (was) modeled…as a direct hit, (with) a large amount of inland rainfall storm. Typically, they use one pump, and to date they have not had to use more than two at a time."

– John McPherson, U.S. Army Corps of Engineers

Barrier Pumps

Critical Equipment: Five pumps have the ability to move 630,000 gallons of water per minute from the Providence River into the bay—about the amount in an Olympic-sized swimming pool (Kuffner, 2019)—and reduce the flooding from river overflows during a compound event (URI, 2018a).

Electrical Power: Two dedicated high-voltage electrical lines operate the pumps; one runs the pumps and the other serves as back up (PEMA, 2016). USACE and National Grid have performed rehabilitation and replacement work on the electrical power system to the barrier (J. McPherson, personal communication, June 18, 2020).

Upgrades: All large pumps have been completely rehabilitated (J. McPherson, personal communication, June 18, 2020).

Worst Case Scenario Unlikely: The triple threat of a major storm, with the barrier gates closed and its pumps inoperable due to a power outage to the dedicated electrical lines, would result in a "bathtub" situation with 14 to 15 feet of water behind the barrier within 24 hours (I. Ginis, personal communications, August 31, 2020). The chance of this happening is low, as barrier gates would almost always be open, with backup generators in place long before extensive flooding took place (J. McPherson, personal communication, June 18, 2020; C. Decerbo, personal communication, June 9, 2020).

Operation and Maintenance of the Barrier

Partnership Effort: The USACE Cape Cod Canal project office operates and maintains the components of the barrier between the banks of the Providence River (river gates, canal gates, and pump house with five pumps). The city of Providence Department of Public Works operates and maintains the land components—the dikes, sewer gates, and five vehicular gates. The Providence Water Supply Board is responsible for freshwater metering, and National Grid provides power to the barrier. PEMA provides overall coordination of operations (PEMA, 2016).

Improvements: Since taking ownership of the barrier in 2010, USACE, in coordination with partners, has performed over $20 million on maintenance work on the structure. Besides pump and related electrical work (see Pumps topic within this section), all gates have had mechanical and electrical upgrades to ensure long term functionality (J. McPherson, personal communication, June 18, 2020). Also, the city of Providence rebuilt a portion of the wing walls during the relocation project of Route I-195 (Kuffner, 2019).

Three Main Operations: Partnerships between local and federal entities target activities associated with infrastructure maintenance; flood damage reduction during hurricanes or other significant storm events; and support of recreational activities such as WaterFire, which needs both sufficient water depth on the upstream part of the Providence River (USACE, 2015) while ensuring that the extreme tides do not flood the walkways.

Thresholds for Activation: Operating procedures include specific thresholds for when the hurricane barrier should be activated for conditions of storm surge or river flooding. These include the procedure and timing for closing river and street gates, coordination with National Grid, and activation of pumps and other components critical to the system.

Climate Challenges

The rate of sea-level rise—which is higher in the Northeast than almost anywhere else in the world and is expected to continue to outpace the global average—is accelerating as waters heat and expand, ocean currents slow and glaciers melt. With seas that are 5 feet higher, which is possible within the next four to five decades, a 500-year storm of today will become a 100-year storm of tomorrow, or one that has a 1 percent chance of happening in any year.

– Alex Kuffner, Providence Journal, 2019

Designed for Storms, Not for Rising Seas: The barrier was designed for and has been effective in reducing impacts from storm surge. However, the mid-20th century design did not consider the impacts of accelerating sea level rise on high tides. In 2019, the National Oceanic and Atmospheric Administration (NOAA) indicated that Providence experienced six flood days (over 1.8' above MHHW), whereas the projection for 2020 is 5-10 days, 2030 is 15-30 days, and 2050 is 40-105 day (NOAA, 2020). This nuisance flooding, occurring twice daily during high tides, would affect low-lying areas around the city. Concern has been raised whether the barrier can withstand near-constant use to reduce flooding from high tides through 2100 (C2ES, 2016; PEMA, 2019).

Future Storms May Damage Structure: Looking at combined effects of storms and rising seas in the later part of the century, the barrier's design may not enable it to withstand the greater increases in sea levels. The structure is likely to be overtopped during a 100-year storm with 7 feet of sea level rise (URI, 2018a). Preliminary height analyses determined that the height of the west dike wing wall has settled about one foot and may be the cause of future overtopping, which could destabilize the rock layer of the riprap on the backside (city side) of the wall (URI, 2018a).

Backup Generator and Water Risk: A backup generator operates the river and canal gates, should they need to be opened in case of electrical failure. Currently, this equipment is only a few feet above Providence's current mean high-water line, meaning these may be unable to function properly during a storm event or with rising sea levels (URI, 2018a).

Efforts to Increase Resilience

Barrier Performance Projected and Examined: A yearlong University of Rhode Island (URI) Ocean Engineering Capstone Program study applied state-adopted mapping and visualization tools (STORMTOOLS, Coastal Environmental Risk Index [CERI]) to make projections on barrier performance together with building damage estimates under several flooding scenarios (URI, 2018a). Results presented and illustrated above and throughout this document, provide a preliminary assessment to expand upon in evaluation, monitoring, maintenance, and reevaluation with changing conditions.

Hypothetical, yet Plausible "Hurricane Ram" Models Flooding Impacts: A URI research initiative with the U.S. Department of Homeland Security's Coastal Resilience Center applies data from past storms and emerging trends to model flooding impacts on pilot site Providence; hypothetical "Hurricane Ram," with over 18 inches of rain in 24-36 hours, is reminiscent of Hurricane Diane in 1955 and reflects the extreme rainfall of recent hurricanes experienced in the U.S.—this scenario storm includes a coastal surge of approximately 12 feet above mean sea level. The findings showed that if all the pumps were functioning properly, they should be able to handle the projected river runoff (I. Ginis, personal communication, August 31, 2020). This effort engaged city and state emergency management staff as well as public and private facility managers in reviewing the modeling and accessing it for training and planning purposes. Linked with this modeling is the

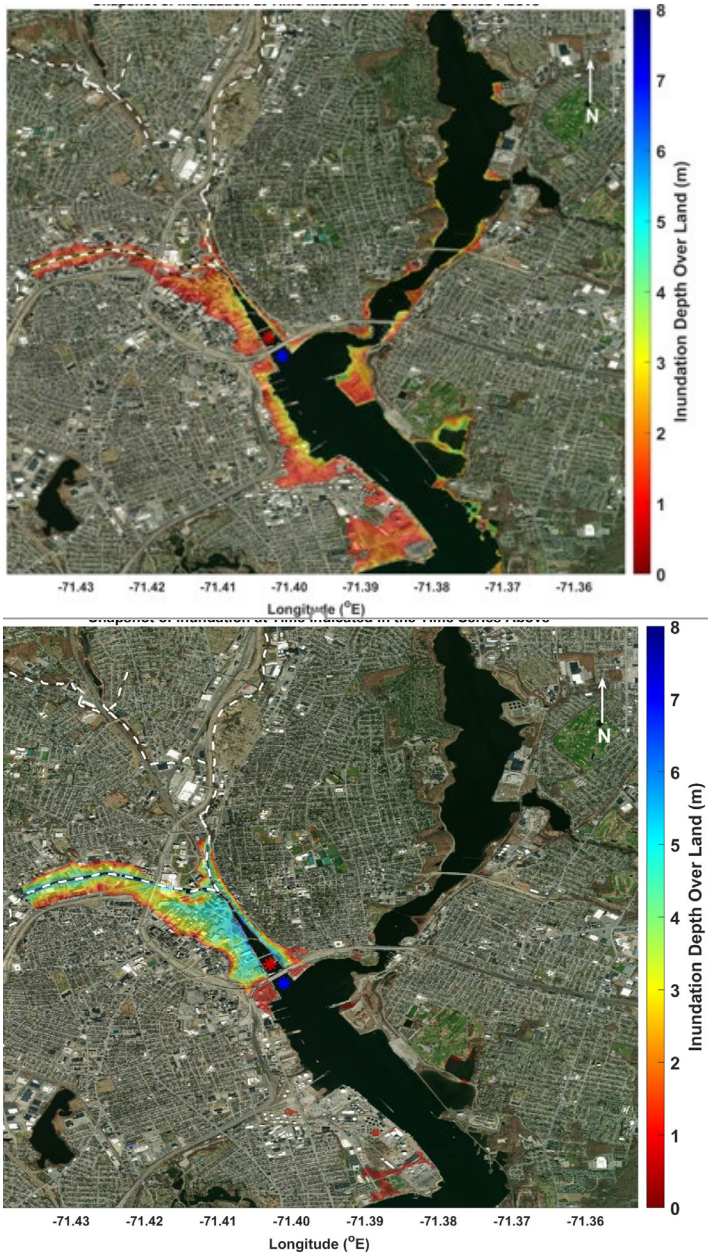


Figure HB-3. Simulations of maximum inundation of two different scenarios of a hypothetical, yet plausible, extreme Hurricane Ram. (D. Crowley and I. Ginis, 2021).

Top – Snapshot with the barrier closed and pumps not operating. The land behind the barrier was impacted with over 18 feet of floodwater after Hurricane Ram made landfall with surge and heavy rains.

Bottom – Snapshot with the barrier open. Shown here is a snapshot 1.5 days after landfall. Surge was almost 15-foot above mean sea level, which flooded the land with over10 feet of water in front of and behind the barrier.

qualitative data that has been collected on the potential consequences resulting from storm impacts to critical infrastructure in the floodplain in Providence. Using the hypothetical Hurricane Ram for this pilot, 305 unique consequences were identified through interviews and site visits of the 45 critical infrastructure facilities located in the floodplain (Becker, 2017). This effort is now being scaled up for a state-wide pilot with the goal of providing support to state and municipal, including Providence, emergency management agencies for planning and response purposes.

Understanding Consequences: Increasing resilience begins with a robust understanding of the potential consequences of storm events. A URI initiative funded by the Rhode Island Department of Transportation focused on the Port of Providence to help stakeholders more deeply understand what is at stake through a storm scenario exercise. The workshop underscored the exposure of the maritime industries and transportation networks that lie outside of the hurricane barrier (Becker, 2016).

Guidance for Decision-Making: Decision-making documents include The Fox Point Hurricane Barrier Coordination Guidebook (PEMA, 2020), which outlines the roles of federal, state and local entities in barrier operations; and Decision-making Guidance for Coastal Flood Protections (C2ES, 2016), which considers Providence's overall resilience challenges and opportunities. The report recommends deciding the barrier's future by 2050 to allow time to address the larger context of climate change impacts and weigh community tolerance for tidal flooding—as it becomes more commonplace and requires heavier use of the barrier.

> *Whether the barrier will continue to protect against future storm surge is very sensitive to the sea level rise projection used. If a low-probability, high sea level rise projection is used, then the optimal strategy is to build a new, taller barrier by the end of the century. However, under the highest-probability, lower sea level rise projections, the existing barrier is expected to be cost effective in protecting the city from storm surge well into the 22nd century (assuming it can be maintained past its design lifetime).*
>
> *- C2ES, 2016*

Recommendations

Monitor and Evaluate the Efficacy of the Hurricane Barrier to Protect the City of Providence: As a component of the five-year updates for the city's Multi-Hazard Mitigation Plan, monitoring of climate change should inform the timing of decisions about the future of the hurricane barrier and/or alternatives for addressing sea level rise impacts. The analysis suggests that a decision about any future hurricane barrier must be made by around 2050; decisions related to construction of sea walls to prevent low-lying nuisance flooding should be begin between 2040 and 2050 (C2ES, 2016; PEMA, 2019).

Build Momentum for Partnering: Existing coordination between key government agencies and the private sector—especially between USACE, PEMA, and National Grid—should be further encouraged and supported to ensure that an approach for adapting Providence and its infrastructure to climate change impacts is both comprehensive and timely (RI House of Representatives, 2016; C2ES, 2016).

Consider Adaptations for the Barrier: A collaborative effort to discern the extent to which the barrier should be retrofitted to manage flooding should ensue now so the infrastructure is ready by 2050, when sea level rise is projected to be considerably higher (RI House of Representatives, 2016; C2ES, 2016). Potential enhancements would include: 1) raising the impermeable core of the west dike wing wall to reduce the amount of water that flows over the core; 2) adjusting the embankment to have a milder slope, thus eliminating the critical shear stress; 3) increasing the rock size on the north side of the dike wing wall to avoid incipient movement and prevent failure; 4) moving the backup generator for the river gates to higher ground, allowing for river flooding and back flow during an event; and 5) providing a constant power source to ensure operation of pumps and river gates during a significant storm (URI, 2018a). It should be noted that an alternative power source may not be feasible or practical, given the amount of power needed to pump the water of the five pumps. However, it should be an option to review with National Grid.

Engage the Community in Anticipating Change: Providence is projected to experience substantially more frequent tidal or nuisance flooding in the future; cautionary closing of the barrier occurs now about 10 times a year but could happen more than weekly by 2050 and twice daily by 2100. Partnership efforts should engage the public in understanding this projected flooding increase so people can both participate in dialogue concerning investment in infrastructure like the barrier and seawalls and can begin to adjust their perspectives to accommodate changes in the appearance and use of the shoreline and the Providence River. Discussion with barrier operators would focus on the barrier's functionality and whether it could withstand near-constant use (C2ES, 2016).

Research

Determine the Life Span and Future Usability of The Barrier: Government and researchers, via several studies, recommend that further examination is needed to determine the barrier's future ability to remain functional and protect portions of Providence, given projected increases in storm frequency, sea level rise, and tides. Other options, such as building a new barrier, should be considered as well, and decisions related to construction of sea walls to prevent low-lying nuisance flooding should begin between 2040 and 2050 (C2ES, 2016) (URI, 2018a) (PEMA, 2019) (Rhode Island House of Representatives, 2016). Given the lag time from concept to construction, discussions will need to be initiated no more than a decade earlier.

Potential Enhancements

Consider Potential Study-Recommended Barrier Enhancements: Such enhancements include: raising the impermeable core of the west dike wing wall to reduce the amount of water that flows over the core; adjusting the embankment to have a milder slope, thus eliminating the critical shear stress; increasing the rock size on the north side of the dike wing wall to avoid incipient movement and prevent failure; moving the backup generator for the river gates to higher ground allowing for river flooding and back flow during an event; providing a constant power source to ensure operation of pumps and river gates during a significant storm; evaluating the option of an alternative power source (URI, 2018a).

Another possible option would be constructing seawalls to prevent nuisance flooding in low-lying areas of Providence (C2ES, 2016).

Partnerships

Strengthen Public-Private Partnership So It Can Drive Community Education: Identifying how best to support coordination between key government agencies and the private sector, including USACE, PEMA, and National Grid, can strengthen the overall partnership so it can better build momentum for community resilience education (RI House of Representatives, 2016 & C2ES, 2016).

Aim for Long-Term Monitoring: Within the city's 2019 Hazard Mitigation Plan, an action item calls for the long-term monitoring of climate change projections and recommends that the information be used to update the Fox Point Hurricane Barrier Coordination Guidebook and enhance barrier planning and management (PEMA, 2019).

Figure HB-4. Fields Point Barrier Concept to Protect the Entire City from Storm Surge. Simulation based on design used in Rotterdam (Becker et al., 2017).

Wastewater Treatment

Overview

Heavily urbanized by the 19th century, the metro Providence area earned global recognition as an industrial hub supported by advanced infrastructure, including its wastewater treatment facilities. Industrial Age engineering guidance leveraged the logic of gravity, locating wastewater treatment plants in American cities—Providence would be among the first—at the bottom of watersheds and next to the ocean, where they treated polluted water funneled downstream via drainage systems. Beyond the work and cost entailed with the consistent effort of replacing and upgrading aged infrastructure, the Providence region, as a coastal metro area, now grapples with climate change impacts to the utilities, including the wastewater treatment facilities at Fields Point and Bucklin Point, which are operated by the Narragansett Bay Commission (NBC).

Key Findings

The wastewater infrastructure system in Greater Providence is highly threatened and therefore vulnerable to increased storm surge, precipitation, urban flooding, and rising tidal water levels.

The Narragansett Bay Commission (NBC) is proactively taking action, building its own capability and capacity to address increasing vulnerabilities, and it is prepared to consider all actions necessary to sustain service in the long term. Building resilience requires balancing the impact that action(s) will have on rate payers against the ability to recover from an inundation event. There is no policy guidance from the Public Utilities Commission or the Rhode Island Department of Environmental Management (RIDEM) for addressing this challenge.

Addressing expected threats through the next few decades, NBC uses the Federal Emergency Management Agency (FEMA) model with added freeboard to accommodate increased flooding potential—consistent with RIDEM guidance—to guide their planning and designs. Other models, including Rhode Island-based STORMTOOLS, incorporate future storm and inundation scenarios with accurate available methodology. Results from these models project greater exposure.

Flooding impact is a key concern. As sea level rises and rain increases, projections are for slower, more intense storms that can lead to serious flooding and related problems. Several studies have been used to evaluate the impacts. Results differ, based on the models used. As noted below, NBC uses the Federal Emergency Management Agency (FEMA) model with added freeboard—per state guidance—to accommodate increased flooding potential. Rhode Island's STORMTOOLS includes projections for sea level rise and reflects a more conservative modeling approach than that employed by FEMA maps, which are the current regulatory standard of the state building code. NBC has already put in place as a foundation for resilience: a combined sewer overflow system with the capacity to collect and store up to 65 million gallons of combined sewage and stormwater until it can be processed to remove pollutants at the Field's Point plant and a productive and collaborative resilience planning and implementation process that involved the NBC and state partners. With NBC's two wastewater treatment facilities (WWTF) already supported with resilience plans and initial activities (i.e., equipment relocations to higher ground), work continues examining opportunities for structural and nonstructural improvements, enhancing the coordination process, and engaging the community via public education. Long before the NBC developed a formal resiliency plan, the agency incorporated considerations of climate change and sea level rise into its construction projects. For example, it is routine practice to install submarine watertight doors and watertight manhole covers into construction designs, if appropriate—with the goal of ensuring that all new projects will be resilient and withstand storm surge and sea level rise

throughout the project life. Part of the work at hand is developing criteria collectively to assist decision makers in determining how to cost-effectively protect existing infrastructure against these potential future climate change impacts.

Situation

Critical Lifeline Sector: Both FEMA and the Rhode Island Emergency Management Agency designate wastewater treatment as a critical lifeline sector, with the treatment facilities operated by the NBC deemed key resources.

Plant Improvements and the PUC: The NBC operates the only two wastewater treatment systems in the state that are regulated by the Public Utilities Commission (PUC). Efforts to undertake and fund plant improvements, including resiliency measures, for the Fields Point and Bucklin Point facilities must be approved by the PUC, who aims to seek a balance that insures that communities are not overburdened with significant rate increases from increased funding for these NBC resilience enhancements.

Fields Point: Rhode Island's largest treatment facility, located on the waterfront in the port area, was built in 1901 and reconstructed in the 1980s and 2000s. It is the primary treatment facility for Providence and the adjacent communities of Johnston and North Providence and receives wastewater from portions of Lincoln and Cranston, serving about 226,000 customers. The city of Providence sewer system, being the oldest in Rhode Island and second oldest in New England, has combined sewer overflows (CSOs) located throughout the city. The CSO Tunnel collects flows from these outfalls prior to reaching the waterways and redirects the flows to a tunnel and ultimately the treatment facility. The Fields Point Facility can provide secondary treatment and nitrogen removal for flows up to 77 million gallons per day (MGD) and primary treatment and disinfection for an additional 123 MGD of wet weather flows. The treatment capacity at Fields Point is 200 MGD. In addition, the CSO Tunnel has the capacity to capture and store an additional 65 million gallons for processing after a storm event (RIDEM, 2017). Fields Point has been built/upgraded with existing industry standard flood-protection measures in mind, including elevated tanks and tank-protecting concrete walls that rise above the roadway level and meet or exceed the required FEMA 100-year storm level (1% annual chance of occurrence) compliance standard established for Rhode Island wastewater treatment facilities.

Elevated Berm at Bucklin Point. The perimeter flood protection levee was modified in 2017 with added flood protection and is designed for a 500-year coastal storm event (NBC).

Bucklin Point: Located in East Providence, the Bucklin Point Facility was built by the state of Rhode Island in 1954, was transferred to the NBC in 1992, and NBC completed significant upgrades in 2005 and 2014. The Bucklin Point wastewater service area includes approximately 130,000 customers in all or portions of the towns of Central Falls, Cumberland, East Providence, Lincoln, Pawtucket, and Smithfield. Both Central Falls and Pawtucket have combined sewer overflows located within the cities. Bucklin Point provides secondary treatment and nitrogen removal for flows of up to 46 MGD and wet weather treatment for flows up to 116 MGD. Located along the Seekonk River, the facility is surrounded by a berm that provides some protection to surge and waves (the extent of which depends on the storm model used). The berm was rebuilt in 2014 to an elevation of 19.3 feet, an elevation that exceeds the FEMA 100-year storm event requirements by 4.5 feet. As a point of reference, the epic flood level associated with the Hurricane of 1938 was elevation 15.7 feet, so the upgraded NBC berm is higher than the 1938 hurricane flood level by an elevation of 3.6 feet. It is also important to note that this facility operated well without flooding during the March 2010 floods that hit Rhode Island, a storm later classified as a 500-year riverine event (.2% annual chance) without significant storm surge. The NBC is presently in the design phase for a CSO abatement tunnel, like the one in operation at Fields Point, that will collect and store an additional 58.5 million gallons of sewage-contaminated stormwater for later treatment at this facility.

Studies Offer Varied Flooding Projections: In 2019, NBC completed its resiliency assessment using FEMA flood maps with freeboard (two to three feet elevation added depending on the criticality of the specific structure) to accommodate for future conditions as outlined in the Rhode Island Department of Environmental Management (RIDEM) guidance. Previous assessments by RIDEM and the University of Rhode Island (URI) Ocean Engineering supervised capstone course used data from STORMTOOLS, a state-supported mapping and visualization application, to base future projections at wastewater treatment facilities. In general, the previous studies indicate a greater flooding risk to wastewater facilities that can be expected because of climate change. While the studies all offer solid, science-based data, their projections—in

Modeling Tools Are Used for Different Purposes

Currently there is not one specific standard required for designing and constructing wastewater infrastructure to accommodate projected sea level rise or increased storm intensity. STORMTOOLS is used in Coastal Resources Management Council (CRMC) permit design assessments and long-term planning, while State building code and flood insurance determinations use FEMA maps. Current RIDEM guidance is flexible regarding which mapping tool is used by each facility.

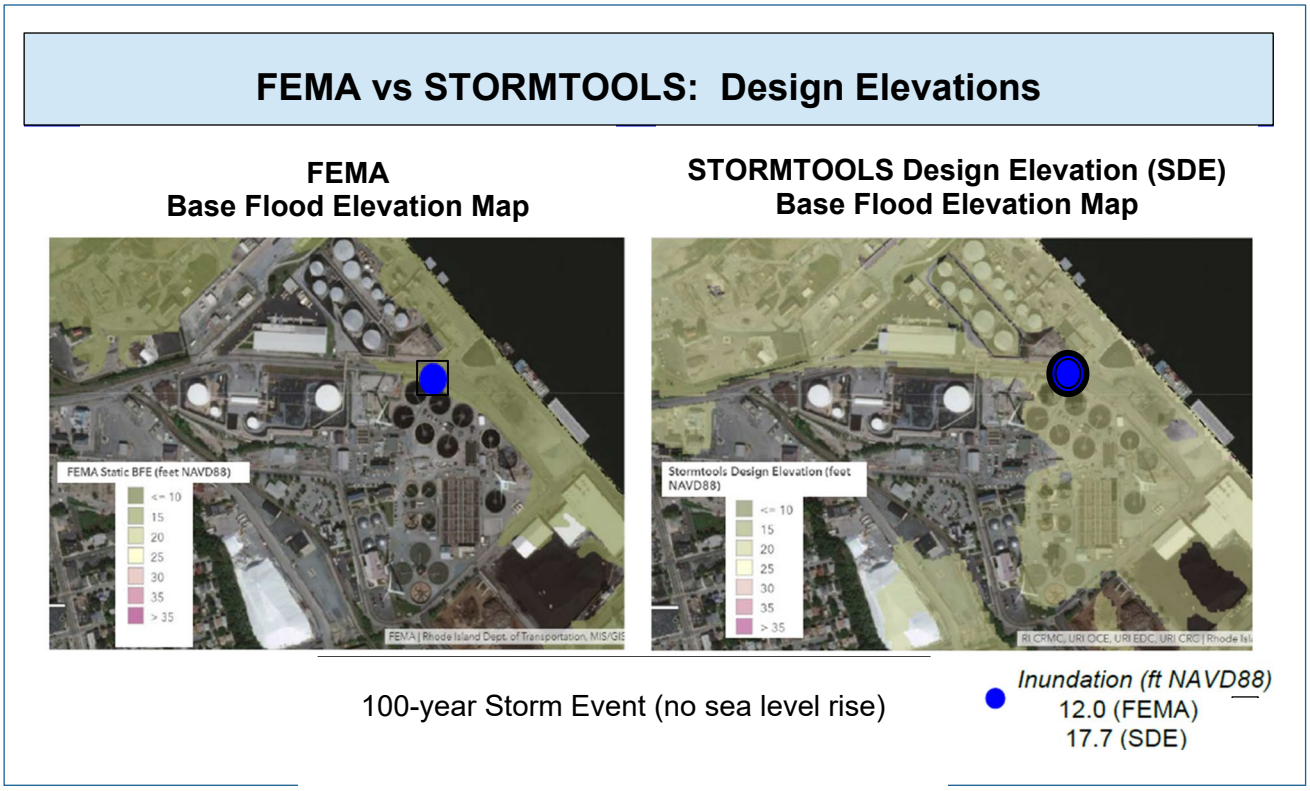


Figure W-1. Comparing Base Flood Elevations Used for Design. The maps above illustrate the difference in inundation levels, and extent, of flooding as predicted by the different tools (URI, 2019). RIDEM guidance allows the use of FEMA maps—with the addition of two to three feet freeboard—for WWTF design (URI, 2019).

terms of the extent to which facilities can withstand flooding impacts—vary widely depending on the data, modeling tools, and techniques used. Typically, STORMTOOLS is more conservative than FEMA; for a given location, the potential flood elevation will be higher since the level of confidence of being exceeded (95%) is greater than that of the FEMA standard (50%).

Establishing Goals for Resilience: It is important to understand that with infrastructure such as wastewater treatment facilities, the goal of resilience is not always to keep zero waters entering the facility. Sometimes it is more practical and cost effective to "keep operating while the water is coming in," and sometimes it is more cost effective to "let it flood and fix it after." Additionally, there is consideration for the type of structure, its design life, and the critical nature of its operation. This is a consideration as NBC evaluates the options of operational resilience, as well as physical resilience, when establishing and prioritizing flood-protection measures. This is especially relevant given that the PUC is balancing the interests of rate payers with the costs for resilience measures (W. Patenaude, personal communication, October 7, 2020).

Climate Challenges

Facilities at Risk: Fields Point and Bucklin Point are among the seven treatment plants in Rhode Island that could be compromised by flooding-associated strong storms, like a 100-year type of event modeled in STORMTOOLS (RIDEM, 2017). As noted, both the Fields Point and Bucklin Point plants are outside the hurricane barrier. While the facilities are not yet dramatically impacted, they could be at future risk, with areas of Fields Point potentially facing inundation from sea level rise. Some ancillary but equally critical facilities, such as pump stations, could also be vulnerable.

Higher Tides May Pose Difficulty: In any tidal community, higher tides have the potential to impact drainage pipes that rely on gravity to drain systems into waterways. In addition, wastewater treatment facilities that discharge by gravity or by pumping need to ensure adequate protections are in place to prevent waters from backing up into the plant. The Fields Point Wastewater Treatment Facility has sufficient elevation difference to allow gravity discharges for the foreseeable future. The Bucklin Point Wastewater Treatment Facility has an effluent pumping system in place. The NBC is keenly aware of the potential rising tide concerns that could impact discharge needs as well as other process needs. As such, efforts will continue to monitor and adjust their processes with time, which may include structural changes in the future. While some models and studies predict that multiple treatment aspects could be impacted in a 100-year type of storm, with or without sea level rise (URI, 2019), NBC has previously weathered extreme rainfall events effectively, as seen in the 2010 floods. Regardless, NBC is not resting on what happened in those past events and will continue to monitor changing conditions and is implementing actions outlined in their 2019 Resiliency Plan.

A Combined High Tide and Sea Level Rise Concern: At issue, among other concerns, is whether plants can overcome greater head pressure to discharge during extreme high tides, which will become more critical as sea level rises (RIDEM, 2017).

Sea Level Rise - Summary of Potential Impacts
Fields Point
• Rising sea levels could have a significant impact on capacity if the receiving waters enter the sewage collection system. Tide gates are installed at the CSO discharge points, but they can easily fail, with debris becoming lodged in the gates" (RIDEM, 2017). It is important to note that the NBC has an extensive program to routinely inspect and monitor tide gates, including daily chloride analyses of each plant's influent to promptly determine inflow to the facilities via an open tide gate.
• **Inundation limited at primary components of wastewater treatment facilities.** All components, including the treatment functionality, is still operational with 10 feet of sea level rise" (URI, 2019).
Bucklin Point
• **The exterior berm withstands sea level rise.** No impact to any components of wastewater treatment facilities. All components still operational with 10 feet of sea level rise (URI, 2019).

Figure W-2. Summary of Potential Impacts of Sea Level Rise with Different Models (NBC, 2019; URI, 2019; RIDEM 2017).

Figure W-3. Summary of Potential Impacts from Storms (NBC, 2019; URI, 2019; RIDEM 2017).

Storms*
Fields Point
• The most significant storm impact of concern to Fields Point is a hurricane, which has the potential to be a short-term, high impact event to the Fields Point Facility. Efforts in place to protect against hurricane impacts also support protections for the more intense storms that may result from climate change. • A significant concern identified during severe storms is the potential wind- and water-borne debris stored at neighboring facilities. NBC recommends that the appurtenant federal, state, and local agencies ensure protective measures are in place to prevent the movement of their stored materials. • The facility was designed to operate through a 25-year storm and protect against a 100-year coastal storm. Access to Fields Point during severe weather has not been an issue in the past (RIDEM, 2017). The facility performed well without flooding during the extreme March 2010 flooding, equivalent to a 500-year riverine storm event. • STORMTOOLS models, which provide the more conservative analysis, predict that much of the facility and the Ernest Street Pump Station would be inundated by storm surge at the 100-year return period. The water depth onsite would vary up to 7 feet (RIDEM, 2017). When adding sea level rise to the storm surge, additional inundation of equipment and the preliminary treatment may be at risk. To date however, the plant has performed well in past hurricanes and the March 2010 storm (NBC, personal communication, December 23, 2020). • FEMA models show much of the facility out of the 100-year floodplain, with more of the areas inundated during the 500-year flood. This, however, does not acknowledge that individual flood protection measures might reduce impacts. • Pump stations: Central Avenue (riverine), Ernest Street (coastal), and Washington Park/Shipyard Street (coastal) are identified as “most vulnerable to climate change;” others are designated as “localized impacts possible” (RIDEM, 2017).
Bucklin Point
• A berm surrounding the Bucklin Point Wastewater Treatment Facility was upgraded in 2014 to provide added flood protection. Projected river levels vary across studies—FEMA maps show the plant could now withstand major events, such as a 500-year coastal storm (NBC, 2019). • The URI assessment using the more conservative STORMTOOLS indicates a 100-year coastal storm would overtop the berm (see Efforts to Increase Resilience section for more information). • The 2017 RIDEM effort projected several flooding impacts to the facility. However, it was further recognized that the elevation data (LIDAR) used was not accurate and has since been refined and corrected (W. Patenaude, personal communication, December 7, 2020). • The facility performed well without flooding during the March 2010 floods, equivalent to a 500-year riverine storm event. • Pump stations at Omega (coastal, riverine) and Saylesville (riverine): the site for the Saylesville Pump Station in Lincoln has previously flooded from the adjacent river during significant rain or flooding events. However, the pump station was upgraded in 1994 to remain operational during these events and has functioned well. NBC has developed alternative access options to this site for any future events of this nature (NBC, personal communication, December 23, 2020).
** The March 2020 flood, which severely impacted the Woonasquatucket River area among others, was characterized as a 500-year flood (.2% annual chance). It should be noted that this was a 500-year riverine event, which is not comparable with a 100-year coastal surge flooding (1% annual chance) event.*

Unusual and Complex Collection System: The Fields Point plant's collection system includes a deep rock CSO Tunnel that allows Fields Point to routinely treat combined sewage and stormwater under most heavy rainfalls; still, the projections for increased flooding from strong storms, tides, and sea level rise could pose problems even for this extensive system (RIDEM, 2017). Bucklin Point is also a combined sewer system; NBC is embarking on its third and final phase of its CSO Improvements Program, which includes construction of a new deep rock tunnel within the Bucklin Point service area.

Increased Rains May be a Concern: Increased rainfall is a concern for localized flooding of roads, with high intensity rainfall, thereby affecting some NBC pump stations and collection components such as pumps. The issue of excess collection system flow from heavy rains is generally equalized at the plant by the tunnel and its wet-weather treatment. Phase III will build a tunnel that will serve the Bucklin Point service area.

Studies Using STORMTOOLS Data Projects Plant Inundation in a 100-year Event: The studies that apply the STORMTOOLS model (RIDEM, 2017 and URI, 2019) show projections that have both Fields Point and Bucklin Point being inundated by a 100-year storm event—even without the complications posed by future sea level rise.

Efforts to Increase Resilience

Following are some of the primary resources providing information and guiding actions for building resilience into Rhode Island wastewater treatment plants, including those serving the Providence area.

Narragansett Bay Wastewater Treatment Facilities Resiliency Plan, with the Complementary Summary (NBC, 2019): The Resiliency Plan (a now-routine permitting requirement of the Rhode Island Pollutant Discharge Elimination System/RIPDES process), administrated by the RIDEM with its companion Action Plan, represents a collaborative effort to comprehensively and realistically address resilience issues for wastewater treatment facilities. While the full report is not available to the public, due to safety and security concerns, the summary provides an overview.

Assessment: Finding the STORMTOOLS model too conservative for planning for the foreseeable future, the NBC consultant that developed the plan used the FEMA maps to evaluate and protect NBC facilities with an additional freeboard. NBC completed a future-looking comprehensive assessment of the potential impacts to its critical infrastructure components and systems and developed feasible strategies for making these vulnerable components and systems more resilient.

Plan: The forward-looking NBC Resiliency Plan builds on the recommendations of the 2017 RIDEM study, assesses impacts through 2050, and provides a schedule of short-, medium-, and long-term resilience actions, which may change as a better understanding of the climate change impacts develops; NBC has committed to account for future conditions as these become better understood. Recommendations cover flood-proofing and flood-protection measures, including flood walls (temporary or permanent), gates, barriers, and backflow and leakage management measures.

Actions: NBC continues to make capital investments to retrofit existing infrastructure, including adding water-tight hatches or doors for critical power supply sources that may be exposed to flooding, relocating critical equipment to higher elevations. NBC will evaluate if making modifications to manholes in low-lying areas could reduce the inflow from flooded areas into the collection system and monitor/seal conduit openings as outlined in the short- and medium-term action items. Both programmatic and operational actions are included to ensure that discussion of potential construction or retrofitting projects takes place in the context of governance, and financial and administrative considerations and constraints. Resilience measures, useful life, cost, and process impacts will all be considered when determining the need and timing of any upgrades. Considered as well will be the critical role of public engagement in fostering resilience for treatment plants (NBC, 2019; personal communication, December 23, 2020).

Improvements reduce vulnerability to the system. A flood protection door at NBC gate structure (top); watertight flood protection doors at the gate and screening facility (middle); and a water-tight utility vault/manhole cover (bottom) (NBC).

Strategy for Reducing Risks from Natural, Human-Caused, and Technologic Hazards: A Multi-Hazard Mitigation Plan (PEMA, 2019): The updated hazard mitigation plan reflects coordination between the city, the state (RIDEM) and the NBC as well as the guidance of other primary resources, and it speaks to the need for a collaborative effort to ensure future system upgrades.

Implications of Climate Change for RI Wastewater Collection and Treatment Infrastructure (RIDEM, March, 2017): This statewide evaluation took stock of the state's 19 wastewater treatment plants and associated collection systems and prioritized actions for upgrading their abilities to withstand flooding tied to strong storms and/or sea level rise. Recommended adaptive strategies are relatively cost-efficient and effective ($50,000 range for each) and include equipment elevation and flood barrier installation at facility entrances. For Fields Point, high priorities include ensuring equipment for the disinfection system, especially for the low-lying Ernest Street Pump Station, are out of danger of being submerged. For Bucklin Point, the focus is on monitoring the protection that the berm and tide gates provide with changing climate conditions along with the plant's ability to maintain process operations by attending to outfall effluent tide gates,

closing tide gates on the stormwater collection ponds, and shutting down the gates north of the barrier when the barrier is closed. Both facilities are supported with emergency action plans.

Evaluating and Improving the Resilience of Waste Water Treatment and Hazardous Material Storage Facilities in Upper Narragansett Bay to Coastal Flooding (URI, 2019): Guided by recognized academic experts and engineering professionals, the yearlong program engaged students in research that produced this report that confirmed the projections of the 2017 RIDEM study on the combined impacts of storm surge and sea level rise on wastewater facilities. As discussed above, this study used STORMTOOLS models, which reflected a more higher flooding potential. Recommendations evaluated include strategic flood protection at different locations, as well as a perimeter protection around the plant to protect it from flood waters with added sea level rise. Several of these options were also assessed in the NBC Plan.

The US Army Corps of Engineers (USACE) Rhode Island Coastline Coastal Storm Risk Management Study: This study is currently underway in the port area, including the Fields Point Wastewater Facility. Structural and nonstructural options are being evaluated that may support the NBC's Resiliency Action Plan.

Recommendations

Resilience Designs

Implement Short-term Resilience Strategies: Continue active implementation for the NBC's Bucklin Point and Fields Point Wastewater Collection and Treatment Facilities, as recommended in the NBC Resiliency Plan (PEMA, 2019). Some actions identified include submarine doors; elevated/watertight protections of motor control centers; waterproofing; standby power systems; and elevated instrumentation, windows, hatches, and vents (Resilient Rhody, 2018).

Provide More Fuel-Storage Capacity: This would be for major wastewater systems, where it is necessary to maintain self-sufficient standby power during times of long-term power grid outages (Resilient Rhody, 2018).

Planning

Maintain Rigorous Review Schedule: Review, update, and revise as appropriate the NBC Resiliency Plan to consider strategies of other studies, including updated information per the USACE risk management study when completed.

Secure Funding and Clarify Potential Projects: Identify funding opportunities that can leverage the goals and resources of collaborating government entities to help reduce the burden on rate payers.

Develop Clear Design Guidance: Engage NBC and RIDEM in developing and disseminating guidance to ensure design requirements reflect changing conditions that can be applied to NBC facilities (W. Patenaude, personal communication, December 7, 2020).

Assess and Plan for Storm Debris Impacts: For the area from the Port of Providence to the NBC facility, convene federal, state, and local agencies to ensure protective measures are in place to prevent the movement of their stored materials, many of which are hazardous to public health, safety, and welfare (NBC, personal communication, December 23, 2020).

Research

Expand Flood Modeling: Expand flood modeling/mapping efforts within inland areas to enhance the recommendations as provided in Implications of Climate Change for Rhode Island Wastewater Collection and Treatment Infrastructure. Data should include statewide precipitation projections that can be used for other sectors as well (Resilient Rhody, 2018).

Continue to Collect Observational Data: This data, as well as advancements in research, are expected to provide NBC with more-certain decisions on investments in the future.

Recognize the Potential Need to Realign Longer-term Goals: The NBC adheres to planning made up of near-, medium- and long-term recommendations and actions; as such, maintain understanding that medium- and long-term actions may change via science advances or as new information on climate change impacts emerges.

Stormwater Systems

The Stormwater section was contributed by Horsley Whitten Group

Overview

One of America's oldest cities, Providence was built at the northernmost arm of Narragansett Bay, along four rivers: the Woonasquatucket, Moshassuck, Seekonk, and Providence Rivers. Throughout its history, Providence experienced significant industrial and residential development, including in the floodplains of these rivers and along the shore of the bay. While its location near a natural harbor along some of the early trade routes facilitated its development as a transportation center, it also makes the city vulnerable to flooding from riverine flooding, coastal storms, and rising sea levels.

Key Findings

The collective expertise within the state and city is perhaps our greatest resource. However, the number and diversity of stormwater stakeholders makes coordination challenging.

The lack of a single, accepted statewide predictive flooding model that incorporates future climate conditions—increased precipitation, coastal and inland flooding, and rising seas—is an impediment to data-driven investment in more resilient infrastructure.

Fragmented jurisdiction over stormwater systems and the absence of a long-term funding/financing solution for stormwater management is a major challenge to proper maintenance, upgrades, and expansion. Studies led by different agencies and organizations should be coordinated to ensure valuable data are shared across jurisdictions, leading to consistency in design criteria to mitigate future flooding.

In Providence, as in many older cities in the U.S., infrastructure systems were built to handle both stormwater and wastewater, and in some areas of the city, these systems were combined to handle both. The stormwater systems are part of an aging infrastructure that was designed and built merely to convey water to the nearest river. Recent trends in increased precipitation are placing greater stress on the system, which in some areas can no longer accommodate the volume and intensity of rainfall that are becoming more common.

Stormwater is a serious environmental and public safety issue because, in addition to water quantity issues (e.g., flooding), runoff results in impacts to water quality (i.e., untreated pollutants reach surface waters). These pollutants lead to surface water quality impairment for both freshwater (e.g., ponds, rivers) and estuaries (e.g., Narragansett Bay). For example, the presence of pathogens can lead to beach and shellfishing closures; excessive nutrients can result in algal blooms and fish kills; and heavy metals accumulate in water bodies, sediment, and fish tissue, making fish unsafe to eat. The impact of these pollutants also increases with warming oceans and other surface water bodies, as temperatures are on the rise.

Under delegated authority from the U.S. Environmental Protection Agency (EPA), the Rhode Island Department of Environmental Management (RIDEM) has responsibility under the federal Clean Water Act to restore and maintain water quality in the state of Rhode Island. RIDEM also has authority to protect water quality under Rhode Island state law. These laws authorize RIDEM to establish the Rhode Island Pollutant Discharge Elimination System (RIPDES) Program to regulate discharges of point sources of pollution, like wastewater treatment facilities and industrial discharges, as well as stormwater drainage systems. In December 2003, RIDEM issued a statewide general Municipal

Separate Storm Sewer Systems (MS4) permit that regulates stormwater discharges to prevent pollution from such discharges. Providence and 24 other Rhode Island municipalities are regulated under the MS4 program, with no ability to apply for waivers. The EPA, Rhode Island state agencies (e.g., Rhode Island Department of Transportation/RIDOT, RIDEM), the city of Providence, the Narragansett Bay Commission (NBC), and many local organizations have been sponsoring, developing, and implementing resilience strategies for improved stormwater management in the form of funding, studies, education and outreach, and on-the-ground projects. In terms of stormwater infrastructure, projects range from small, green infrastructure/low impact development (GI/LID) projects targeting onsite treatment and recharge of stormwater to large infrastructure projects targeting the combined sewer system in Providence.

Situation

The Built Environment

Location: Due to its geographic location, and a typically mild climate, Providence is vulnerable to hurricanes and tropical storms, where heavy rainfall affects the metro region, and storm surge affects the coastal area. Vulnerability to weather events will increase with climate change (PEMA, 2019). Providence is located at the bottom of the watershed (farthest point downstream), meaning the full volume of stormwater runoff for large drainage areas collects in the city's rivers.

Floodplains: Floodplain development has occurred extensively throughout the Providence metro area, along the rivers that border and wind through the city. This area is also home to the NBC Bucklin Point and Fields Point wastewater treatment facilities, as well as the Port of Providence. This type of development presents a high risk of flooding during heavy rainfall from a combination of stormwater runoff from impervious areas, saturated soils, and increased river flow—with no place for excess water to drain. The Providence Multi-Hazard Mitigation Plan provides maps of the extent of flooding under these events (PEMA, 2019).

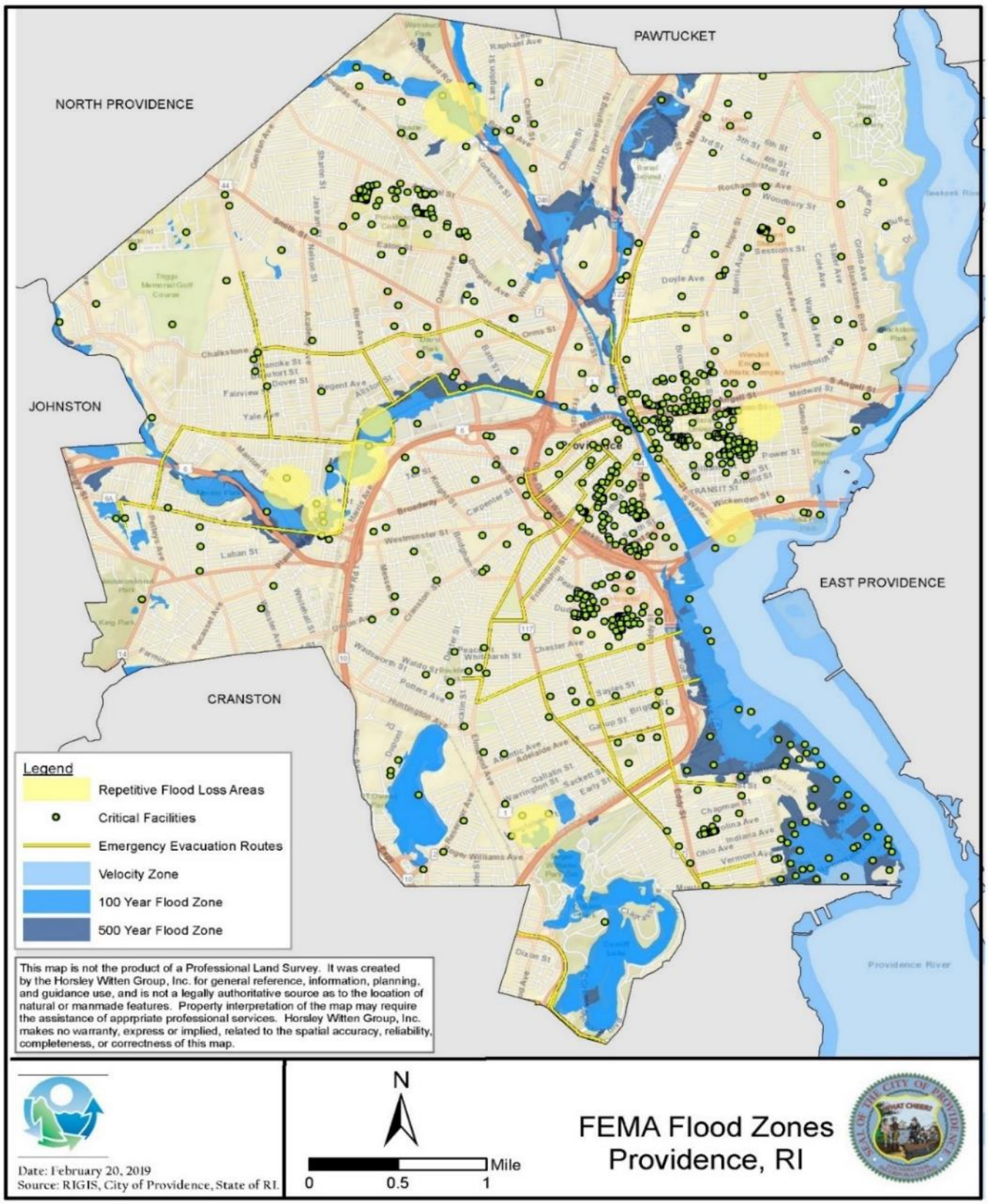


Figure S-1. FEMA Flood Zones in Providence. The City's Hazard Mitigation Plan shows the extent of flooding related to the location of critical facilities (PEMA, 2019).

The Stormwater Infrastructure

'Old-School' Design: Stormwater was primarily managed, from a drainage standpoint, to prevent flooding, with little consideration for treatment (i.e., water quality). It was routed from newly built impervious surfaces (e.g., roads, buildings) directly to the closest discharge location, either as surface flow or channelized and piped flow. Limited infiltration occurred, along with limited or no pre-treatment.

Existing Capacity: As an older New England city, Providence's stormwater infrastructure was first installed about a century ago—when some neighborhoods were far less developed and storms were generally less intense. As the city continued to develop, natural areas were converted to impervious surfaces. The city is still developing today, and this process, combined with increases in precipitation, is placing additional stress on the existing drainage systems, thus contributing further to flooding and water quality issues (Resilient Rhody, 2018).

Combined Sewer System: In a combined sewer system, stormwater and sanitary wastewater are carried in the same pipe. While this enables some treatment of stormwater by a wastewater facility during normal operations, during large precipitation events, the combined flow exceeds the treatment system's design capacity. In that situation, overflow releases untreated wastewater to receiving waters (RIDEM, 2017). Further complicating the matter in Providence, separated stormwater systems are the property of the city, and combined sewer overflows (CSOs) are the property of NBC. Where interconnections occur, this situation creates complexities around maintenance and permitting (see Wastewater section for more information).[1]

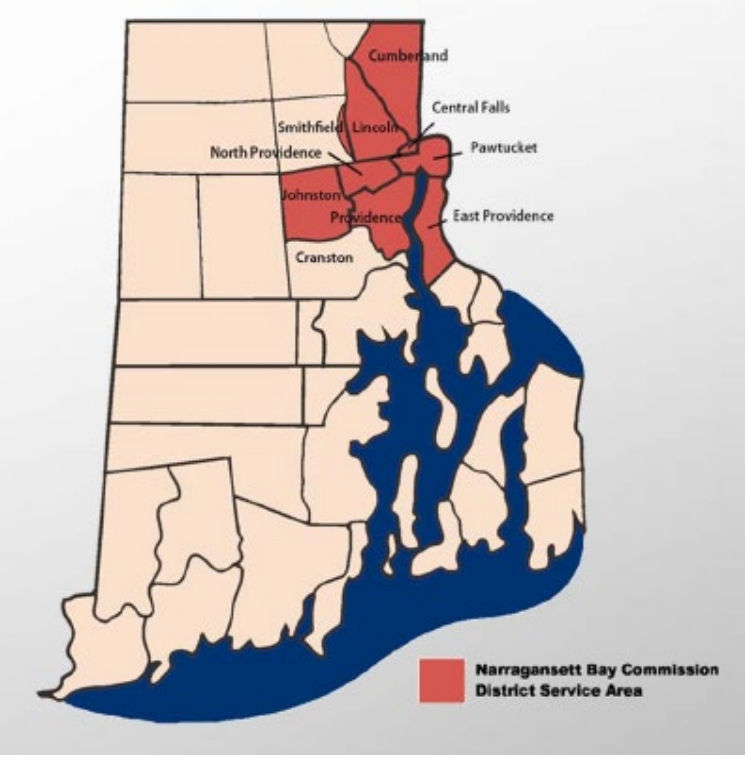


Figure S-2. Narragansett Bay Commission Service Area (in red) serviced by Fields Point and Bucklin Point Treatment Facilities (NBC).

Administration and Regulation

State Regulatory Framework: RIDEM regulates stormwater discharges from the city of Providence under Phase II of the RIPDES MS4 program, and the city is subject to a 2017 consent agreement with RIDEM to improve stormwater management. According to its 2019 annual Rhode Island Pollutant Discharge Elimination System (RIDPES) permit report, the city is implementing a range of strategies and projects to improve stormwater management and measure progress towards achieving the city's minimum control measures specified in its RIPDES general permit (City of Providence, 2019a).

[1] https://www.fema.gov/disasters/disaster-declarations

Providence has considerable work to do in order to meet the obligations of the consent decree, and anecdotal accounts suggest maintenance of the existing system is currently inadequate. Efforts have been largely dedicated to baseline work: systems monitoring, maintenance, and most importantly, identification of illegal sewer connections to the stormwater system.

Legal Actions: A number of legal actions are providing an impetus for improved stormwater management in Providence, including the following.

- The 2015 RIDOT and U.S. EPA consent decree under the Clean Water Act identifies stormwater management improvements in Rhode Island, including high priority illicit discharges and necessary stormwater treatment to address water quality impairments caused by pollution discharged from RIDOT's stormwater system in Providence and elsewhere across the state (U.S. EPA, 2015).
- RIDEM and NBC renegotiated its consent agreement in 2019 to direct NBC's wastewater CSO project. In addition to establishing an enforceable schedule for NBC to come into compliance with their RIPDES discharge permit limits, the consent agreement also requires NBC to develop and submit to RIDEM a resiliency plan to address climate change impacts on NBC's facilities (NBC, 2019).

The Rhode Island Stormwater Management Standards: These state-level development standards serve as the ultimate state stormwater compliance document and are designed to encourage onsite treatment and recharge of stormwater, to the maximum extent practicable. New and redevelopment projects must implement LID site planning and design strategies (minimum standard 1). Stormwater must be recharged within the same sub-watershed (minimum standard 2), and stormwater runoff must be treated before discharge (minimum standard 3) (RIDEM, 2015). When implemented, these standards help reduce stormwater runoff and the need to manage and treat large volumes of stormwater.

Mapping Future Impacts: Many states and municipalities in the U.S. are trying to develop updated maps that provide a reasonable basis for regulating development and investing in infrastructure in a manner that anticipates future impacts. Historically, the FEMA flood maps used for insurance purposes have been the most reliable, widely applied, mapped information. The obvious limitation of these maps, in the context of climate change, is that they use historical data to identify high risk zones, and they do not consider future sea level rise. While the maps are used as the regulatory standard for facility compliance, they are essentially inadequate for that purpose. Other modeling applications like STORMTOOLS (Rhode Island) or the Coast Flood Risk model (Massachusetts) have been used in an effort to incorporate better estimates of sea level rise into regulation and planning; it should be noted that these do not link riverine and coastal flooding in the models and do not incorporate the Fox Point Hurricane Barrier. Policy makers and regulators in Rhode Island will need to reach an agreement on the best predictive model for planning related to hazard mitigation, adaptation, retreat, facility resilience, and regulation in high-risk areas. Once the best tool is identified, future inundation scenarios should be woven into state and local planning and regulation.

Climate Challenges

The stormwater management system is currently taxed by heavy rainfalls and other events. Climate change will continue to challenge the city's stormwater infrastructure system, and investments in improved stormwater management will have to continue, despite limited funding.

Infrastructure impacted by upland flooding on River Drive, Seekonk River. Upland flooding flowing down Irving Avenue has eroded the bank. Restoration is planned with grants awarded to the City (D. Everett, 2015).

Coastal Storms: The funnel-like shape of Narragansett Bay amplifies the height of a storm surge as it moves up the bay, resulting in the highest flood levels in the state occurring along the Providence River. This natural effect places the city of Providence at higher risk of flooding and can place a significant strain on its stormwater system (PEMA, 2019).

Precipitation and Resulting Flooding: In 2010 alone, Rhode Island experienced two 100-year (or 1% annual chance) floods, and increased precipitation intensity and frequency from a changing climate will significantly worsen the impact of such incidents. Since 1991, the Northeast has already seen an 8% increase in overall precipitation; since 1930, Rhode Island's average precipitation has increased by more than 10 inches, and since 1958, the Northeast has experienced a 71% rise in heavy rain events (RIDOH 2015; Resilient Rhody, 2018).

Winter Hazards: Winter hazards include heavy snow, ice, and extreme cold that can threaten the city and its infrastructure by downing trees and utility lines, blocking storm drains, causing structural issues in older pipes and building, and reducing mobility. Although winters are becoming shorter and warmer, they are also becoming wetter, with the possibility of a greater number of freeze/thaw cycles during which sleet and freezing rain may replace snow (RIDOH 2015; Resilient Rhody, 2018).

Increased Intensity of Atlantic Hurricanes: Model results summarized in the most recent National Climate Assessment indicate that while the total number of hurricanes may decrease slightly, rainfall rates in hurricanes will increase in warmer climates, as will the number of Category 4 and 5 hurricanes (RIDOH, 2015). More intense storms, with greater amounts of rainfall in short periods of time, stress the stormwater system, resulting in street flooding among other impacts.

Sea Level Rise: Sea level is rising faster than average in Rhode Island and will continue to affect low-lying areas. Extreme high tide flooding will occur more frequently with rising sea level, thereby potentially affecting the proper functioning of many stormwater outfalls, including those without tidal flap gates to prevent backing up into storm drains.

Extreme high tide at the stormwater outfall on Gulf Ave, into the Seekonk River. The tide measured 1.9 feet above mean higher high water—the projected sea level in around 15 years (D. Everett, 2020).

Efforts to Increase Resilience

The U.S. EPA, Rhode Island state agencies (e.g., RIDOT, RIDEM), the city of Providence, NBC, and many local organizations have been sponsoring, developing, and implementing resilience strategies for improved stormwater management in the form of funding, studies, education and outreach, and on-the-ground projects. In terms of stormwater infrastructure, projects range from small GI/LID projects targeting onsite treatment and recharge of stormwater to large infrastructure projects targeting the combined sewer system in Providence. Key efforts are summarized below, but others may exist beyond this list.

Federal and State

Federal Funding: The U.S. EPA provided funding for both large and small stormwater management projects in Providence:

- In 2014, EPA sponsored the construction of a stormwater bio-infiltration system at J.T. Owen's Park on Mashapaug Pond[2] to treat runoff from neighboring streets that previously discharged untreated to the pond.
- EPA recently funded NBC's large CSO management projects in Providence through its Water Infrastructure Finance and Innovation Act (WIFIA) program,[3] which provides long-term, low-cost loans

[2] https://www.epa.gov/snep/providence-ri-green-infrastructure-project
[3] https://www.epa.gov/wifia/providence-combined-sewer-overflow-phase-iii-facilities

to regionally and nationally significant projects. In addition to the $269 million WIFIA loan,[4] the NBC projects will rely on funding from other entities and continued revenue from property rates.

Recurring State Investment: The state of Rhode Island has been approving bonds to support a "Green Economy."

- In November 2016, Rhode Island voters approved a $35 million Green Economy Bond, which included $3 million in matching grants to help communities improve their stormwater systems, in addition to $3.4 million in other state and federal grant funds for flood and pollution prevention grants.

Key Grants Awarded funding from the Green Economy Bond

Farm Fresh RI: $167,500 for the construction of stormwater pollution abatement best management practices incorporating green infrastructure at 498 Kinsley Avenue, Providence. The highly impervious site is being converted from a former manufacturing site into a hub for food and agriculture and is adjacent to the Woonasquatucket River.

City of Providence: $118,000 for construction of stormwater pollution abatement best management practices including (1) installing permeable pavers and other green infrastructure at Riverside Park, reducing pollution into the Woonasquatucket River; and (2) removing pavement installing bioretention and erosion control measures along River Road, reducing pollution into the Seekonk River.

Woonasquatucket River Watershed Council: up to $133,900 for the construction of stormwater pollution abatement best management practices incorporating green infrastructure at 1917 Westminster Street, Providence. RIDOT Is partnering on the project.

City of Providence: Up to $300,000 for the purchase of a vacuum-assisted street sweeper and a vacuum/jet truck for enhanced stormwater pollution management practices. Improved maintenance will reduce the pollutants entering fresh and coastal waterbodies, including those with known pollution problems—i.e., Roger Williams Park Ponds, Mashapaug Pond, and Providence River.

- The proposed 2018 Green Economy and Clean Water Bond was for $47.3 million,[5] and the proposed 2021 bond would be for $69 million.[6]

The Rhode Island Infrastructure Bank (RIIB): The bank partners with RIDEM and other entities to provide loans for infrastructure projects through a range of programs, including:

- The Clean Water State Revolving Fund[7] funds eligible projects on RIDEM's annual Project Priority List and has supported the NBC infrastructure improvement projects.
- The Municipal Resilience Program[8] helps RI municipalities identify priority projects and strategies to improve their resilience and apply for grants to implement those projects. Providence is scheduled to participate in the 2021 cohort.

[4] https://eponline.com/articles/2019/09/24/the-water-infrastructure-finance-and-innovation-act-cleaning-up-narragansett-bay.aspx
[5] http://dem.ri.gov/growgreenri/index.php
[6] http://dem.ri.gov/greenclean/
[7] https://www.riib.org/cwsrf
[8] https://www.riib.org/mrp

- The Stormwater Project Accelerator[9] provides upfront capital for green stormwater infrastructure projects in Rhode Island that will eventually be funded through state and local reimbursement grants. In January 2021, the RIIB solicited the services of an engineering consultant to facilitate the implementation of the Stormwater Project Accelerator. A minimum of five green infrastructure projects are expected to be designed as part of this one-year engagement.

Completed Tunnel for CSO Phase I Construction (NBC).

Other Statewide Efforts:

- RIDOT is implementing a 10-year strategic program to improve stormwater management consistent with its 2015 federal consent decree and offers to provide municipalities and nonprofit organizations with engineering designs for green infrastructure, which reduce off-site runoff (Resilient Rhody, 2018).
- RIDEM and CRMC (as part of CRMC's Urban Coastal Greenways policy have also been requiring the implementation of LID strategies that reduce stormwater impacts in projects they permit (Resilient Rhody, 2018).

Regional and Local

Large Stormwater Infrastructure Projects for Narragansett Bay: The first consent agreement between NBC and RIDEM in 1992 established a schedule for CSO control facility planning, design, and construction—based on a three-phase program. Phase I and II, completed in 2008 and 2014 respectively, focused on the Fields Point service area and outfalls in Providence; while Phase III implementation, with an anticipated completion by 2041, primarily focuses on the Bucklin Point service area and outfalls. In addition to pulling large quantities of polluted runoff into underground chambers, a number of stormwater improvements "upstream" in the urbanized watersheds will help to reduce flooding and filter pollutants from stormwater runoff.

Initially, Phase III included a deep rock tunnel with a series of interceptors to connect outlying outfalls as well as sewer separation for a few residual areas. Due to the projected cost and impact on ratepayers, the Phase III project was re-evaluated to assess affordability and potential for alternative stormwater management, including GI. The Phase III re-evaluation study concluded that GI could be used to supplement grey infrastructure because GI could only address a portion (36%) of the CSO volume (NBC, 2017).

Following re-evaluation, the Phase III project was divided into four segments to be completed by 2041. Each phase incorporates green stormwater facilities to reduce stormwater inflow to the existing CSO system through infiltration projects, with expenditures of $10 million on GI in each phase. Some of these GI projects will be located in Providence (NBC CIP, 2020).

[9] https://www.riib.org/spa

Regional Stormwater Utility: Jurisdiction over stormwater infrastructure is complicated because of the CSO design and because adequate, reliable funding mechanisms to maintain and upgrade the system are not in place. With funding from RIDEM, seven municipalities at the head of Narragansett Bay, led by the city of Providence, started working together in 2013 to explore regional solutions to stormwater management issues in the form of a potential stormwater utility: The Upper Narragansett Bay Regional Stormwater Management District[10]. In a letter sent by Mayor Angel Tavares to the other municipal leaders, inviting them to participate in the study, he stated, "Providence, like many of our neighbors in the region, has inadequate resources to address either our practical stormwater management challenges including flooding, pollution, and degraded infrastructure, or our regulatory requirements to comply with our stormwater permits."

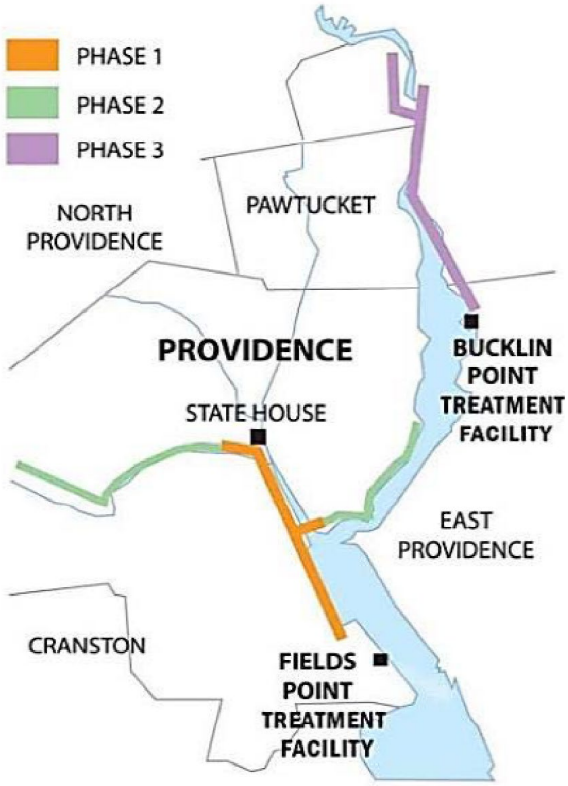


Figure S-3. Combined Sewer Overflow Phases of Construction. Phase I and II are completed (NBC).

Why a Stormwater Utility?

Developing a sustainable solution to stormwater management stems from the fact that Rhode Island cities and towns face a familiar set of problems that include:

- An inability to meet funding requirements and get necessary work completed;
- Flooding of streets, homes and businesses;
- Deteriorating and undersized infrastructure;
- Regulatory non-compliance and enforcement actions;
- Pollution of local ponds, rivers, and Narragansett Bay; and
- Impacts on businesses and tourism.

- The Phase I feasibility study, completed in June 2014, focused on the viability of a regional approach to funding stormwater management (AMEC, 2014). A second phase feasibility study (2015 - 2016) defined the scope and governance of the proposed stormwater management district and developed a 10-year projection of program costs and funding and an implementation plan (CDM, 2016).

- The lack of county or regional government in New England can make it difficult for communities to work together without a legal or regulatory requirement. During the planning process, NBC was encouraged to assume greater responsibility as a regional agency and manage the separate stormwater systems owned by the cities within the NBC district. However, from a legal perspective, NBC cannot charge an additional fee for stormwater. Once the stormwater enters the system, NBC is obligated to treat it under the current fee structure.

- The non-NBC communities were hesitant to be involved with a regional approach because of their heavy debt burden (resulting from treatment plant upgrades and CSO Phases I and II improvements) and a previous court decision that would allow NBC to manage their system holistically. The impact of this decision is that those communities that are within the NBC service area but that do not have a

[10] http://www.unbstormwater.org/

CSO system will still share the cost of the CSO infrastructure improvements. Cranston and Warwick did not want to pay for improvements from which they would not benefit. This resulted in the Advisory Committee recommending two stormwater utilities—one for the communities connected to a CSO system and the other for the non-CSO communities.

- NBC did not wish to assume responsibility for these systems without full control of fees and funding. As noted, they were carrying a heavy debt burden and had significant investments remaining to complete all required CSO abatement measures.

City Planning Efforts

- The first goal of the city's comprehensive plan is to "Protect and preserve the natural environment and strive to make Providence a 'green', sustainable city." This includes addressing flood mitigation and stormwater management and seeking funding for public outreach and education efforts related to non-point source pollution and stormwater (City of Providence, 2014a).
- The city of Providence's Great Streets Initiative has been very successful at improving traffic and creating opportunities for biking-friendly routes by creating greenways and urban trails to connect neighborhoods, while increasing green spaces and improving stormwater management. The city's Great Streets Master Plan identifies the characteristics that make safe, clean, healthy, and vibrant streets and the goals required to create "great streets." One of those goals is to reduce stormwater runoff and flooding (City of Providence, 2020c).
- One goal of the city's Sustainable Providence Plan is to "strive for all water bodies to be fishable, swimmable, and accessible, and to provide high quality, affordable drinking water to all residents." To achieve that goal, the city highlights the need for stormwater management strategies to improve surface water quality and mitigate flooding, and identified number of high priority actions, including pursuing pavement reduction, implementing green infrastructure, and cleaning storm drains (City of Providence, 2014b).
- In its most recent Capital Improvement Plan (CIP), the city mentioned investments related to improving green spaces to manage stormwater runoff, as well as stormwater management system maintenance, repair, and construction, including the installation of green infrastructure. In addition, the CIP budgeted specific funds for Pleasant Valley Parkway Stormwater improvements in FY 2021. (City of Providence 2020a).

City Initiatives and Partnerships: Various entities, including nonprofit organizations, are sponsoring and implementing GI/LID stormwater projects throughout the city of Providence to manage stormwater locally and prevent runoff from entering the city's stormwater system.

- At the neighborhood level, the city leveraged EPA funds to develop a long-term community vision plan for the Woonasquatucket Corridor, a 560-acre area spanning three neighborhoods along the Woonasquatucket River that are prone to flooding. Part of the plan focuses on sea level rise and inland flooding, and it points to improved stormwater management practices through the use of LID and GI practices and to improved stormwater infrastructure maintenance (City of Providence, 2018b).
- Managed by the city of Providence Parks Department, Roger Williams Park has implemented several stormwater best management practice (BMP) projects throughout the park in compliance with the city's consent agreement with RIDEM.


Stormwaters retrofit projects in Roger Williams Park completed under the 2015 consent decree. Swales and natural filters were constructed that will remove pollutants from urban stormwater before it enters the existing pond (Horsley Whitten Group).

- The Providence Stormwater Innovation Center,[11] located in Roger Williams Park, provides hands-on training for stormwater professionals, and community outreach and education. It was developed as a partnership between the Providence Parks Department, RIDOT, nonprofit organizations (Audubon Society of RI, The Nature Conservancy), and academic centers (University of Rhode Island Cooperative Extension and University of New Hampshire Stormwater Center). The city saw the opportunity to leverage its investment in drainage improvements required by the consent agreement by creating a center where others could learn about green infrastructure.

Nonprofit Initiatives

- The Rhode Island Green Infrastructure Coalition has been very active and successful in identifying GI (including stormwater) projects and seeking funding and implementation for these projects.
- The Woonasquatucket River Watershed Council (WRWC) has been instrumental in the restoration, preservation, and greening of the Woonasquatucket River Watershed through participation in planning efforts for over two decades. As part of its restoration and revitalization efforts, the WRWC has successfully implemented GI and stormwater management projects in the watershed and along what is now referred to as the Woonasquatucket River Greenway[12]. Most recently, the WRWC is working with Natural Resources Conservation Services (NRCS) to develop a comprehensive watershed plan. Products will include the identification, conceptual design, and planning-level cost estimates for stormwater improvements. The study is expected to yield a second round of funding for engineering design and construction.
- Other nonprofit organizations in Providence actively support GI/LID and local stormwater projects by garnering neighborhood, government, and private support and funding for them. These organizations

[11] https://www.stormwaterinnovation.org/about
[12] https://wrwc.org/wp/what-we-do/greenway/

include Groundwork Rhode Island,[13] the Environmental Justice League of Rhode Island,[14] and the Blackstone Park Conservancy.[15]

Common Themes Seen Throughout Efforts

Themes from Previous Plans: Research conducted for this project included developing an aggregate list of all the recommendations from state, regional, and local planning documents related to stormwater. These documents included the city's Multi-Hazard Mitigation Plan, Resilient Rhody, the Woonasquatucket Vision Plan, Sustainable Providence, and the city's Comprehensive Plan.

Funding: A common recommendation across planning documents and efforts centers around identifying sustainable financing for current and future stormwater management, including the maintenance of existing infrastructure and needed infrastructure replacement. Recommendations included, but are not limited to, the renewed call for studying the use of local or regional stormwater utilities, increased and strategic use of RIIB resources, and more strategic use of RIDOT funding.

GI/LID and Related Projects: It is often easier to treat and manage stormwater to the maximum practicable extent at the local level, rather than having to address large, potentially contaminated flows further downgradient/downstream. Consistent with the requirements of the RI Stormwater Manual, the general recommendations of implementing GI and promoting LID is consistent with most planning documents that address stormwater in Providence. Implementation of GI/LID practices will enable the city to support growth while managing stormwater in a changing climate.

Case Study: Portland, Oregon Stormwater Program

Prior to designing and building a large infrastructure project for managing its CSOs, the City of Portland adopted a comprehensive approach to stormwater management by promoting and incorporating small, low-cost initiatives into their plan, while setting up a stormwater utility to fund the program. Four main cornerstone projects (i.e., sewer separation, stormwater sump installation, stream diversion, and broad-scale downspout disconnection) enabled the City to reduce stormwater flow by about a third and saved close to $300 million on the large-scale infrastructure (tunnel and other control facilities).

Infrastructure Maintenance: Several plans, including those developed both by the city of Providence and WRWC, acknowledge the need to provide regular maintenance for existing and future stormwater

[13] https://groundworkri.org/about/
[14] https://ejlri.org/toxic-hazards/urbanponds/
[15] https://www.blackstoneparksconservancy.org

infrastructure facilities. This ensures long-term viability for these investments and requires sustained funding.

Studies/Document/Policy Updates: State, city, and nongovernment groups have all called for continued revisiting of policy and regulations related to stormwater. Documents identified by these groups include the Multi-Hazard Mitigation Plan, state Guide Plans, the state's Stormwater Design and Installation Standards Manual/Rules, and Providence development standards (e.g., zoning, etc.).

Floodplain Management: The city's Comprehensive Plan and Hazard Mitigation Plan have clear policies and action items designed to increase protection of flood-prone areas.

Recommendations

Stormwater Utility: Revisit the discussion of a regional, or even a statewide, authority for stormwater system funding and maintenance. This could mean restructuring/redefining the role of RIDEM, CRMC, and NBC, or creating a new entity. The political challenges, administrative complexity, and intricacies of the physical stormwater system make this task enormously complex. The agency responsible for coordinating stormwater at the state level could have the power to assess fees on a regional scale and maintain systems with both local and regional (i.e., NBC) components.

Predictive Modelling: State and local agencies/facilities operators must identify and agree to a predictive model around which to plan/regulate land use and facility operations planning. Rhode Island (RIDEM and CRMC) should consider using the STORMTOOLS modeling already developed or developing a flood risk model similar to what currently is being rolled out in Massachusetts.

Asset Management: While a regional approach is considered, the city requires the resources to implement a more "asset management" approach to both its wastewater and separate stormwater systems. This would include a detailed inventory of their drainage structures (age and condition), a schedule for routine maintenance and planned replacement/upgrades, a detailed budget for both routine and capital expenditures, and a revenue stream to support proper operation of their infrastructure now and into the future.

Nuanced Approach: The new MS4 permit could incorporate a more nuanced approach to the issue of stormwater management. Issues that could be considered include: a water quality-driven approach that prioritized the use of green stormwater infrastructure; a regional focus on the NBC service area; and threats to infrastructure based on predicted future flooding and inundation.

Combined Sewer Overflow Funding for Green Infrastructure: CSO Phase III implementation includes dedicated funding for green infrastructure design and implementation. Efforts to undertake more intensive planning to identify sites at the municipal level would be beneficial, with results coordinated with NBC.

Further Assessments of Risk: Conduct a risk assessment to determine the degree to which storm-related inundation would compromise stormwater outfalls or other low-lying infrastructure.

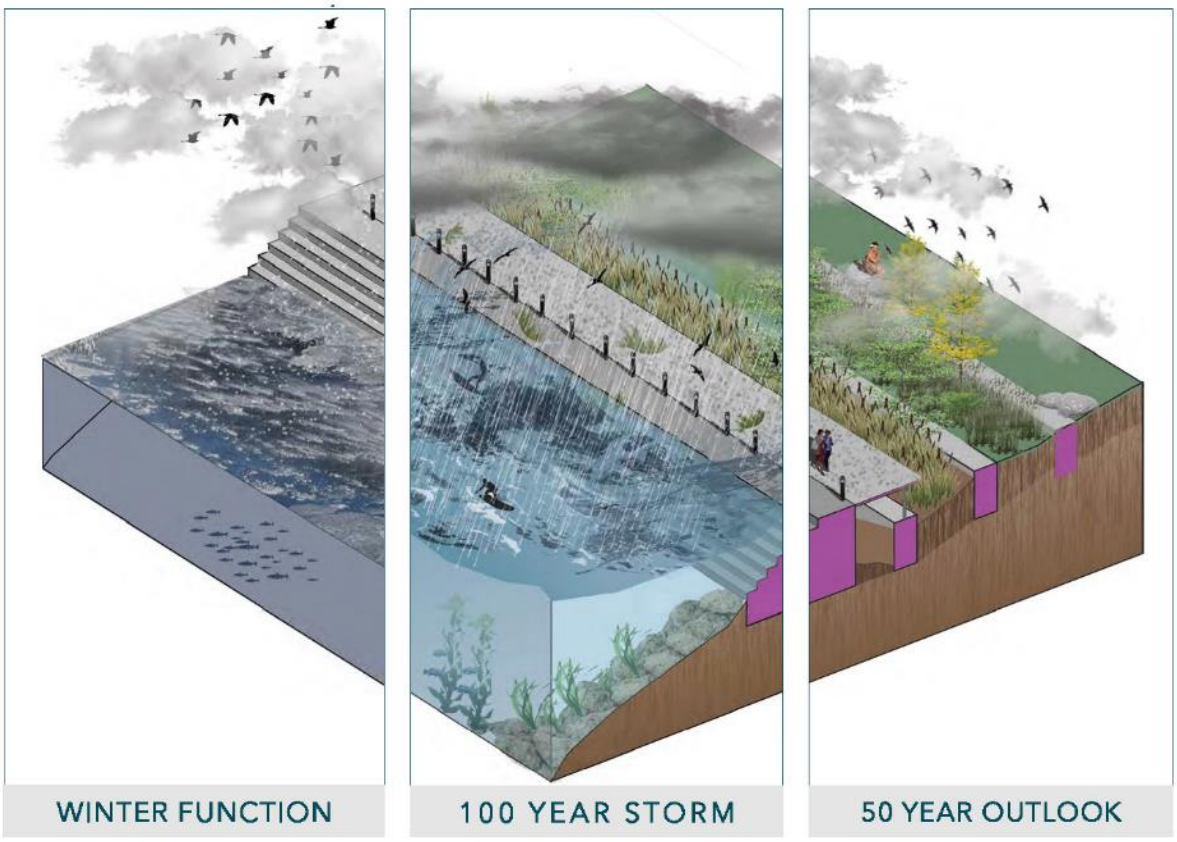


Figure D-4. Creative Solutions to Stormwater Infiltration with Shoreline Stabilization, and Waterfront Access. While the design does not prevent inundation from a 100-year storm, it is designed to be resilient to such events and reduce stormwater contamination to the river (URI, 2018).

Providence Port Area

Overview

The port area of Providence has existed for hundreds of years, serving a globally important role during the 19th century Industrial Revolution and into the early 20th century heyday of manufacturing. Even with the decline of traditional manufacturing in the country, the port area has continued to support the Northeast Region. With some of the only state waters in Rhode Island designated as Type 6—i.e., for industrial use—and a federally managed channel with a 40-foot depth, it is the second busiest deep-water port in New England (ProvPort, 2020). Significant focus is dedicated today to planning how port facilities and assets can participate in new industries, such as offshore renewable energy and the development of windfarms.

The port area of Providence extends from the Fox Point Hurricane Barrier (Collier Point Park) at its northern end to Washington Park (Fields Point) at its southern tip, in

Key Findings

Several studies using predictive models effectively define the threat of coastal storms and sea level rise for the port area. Much less is known about how the threat of coastal storms and sea level rise will physically, economically, and socially impact the port area, the state, and the Northeast Region that it serves.

An understanding of and attention to threats—and taking action to build resilience—is uneven across port area stakeholders and decision makers.

The lack of a unifying agency, such as a Port Authority, may increase the difficulty of making decisions on investments in infrastructure that affect the port as a whole.

Ongoing Port/Community Working Group discussions are an opportunity to understand stakeholder concerns, assess vulnerability, and define actions that will advance all aspects of social and physical resilience.

Looking towards a 21st century economy, renewable energy can provide energy security while supporting the goal for Providence to be carbon-neutral by 2050 (RI Sea Grant).

addition to a section of East Providence, from Bold Point to Sabin Point. The area covers approximately 515 acres of land. Port-reliant businesses and adjacent communities are included in the area, including property (land and structures), totaling over $660 million in value, excluding East Providence (City of Providence DPD, 2019). This area is also home to Providence's regional wastewater treatment facility that services the larger region and local institutions, including Johnson and Wales University, Save The Bay, and the adjacent frontline communities of Washington Park and South Providence. Rhode Island Hospital, Hasbro Children's Hospital, and Women and Infants Hospital also are located close by.

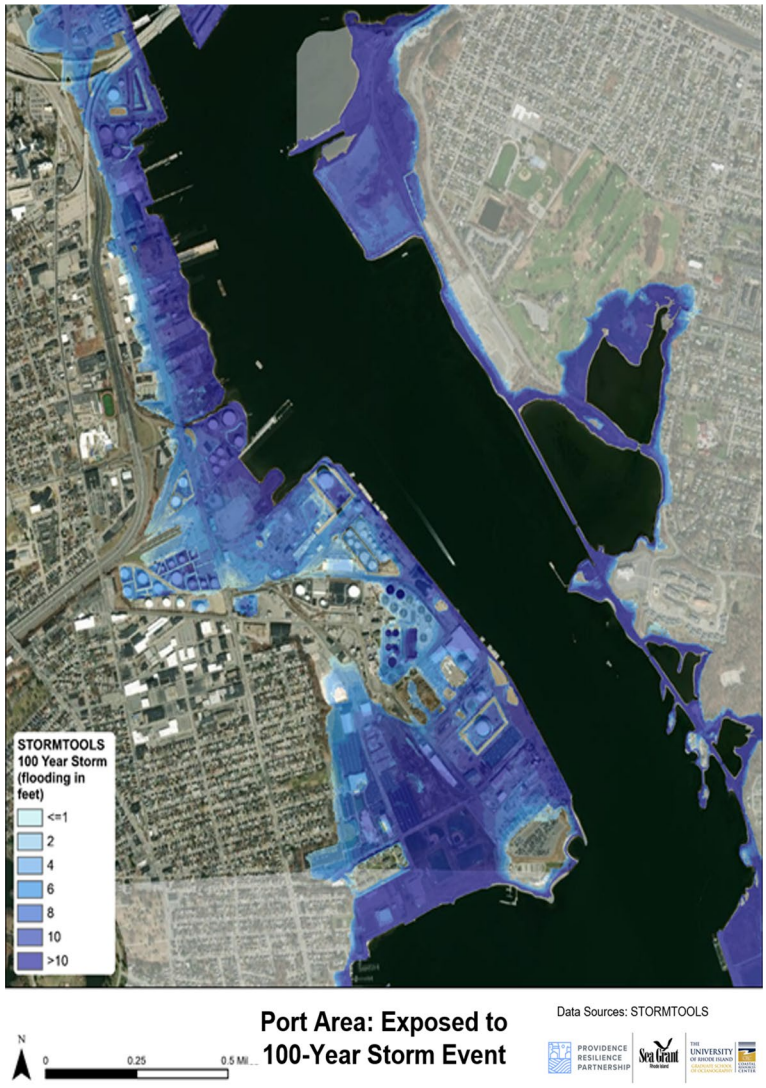


Figure P-1. Port Area Exposed to 100-Year Storm Event (STORMTOOLS).

By virtue of its location south of the Hurricane Barrier, the port area is extremely vulnerable to natural hazards and climate change impacts: from flooding tied to storm surge and rising sea; and from rising temperatures, which can impact frontline communities and port workers. On one hand, historic photos show tanks displaced during the Great Hurricane of 1938; on the other, the Fields Point Wastewater Facility still utilizes some of its original infrastructure. The impacts and consequences not of natural hazards not only affect port infrastructure, but the overall economic viability and social well-being of the entire low-lying area. Addressing these complex vulnerabilities requires policy, management, and leadership, as well as a collaborative undertaking by the port area community—government, the private sector, residents, community groups, and academia—to meet such challenges.

Situation

Location of the Port: Given its location, at the top of the bay and south of the hurricane barrier, the port area is exposed to storm surge from extreme storms including Nor'easters and hurricanes.

Key Industries: The area hosts many industries. Primary bulk products passing through the port include both imports (petroleum, asphalt, cement, liquified petroleum gas, coal, aluminum oxide, project

cargoes, and road salt) and exports (scrap metals, automobiles, and project equipment and materials). Several of these industries have been identified as critical infrastructure (PEMA, 2019).

Worth: The combination of businesses in the port area of Allens Avenue accounts for "$294 million in annual business sales, 372 workers; direct, indirect, and induced efforts for a combined total of $324 million in business output within the state; more than 700 jobs; and nearly $30 million in household incomes" (URI Coastal Resources Center, 2020). In addition, numerous ancillary businesses depend on the port's functionality. This includes trucking companies, rail service, manufacturing companies, ship repair facilities, marine pilots, and dredging companies—generating more than $200 million in economic benefits for the region and over 2,400 jobs (Resilient Rhody, 2018).

Dredging: As noted earlier, the section of the Providence River that serves the port area is designated Type 6, or industrial waters, by the state/Rhode Island Coastal Resources Management Council (CRMC). A $65 million dredging project two decades ago returned the commercial navigation channel to a depth of 40 feet (Providence Working Waterfront Alliance, 2007). Maintenance dredging through the U.S. Army Corps of Engineers (USACE) for the federal channels and for new confined aquatic disposal (CAD) cells will likely take place in 2021-2022.

Critical Community Energy and Utility Resources:

Fuel: Most transportation and heating fuel products for Rhode Island, eastern Connecticut, and parts of Massachusetts are supplied via marine shipments through the port area, which has petroleum storage tanks and a petroleum product pipeline that runs from the port to central Massachusetts (U.S. Energy Information Administration, 2020).

Liquid Natural Gas (LNG): A National Grid LNG processing plant, approved federally in 2018, is expected to be operational by 2021.

Wastewater Treatment: The Fields Point Wastewater Treatment Facility and combined sewer overflow (CSO) system serve the Providence metro area.

There are various entities that have jurisdiction, however there is no single entity that manages the entire port area. ProvPort, created in 1994 as a public-private partnership, is the largest entity and holds operating rights through 2036 when the land and improvements return to the City.

- ProvPort

Government and Stakeholder Roles in Port Management

Government Jurisdictions: The city of Providence has authority over land use and zoning. Its Harbor Management Commission, a citizen's advisory group, is responsible for preparing the harbor management plan, initiates studies related to management, and makes recommendations for policies, rules, and regulations. CRMC has permitting authority for projects within their water and adjacent land areas. The Rhode Island Emergency Management Agency (RIEMA) administers a disaster plan in coordination with the U.S. Federal Emergency Management Agency (FEMA) and other state agencies such as Rhode Island Department of Environmental Management (RIDEM). The plan to manage the heavy industrial uses within the port during a natural disaster includes actions for mobile command centers, an emergency operations center, and the Rhode Island Statewide Communication Network (RIEMA, 2018). The USACE maintains the Providence River and Harbor Navigation Project, taking the

lead for maintenance dredging and development of a Dredged Material Management Plan. The U.S. Coast Guard is responsible for all maritime search and rescue; manages the navigable waterways; oversees all foreign and domestic vessel inspections including commercial fishing, passenger, and cargo vessels; conducts marine facility inspections; and performs marine investigations in the port area and beyond (K. Blount, personal communication, January 12, 2021).

ProvPort Manages a Significant Portion of the Port Area: Today, port management is more piecemeal; a significant portion of the port area is operated by ProvPort, which is overseen by Waterson Terminal Services. ProvPort holds and manages its assets leased by the city of Providence through a public-private partnership with the city. At 115 acres, ProvPort is the largest port area entity. It provides shipping and the importing and exporting of commercial and industrial products, including cars, salt, cement, and chemicals. Tenants include New England Petroleum, Morton Salt, Univar, and Washington Mills. Outside of ProvPort, individual commercial enterprises in the area include nationally and regionally important businesses such as Shell, ExxonMobil, National Grid, Simms Metals, and Sprague Operating Resources.

Harbor Management Plan: The plan for the 2016 - 2021 period, submitted by the Providence Harbor Management Commission, addresses the management of the tidal waters of the city. The issues of specific focus are public access; water quality; mooring management; and shipping, navigation, and multi-use of harbor waters. Among many of the associated goals and policies, it is important to note that one of these is to “Promote resiliency, protection of water quality, compatible mixed use, and economic vitality in the port area.” Actions include development of a “green port” initiative, compliance with hazard mitigation and debris management regulations, and cooperation with the harbormaster to manage cleanup after storms (City of Providence, 2015).

Port/Community Working Group: Initiated in 2018, this ongoing engagement of port, community, government, and nongovernment organizations acts as a forum for discussion and a clearinghouse of information on initiatives. These include projects addressing air quality, truck traffic, safety, waterfront access, environmental best practices, and environmental justice. Interest has been expressed about climate resilience, including emergency planning and hurricane preparedness (Port Area Working Group, personal communication, June 15, 2020). It has provided a springboard for future Green Justice Zone and Climate Resilience Hubs, as promoted by the Climate Justice Plan (City of Providence, 2019), as well as project initiatives related to diesel engine truck replacement and air toxics monitoring through RIDEM.

Problem of Aging Infrastructure: Some of the port infrastructure—structures (such as bulkheads and piers), buildings, and equipment—is severely in need of renovation, with more study needed to determine which assets are aging and out of compliance with updated building codes (Becker, 2015).

Future Plans: As noted, efforts are underway to identify opportunities for the port area to participate in commercial wind farms and offshore renewable energy development across the northern Atlantic seaboard. Specifically, the Ørsted and Eversource plan to invest $40 million in Rhode Island for local port improvements, aiming by 2023 to establish the Port of Providence as a major construction hub, with hundreds of new construction, permanent operations, and maintenance jobs (IBES & URI, 2019). Similarly, a concept for South Quay, a 36-acre site along the shoreline in East Providence, is being promoted as a staging area for offshore wind construction, with the state aiming to support a port study and commitment of multimillion tax credits for the proposed project.

A significant portion of the region's critical facilities and coastal infrastructure located in the floodplain is not protected or was built before the current building standards were adopted in the 1970s.

- Becker, 2015

Climate Challenges

Risk to the State and Regional Economy: A port area compromised by climate change impacts tied to flooding and exacerbated by wind and heat could pose problems for the state and regional economies. It could hinder work for many, interrupt the provision of fuel and electricity to homes and businesses, expose hazardous materials, and deter investors from commercial and community development efforts (Resilient Rhody, 2018).

Low-lying Facilities at Increasing Risk of Flooding: Extreme high tides will increasingly become nuisance flooding to port infrastructure, with implications to operations. Older buildings and structures that do not meet today's flood elevation codes will be especially affected as sea levels rise with daily tidal flows.

Focus on Critical At-Risk Infrastructure: As noted, the port area hosts a concentration of infrastructure—from a wastewater treatment plant to electrical resources; to facilities for gasoline, diesel fuel, and heating oil; to the port piers themselves. Much of that infrastructure is located within the floodplain and vulnerable to flooding from strong storms and sea level rise (Becker, 2015).

Major Facilities	Sea Level Rise Inundation, Cumulative Rise (acres)		
	1 ft	3 ft	5 ft
TOTAL PORT	5.5	12.1	32
Abhu Mehri			0.9
Exxon Mobil (E. Prov)	0.9	2.8	8.7
Glen Falls			0.1
Goodison		0.2	1.6
Hudson		0.1	0.2
Keyspan LNG		0.1	0.4
Motiva	1.8	4	7.3
Simms	1.8	2.2	5.5
Providence Steamboat			0.1
ProvPort		0.2	0.7
Sprague	0.1	0.2	0.7
Wilkes Barre (E. Prov)	0.8	1.6	2
Waterson	0.1	0.6	3.5

Figure P-2. Major Commercial Port and Harbor Facilities Affected by Sea Level Rise (RISP, 2015).

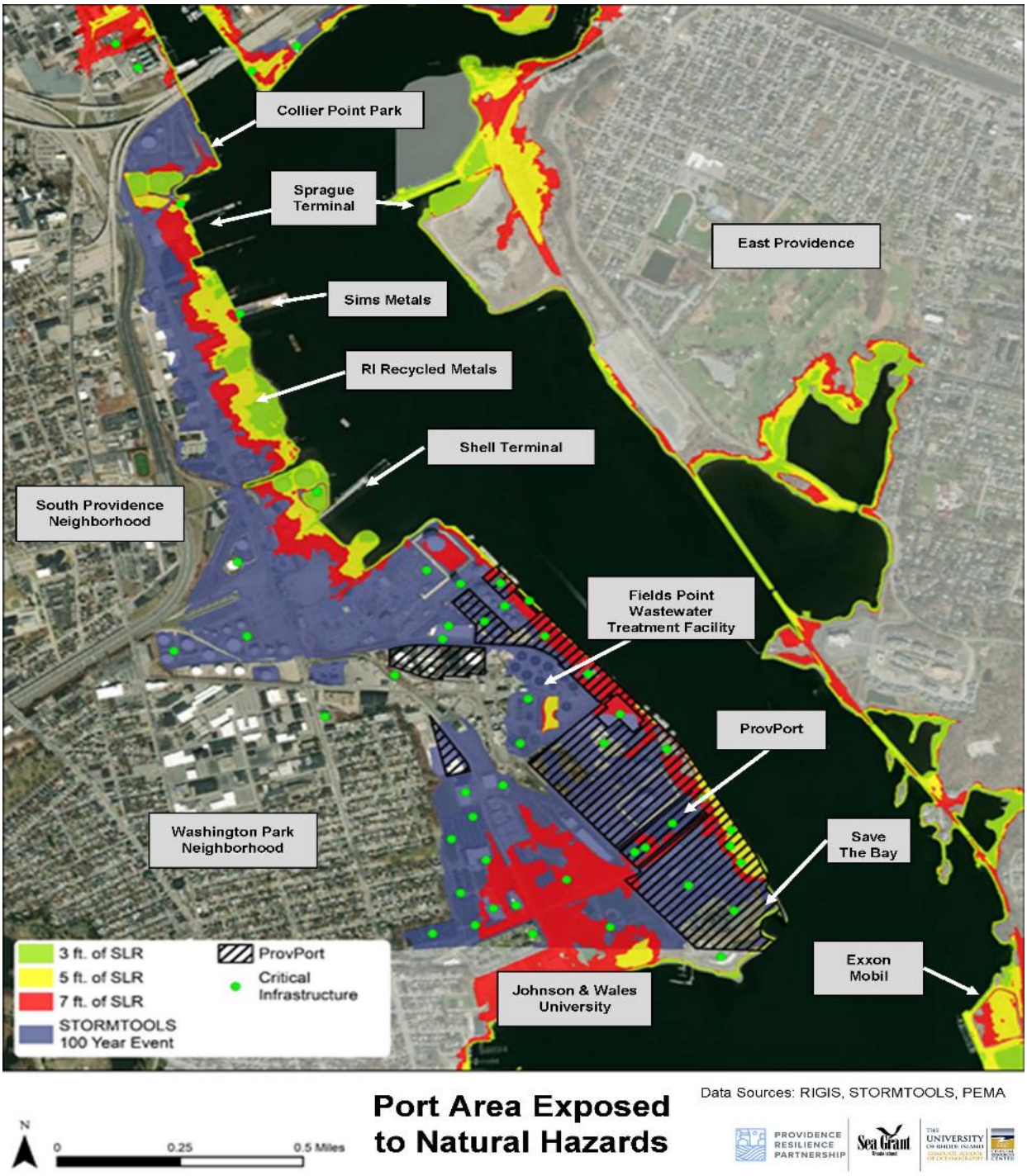


Figure P-3. Port Area Exposure to Natural Hazards. Given current sea level rise and storm projections, the port area is among the most exposed regions to flooding in Providence.

Risk to Storage Tanks with Hazardous Materials: A preliminary study of the University of Rhode Island (URI) Ocean Engineering (OCE) capstone analyzed 101 above-ground storage tanks for exposure and potential damage to flooding from storms and sea level rise scenarios. Used for storage of fuel oils, liquid asphalt, and natural gas—among other hazardous materials—the tanks varied in design and their mitigation measures to reduce flooding and/or contamination from spills. Analysis using the state's STORMTOOLS models revealed that the area around 60% of the tanks would be inundated during a 100-year storm. Adding sea level rise to the storm for future scenarios, this increases to 74% and 98% inundation with projected 5 feet and 10 feet of sea level rise, respectively. Evaluation of risk for failure confirmed that the tanks' internal liquid height was a key critical element for determining damage potential with surrounding flooding (URI, 2019). The Harbor Management Plan's risk assessment addresses spills of hazardous materials-related flood/surge threats as well as a short-term preparedness, response, and recovery plan (PEMA, 2019).

An oil tank floated to the center of the road by the 1938 Hurricane Storm Surge in East Providence (NOAA).

Multiple Vulnerabilities for Frontline Communities in the Port Area: Climate change impacts stand to be intensified or multiplied for the port area neighborhoods of South Providence and Washington Park. While not directly vulnerable to flooding, transportation access to/from residential neighborhoods is vulnerable to coastal and urban flooding. The communities are also at risk from the "heat island" effect tied to blacktop and impervious surfaces and from industrial pollution that affects air quality. In addition, residents in these communities are more likely to suffer health complications and to lack food, shelter, fuel, transportation, and healthcare resources and access during emergencies (City of Providence, 2019).

Efforts to Increase Resilience

Protecting and Adapting Structures and Infrastructure

Vulnerability Studies: There are three useful studies for port area vulnerability issues:

- A statewide study of effort on transportation assets at risk from sea level rise and storm surge included the port (RISPP, 2015);
- A URI wastewater treatment facility study modeling effort projected the potential wave inundation and damage to the wastewater and hazardous material storage facilities (URI, 2019); and,
- The city's Multi-Hazard Mitigation Plan includes port and critical infrastructure risks in their assessment and recommendations (PEMA, 2019).

Adaptive Design: The new wind farm trans-shipment facility in East Providence's South Quay is designed to flood and be back in business when the water goes down. For example, the area is being elevated three feet, all buildings will be off site with only a guard shack set back from the water, and underground utilities are made to flood (D. Goulet, personal communication, November 12, 2020).

Storm Risk Management Alternatives: The port area is included in the USACE study initiated in 2019. Discussion with stakeholders and a preliminary review of ProvPort, other industries, the Fields Point Wastewater Treatment Facility, above-ground storage tanks and other infrastructure led to a list of alternatives currently being studied further by the USACE. The study is based on a 50-year horizon, focused on coastal storm risk within the scenario of projected sea level rise. It considers alternative measures to reduce risk to this infrastructure, both structural (e.g., bulkheads) and nonstructural (e.g., elevating or flood-proofing individual structures). The study also will include a review of the likely economic impacts of these measures, first understanding the overall economic value of this area—beyond just property and structure values (USACE, July 2020; M. Riccio, August 14, 2020). Follow-up action and potential federal funding will depend on the cost-benefit analysis that emerges from the study.

Figure P-4. Fields Point Barrier Concept. Simulation based on design used in Rotterdam (Becker et al., 2017).

Stakeholder Engagement Identified Adaptation Options: Interviews and workshop activities with area businesses in 2015 evaluated options for adaptation. Thirty stakeholders considered options including business relocation, incremental improvements, and building a new storm barrier; participants generally agreed that a storm barrier at Fields Point would be best suited to meeting their business goals and reducing hazard risk (Becker et al., 2017).

Protecting and Adapting Structures: Some efforts or dialogues concerning facilities and infrastructure:

Hurricane barrier/port stakeholders generally indicated that if given the choice between relocating a business, implementing incremental improvements for their facilities, or supporting a new storm barrier at Fields Point, their choice would be the storm barrier (Becker et al., 2017).

Both Save The Bay and Johnson & Wales University adapted design plans to include measures, such as green infrastructure and increased elevations, to protect buildings from flooding associated with strong storms and sea level rise.

Stakeholder and Leadership Focus: Information useful for port area constituency building:

Port area businesses: While port businesses are generally aware of how to prepare for an approaching hurricane, many have not yet undertaken preventative or adaptive measures to protect buildings and assets from storm, tide, and sea level rise flooding (Becker et al., 2017).

Leadership for port area resilience: A gap is likely due to, at least in part, piecemeal or patchwork management of the port area (Becker et al., 2017; Kretsch & Becker, 2016).

Frontline communities: RIDEM, with funding from the Environmental Protection Agency (EPA), is leading a collaborative Green Justice Port Initiative to expand dialog and capacity building with the diverse communities of Washington Park and South Providence and to discuss environmental issues of concern in and around the Port of Providence (E. Stone, personal communication, October 28, 2020). The Port/Community Working Group has discussed the absence of a concerted approach to hazard mitigation and response, as well as the possible need for an overarching authority (D. Everett, personal communication, January 4, 2021).

Reducing Environmental Impacts

Green Marine Certification: Waterson Terminal Services, terminal manager of ProvPort, undertook this multi-year environmental certification program in 2018 so it could reduce environmental impacts of port-based operations—with benefits to water, air, and the neighboring communities. Green Marine is a voluntary initiative by the maritime industry in the U.S and Canada. Annual benchmarks are recorded and independently verified, including measures of cargo residues, community impacts, pollutant emissions, and prevention of spills and leakages (ProvPort, 2020).

Stormwater Treatment: ProvPort worked with RIDEM, starting in 2016, to introduce stormwater mitigation measures at impervious surfaces at the site. An example would be a sediment boom barrier on dock edges that catches solids before stormwater overtops into the river (Anderson, 2018).

ETHOS and the Port Area: The port could be one of the focal initiatives of the Energy Transformation Hub of the Ocean State (ETHOS). The coalition will focus on energy equity and is tasked with identifying and applying renewable technologies to solve energy problems across the state. ETHOS is an initiative of The Partnership for Rhode Island—a CEO roundtable of the largest employers in the state, in collaboration with National Grid and the Ørsted energy company—that seeks to address the

2030 energy renewable goals set forth by Governor Gina M. Raimondo (T. Giordano, personal communication, August 24, 2020).

Recommendations

Research

Economic Valuation Study Needed for Informed Decision Making: A detailed economic valuation to capture the full value of the port area, including a cost-benefit analysis, would improve understanding for informed and effective decisions about the port area and the barrier. Specific inquiry into the consequences of a "port shutdown" is critical for the city, state, and Northeast Region that the port serves (Becker & Caldwell, 2015; RI House Commission, 2016; C. Waterson, personal communication, October 28, 2020).

Complete Ongoing Risk Assessment and Strategy: Support efforts of the USACE, in collaboration with the city, port area businesses, and the congressional delegation to complete the Rhode Island Coastline Coastal Storm Risk Management Study and initiate financial and implementation planning. This assessment would benefit from a more detailed economic evaluation, as identified above, to accurately evaluate the most feasible alternatives.

Structures

Protect Fuel Terminals: Ensure fuel terminals have undertaken all appropriate hardening and resilience measures and have made provisions to restore operations after storms. This includes continuing strategic long-term planning for improving the resilience of marine terminals (Resilient Rhody, 2018). Evaluate the strength and resilience of fuel storage tanks (URI, 2019), as well as the potential for a microgrid program that could keep resources above storm surge level (RIOER, 2017). Any studies focused on improvements for the port area or the hurricane barrier (Becker et al., 2017) would significantly inform protection activities.

Promote the Use of Resilience Designs and Construction: State policy currently requires analysis of potential future coastal hazards—including sea level rise, storm surge, and erosion—for projects on a coastal feature or within a 200-foot contiguous area (CRMC, 2019). It is important to encourage designers and project proponents to consider opportunities to exceed the CRMC Coastal Hazard Application Guidance requirements and incorporate even more stringent design standards to withstand conditions throughout a project's design life.

Stakeholders and Leadership

Consider a Lead Authority: Evaluate the need for a lead agency or authority to oversee port resilience, safety, and community/environmental impacts of port operations. This builds upon past discussions and current engagement of the Port/Community Working Group, while supporting the coordination of stakeholders (Becker et al., 2017).

Engage Port Business Community in Early Wins: Engage the business community so it can undertake early, cost-effective resilience activities, including backing up computer data, attending

hurricane preparedness meetings, developing business continuity plans and retrofitting assets to flood- and wind-proofing facilities. Compiling the standard resilience measures in a database would allow alternatives to be indexed and assessed by businesses (RI House of Representatives, 2016, Becker et al., 2017).

Leverage Opportunities for Collaboration and Social Justice: Build upon existing momentum with the port's frontline communities to advance the Green Justice Zone and Resilience Hub through combined efforts of government, business, and community entities. Community-serving facilities already in existence could be augmented or leveraged to support residents and coordinate resources distribution and services before, during, or after a natural hazard event (City of Providence, 2019).

Reducing Environmental Impacts

Support Development of Green Port Initiative: This initiative could encourage operators to adopt best practices in stormwater management, green infrastructure, renewable energy, air quality, and public access among others (City of Providence, 2015). Build on the RI Blue Economy priorities to articulate a vision and establish green, smart, and resilient ports (URI CRC, 2020). Ongoing collaborations provide a foundation for a Green Port for building offshore renewable energy support facilities, expansion of Green Marine Certification to more entities, and use of renewable energy to support the port and its functions.

Focus on Collaboration for Environmental Health: A public process with private sector participation would focus on creating a long-term vision for fostering environmental and social health, including resilience building, for the port area and surrounding frontline communities (City of Providence, 2019).

Revisit Hazardous Materials: Consider issues that include potential restriction of the import and storage of hazardous and polluting materials in the port area, with a goal to phase out such materials by 2040. Also consider a potential increase in import fees for fossil fuels, with revenue designated to support frontline communities (City of Providence, 2019).

Expand Welcome to Clean Energy Business: Continue efforts to ensure the growing offshore wind industry can use Providence's industrial waterfront to site supply chains (City of Providence, 2019).

Downtown

Overview

Having suffered historic flooding from strong 20th century hurricanes, the downtown area of Providence has since benefited from the protection of the Fox Point Hurricane Barrier. Downtown—a center, and crossroads of activity for all city residents—continues to serve as Rhode Island's primary urban hub for government, transportation, financial and educational institutions, and cultural and social activity. It also provides significant tax revenue for the city. While built to keep strong storms from flooding Downtown, the barrier may not be equipped to manage inundation heightened by projected sea level rise. Providence, in concert with state and federal partners, is increasingly considering how best to support barrier infrastructure, while also promoting the role of community education and other initiatives in reducing risks tied to the Providence waterfront flooding as a result of climate changes. Downtown, along with the port and areas of Fox Point, are the most vulnerable to future daily projected inundation from rising sea levels.

Key Findings

Downtown, a hub for the city and state alike, is currently designated by FEMA as an 'area of minimal risk flooding' from the .2% annual chance (500-year) flood. The Fox Point Hurricane Barrier, reconditioned over the last decade and operated by the federal government in partnership with the City, affords protection to 'design' floods from hurricanes and other coastal storms that will likely threaten Providence over the next several decades.

The low-lying areas that characterize much of Downtown are vulnerable to more frequent, higher, chronic tidal flooding with increasing sea levels. The majority of the city's infrastructure that is at risk from sea level rise—its roads, bridges, and buildings—are located Downtown. Used intermittently to reduce tidal flooding, the hurricane barrier is not designed to operate on a regular basis for this purpose.

Developing a predictive modeling capability for combined future risk (and its implications for infrastructure, business, and society) from sea level rise, storm surge, precipitation, and riverine flooding from hurricanes and other storms is complicated but necessary. Two complicating factors, the presence of the barrier and the city's coast/river geography, are key components of effective modeling and assessment for Downtown and Providence as a whole

Situation

Economic Hub for City and State: Downtown—which includes the old Downcity, the Capital Center, the Jewelry District, and the Innovation & Design District (aka Jewelry District)—is the economic hub for the city and the state, with government, private sector, academic, cultural, historical, and community assets. Measuring more than 150 acres, these areas are slated for growth (City of Providence, 2014). The emerging Innovation & Design District is a hallmark of the Interstate I-195 relocation project and is host to significant new developments such as the new commercial building, Point225, developed by Wexford Science & Technology. These Downtown districts are located behind the barrier and consequently benefit from the reduced risk of storm surge flooding and associated floodplain management building standards.

Geography of Downtown: The downtown area is located at the head of Narragansett Bay, behind the Fox Point Hurricane Barrier, and is characterized by its riverine location at the convergence of the Providence, Woonasquatucket, and Moshassuck Rivers. This low-lying floodplain is thus prone to

Downtown Riverwalk provides multiple benefits for the city related to public access, stormwater management, and a buffer for buildings at risk from future sea level rise (RI Sea Grant).

flooding from tides and rivers as it lies at the bottom of the watershed basin and is also prone to localized upland stormwater flooding.

Recognition of the Environment, History, and Culture: Paved over in portions during the 1950s, the Providence River has since been reinvigorated, with several major public-private efforts focused on enhancing the downtown area, including the riverfront park system, which provides multiple benefits including locating buildings away from the low-lying waterfront. The district was "designed to direct Downtown development, protect historic and architectural character, encourage round-the-clock pedestrian activity, promote the arts and entertainment, and support residential uses" (City of Providence, 2010). Similarly, the developing Innovation & Design District will feature a mix of uses, as well as adding a new, nearly 7-acre park built along the river in the most vulnerable area of the I-195 Redevelopment District. Events such as WaterFire contribute to the vibrancy of Downtown and build upon these assets to bring economic benefits, tourism, and international recognition, as well the motivation to support a healthy riverine environment accessible to the entire community.

A Protective Barrier: The Fox Point Hurricane Barrier, put into service in 1966, was built in response to the 1938 Great New England Hurricane that devastated the downtown area with over 16 feet of storm surge above mean sea level (MSL), followed by Hurricane Carol in 1954. The barrier is designed to reduce risk of flooding behind it—including Downtown—from coastal surge tied to strong storms such as hurricanes and has since prevented over $3 million in damages (USACE, 2017). In fact, modeling shows that if the barrier was not built (or not functioning), a major storm (e.g., the 100-year storm of 1954) could impact more than 600 structures behind the barrier, with a third of them being damaged by over 50% (URI, 2018a). The barrier's effectiveness today is dependent on the active management,

maintenance, and monitoring by the federal government in collaboration with the city (see the Infrastructure and the Environment and the Hurricane Barrier sections for more information.)

Flood insurance is not required, however is encouraged to protect the risk: Due to its location behind the barrier, much of Downtown is designated as 'shaded-X' areas. For areas with this designation, flood insurance is not required, and properties are not required to meet FEMA's minimum regulatory standards for the National Flood Insurance Program (NFIP). NFIP is administered and enforced at the local level, most commonly through building codes. Therefore, the city of Providence and the state of Rhode Island (where applicable on state-owned property, including land owned by the I-195 Redevelopment District) can suggest and/or require flood-resistant design standards even though this is not required by FEMA and as long as these standards do not conflict with other state building codes. Similarly, lenders may still require a borrower to obtain flood insurance even though it is not required through the NFIP. In fact, FEMA also strongly advocates that properties within a shaded-X area still obtain a subsidized policy to protect their property, which would be insured for damages in flood events that fall under FEMA's definition (J. Dwyer, personal communication, December 9, 2020).

Flood Standards Behind the Hurricane Barrier

The barrier is considered an "accredited levee" by FEMA standards. Based on its design, it is expected to provide sufficient protection of the 'shaded-X' areas on the map during a flood with a base flood event, i.e., one that has a 1% annual chance of occurring (the 100-year flood). The accreditation distinction is important, as flood insurance is not required in a shaded-X zone, while flood insurance would be required for those areas if the barrier was not an "accredited levee". Additionally, X zones (.2% annual chance or 500-year flood areas), including shaded X zones, are not considered part of the regulatory Special Flood Hazard Area (SFHA). This means properties within a shaded-X zone are not required to meet FEMA's minimum regulatory standards for the National Flood Insurance Program (NFIP). Refer to FEMA's Living with Levees for more information on accredited levees and shaded X zones and insurance requirements for shaded-X zones

- J. Dwyer, RIEMA

Climate Challenges

The protection of Downtown provided by the hurricane barrier has shaped its development and activities over the past half century. The collaborative maintenance and operation over the past decade provide security of continued protection. The design in the mid-19th century considered protection from coastal surge like that of Hurricane Carol, together with heavy rainfall and riverine flow. This design was considered overly conservative at the time. However, it did not consider the effects of climate change in the years ahead—i.e., with increases in sea level, storm intensity, and rainfall. Today the preferred approach is to look forward and project scenarios for decades ahead. Such efforts, as discussed below, support the need for more expansive and updated assessments in order to make more effective long-term decisions.

Stronger Storms: Storm intensities are increasing; recent hurricanes throughout the Atlantic basin have shown excessive precipitation, with slower storms staying over land for longer periods, resulting in increased riverine and localized street flooding.

Figure D-1. What Would Sea Level Rise Look Like in Providence? A simulation, based on the average high tide today (left), illustrates future high tides with 3 feet (middle) and 7 feet (right) of sea level rise (RI Sea Grant, 2007).

Rising Seas, Two Tides a Day Every Day: Since 1938, sea levels have risen almost 9 inches in the city; local tide gauge records indicate that the rate of rise has accelerated over the past three decades (PEMA, 2019). Future projections for Rhode Island, adopted by the Rhode Island Coastal Resources Management Council (CRMC), track the projections of the National Oceanic and Atmospheric Administration (NOAA), which are updated as the global science warrants. Projections for Rhode Island are currently for 3 feet of rise by 2050, 7 feet by 2070, and 10 feet by 2100 (CRMC, 2018). Models focusing on areas behind the barrier indicate that the tipping point for building impacts behind the barrier in Providence is projected at 5 feet of sea level rise, where 26 structures (citywide) would sustain permanent damage. This increases to 184 buildings and 363 buildings at 7 feet and 10 feet respectively in the low-lying areas behind the barrier. These buildings would be inundated twice daily due to high tide levels and, as such, are considered completely inoperable (URI, 2018a). The majority

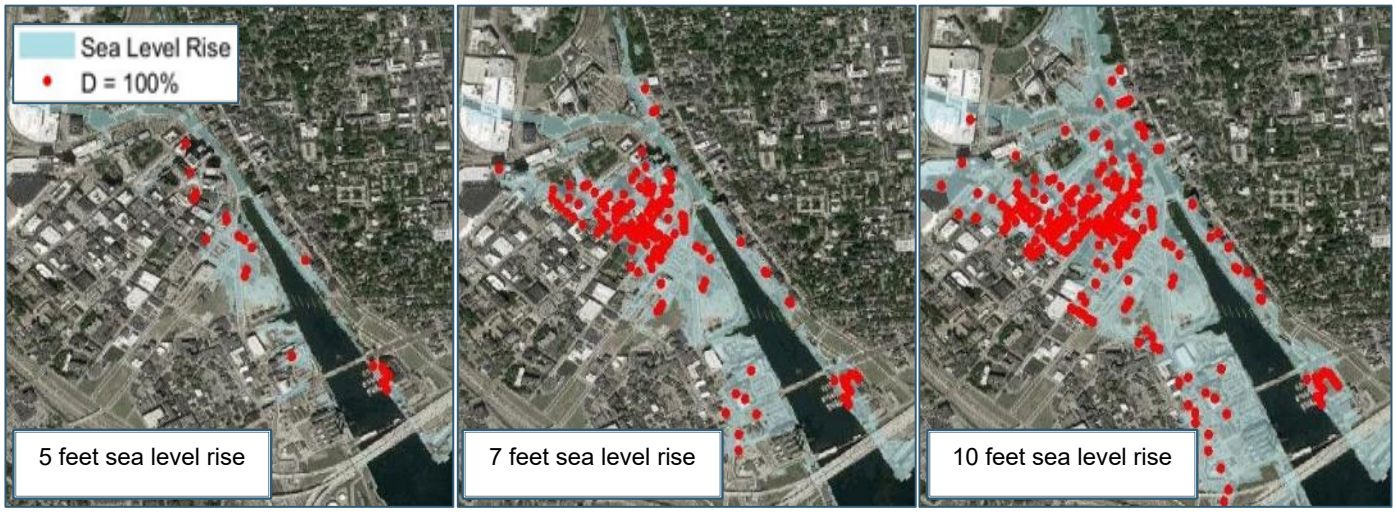


Figure D-2. Projected Damages to Buildings from Sea Level Rise Downtown. The number of buildings behind the barrier that are projected to be damaged 100% increases with sea level rise scenarios: 5 feet rise (26 buildings), 7 feet rise (184 buildings), and 10 feet rise (363 buildings) (URI, 2018a).

of these buildings are in Downtown and, to a lesser extent, the areas along the Woonasquatucket and Moshassuck Rivers.

Nuisance flooding at Waterplace Park is increasing in frequency, where projected flooding like this may be a daily occurrence by around 2035 (J. Boyd, 2015).

Sunny Day Flooding: High tide flood days (i.e., flood thresholds at 1.8 feet above mean higher high water (MHHW), often referred to as 'sunny day flooding' or 'nuisance flooding,' will increasingly impact low-lying parts of the downtown area with projections of 5 to 10 days for 2020, 15-30 days for 2030, and 40-105 days for 2050 (NOAA, 2020). Occasional nuisance flooding will become chronic where areas will experience tidal flooding—two tides a day every day—that will impact structures, roads, and many Downtown activities critical to the city.

Barrier Issues—Design Context

The value of the barrier to Downtown: The value of the barrier perhaps is best seen by looking at a hypothetical scenario without the barrier in place today. If a 100-year coastal storm hit today and the barrier were not in place, modeling shows that over 600 structures would be damaged by storm surge, with over a third incurring greater than 50% structural damage. This damage projection increases with

Downtown Risk is Tied to the Hurricane Barrier

"Whether the barrier will continue to protect against future storm surge is very sensitive to the sea-level rise projection used. If a low-probability, high sea-level rise projection is used, then the optimal strategy is to build a new, taller barrier by the end of the century. However, under the highest-probability, lower sea-level rise projections, the existing barrier is expected to be cost effective in protecting the city from storm surge well into the 22nd century (assuming it can be maintained past its design lifetime).

The analysis suggests that a decision about any future hurricane barrier must be made by around 2050, giving city leaders time to focus on other climate challenges."

"A key emerging challenge is the increase in the frequency of tidal flooding (so-called nuisance flooding). Tide heights that prompt a precautionary closing of the barrier occur about 10 times a year today, but they would occur more than weekly by 2050 and twice daily by 2100. While the Fox Point Hurricane Barrier can be used to mitigate nuisance flooding through 2100, questions remain about whether the barrier can withstand near-constant use.

To defray much of these operating costs, construction of sea walls to prevent nuisance flooding in low-lying areas of the city (the examined alternative) should optimally begin in 2040 – 2050."

- Analyzing Coastal Flood Protection Strategies for Providence (C2ES, 2016)

future sea level rise added to the storm surge (URI, 2018a). This type of assessment has not been developed for these same scenarios using the assumption that the barrier is functioning (see the Hurricane Barrier section for more information).

Stronger hurricanes combined with sea level rise: The barrier was designed to accommodate a Category 3 storm, similar to Hurricane Carol in 1954 (J. McPherson, personal communication, June 18, 2020) and comparable to FEMA's 100-year storm in Providence. However, maps indicate that a Category 4 storm, which has not been recorded to date in the Northeast, could overtop the barrier (PEMA, 2019). It should be noted that preliminary studies indicate that a 100-year storm—with 7 feet of sea level rise—can overtop the structure and cause it to fail (URI, 2018a).

Sea level Rise – Wear and Tear: The downtown area is vulnerable to sea level rise and the barrier was not designed in the mid-to-end of the century to accommodate today's projections for future storm surge or increasingly intense storm precipitation and sea level rise. There is concern as to whether the barrier, designed to protect the city from storm surge, can withstand near-constant use as a tidal gate to reduce flooding from high tides through 2100 (C2ES, 2016 and PEMA, 2019).

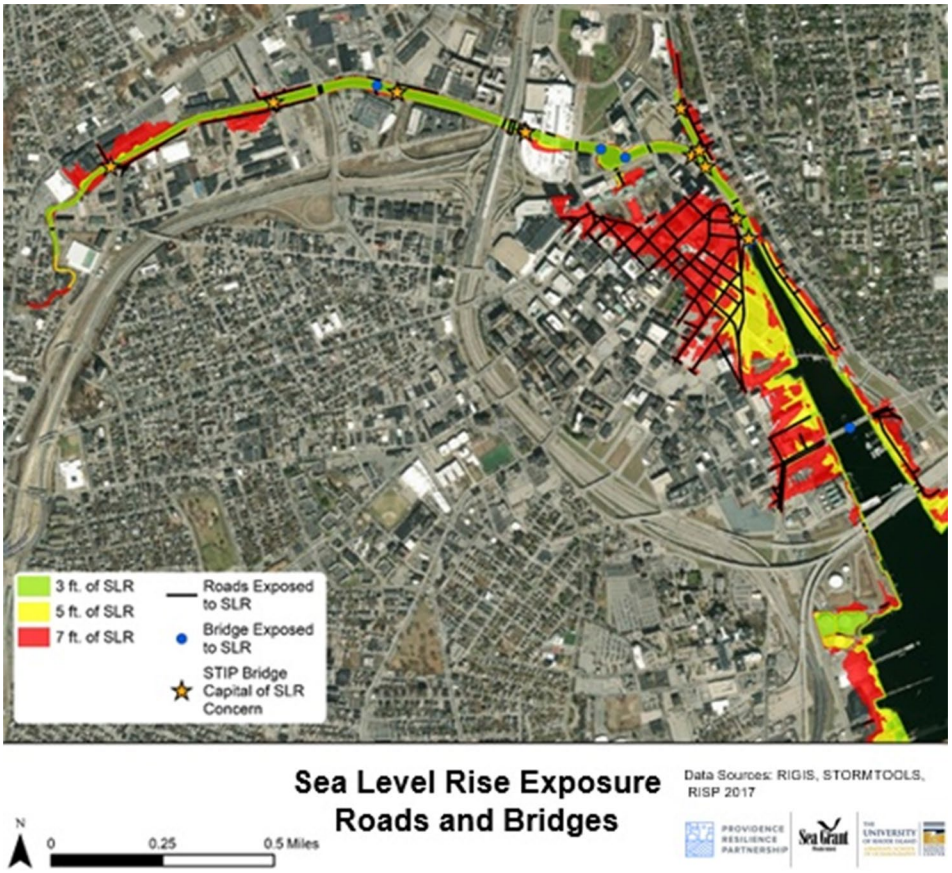


Figure D-3. Transportation Assets Exposed to Sea Level Rise. Most city roads at risk to rising seas are Downtown. Several at-risk bridges are scheduled for maintenance through 2021 on the State Transportation Improvement Plan (STIP).

Increased precipitation and river flow: With increasing storm intensities and precipitation, questions arise about the ability of the barrier to sufficiently pump riverine waters to reduce the river overflowing its banks. One recent University of Rhode Island (URI) research effort modeled a hypothetical, yet feasible, Hurricane Ram with 19 inches of rain over a 24–36-hour period flowing into the rivers and a surge of 14.8 feet above MSL. While this effort did not model the specific response and capability of the barrier, the findings showed that if all the pumps were functioning properly, they should be able to handle the projected river runoff; if the pumps do not operate properly, the water elevation north of the barrier will reach the top (~23 feet) in over a day after the hurricane makes landfall (I. Ginis and D. Ullman, personal communication, January 29,

2021). More study is required to model specific operational procedures and capabilities of the structure and its pumps tied to a broad range of storm scenarios that combine riverine and coastal risk, as well as increased storm intensity and rising seas.

Barrier Issues—Implications for Planning and Regulations

Different data sets: Rhode Island planning and regulatory agencies apply different tools and associated modeling scenarios. Rhode Island STORMTOOLS is used by CRMC for assessment and planning purposes. Meanwhile, other agencies use the FEMA modeling scenarios for implementing state building codes and flood insurance rates, which often indicate less flooding risk (see Hazards section for more information).

Statewide models and studies do not necessarily consider the barrier: STORMTOOLS, a statewide modeling tool for inundation from storms and rising seas, does not consider the presence of the barrier. While sea level rise projections are extremely instructive, the applications related to storm risk for the downtown area need to take this into consideration. Examples include CRMC's Coastal Hazard Application (CHA) (required for permitting projects within their jurisdiction), the CRMC/URI Coastal Environmental Risk Index (CERI) damage assessment tool, as well as assessments developed by state agencies to understand the vulnerability of transportation and wastewater infrastructure.

The barrier can be seen as an insurance benefit for Downtown structures: While flood insurance is still recommended, it is not required for most of the downtown area designated as areas of minimal risk for the .2% storm (X zones and shaded-X zones). However, the barrier is not designed to protect those properties from increased elevations of tidal flooding and chronic sea level rise.

More study needed: Additional modeling is needed to assess how well the barrier can continue to function under projected storm and sea level rise scenarios, as well as which potential enhancements could appropriately improve its performance in the future (see Hurricane Barrier section for more detail).

Underground Utilities: The integrity of underground utilities in low-lying areas such as Downtown are also an emerging concern. Some of the questions being raised involve the design of these underground systems and the ability of such systems to continue to function during power outages and emergencies (URI, 2018b).

Transportation Impact: With projected increases in the frequency of occasional extreme high tide flooding days and the height of daily high tides, flooding will become more of a chronic issue for roads and bridges in the downtown and surrounding areas. The 2015 study showed that a quarter of a mile of roads would flood at 3 feet of sea level rise, 1.4 miles at 5 feet, and almost 6 miles would flood at 7 feet of sea level rise. Most of the bridges in Providence projected to be threatened by future flooding impacts are located Downtown. Similarly, disruption in transportation services such as train travel and bus travel through RIPTA (Rhode Island Public Transportation Authority) will increase with time (RISP, 2016). (See Infrastructure and Environment section for more information.)

Critical Facilities: Many of the critical facilities such as healthcare/hospitals, universities, communication networks, and government offices (e.g., City Hall) are within the downtown area. As

identified in the hazard mitigation plan, these are currently in the floodplain and will have increasing exposure with higher seas and increasing storms (see Infrastructure and Environment section for more information).

Small Business: Small businesses exposed to flooding are especially vulnerable to business interruption or complete closure. There are approximately 7,000 small businesses in Providence, many of which are located Downtown. When considering both inland and coastal flooding, over 15% are impacted in moderate storms, while over 22% are impacted in severe storms. This modeling assumes no protection from the hurricane barrier (RPS, 2018).

Efforts to Increase Resilience

Expansion of the Waterfront Park System: Public-private efforts to expand river greenway areas increases open space in urban areas, while reducing flooding impacts by using green infrastructure and reducing impacts to buildings that otherwise might line the waterfront. Public access and natural habitats are also promoted by the CRMC Urban Coastal Greenway policy developed in the 1990s given their joint jurisdiction of waterfront lands. Integrating green infrastructure, such as the "rain gardens" adjacent to the river's Michael Van Leesten Pedestrian Bridge in the new Providence Innovation District Park, provide multiple benefits for resilience as well as community education.

Overt Efforts to Encourage Developers to Consider Impacts in their Designs: The I-195 Redevelopment District Commission oversees the redevelopment of approximately 20 acres of developable land made available when I-195 was relocated. There is a master permit with CRMC governing the build-out of the entire district, but it predates CRMC's 2018 regulation to review coastal hazards. The commission has taken steps to prompt developers to proactively think about how changing climate conditions will affect their proposed projects (C. Skuncik, personal communication,

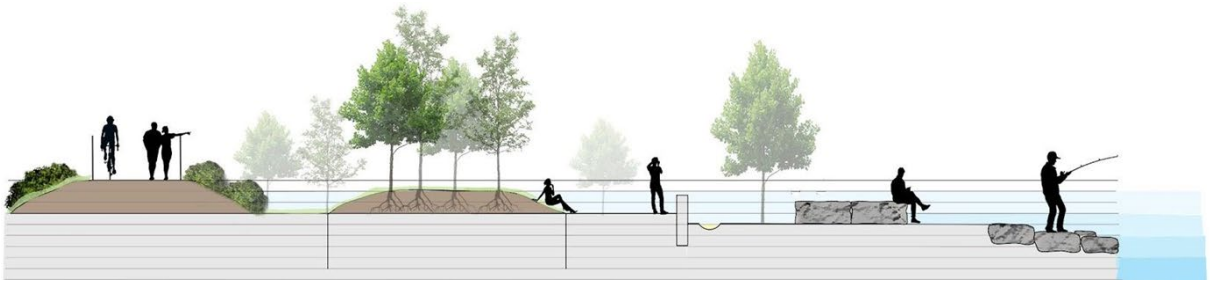


Figure D-4. Concepts for an Adaptive Waterfront Supports Rising Seas and Waterfront Access(URI, 2018a).

June 18, 2020).

Public-Private Workshop on Climate Resilience Planning: A collaboration of the city and the Center for Climate and Energy Solutions (C2ES), drew representatives from multiple city departments, local universities, businesses, hospitals, state government, and others who collaborated on a baseline assessment of Providence's preparedness for climate risks related to rising seas and the hurricane barrier. Their report emphasized the need for activities like a holistic look at climate resilience planning and a public engagement process to determine community tolerance for flooding from rising seas given

that the barrier is not designed to prevent tidal flooding on a daily basis (C2ES for the city of Providence, 2016).

Barrier Planning for the Future: Government, private sector, academic, and community interests have done cursory reviews to examine impacts and weigh options for retrofitting barrier components to accommodate greater flooding and increased usage. Further dialogue is also expected to focus on options for protecting those waterfront areas outside of the barrier's reach (see Hurricane Barrier section for more information).

Energy Reduction Efforts: Downtown entities participate in the RePowerPVD Energy Challenge Program, which includes two tracks—a 20% by 2025 energy reduction challenge; and the 'Race to Zero', a competition for aspiring zero energy buildings in Providence. Since its 2018 launch, 1.7 million square feet of real estate have enrolled in the energy reduction challenge. This includes a handful of city buildings, the Providence Housing Authority, the Marriott Downtown, buildings owned by Cornish Associates, and the Regency Plaza (City of Providence, 2018). Today the program is voluntary. However, there is a proposed ordinance to make the program a required element for large buildings.

> *These are "wicked problems", and they demand creative, innovative thinking to synthesize and evaluate complex scientific data, policy protocols, technical solutions, and social science dimensions. Design provides a means to visualize cultural values and new possibilities*
>
> *- RISD, 2019*

Adaptive Landscapes and neighborhoods: Landscape design is an effective approach to support community resilience by incorporating benefits of flood mitigation, green infrastructure, and public access. In 2019, a design competition of the CityWorks Collective, a participatory studio hosted by DownCity Design, resulted in the Living Edge installation along the Riverwalk on South Water Street to demonstrate how community resilience can be improved by integrating flood mitigation, green infrastructure, and public access. In 2018-2019, student practicums from the Rhode Island School of Design (RISD) and URI focused on adaptive approaches for shorelines and adjacent areas by considering changes to the natural and built environment together within the context of the community. A Coastal Futures event, hosted by RISD in April 2019, brought together a multidisciplinary group of experts and students to discuss and roll up their sleeves to address the innovative ways to preserve coastal environments and live in areas with rising seas, within a context of achieving sustainable and habitable communities.

Recommendations

Planning, Collaboration, and Decision Making

Stakeholder Priority Focuses on Holistic View: Input from private and public stakeholders in 2017 revealed a priority for the city to take a holistic look at climate resilience planning, understanding that inland, tidal, and storm surge flooding can interact to impact the downtown and riverfront areas (C2ES, 2016).

Keep Deadline in Mind: An analysis of costs of different strategies suggests that a decision about the future of the barrier and/or alternatives for addressing sea level rise impacts must be made by around 2050 with stakeholder discussion and inclusion (C2ES, 2016 & PEMA 2019). Such decisions require extensive assessment on the barrier, protection and adaptation alternatives, and flooding conditions—all of which will take time, funds, and leadership to implement in the coming years, long before the 2050 target.

Collaboratively Monitor and Evaluate the Efficacy of the Barrier: As a component of the five-year updates for the city's Multi-Hazard Mitigation Plan, monitoring of climate change should inform the timing of decisions about the future of the barrier and/or alternatives for addressing sea level rise impacts. The analysis suggests that a decision about any future barrier must be made by around 2050 (C2ES for the city of Providence, 2016 and PEMA, 2019). (See the Hurricane Barrier section for more information).

Today's occasional nuisance tide provides a glimpse of what in the future might be dally tides, 1.6 MHHW (Boyd, 2014).

Examine Public Tolerance for Flooding: A public engagement process should be undertaken to determine the community's tolerance for flooding along the Riverwalk. The process should focus on whether the community wants to invest in sea walls (and accept the resulting change in character to low-lying waterfront areas) or maintain current views and character and accept periodic flooding. This question comes from the model's finding that the least costly way to address tidal flooding is to raise the threshold at which the Fox Point Hurricane Barrer is shut and prepare the waterfront to be periodically flooded rather than invest in infrastructure to stop water (C2ES, 2016, City of Providence, 2014a). (See the Hurricane Barrier section for more information).

Make Use of Business Sector Resources: Engage business organizations such as the Providence Chamber of Commerce or the Providence Foundation to support outreach to small businesses on the issue of resilience building. One tool they could use as part of this effort is the state's series of guides that different sectors can use to increase awareness of techniques and best practices for reducing risk (RPS, 2018).

Policy

Encourage Planning to Exceed State Standards: As noted for the hurricane barrier, the city, in collaboration with the planning and design community, could consider requiring the use of the added design element of the CRMC Coastal Hazards Application Guidance and the increased design height to withstand conditions throughout a project's design life with rising sea level (CRMC, 2018). Similarly,

there may be opportunity to expand the use of that guidance to areas outside the narrow strip of CRMC jurisdiction—as a measure to increase understanding of future risk from future storms and rising seas. This can be applied to procedures of the city as well as well as the permitting process, involving the state, including those projects in the I-195 Redevelopment District.

Research

Update and Expand Modeling, Assessment, and Valuation of Risks: As seen in the Overarching Recommendations section of this report, there is a need to update and expand the modeling and assessment of the true risks to the built, natural, and socio-economic environments from the combined flooding from upland, riverine, and coastal storm surge.

The pedestrian bridge design incorporated three feet of additional height to accommodate rising sea levels (K. Davis).

Woonasquatucket River Corridor

Overview

In pre-colonial times, the "Woonasquatucket," a Narragansett word interpreted as "the place before the bend in the river" or "where the river meets the sea," was established by the Algonquin Nation as an important trading route for the coastal tribes, including the Narragansett, Wampanoag, and Massachuset (City of Providence, 2018b). Today, the Woonasquatucket River Corridor, and the urban communities settled within its floodplain, face multiple challenges in building resilience to climate change impacts. With proximity to Narragansett Bay, river corridor communities—the Olneyville, Smith Hill, and Valley neighborhoods—are subject to flooding from tidal and storm surges up the Providence River. The urban floodplain in Olneyville and Valley is also subject to storm-based flooding. This combination creates huge floods where the storm and tidal floods come together. However, further complications exist; settled since the Colonial era and heavily industrialized by the 19th century, the corridor hosts numerous examples of historic structures and buildings (PEMA, 2019)—many of which have been restored and converted into multi-use commercial, retail, and residential properties—and there is concern about the need to protect people and business while still preserving valued aspects of history and heritage. A unique feature of the corridor is that the Woonasquatucket River water depth can vary, depending on the use of the Fox Point Hurricane Barrier to either manage tides and surges or to supplement use of the downtown portion of the waterway for public events, like WaterFire (City of Providence, 2018b). (See the Hurricane Barrier section for more information). Neighborhood residents and landowners within the Woonasquatucket Corridor, especially the frontline communities that typically experience the worst flood events, engage in resilience and health programming and stand as models for the practical implementation of community flood management protocols that link environment, infrastructure, and social goals (A. Lehrer, personal communication, August 28, 2020). These issues are among those being addressed through an active series of partnerships and initiatives in the Woonasquatucket River Corridor. The vision for local neighborhoods and the Greenway is that there be bike access, stormwater management, green infrastructure, job creation, and neighborhood well-being—all contributing to increased resilience in these vulnerable neighborhoods.

Key Findings

- Chronic flooding associated with regular rain events is impacting the well-being of near-river neighborhoods as well as those throughout the watershed.
- The federal stormwater Consent Decree agreement with the Rhode Island Department of Transportation (RIDOT) together with the RIDOT partnership with the Woonasquatucket River Council and the Rhode Island Infrastructure Bank is facilitating the most ambitious green infrastructure stormwater remediation program in Rhode Island.
- Woonasquatucket River Corridor initiatives, including its vision plan and the current watershed-wide flood resilience study, is a model approach to build community resilience by integrating stormwater improvements, brownfield remediation, economic development, and citizen engagement through local place-based partnerships, planning, and implementation.

Situation

Modified River with Altered Floodplain: The watershed area for the corridor covers 50 square miles and includes portions of the municipalities of Providence, Cranston, Johnston, North Providence, Smithfield, Glocester, and North Smithfield. During the industrial heyday of the Providence region, the Woonasquatucket River was modified by human forces, with the natural floodplain being replaced by a new flood zone (City of Providence, 2018b).

Flood impact on the Woonasquatucket Corridor from 2010 floods. Riverside Park (left), and Sims Avenue and Kinsley Avenue Intersection (right) (A. Lehrer).

Diverse Neighborhoods Experiencing Flooding: The Woonasquatucket River Corridor is a racially diverse and culturally vibrant community located between a double bend of the river, surrounded by water on three sides. The location, as a low point within the altered floodplain along a narrow section of the river, is prone to flooding. The historic March 2010 floods are an example of the impacts flooding can have on residents and businesses. And floods like those of 2010 are likely to occur again.

Historic and Green Buildings are Flood-Prone, Support Arts Community: Historic industrial buildings with large spaces have given way to a unique blend of thriving creative arts and small business communities along the river. Many of these restored properties, once brownfields, are now remediated. The network of artists, small businesses, and food services help sustain the buildings and surrounding neighborhood areas with a mix of economic, social, and cultural benefits (City of Providence, 2018b). While the area between Olneyville Square and Downtown has the highest concentration of green buildings, businesses, and green economic growth zones across the state (City of Providence, 2019), the historic buildings around the area typically do not meet modern floodplain standards.

Partnerships Link Community Needs and Resilience: The area has several community-based organizations committed to helping connect the community, resources, and the municipality. Examples include the Woonasquatucket River Watershed Council, the Central Providence Health Equity Zone (HEZ), and city resources allocated through the Climate Justice Plan and the designation of the area as a Green Justice Zone. The 2018 Woonasquatucket Vision Plan is a product of collaboration between community stakeholders, the city, and the Environmental Protection Agency (EPA). The goal was to

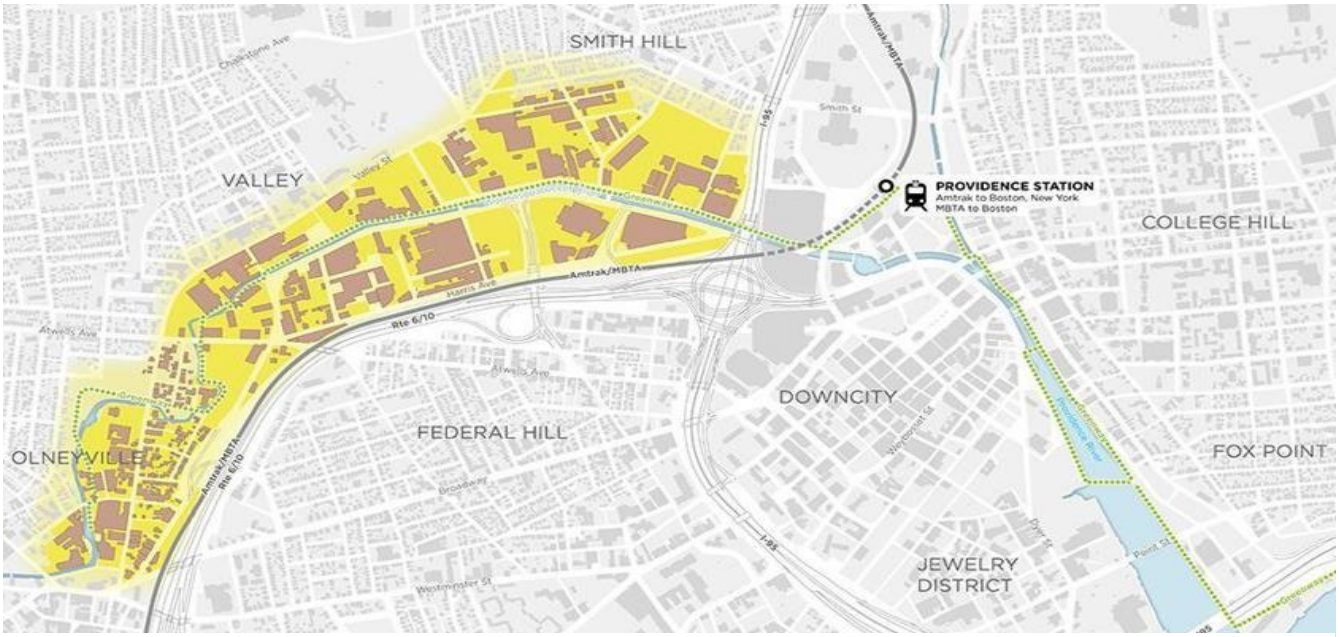


Figure W-1. Planning area for the Woonasquatucket Vision Plan (City of Providence, 2018b).

develop a long-term strategy to guide the development of industrial sites as part of the city's capital improvement plan. One of the intended outcomes of the vision plan was to have local economic development that benefits neighborhood stakeholders while strengthening community resilience to environmental and social issues such as flooding and racism (City of Providence, 2018b).

Climate Challenges

Impervious Surfaces Exacerbate Flooding and Cause Overheating: Increased precipitation events will continue to increase flooding risks (City of Providence, 2018b), a problem exacerbated by the high proportion of impervious cover, outdated infrastructure, and deferred maintenance. Buildings, sidewalks, and streets cause polluted stormwater to run directly and quickly into local waterways rather than allowing it to be captured, slowed down, and cleaned. Dark hardtop also holds the sun's heat—creating a "heat island" effect, or excessive warming, in urban neighborhoods.

> *"Nearly half of the Olneyville neighborhood of Providence is in the existing regulatory 100-year floodplain as well as the mapped Hurricane Surge area from a Category 3 or 4 hurricane. Many of the residents in Olneyville are renters and do not have insurance coverage for their belongings. In addition, many of the landlords do not have flood insurance coverage on existing three-story tenements."*
>
> *- City of Providence, 2016*

Transportation Issues: In addition to road flooding due to bigger and more frequent storms in areas with so much impervious cover, sea level rise will impact three bridges and bus routes. This could isolate the neighborhoods bordered by the Woonasquatucket and Moshassuck Rivers.

Historic Buildings at Risk for Flooding: Many historic structures are within the flood zone, and several have been flooded in recent years. Among these are the low-lying and frequently flooded areas

of Eagle Square and Rising Sun Mills. The cause of the flooding is tied to stormwater management issues such as clogged storm drains (City of Providence, 2009).

Brownfields, If Flooded, Could Contaminate: The Woonasquatucket River area has some of the most contaminated brownfield sites in the state. Many are situated in the lowest lying and most flood-prone areas of Olneyville, increasing the risks of flood-related pollution (City of Providence, 2018b).

Efforts to Increase Resilience

Protecting and Modifying Critical Services and Infrastructure

Watershed-wide Flood Resilience Studies: The Woonasquatucket River Watershed Council (WRWC) and the city of Providence are working with other Woonasquatucket Watershed municipalities and the U.S Department of Agriculture (USDA) Natural Resources Conservation Services (NRCS) to undertake a watershed-wide flood resilience study. The study will recommend strategies to mitigate flooding that could include capturing, storing, and treating stormwater—both in the uplands throughout the watershed and in the riverine floodplain. The completed study will provide the basis for implementation design and funding, also through NRCS. Measures implemented may be large or small and strategic, depending on analysis, community input, and feasibility (A. Lehrer, personal communication, August 28, 2020).

Infrastructure and Transportation: Current Systems that Need Enhancements or Improvements

Providence has slated money within its Capital Improvement Plan (CIP) for road, building, and other infrastructure improvements to take place over the next five years—with work targeted for frontline communities, including those in the corridor. The CIP is updated and revised yearly to reflect the upcoming goals and priorities for the city.

The Complete Streets plan enhances selected streets within the corridor, with a focus on creating pedestrian- and bicycle-friendly paths and connections across the city (City of Providence, 2018b). The Urban Trail Network creates stronger connections between Downtown and the Smith Hill, Valley, and Olneyville neighborhoods and is adding 10 new “neighborhood greenways,” with four located within the corridor.

Green Infrastructure and Green Spaces: Continued "greening" efforts in the region: To tackle stormwater management at the homeowner level, the WRWC, in partnership with the Providence Parks Department, Providence Councilwoman Jo-Ann Ryan, and local neighbors, completed a pilot project to create stream-friendly homes. Twelve neighborhood homes were retrofitted to capture and treat roof, walkway, and driveway runoff on site using a suite of options such as downspout redirection into existing yards, rain barrels, rain gardens, planter boxes, or interrupting impervious walkways and driveways with permeable pavers. This pilot showed that relatively inexpensive treatments can capture, store, and treat stormwater right at the individual property level and that these small changes can add up to less flooding and cleaner rivers and streams. Neighborhoods in Newport and Middletown have already duplicated the pilot project. More homes will be retrofitted over 2021 and 2022 in the Elmhurst and Smith Hill neighborhoods of Providence (within the Woonasquatucket Watershed) as part of a recent RIDEM Resilience Grant (A. Lehrer, personal communication, August 28, 2020).

Installation of new green infrastructure at Citizens Bank, next to the Woonasquatucket River (WRWC).

In July of 2020, a $500,000 Rhode Island Department of Environmental Management (RIDEM) grant was awarded to Groundwork RI to initiate construction of green infrastructure and plantings along the Woonasquatucket River to absorb runoff, which will reduce flooding and restore native habitat to increase green cover. Farm Fresh RI also received a $370,000 grant to continue implementing nature-based projects to increase permeable surfaces to reduce runoff and heat impacts at their new Food Hub site adjacent to the river in the Valley neighborhood (State of Rhode Island, 2020). Low-impact design and green infrastructure techniques such as filter strips, vegetated swales, vegetated detention ponds, bioretention areas, stormwater infiltration planters, and green roofs, among others, have been incorporated into projects (City of Providence, 2019). Southern New England Program funds, awarded to the city on behalf of WRWC, are supporting greenspace, tree trench, bioretention, underground filtration, and canopy cover projects (Pflaumer, 2020).The Olneyville and Valley neighborhoods are benefitting from the green stormwater infrastructure (nature-based solutions that use plants and soils to capture and treat polluted stormwater runoff) projects along the Fred Lippitt Woonasquatucket River

Greenway, and from a new parklet under construction along the Riverwalk (City of Providence, 2019). This effort has included partially de-paving parking lots and sidewalks adjacent to the Greenway and replacing pavement with engineered green stormwater systems such as StormTrees (trademark) that direct stormwater from the street into soil and tree systems and/or with rain gardens, bioswales, and bioretention areas—planted landscape depressions that hold and filter stormwater.

	Type	Woonasquatucket River Greenway
Clean Water State Revolving Fund	RIIB	Green Stormwater Infrastructure
Clean Water and Stormwater Infrastructure Fund	RIIB	Stormwater Accelerator
Commercial Property Assessed Clean Energy	State	TBD
Brownfield Revolving Loan Fund	RIIB / Local	TBD
Rebuild Rhode Island Tax Credits	Commerce	Mill Renovations and Redevelopment / Farm Fresh
RIDOT Stormwater	State	Stormwater Management and Bike Infrastructure
Rhode Island Green Economy Board	State	Bay and Watershed Restoration, Bike Grants, Brownfield Grants
Southeast New England Estuary Program (Federal / EPA)	Federal	Stormwater Infrastructure
National Fish and Wildlife Foundation & NRCS Conservation Grants	Federal	Green Infrastructure Demonstration

Figure W-2. Funding Sources for Woonasquatucket Restoration and Infrastructure Create a 'Funding Quilt' (Rhode Island Infrastructure Bank Presentation, 2020).

Stakeholder Assistance and Funding Collaboration

Funding Quilt Approach: A 'funding quilt' (i.e., funding that comes from several different sources to work toward a common goal) is illustrated by the collaborative efforts in the Woonasquatucket River area; entities such as the Rhode Island Infrastructure Bank are critical in helping broker such partnerships.

Small Business Assistance: The Woonasquatucket Brownfields Assistance Program promotes economic development, job provision, and business finance assistance (City of Providence, 2020).

Social Equity

New Voices at The Water Table Initiative: The WRWC effort, in concert with the Providence Racial and Environmental Justice Committee's Green Justice Zone, is focused on neighborhood-level education on flooding and water management issues, with emphasis on building frontline community

resident leadership to directly address community flooding issues, with solutions developed by the community (A. Lehrer, personal communication, August 28, 2020). (See Health and Wellbeing section for more information on frontline communities).

Farm Products for Olneyville: Local businesses Farm Fresh RI and Gotham Greens participate in efforts to engage the Olneyville neighborhood in activities that highlight resilience and food security issues (City of Providence, 2018b).

Flood Awareness Video: A Health Equity Zone activity, as part of a climate resilience program, in collaboration with the Rhode Island Department of Health and the WRWC, produced a bilingual video for residents and businesses to better understand flooding risks and actions, with Rhode Island's 2010 flood serving as a backdrop story (One Neighborhood Builders, 2019).

Figure W-3. Outreach Efforts to Increase Preparedness for Floods and other Hazards are Key to Community Resilience through a Bilingual Video (One Neighborhood Builders).

Recommendations

Planning

Develop a Comprehensive Flood Resilience Plan: A comprehensive plan can build upon the existing Woonasquatucket Vision Plan and other current efforts by community and civic groups. Such a comprehensive plan should account for both existing flooding and also making the corridor more resilient to future changes (PEMA, 2019).

Enhance Stormwater Management Practices: Develop a stormwater management master plan across the Woonasquatucket Corridor that monitors existing conditions and provides upgrades. The plan would be most effective with input from and partnerships facilitated by city departments to identify resources necessary to maintain the network (City of Providence, 2018b).

Collaboration

Watershed-wide Collaboration Toward Common Goals: Work with active watershed and other organizations to identify or fund already identified Green Infrastructure/Low Impact Development (GI/LID) projects. For example, the Woonasquatucket River Watershed Council maintains a database of active and potential stormwater management projects within the watershed (A. Lehrer, personal communication, August 28, 2020).

> *"Pursue additional brownfields assessment and remediation grant opportunities to replenish and sustain current funding levels available to properties within the Woonasquatucket Corridor."*
>
> *- City of Providence, 2018*

Educate Property Owners: Conduct direct outreach to property owners to raise awareness about owner liability and available cleanup resources and invite owners to participate in the implementation of the Vision Plan. Where appropriate, inform property owners about Limited Design Investigations as a means to reduce the cost burden of conducting brownfield assessments" (City of Providence, 2018b).

"New Voices" Expansion: It is imperative that frontline community voices are elevated in developing solutions to the issues that impact them. The "New Voices at the Water Table" program and the Racial and Environmental Justice (REJC) Green Justice Zone are just the first step in this process. There is a need to build on and maintain any successes by expanding into other neighborhoods and finding funding to support local engagement in this process. Community members should be as well compensated for their work to prepare and improve their neighborhoods in the face of climate change as are city staff and consultants (A. Lehrer, personal communication, August 28, 2020).

Collectively Answering Key Questions: A partnership effort could address questions such as these and more: "What are the critical services that could be shut down by a weather event?" "What is the evacuation plan for people in vulnerable areas in case of a major weather event?"

Resilience Designs

River Improvements: Restore natural floodplain features, including the re-vegetated wetlands, to absorb flood waters. These groundwork and preventative measures, together with education, are imperative to alleviate the “clean-up” and disaster impacts of flooding (A. Lehrer, personal communication, August 28, 2020; City of Providence, 2018b). Make in-stream channel improvements to return the Woonasquatucket River to a more meandering pattern, return floodplain areas, and create wetlands. The RIDEM has designated wetland buffer reports concentrating on the river zone (City of Providence, 2018b).

Potential Relocation: For individual structures and developments, relocating to higher, safer ground is encouraged. If not feasible or appropriate, adaptive approaches can include raising structures and infrastructure, floodproofing, or fortifying components at risk (City of Providence, 2018b).

River improvements at Black Locust Pocket Park along the Woonasquatucket River. The park serves as a pilot project, illustrating the potential for engagement along the river to provide education, green spaces, and habitat restoration (WRWC).

Resources

AMEC Environment & Infrastructure, Inc. "Exploring Regional Solutions to Regional Problems, Upper Narragansett Bay Regional Stormwater Utility Feasibility Study Phase I, Final Report," June 2014.

Anderson, V. "Green Port Initiatives: A Review of Best Practices for the Port of Providence (RI)," 2018.

Becker, A. "Using boundary objects to stimulate transformational thinking: storm resilience for the Port of Providence, Rhode Island (USA)," 2016. https://link.springer.com/article/10.1007

Becker, A., and Caldwell, M. "Stakeholder Perceptions of Seaport Resilience Strategies: A Case Study of Gulfport (Mississippi) and Providence (Rhode Island)," 2015. https://www.tandfonline.com/doi/abs/10.1080/

Becker, A., Burroughs, R., Kretsch, E., McIntosh, R., & Haymaker, J. "Stakeholder vulnerability and resilience strategy assessment for maritme infrastructure: Pilot project for the Port of Providence, RI," 2017. https://www.researchgate.net/publication/339613120_Stakeholder_vulnerability_and_resilience_strategy_assessment_of_maritime_infrastructure_Pilot_project_for_Providence_RI

Blount, K. Marine Transportation Recovery Specialist USCG Providence. Personal communication, January 12, 2021.

Calabro, R. Climate Specialist, RI Department of Health. Personal communication, January 18, 2021.

Carini, F. "Providence's Toxic Avenue Leads to Neighborhood Problems," April 22, 2019. https://ecori.org/public-safety

CDM Smith. "Upper Narragansett Bay Regional Stormwater Management District Phase II – Feasibility Study Report," 2016. https://www.unbstormwater.org/pdf/Upper_Narragansett_Bay_Phase_II_Feasibility_Report.pdf

Centers for Disease Control and Prevention (CDC). "Health-Related Quality of Life/Well-Being Concepts," 2018. https://www.cdc.gov/hrqol/wellbeing.htm#one

Chalchinsky, J. "The Providence hurricane barrier: an assessment," 2006. https://docs.rwu.edu/cmpd_working_papers/29

City of Providence Department of Planning and Development, "Providence Great Streets Master Plan," January 2020c. https://www.providenceri.gov/wp-content/uploads/2020/01/Providence-Great-Streets-Plan-January-2020.pdf

City of Providence Emergency Management Agency (PEMA). "Fox Point Hurricane Barrier Coordination Guidebook," 2020.

City of Providence Emergency Management Agency (PEMA). "Strategy for Reducing Risks from Natural, Human-Caused and Technologic Hazards: A Multi-Hazard Mitigation Plan," 2019. https://www.providenceri.gov/2019/12/Providence-Multi-Hazard-Mitigation-Plan-2019.pdf

City of Providence. "Providence Tomorrow: Olneyville, Smith Hills, and Valley Neighborhood Plan," 2009. https://www.providenceri.gov/2017/05/Planning-OSV_NeighbrhdPlan_Digital.pdf

City of Providence. "Design and Resilience Team," 2016. https://slideshare.net/Climate-adaptation

City of Providence. "Harbor Management Plan," 2015.

City of Providence. "Climate Justice Plan," 2019. https://providenceri.gov/ClimateJustice.

City of Providence. "Draft RIPDES Small MS4 Annual Report. Jan 2019-Dec 2019," 2020.

City of Providence. "Providence Capital Improvement Plan 2020-2024," January 2020a. https://providenceri.gov/CIP

City of Providence. "Providence Tomorrow, Our City, Our Neighborhoods, Our Future: The Comprehensive Plan," 2014a. https://providenceri.gov/wp-content.pdf

City of Providence. "RePowerPVD: Creating Buildings of the Future," 2018a. https://providenceri.gov/repower

City of Providence. "Sustainable Providence Plan," 2014b. https://providenceri.gov/sustainability

City of Providence. "Woonasquatucket Brownfields Assessment Program," 2020b. https://providenceri.gov/BrownfieldsBrochure.pdf

City of Providence. "Woonasquatucket Vision Plan," 2018b. https://www.providenceri.gov/wp-content/uploads/2017/08/Woonasquatucket-Vision-Plan_Full.pdf

Climate and Energy Solutions (C2ES) and Johns Hopkins University. "Analyzing Coastal Flood Protection Strategies for Providence, Rhode Island," 2016.

Dahlberg, A. Asst. Vice President, Government & Community Relations, Brown University. Personal communication, January 3, 2021.

Decerbo, C. Director, Providence Emergency Management Agency (PEMA). Personal communication, June 9, 2020.

Drix, J. "Port of Providence: Health, Climate Change, and Environmental Justice at an Urban Deepwater Port," March 6, 2020.

Environmental Protection Agency (EPA). "Community-Port Collaboration Pilot Projects," 2017. https://epa.gov/community-port-collaboration

Everett, D. Principal Planner, City of Providence. Personal communication, January 4, 2021.

First Street Foundation. The First National Flood Risk Assessment: Defining America's Growing Risk, 2020. https://assets.firststreet.org/uploads/2020/06/first_street_foundation__first_national_flood_risk_assessment.pdf

Ginis, I. and D. Ullman. URI Graduate School of Oceanography. Personal communication, January 29, 2021.

Giordano, T. Executive Director, Partnership for Rhode Island. Personal communication, August 24, 2020.

Goulet, D. CRMC Marine Infrastructure. Personal communication, November 12, 2020.

Green Marine. Press release, December 18, 2018. https://green-marine.org/waterson-terminal

Groundwork Rhode Island. "Climate Safe Neighborhoods," 2020. https://maps.arcgis.com/Groundwork

Institute at Brown for Environment & Society (IBES) and The University of Rhode Island (URI). "Building a Resilient Future for Providence, Business and Civic Leader Forum: Proceedings," 2019. https://prep-ri.org/Providence_forum_proceedings.pdf

Kelly, G. "Providence Plans to Connect Neighborhood Greenways to an Urban Trail Network That Creates Great Streets," August 26, 2020. https://providenceri.gov/Great-Streets-Plan

Kretsch, E. and Becker, A. "Leadership and Responsibility for Long-Term Hurricane Resilience: Port of Providence, RI," 2016. https://web.uri.edu/maf/files/Kretsch_SocialCoastPresentation_V@.pdf

Kuffner, A. "Rising threat: Can Providence's hurricane barrier withstand sea-level rise?" April 2, 2019. https://usatodaynetwork.com/risingthreat

Lehrer, A. Executive Director, Woonasquatucket River Watershed Council. Personal communication, August 28, 2020.

McCann, J., Poll S., Kennedy, S., O'Neill, E., Robadue, D., Kotowicz, D. "The Value of Rhode Island's Blue Economy," March 2020. https://web.uri.edu/gso/files/ri-blue-economy-report-2020.pdf

McPherson, John. U.S. Army Corp of Engineers. Personal communication, June 18, 2020.

Morang, A. "Hurricane barriers in New England and New Jersey: History and status after five decades," 2016. https://meridian.allenpress.com

Narragansett Bay Commission Management Team (NBC), Uva, T., Bowen, D., Goulet, M., and J. McCaughey. Personal communication, December 23, 2020.

Narragansett Bay Commission, "Capital Improvement Program, Fiscal Year 2021 - 2025." https://www.narrabay.com/media/1733/fy-2021-fy-2025-capital-improvement-program.pdf

Narragansett Bay Commission, "CSO Control Facilities Phase III Amended Reevaluation Report," November 2017. https://www.narrabay.com/media/1499/PROG_Vol1PhIIIAmendedReevalReport_20171113.pdf

Narragansett Bay Commission, "NBC, RIDEM Announce Consent Agreement," January 2019. https://narrabay.com/about-us/news/nbc-ridem-announce-consent-agreement

National Climate Assessment. "Volume II: Impacts, Risks, and Adaptation in the United States," 2017. https://nca2018.globalchange.gov/

National Oceanic and Atmospheric Administration (NOAA). The State of High Tide Flooding and Annual Outlook. 2020. https://tidesandcurrents.noaa.gov/HighTideFlooding_AnnualOutlook.html

One Neighborhood Builders. "2010 Flood Film," September 13, 2019. https://vimeo.com/359888817/6c75fdddfe

One Neighborhood Builders. "Central Providence Health Equity Zone," 2020. https://oneneighborhoodbuilders.org/our-work/hez/

Patenaude, W. Principal Engineer, RIDEM. Personal communication, October 7, 2020.

Pflaumer, J. "SNEP Watershed Grant Announcement video," 2020. https://RestoreAmericasEstuaries/video

Port/Community Working Group. Personal communication, June 15, 2020.

ProvPort https://www.provport.com/provport/provport.html

Providence Neighborhood Planting Program https://pnpp.org/pvd-tree-plan/

Rhode Island Coastal Resources Management Council (CRMC). "Rhode Island Shoreline Change Special Area Management Plan," 2018. http://www.beachsamp.org/

Rhode Island Coastal Resources Management Council (CRMC). "Urban Coastal Greenways," 2007. http://www.crmc.ri.gov/samp_mb.html.

Rhode Island Department of Environmental Management (RIDEM). "Implications of Climate Change for RI Wastewater Collection & Treatment Infrastructure," 2017. http://dem.ri.gov/wwtf

Rhode Island Department of Environmental Management, (RIDEM) and Coastal Resources Management Council (CRMC), "Rhode Island Stormwater Design and Installation Standards Manual," Amended March 2015. http://dem.ri.gov/programs/water/wwtf/wwtf-climate.php

Rhode Island Department of Health (RIDOH). "Climate Change and Health Resilience," 2015. https://health.ri.gov/HealthResilience

Rhode Island Department of Health (RIDOH). "Ensuring Safe Water for Rhode Island's Future," July 2013. https://health.ri.gov/SafeWater

Rhode Island Department of Health (RIDOH). "Rhode Island Urban Forests for Climate and Health Initiative/Why Climate & Public Health," 2019. https://health.ri.gov/Urban-Forests-for-Climate-and-Health-Initiative

Rhode Island Emergency Management Agency (RIEMA). "DRAFT/State of Rhode Island Hazard Identification and Risk Assessment," August 2016. http://www.riema.ri.gov/hazardmitigation

Rhode Island Green Infrastructure Coalition. "Providence Metro Area," 2020. http://www.greeninfrastructureri.org/providence.html

Rhode Island House of Representatives. "Special House Commission to Study Economic Risk Due to Flooding and Sea Level Rise," May 12, 2016. http://rilin.state.ri.us/commission

Rhode Island Office of Energy Resources (RIOER). "Energy 2035: Rhode Island State Energy Plan," October 8, 2015. http://www.energy.ri.gov/documents/SRP/RI-microgrid-report-170331.pdf.

Rhode Island Office of Energy Resources (RIOER). "Resilient Microgrids for Rhode Island Critical Services," 2017. http://www.energy.ri.gov/documents/SRP/RI-microgrid-report-170331.pdf

Rhode Island Office of Energy Resources (RIOER). "Solar Siting Opportunities for Rhode Island," August 18, 2020. https://synapse-energy.com/sites

Rhode Island Statewide Planning (RISP) Program. "Transportation Improvement Program FFY 2018 - 2027," 2017 plan http://www.planning.ri.gov/planning-areas/transportation/tip.php

Rhode Island Statewide Planning (RISP) Program. "Providence, RI Coastal Sea Level Rise and Storm Surge: Transportation Fact Sheet," 2016b. http://www.planning.ri.gov/documents/sea_level/fact/Providencefs.pdf

Rhode Island Statewide Planning (RISP) Program. "Rhode Island Sea Level Rise: Impacts on Transportation Assets," 2019. Online Mapper. https://ridoa.maps.arcgis.com

Rhode Island Statewide Planning (RISP) Program. "Vulnerability of Municipal Transportation Assets to Sea Level Rise and Storm Surge," Technical Paper 167; 2016a. http://www.planning.ri.gov/documents/sea_level/2016/TP167.pdf

Rhode Island Statewide Planning (RISP) Program. "Vulnerability of Transportation Assets to Sea Level Rise," Technical Paper 164; 2015. http://www.planning.ri.gov/documents/sea_level/2016/TP167.pdf

RI Executive Climate Change Coordinating Council, Science and Technical Advisory Board (STAB). Annual Report, 2020.

RPS Group. "Risk Reduction for Small Business Resiliency in RI Exposure Analysis Report," 2018. http://climatechange.ri.gov/businesses/small-biz.php

Skuncik, C. Executive Director, I-195 Commission. Personal communication, October 29, 2020.

Sea-Level Change Curve Calculator (Version 2019.21) https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html

State of Rhode Island. "DEM Awards $4,360,600 to Help RI Communities Confront the Effects of Climate Change," Press Release, July 29, 2020.

State of Rhode Island. "Resilient Rhody: An Actionable Vision for Addressing the Impacts of Climate Change in Rhode Island," (Resilient Rhody) 2018. http://climatechange.ri.gov/documents/resilientrhody18.pdf

Stone, E. Office of the Director, RIDEM. Personal communication, October 3, 2020.

U.S. Army Corps of Engineers (USACE). "Fox Point Hurricane Barrier, Providence, Rhode Island: Continued Operation and Maintenance Environmental Assessment," August 2015. https://www.nae.usace.army.mil/FoxPointHurricaneBarrier-Final-EA-20150814.pdf

U.S. Army Corps of Engineers (USACE). "Site visits, briefings keep North Atlantic Division Commander busy," January 6, 2017. https://www.nae.usace.army.mil/SiteVisits

U.S. Army Corps of Engineers (USACE). "Update Report for Rhode Island," July 31, 2020. https://www.nae.usace.army.mil/UpdateReport

U.S. Army Corps of Engineers (USACE). New England District Website. "Hurricane Sandy aftermath: Hurricane barriers managed by Corps engineers in New England prevent $29.7 million in damages," November 21, 2012. https://www.nae.usace.army.mil/hurricane-sandy

U.S. Environmental Protection Agency (USEPA), "Consent Decree for Rhode Island Department of Transportation Settlement," 2015. https://www.epa.gov/enforcement/consent-decree-rhode-island-department-transportation-settlement

University of Rhode Island (URI). "Application of Coastal Environmental Risk Index to Providence and Fox Point Hurricane Barrier," Ocean Engineering Senior Design Report, May 14, 2018a.

University of Rhode Island (URI). "Economic Climate Vulnerability Assessment for Providence," Environmental and Natural Resource Economics Senior Report, 2018b.

University of Rhode Island (URI). "Evaluating and Improving the Resilience of Waste Water Treatment and Hazardous Material Storage Facilities in Upper Narragansett Bay to Coastal Flooding," Engineering Senior Design, March, 22, 2019.

Waterson, C. General Manager, Waterson Terminal Services. Personal communication, October 28, 2020.

Youngken Associates. "Historic Coastal Communities and Flood Hazard: A Preliminary Evaluation of Impacts to Historic Properties," August, 2015. http://www.preservation.ri.gov/historic-coastal-report


PROVIDENCE
RESILIENCE
PARTNERSHIP