

CITY OF PORTLAND, MAINE
Standing Committee on Sustainability and Transportation
Councilor Spencer Thibodeau (D2), Chair
Councilor Belinda Ray (D1)
Councilor Jill Duson (D3)

Agenda
August 26, 2020
5:30 PM
Remote Meeting

1. Meeting Information

This meeting will take place as a Zoom webinar. Please use the link below to join the webinar:

[https://us02web.zoom.us/j/88921215171?pwd=UDh1RXIzSURDZFkZHK3MmxWblUxZz0](https://us02web.zoom.us/j/88921215171?pwd=UDh1RXIzSURDZFkZHK3MmxWblUxZz09)

9 Passcode: 664189 Or iPhone one-tap : US:

+13017158592,,88921215171#,,,,,0#,664189# or

+13126266799,,88921215171#,,,,,0#,664189# Or Telephone: Dial(for higher quality,

dial a number based on your current location): US: +1 301 715 8592 or +1 312 626 6799

or +1 929 205 6099 or +1 253 215 8782 or +1 346 248 7799 or +1 669 900 6833 Webinar

ID: 889 2121 5171 Passcode: 664189

2. Review and approve minutes from June 17, 2020

a. Minutes from June 17, 2020

3. Sustainability Program Updates

a. Sustainability Updates

4. Presentation and Discussion

Public comment may be taken

a. Public Hearing -- Petition for restricted parking on Cottage Street
Public comment will be taken

b. Time Limited Parking
Presentation from staff regarding procedures for request time limited parking in residential neighborhoods

c. Presentation of the One Climate Future Vulnerability Assessment

As part of the One Climate Future climate action planning process, staff and the consulting team conducted a vulnerability assessment for the Cities of Portland and South Portland that informed strategies outlined in the plan. This presentation prepares the committee to receive the final draft plan by providing context about the climate hazards faced by the City.

5. Workshop - Air Quality Monitoring

CITY OF PORTLAND, MAINE
Standing Committee on Sustainability and Transportation
Councilor Spencer Thibodeau (D2)
Chair Councilor Belinda Ray (D1)
Councilor Jill Duson (At large)

Draft Minutes June 17, 2020

Members Present: Councilor Thibodeau, Councilor Ray, Councilor Duson

Staff Present: Troy Moon, Lena Geraghty, Dena Libner

External Attendees Presents: Andy Johnson from Maine Department of Environmental Protection and Dr. Andy Smith, State Toxicologist from Maine CDC

Meeting called to order at 5:36.

May Minutes

May meeting minutes approved by Councilor Duson and seconded by Council Ray. Passed unanimously, 3-0.

Update on barriers for streets closed to support local business

Dena provided updates on phase 2 of the downtown barricades. The changes will include a painting of the concrete blocks to make that fresher and installing rustic wooden planters that the Parks Department is making themselves. The Chamber is partnering with the City to help with the daily maintenance. The changes are starting on Exchange and will move on to the other areas to be complete by the end of the month.

Councilor Ray is thankful that this project is moving along so quickly. She asked if there is a timeline for how long these barricades stay up and how will it be decided what may remain.

Dena believes that the streets are expected to remain closed until November but will be re-evaluating on a weekly basis.

Councilor Duson thanks the team for all the work and quick response.

Report from Maine DEP and Maine CDC on Air Quality Monitoring

Andy Johnson from Maine Department of Environmental Protection and Dr. Andy Smith, State Toxicologist from Maine CDC, are here to present on the air quality monitoring happening on the waterfront.

Andy Johnson gave background on the SoPo/Po VOC project. There have been concerns about air quality in the region going back to 2015. DEP made a commitment to work with South Portland on getting a better understanding of the air quality situation. The goal was to measure VOCs to increase knowledge, share information with the public and subject matter experts,

identify potential sources of VOC emissions that need control, and determine if there is a connection between odor and presence of VOCs.

Phase 1: Grab sampling completed in South Portland June 10-September 9.

Phase 2: Fixed 24-hour sampling in Portland beginning in November 2019 (two new sites: one at International Marine Terminal on West Commercial St and one at Ocean Gateway). This will continue until November 2020.

Maine DEP is sharing data with Maine CDC and updating it online monthly.

There have been 36 samples at Ocean Gateway and West Commercial St locations.

Maine DEP is working on installing and operating meteorological sensors to get more insight into the 24-hour site samples. Maine DEP is working on a floating sampling sensor to deploy in specific areas for increased collection. They are considering exploring other pollutants to measure.

Councilor Ray is curious about the history of the Deering Oaks testing location. Andy Johnson explained where testing has happened in the City.

Councilor Ray asked if the VOC data has been correlated with the odor data yet. Andy Johnson says that hasn't happened yet but is in the plans.

Councilor Thibodeau is curious about how location relative to the waterfront affects VOC readings and See Click Fix odor reports.

Dr. Andy Smith has been redeployed to focus on covid-19 since March. He's excited to talk about air quality again for the first time in a few months. He directed interested parties to the report that's been released for more details.

Dr. Smith explained how to read different air quality result charts and how health-based guidelines are determined.

Using naphthalene as an example, Dr. Smith talked through the process and analysis of air quality monitoring efforts.

Higher levels mean that Maine CDC and DEP are more likely to consider policy and opportunities to limit exposure and explore sources of pollutants further.

Dr. Smith showed a data visualization of emergency department visits for asthma to get a better understanding of air pollution effects on health outcomes.

There was a presentation of January 1 - June 15, 2020 See Click Fix odor complaints.

Councilor Ray is wondering about the cause of naphthalene in Portland.

Councilor Thibodeau is wondering what's next for the project. He asked how to take the smell and explain the potential health outcomes to residents. Dr. Smith is interested in taking SCF reports to determine proper placing of the sampling to begin to more fully address citizen concern.

Discussion about the goal of the studies and this work: Is the air safe to breathe? Does the City need to take steps to mitigate air pollution and quality?

Motion to adjourn made by Councilor Duson and seconded by Councilor Thibodeau. Passed unanimously. Meeting adjourned at 7:58pm.

Sustainability Updates

August 2020

Staffing

Like many City operations, the Sustainability Office is working reduced hours. We are doing our best to advance our work and keep up with questions from residents and businesses during this unprecedented time for the City budget. We are asking people to please be patient because it will take longer than normal for us to respond to them.

The proposed FY 21 City budget eliminates the Sustainability Associate position.

One Climate Future

Completing work on the final draft of One Climate Future has taken up much of our available capacity. We have been meeting with staff and community stakeholders to get feedback on recommendations and revising the text appropriately. We worked very closely with the Planning Department to ensure that the plan builds on and operationalizes Portland's Plan 2030. We presented an overview of the plan and recommended strategies to the City Manager and the Leadership Team in July and received favorable feedback. We look forward to presenting the final draft to Sustainability and Transportation as soon as the September meeting. The plan is ambitious and designed to achieve the climate and resilience goals established by the City Council. It contains recommendations for actions in Buildings and Energy, Waste Reduction, Transportation and Land Use, and Resilience.

Solar Consortium

See attached memo

Straw Ordinance

The City of Portland Straw Ordinance went into effect on April 1, 2020. During this first phase of the ordinance food service establishments may only provide customers with a plastic straw upon request. We haven't had an opportunity to do proactive outreach to the businesses that are re-opening but will respond to questions or resident complaints.

<http://www.portlandmaine.gov/2558/Straw-Ordinance>

Legislative / Policy

We continue to lead the City's engagement with the Maine PUC and CMP on several issues related to the LED streetlight program. We've drafted and filed comments in response to PUC questions, responses to comments submitted by CMP, and attended formal Inquiry Hearings on

Sustainability Updates

August 2020

behalf of the City. The issues related to ownership of and maintenance responsibility for underground utilities. We've also begun to engage about amending the street lighting tariff so we can pay for the energy we actually consume instead of a flat rate tariff. The proceedings are ongoing and we anticipate another round of questions from the PUC.

Energy Benchmarking

Buildings with 20,000 square feet and a single primary occupant were required to report their energy and water consumption to the Sustainability Office by May 1, 2020. We haven't received any additional reports since June so the total submissions is 31.

<http://www.portlandmaine.gov/2389/Energy-Benchmarking>

Pesticide Ordinance

We have received about a dozen complaints on FixIt! Portland regarding illegal pesticide use. We haven't had the staff to do extensive follow ups but we prepared an informational postcard and mailed it to the owners of each property.

<http://www.portlandmaine.gov/2168/Pesticide-Use-Ordinance>

Air Quality Monitoring

The ME DEP is monitoring the odor reports submitted by residents using the SCF platform. They have asked us to assist them with access to the monitoring station in Deering Oaks where DEP staff has had trouble with individuals camping and blocking access to the equipment.

EV Chargers

We completed the installation of EV Chargers at the Portland Jetport. There is now a bank of level 1 (trickle) chargers in the long term parking section and a bank of level 2 chargers in short term parking. Installations in Payson Park and in front of City Hall are scheduled soon.

Outreach and Education

We've had limited time to devote to education and outreach but have continued regular Instagram posts -- which has been our most effective platform. We are pleased to have passed the 1000 follower milestone!. Follow us on Facebook and Instagram at @sustainableportlandme.

Sustainability Updates

August 2020

We now have a YouTube Channel, City of Portland, ME Sustainability Office. We'll host the videos we produce as well as curated playlists to help educate residents and businesses about sustainable practices. For instance, we have a featured playlist with videos about how to manage your lawn organically.

We invite people to participate in One Climate Future by visiting the webpage at www.oneclimatefuture.org



CITY OF PORTLAND

Sustainability Office

Troy Moon

Sustainability Director

To: Mayor Snyder and Members of the Portland City Council

Re: Update on Solar Consortium

Date: August 17, 2020

On February 19, 2020 the City Council authorized the City Manager to enter into net energy bill credit agreements with a number of developers as part of a consortium of large energy users organized by Competitive Energy Services ("CES"). This opportunity arose because of changes to the State of Maine's net energy billing policy that now allows municipal and other large electricity customers to receive financial compensation for purchasing renewable energy produced by eligible renewable energy projects. The previous policy primarily benefited small, non-municipal customers because it compensated renewable energy purchasers with kilowatt hour credits, which are less attractive to customers who pay large demand charges.

Progress Report

Since February, City staff and the team at CES have worked together to execute agreements with the developers who submitted the most attractive offers to the consortium participants. In most cases, the projects proposed are proceeding through the various approval processes required by state and local agencies, Central Maine Power, and the finance partners involved with each project. One developer who had submitted several projects to the consortium ran into a number of difficulties and has chosen to leave the Maine market. Their projects have been withdrawn. CES approached other developers working in the state to find suitable, cost competitive projects as replacements. They reached agreements with a very successful and well known solar developer, Borrego. Following a review of the terms by Corporation Counsel and outside counsel, the City Manager executed these replacement agreements under the authority granted by the City Council in February. These replacement projects allow the consortium to achieve its goal to save participants a substantial amount of money on their electric bills while accessing renewable energy.

City of Portland participation in the revised Renewable Energy Consortium project

Original Load Offered	Original Annual Bill Savings	New Load Offered	New Annual Bill Savings	Difference
19,815 mWh	\$844,254	20,166 mWh	\$781,761	(\$62,493)

Timing of anticipated savings and revenue

All but two of the projects participating in the Consortium are for solar arrays that will be throughout the Central Maine Power service area. Each individual project must complete local site plan review, receive the necessary DEP permits, as well as complete the interconnection process with the utility. All of this will take time. Consequently, we anticipate our bill savings will phase in over the next several fiscal years as the individual projects come on line and begin producing electricity. Two existing hydroelectric projects that are part of the Consortium have recently begun producing credits for us but they are a very small portion of the overall portfolio.

As staff noted during the presentation to the City Council in February, the agreements we have made as part of the Consortium allow us to retain the renewable energy credits (RECs) associated with the power produced by participating facilities. The City will receive its proportionate share of these RECs as they are produced. Because we offered 20,166 mWh of load, we will receive this number of RECs when the projects are fully completed. The City Council will have the option to monetize these credits by selling them or to retain them. Retaining them would allow the City to claim the energy produced as renewable. Selling them would provide revenue but would transfer the green attributes to the purchaser of the RECs.

We currently expect RECs from the solar projects will have a value of approximately \$30 each. As with the bill credits, the financial benefits of the RECs will phase in over the next few years.

Anticipated savings and potential REC revenues in upcoming Fiscal Years

FY 21	(Hydro only)	FY 22	25% available	FY 23	75% available	FY 24	100% available
Bill Credits	RECs	Bill Credits	RECs	Bill Credits	RECs	Bill Credits	RECs
\$70,715	n/a (low value class 2)	\$195,000	\$151,245	\$586,340	\$453,735	\$781,786	\$604,980

We look forward to keeping the City Council updated regarding progress of the Renewable Energy Consortium as the constituent projects complete their approvals and begin to come on line.

Petition for Parking/Traffic Mitigation Changes



Petitioner information

Name: Lisa Hicks

Address: 22 Cottage Street

Email: lhicksdance@gmail.com

Phone #: 207-712-1714

I am a: ☒ resident

Location of parking change request

Street: ~~22~~ Cottage Street

Cross street 1: Ashmont Street

Cross street 2: Longfellow Street

Time-limited parking requested (circle one):

Odd side

Even side

Both

Time limit (circle one):

1 hour

2 hours

Note: we would like to have parking restricted to one side of the street only and prefer the even side.

The petition must contain signatures of at least 60% of households and/or businesses (a unit of housing, e.g., single family home, a unit in a multi-family building, commercial businesses) on the requested block. No more than one signature per household or business may be represented on the petition.

Submit petition by mail or email to:

Assistant to the City Manager for Constituent Services

Re: Parking/Traffic Petition

Room 208

Portland, ME 04101

Petition for Parking/Traffic Mitigation Changes

Street: Cottage Street



Address	Unit #	Printed Name	Signature	# of vehicles in household	Email *if you wish to be contacted by email in the event of a public meeting
22 Cottage Street		Lisa Hicks	<i>Lisa Hicks</i>	1	lhicksdance@gmail.com
16 Cottage Street		Susan Hicks	<i>Susan Hicks</i>	1	susanhicks555@gmail.com
15 Cottage St.		Dawn Tackels	<i>Dawn Tackels</i>	2	dtackels@gmail.com
14 Cottage St.		LARS BOTE ZELITCH	<i>Lars Bote Zelitch</i>	2	larszielack@gmail.com
18 Cottage St		Catherine Vasconia	<i>Catherine Vasconia</i>	2	Cvasconia@hotmail.com
25 Cottage St.		Tom McAdams	<i>Tom McAdams</i>	3	Barbel2@aol.com
14 Cottage St		Bo Yoon	<i>Bo Yoon</i>	2	BoYoon@Comcast.net
12 Cottage St		Judith Carlstrom	<i>Judith Carlstrom</i>	1	Jmcmanagers@aol.com

Received: Dea Liber
Name

8/12/20
Date

For Office Use Only

Time-Limited Residential Parking Program

Purpose

The City of Portland's time-limited residential parking program is for establishing time-limited parking in residential parking zones where there is a scarcity of convenient off-street daytime parking for residents and the majority of legal on-street parking spaces are used by commuters and non-residents.

With a residential parking permit (RPP), vehicles owned by residents and medical caregivers can park in an RPP neighborhood beyond the posted 1 or 2 hour time limits Monday through Friday, 9am-6pm, without being ticketed. Residents can apply to participate for time limits in their residential parking zone on a block by block basis. If your block is participating in the RPP program, you will need to acquire and display an RPP decal or hang tag (for medical caregivers only) for every vehicle that will park on neighborhood streets during the specified enforcement period to be exempt from the time-limited parking.

To have time-limited parking, your block must be a part of a residential parking zone. Many areas of the City are in residential parking zones (see [map](#)). If you want to establish a residential parking zone in your area, you can learn more about the process in City Code [Sec. 28-91 Residential parking permits](#). You can also find out more about the residential parking permits on the City's [website](#).

Eligibility

Who qualifies?

- Residents and property owners who reside at the address: If you live in a residential parking permit area, a residential permit will exempt you from the posted 1 or 2 hour time limit.
- Medical caregivers: Caregivers who work with residents who require home health care services are eligible for a residential permit and will be exempt from the posted time limit with a hangtag eligible while on-duty.

Residents must present the following documentation to receive a residential parking permit:

1. Must show valid Maine Driver's License & Registration, reflecting applicant's address within the zone and with the name of applicant on the Registration (Exceptions a, b,c,d below).
 - a. Students must show student I.D. from a school located in Portland, in addition to a Driver's License.
 - b. Military must show military I.D. in addition to a Driver's License.
 - c. Caregivers must have a medical affidavit for care of a resident or property owner who resides in the RPP.

- d. Applicants who are property owners and reside at an address in the zone for at least 5 months a year, whose license and registration show a non-Portland address, are eligible but required to pay a \$50 fee per vehicle per year.
2. For proof of residency from a, b, c, and d above, applicants must provide a lease, recent utility bill, voter registration card, or document verifying residency within the zone approved by the Parking Manager.

RPP PETITION PROCESS FOR TIME-LIMITED PARKING

1. Using the petition for time-limited parking in a residential parking permit zone, petitioner(s) must receive signatures of support from at least 60% of households on the block(s) listed on the petition to establish time-limited parking. A household is one unit of housing (e.g., single family home, a unit in a multi-family building, commercial businesses). Only one signature per household or business will be counted toward the total collected.
2. Petitioner must submit the petition to the Assistant to the City Manager for Constituent Services for verification.
3. If the petition has signatures from at least 60% of households, the petition will be referred to the Sustainability & Transportation Committee to allow for an opportunity to request a review or elect to send directly to the Council. All residents and property owners will be given notice of this meeting, and the opportunity to share their public comment.
4. If the petition does not have signatures from at least 60% of households, the petitioner will have the right to review the verification documentation and an opportunity to appeal or get additional signatures. Additional signatures must be resubmitted along with the original signatures within 30 days. Otherwise the petition process will begin again.
5. The Sustainability & Transportation Committee will make a recommendation on the petition and refer it to City Council in cases where it hosts a meeting item on residential parking permits.

INTERNAL PROCESS FOR TIME-LIMITED PARKING

1. Petitions will be made available by request to the Assistant to the City Manager for Constituent Services, and on the City of Portland's website.
2. The Assistant to the City Manager for Constituent Services receives completed petition and notifies City Manager's Office, Parking Division, and DPW.
3. The Assistant to the City Manager for Constituent Services works with the Assessor's Office and the Clerk's Office to verify signatures and the 60% threshold within 30 days of receiving petitions.
4. If the 60% threshold is met:
 - a. the Assistant to the City Manager for Constituent Services, the Parking Division, and DPW coordinate with the Sustainability Coordinator to get on the Sustainability & Transportation Committee agenda.

- b. The Assistant to the City Manager for Constituent Services will work with the Communications Director to get postcards mailed to all affected property owners and residential units.
 - c. DPW will write up an agenda and background materials for Sustainability & Transportation Committee meetings.
- 5. If the 60% threshold is not met, the Assistant to the City Manager for Constituent Services will respond to petitioner with information about the review and appeal process.
- 6. The Assistant to the City Manager for Constituent Services, the Parking Division, and DPW will monitor results of Sustainability & Transportation Committee discussion. If the petition is recommended to the Council, the Assistant to the City Manager for Constituent Services will support the Sustainability Coordinator and DPW with getting the item on the agenda and fully documented.

Petition for Time-Limited Parking in a Residential Parking Permit (RPP) Zone

Petitioner information

Name: _____

Address: _____

Email: _____

Phone #: _____

I am a: ☐ resident

Location of parking change request

Street: _____

Cross street 1: _____

Cross street 2: _____

Time limited parking requested:	Odd side	Even side	Both
Time limit:	1 hour	2 hours	

The petition must contain signatures of at least 60% of households (a unit of housing, e.g., single family home, a unit in a multi-family building, commercial businesses) on the requested block.

Submit your petition by mail or email to:

Assistant to the City Manager for Constituent Services

Re: Residential Parking Permit Petition

389 Congress Street

Room 208

Portland, ME 04101

Petition for Time-Limited Parking in a
Residential Parking Permit (RPP) Zone

Street: _____

Address	Unit #	Printed Name	Signature	# of vehicles in household	Email *if you wish to be contacted by email in the event of a public meeting

For Office Use Only

Received: _____
Name Date

Medical Affidavit for Caregivers

I, _____, am the ATTENDING PHYSICIAN for
_____, who resides at _____.

This address is located within the boundaries of residential permit parking zone # _____.

He/She requires health care during the time each day that the time-limited parking is in effect. I
declare under penalty or perjury that the foregoing is true and correct.

Physician's Signature

Date

Physician's License Number

I am a HEALTH CARE PROFESSIONAL caring for _____ who resides
at _____. I hereby apply for a residential parking permit for zone #
_____. I declare under penalty or perjury that the foregoing is true and correct.

Health Care Attendant's Name (Printed)

Signature

Date

For Office Use Only

Zone # _____ Permit # _____

Issued by: _____
Name Date

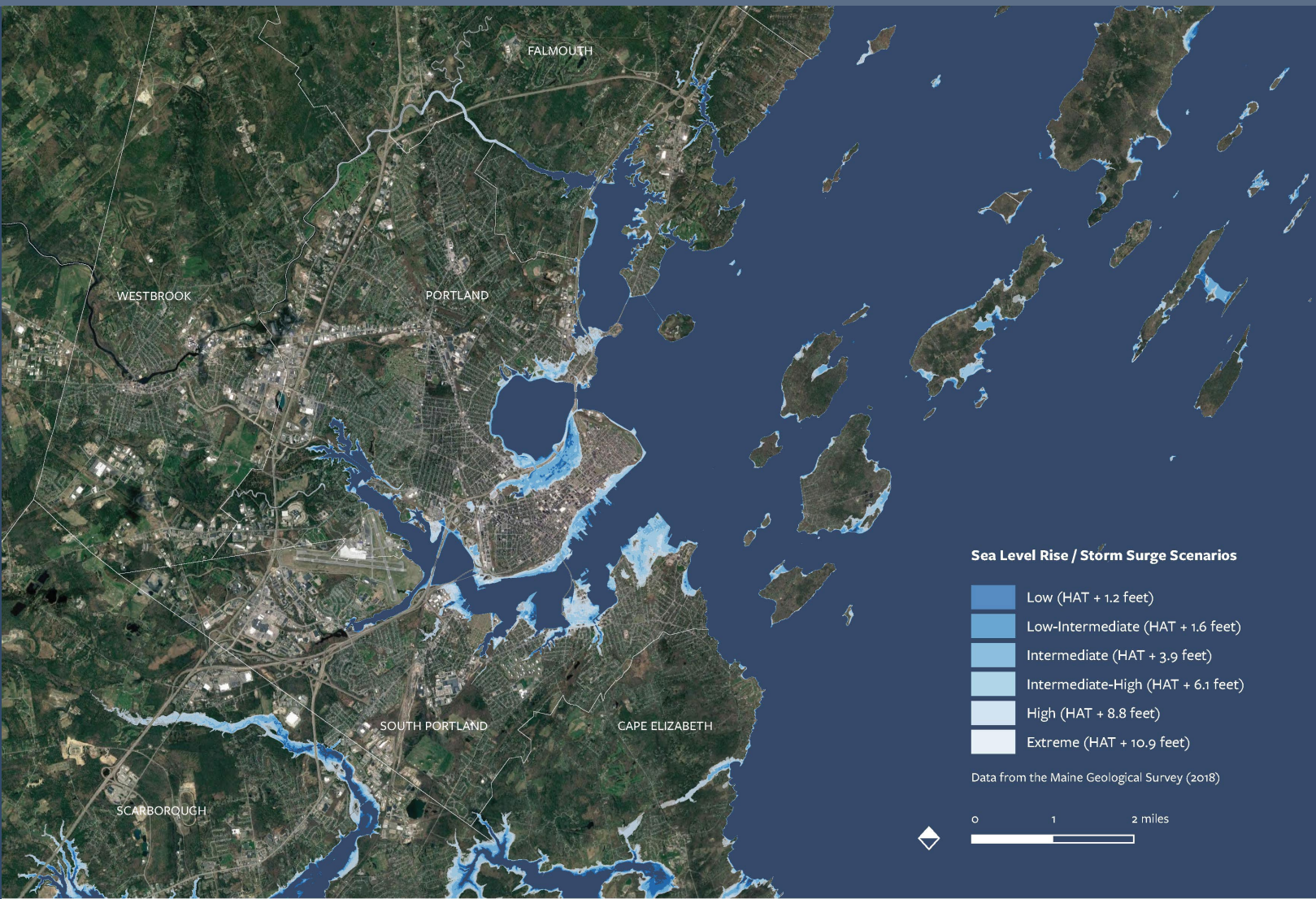
Entered by: _____
Name Date

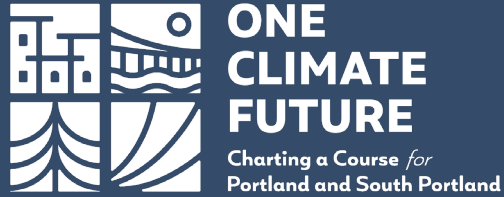


**ONE
CLIMATE
FUTURE**
Charting a Course *for*
Portland and South Portland

ONE CLIMATE FUTURE Climate Change Vulnerability Assessment

Cities of Portland and South Portland ■ 2019





The **One Climate Future** Vulnerability Assessment is a joint project between the Cities of Portland and South Portland, led by the Portland and South Portland **Sustainability Offices**.

We extend a large thank you to the city staff and members of the community who participated in workshops, shared research, and provided feedback in the production of this assessment.

This is the first phase of the One Climate Future planning process. The hazards and vulnerabilities documented in this assessment directly inform the One Climate Future Plan—which charts our ambitious and collaborative course to a thriving, inclusive, carbon-neutral, and resilient future.

The One Climate Future Vulnerability Assessment was produced by **Linnean Solutions** with contributions from Woodard & Curran.

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1. Executive Summary

Portland and South Portland are taking action together to address climate change.

THE GOAL

Through a joint climate action and adaptation plan, **One Climate Future**, our two cities are charting a course for reducing greenhouse gas emissions, while also increasing our ability to adapt to new climate hazards. In other words, we are working to be inclusive, vibrant communities that provide opportunities for residents and businesses to thrive in a changing climate.

This vulnerability assessment is one key step in that process. Its purpose is to identify the hazards that Portland and South Portland will likely face from climate change (such as sea level rise, higher temperatures, or more extreme storms), as well as the ways in which our infrastructure, ecosystems, economies, and communities may be most vulnerable to its impacts. Identifying those vulnerabilities will help us prioritize and invest in actions that can best build our community resilience.

HOW THIS ASSESSMENT WAS DEVELOPED

This assessment does not start from scratch—in fact, far from it. For nearly two decades, research institutions, advocacy groups, businesses, nonprofits, state and city governmental departments, and concerned residents across Portland and South Portland have been tracking environmental indicators, assessing flood vulnerability, and developing climate adaptation recommendations. This assessment starts by gathering and integrating that existing research, including information from local, regional, state, and national vulnerability assessments, as well as regional reports on topic areas ranging from food security, to watershed management, to public health concerns. (See the full bibliography at the end of this report.)

So much of this existing research takes a deep dive into specific areas of vulnerability; this report seeks to highlight those specifics, while creating a stronger understanding around how that vulnerability compounds across systems across the two cities. New map-based assessments provide further information about potential vulnerability. Likewise, the assessment integrates insight from city staff, representatives from businesses and organizations, and residents who participated in the One Climate Future Resilience Workshop in April 2019, as well as provided direct input into various areas of this assessment.

WHAT THE ASSESSMENT TELLS US

Portland and South Portland will continue to experience greater *shocks* and *stresses* related to climate change. “Shocks” refer to acute events that occur in a specific period of time, such as a powerful storm or a heat wave. These events can lead to business closures, transportation interruptions, and/or require enacting emergency management systems to keep residents safe. “Stresses” refer to chronic conditions—challenges that will affect us gradually on a daily basis, such as nuisance flooding, rising food prices, or worsening air quality. These conditions can strain household resources as well as our health and wellbeing. Both acute shocks and chronic stresses related to climate change will become more problematic when they overlap with other chronic stresses people face in their daily lives. These could include illnesses, financial insecurity, or poor-quality housing.

The assessment discusses the implications of these shocks, stresses, and sources of amplified vulnerability in the following sections of the report:

Section 2. Climate Hazards – Details the climate changes that we are already seeing in the Greater Portland area, as well as the changes we may see through 2100.

Survey Findings

IN SPRING OF 2019, residents across Portland and South Portland responded to a survey about climate change. Approximately 79% of 663 respondents indicated that they are “very concerned” that climate change will affect Portland and South Portland, and 69% of respondents reported being “very concerned” that climate change will affect them personally.

More specifically, 68% of 663 respondents reported sea level rise as one of their top three concerns, followed by intense storms (56%), ocean acidification (52%), extreme heat (39%), and flooding (38%).

What are the top three climate hazards you are most concerned about?

Answer Choices	Percent of People Who Ranked Answer in Top 3 Risks	Number of People Who Ranked Answer in Top 3 Risks
Drought	23%	151
Extreme Heat	39%	251
Flooding	38%	248
Intense Storms	56%	362
Ocean Acidification	53%	342
Sea Level Rise	68%	442
None of these	3%	21
Other	7%	41

Table 1.1. One Climate Future survey responses to the question: “Please indicate the top three climate hazards you are most concerned about,” as part of a survey disseminated to Portland and South Portland residents in spring 2019. Total number of answers (n) is 663. Percentages do not add up to 100 because respondents were asked to choose three responses.

Section 3. Infrastructural Risk, Exposure, and Vulnerability – Details how local climate changes may impact energy, transportation, water, and communication infrastructure systems, as well as affect hazardous waste sites.

Section 4. Environmental Risk, Exposure, and Vulnerability – Details how local climate changes may impact the health of terrestrial, tidal, and marine ecosystems, water quality, and coastal erosion.

Section 5. Socioeconomic Risk, Exposure, and Vulnerability – Details how local climate changes may impact local economic sectors, household financial security, housing markets, access to resources, food security, public health, and social equity.

Section 6. Social Vulnerability and Adaptability – Details how aspects of people’s current lives may increase their vulnerability and make it harder to adapt to climate change.

Across these sections, ten key areas rise to the surface. These areas show critical and cascading vulnerability with climate change, and also opportunity for resilience interventions that can have significant impact. Although all vulnerabilities in this assessment are relevant for businesses, organizations, residents, and city departments for planning and future investments, focusing on these ten key areas will help us take bigger steps towards becoming resilient cities. The top ten areas are listed below, not in any particular order.

1. RELEASE OF HAZARDOUS WASTE

Historic and present-day industrial uses have led to a concentration of contaminated sites and hazardous material storage facilities in the cities. There is significant risk that shoreline retreat due to sea level rise, changes in groundwater tables, as well as wind and wave action from severe storms could submerge or erode these sites, causing structural damage to above ground or subsurface hazardous waste containments (as well as releasing soil-bound contaminants). While a number of sites are vulnerable, this study concludes that the potential transport of the significant volumes of hazardous materials stored in containment systems along the Fore River shoreline in South Portland and, to a lesser extent, materials potentially stored by Resource Conservation and Recovery Act (RCRA) Generators in the Bayside Area of Portland, are of the highest concern. These containment sites are required to have written contingency plans, and yet the release of hazardous waste poses potentially one of the most significant risks for human and environmental health and safety. See section 3.5 for more details.

2. GRID SYSTEM RELIABILITY AND BUSINESS CONTINUITY

The electrical power system in New England is undergoing significant change, addressing how to continue to meet peak electricity demand in cold winters, while following a trajectory towards decarbonization.¹ Renewable energy sources, as well as natural gas-based generation, rely on “just-in-time” delivery of energy, which—without energy storage or fuel reserves—creates challenges for reliability. Recent studies by GridSolar suggest that as the cities move towards further electrification to reduce fossil fuel use, electricity load profiles in the Greater Portland area will experience significantly higher relative peak loads. These system transformations provide context for the intensified challenges brought by climate hazards that may reduce system function (i.e., from high heat) or compromise system components (i.e., from flooding or severe storms). Studies suggest that power outages are one of the top climate-related concerns for businesses in the northeast both because of their likelihood and the economic costs they create.² Likewise, power disruptions have shown to be the most frequent root cause of cascading system failures

across other infrastructural systems.³ Thus prioritizing vulnerabilities in power supplies, distribution systems, and the power-dependence of other infrastructure systems can help contain risk. See sections 3.1 and 5.1 for more details

3. IMPACT TO PROPERTY VALUES, COMMERCIAL AREAS, AND TAX BASE

Rising sea levels and storm surge are expected to not only create direct damage to buildings and property, but are predicted to create more lasting effects on property values, real estate markets, and the cities’ tax bases. Recent research in the southeast United States documents that homes within a quarter mile of a road that will flood completely within 15 years are already showing declines in value by \$3.71 per square foot annually—a pattern which can eventually leave residents with mortgages that exceed the value of their homes.⁴ Many of the most vulnerable areas in Portland and South Portland are also centers for commercial and industrial activity, including the waterfront, Back Bay, Knightville, Turner Island, and portions of Ferry Village, which would lead to loss of economic activity in addition to hurting the tax base. Expanding information on risk and identifying ways to retain value in these areas through zoning for alternative uses will be critical for mitigating economic repercussions. The cities’ access to additional capital (e.g., bonds) for resilience investments is also dependent on municipal credit ratings, which can become a “catch-22” if credit ratings are lowered based on flood risk.⁵ See section 5.1 for more details.

4. DISRUPTION TO CRITICAL TRANSPORTATION ROUTES

Sea level rise and storm surge are expected to increasingly inundate roads in Portland and South Portland, and most critically portions of I-295, a key corridor for travel in and out of the cities from the north and south. Sea level rise and storm surge inundation models suggest that I-295 directly south of exit 8 (before reaching Tukey’s Bridge from the south) will likely be the first bottleneck area due to flooding with a category 1 hurricane or sea level rise 6.1 feet above the highest astronomical tide. A category 2 hurricane could impact the same location on I-295, as well as cut off connections between the two cities by

affecting the I-295 bridge, Casco Bay Bridge, Veteran's Memorial Bridge, and the Congress Street (ME-22) bridge, all crossing the Fore River. Sea level rise could likely lead to regular flooding of I-295 exits 6A and 7 as early as 2050. Marine terminals, along with railroad corridors along Commercial Street and Turner Island will likely experience regular flooding by 3.9 feet of sea level rise. See section 3.3 for more details.

5. VULNERABILITY OF SEWER AND STORMWATER CRITICAL ASSETS

The sewer and stormwater systems in both cities show vulnerability to storms and sea level rise in areas along the waterfronts, including Back Cove and the Fore River. Most critically, the South Portland wastewater treatment facility shows vulnerability to storm surge under a category 2 hurricane or higher, as well as to sea level increases at 6.1 feet above the highest astronomical tide. Likewise, the Peaks Island wastewater treatment facility may see storm damage from a category 3 hurricane or higher. Sea level rise inundation models suggest that four pump station sites in Portland and five pump stations sites in South Portland are expected to experience regular flooding under 3.9 feet of sea level rise above the highest astronomical tide. See section 3.2 for more details. Note that it is possible that the city's drinking water infrastructure may be exposed to similar vulnerability; however, these assets were not included in this assessment for homeland security concerns.

6. DEGRADATION OF ECOSYSTEM HEALTH

The health of the cities' ecological resources will likely be affected by climate change. In particular, sea level rise may lead to habitat loss for sensitive tidal wetlands, which provide enormous benefit to aquatic species, and the surrounding built environment by serving as habitat and a protective barrier against storm surge. Without effective areas for marshes to migrate inland, the cities will lose significant wetland resources. Higher volumes of stormwater runoff from extreme precipitation events are likewise expected to lead to higher pollution levels in water systems, exacerbating coastal ecosystem degradation and coastal acidification. In both land and marine ecosystems, changes in temperature and precipitation patterns are also leading to the growth in invasive

species, which can outcompete and choke out native species. Changes in temperature are facilitating pest outbreaks that, in particular, can cause significant damage to the cities' tree canopies. Without new restoration and adaptive management efforts, these stressors can lead to significant losses in the cities' native ecosystems. See sections 4.1–4.5 for details.

7. PUBLIC HEALTH CHALLENGES, PARTICULARLY HIGH HEAT

Unseasonably hot days, extreme heat, as well as extended heat waves can have a significant physiological impact on people whose bodies are less acclimated to warmer weather, which both affects people in historically cooler climates and makes extreme temperatures in the spring more deadly than those later in the summer.⁶ Likewise, air conditioning is much less prevalent in homes, businesses, and public spaces in northern parts of the United States, including Portland and South Portland. Therefore, although Maine is not expected to see the same extreme temperatures as other parts of the country, cities in cooler climates tend to see more heat-related deaths and hospitalizations.⁷ Areas in western South Portland, particularly around the Maine Mall, are likely to feel the effects of extreme heat more acutely due to large areas of impervious surfaces (e.g., parking lots). Many types of disabilities and medications can also enhance vulnerability to heat. Likewise, children, elderly, and residents with limited financial means will also be disproportionately affected. See section 5.4 for more details. Climate change is also likely to exacerbate other public health challenges, including asthma from worsened air quality, higher rates of vector-borne disease, and strain on mental health.

8. GREATER NEED FOR SOCIAL SERVICES

Climate change is expected to amplify some of the burdens residents in Portland and South Portland already face—whether that's financial, food, or housing insecurity, or physical and mental health stress. Without proactive plans to support, fund, modify, coordinate, and/or expand social service systems in the cities, current programs risk becoming overstrained and under-resourced to adapt to changing needs. Service needs will likely spike during acute climate hazards such as severe storms or flooding—a time in

which social service locations may also be impacted. The Bayside area in Portland, which shows some of the highest vulnerability to sea level rise and storm surge flooding between now and 2050, may be most at risk for this scenario. The neighborhood has a higher proportion of residents with higher “social vulnerability” (based on a number of factors, such as income), as well as a significant proportion of the social network resources that residents in the area rely on (e.g., the Human Services Department building). Losing access to such resources can amplify hardship and prolong recovery from severe storms or flooding. Both the Portland and South Portland Housing Authority buildings are vulnerable to a category 2 hurricane or higher. See section 5.3 as well as 6.1–6.5 for more details.

9. VULNERABILITY OF FOOD SYSTEMS

International research increasingly suggests that droughts, floods, and new pests introduced by climate change will impact global food systems with a potential net rise in food prices; however, the nature and extent of the impact is both complex and uncertain. Locally, however, the most direct and apparent risk to the food system will likely come from compromised distribution chains and challenges to food access. Road closures due to flooding from severe storms, particularly on I-295 and local roads to supermarkets, could likely restrict food delivery. Sea level rise and storm surge models suggest that five of eleven large grocery stores across both cities may see significant inundation in a category 2 hurricane, or in a scenario where sea levels reach 3.9 feet above the highest astronomical tide. Four of those grocery stores may see flooding around their sites at 1.6 feet of sea level rise. Portland and South Portland residents that rely on public transportation and/or food assistance will likely face greater food insecurity driven by closures in public transportation, social services, or rising food prices. See section 5.3 for more details.

10. RISK OF INCREASING SOCIAL INEQUITY

There is a significant risk that climate change may contribute to greater social inequity. Portland and South Portland residents facing poverty, a disability, or other forms of social marginalization will have

more limited access to resources to respond in an emergency or proactively adapt to climate stresses. At the same time, climate change is expected to further impact livelihoods, housing security, food security, and health—thereby enhancing many of the vulnerabilities that make the impacts of climate change more acute for individuals and households. In other words, climate change creates a vicious cycle that increases social vulnerability, and with that, more susceptibility to climate hazards. Evidence from other cities have shown ways in which adaptation measures have also inadvertently enhanced inequity by continuing to invest in areas that have more resources. See section 5.5 for more details. Considering the equity implications of both processes and outcomes of climate adaptation efforts will be critical to ensuring that further sources of inequity do not become a byproduct of climate change response.

ACTION TO DATE AND NEXT STEPS

Climate change studies and instances of extreme weather prior to the release of this assessment have already prompted Portland and South Portland to begin integrating climate planning into city investments in a number of ways. Portland and South Portland City staff are currently participating on working groups for the Governor’s Climate Council in the areas of Transportation, Energy, and Coastal and Marine issues. The Cities have also participated in several studies exploring the impacts of climate change and sea level rise, such as the Maine Climate Change Adaptation Task Force in 2010, the Waterfront Vulnerability Assessment in 2013, and the Department of Homeland Security Regional Resiliency Assessment Program in 2014.

In 2007, the Portland City Council created a “green ribbon” task force that drafted the Sustainable Portland Report which identified sea level rise as the greatest threat to Portland since the Great Fire of 1866. In 2014 and 2015 Portland experienced significant rainfall events that dropped over six inches of rain in short periods of time. The 2015 storm coincided with

a high tide and resulted in widespread flooding in the Bayside neighborhood. Following this event, the City of Portland launched Bayside Adapts, a community scale resiliency planning process that sought to pave the way for more comprehensive planning by establishing a set of guiding principles and identifying key gaps in knowledge about civic infrastructure in the area.

Portland city projects have included resiliency elements as far back as the 2005 Ocean Gateway infrastructure upgrade. Ongoing resilience projects include improved stormwater management infrastructure designed to reduce impacts on the water treatment facility to reduce overflows of untreated water during significant rain events. City of Portland staff have also begun exploring ways to use incentives and mandates to encourage private developers to include resilience features in their buildings.

South Portland is not currently experiencing the increased levels and occurrences of flooding that Portland and many other communities are facing with climate change. This is due in part to the considerable steps the City has taken to improve its water management infrastructure.

Though planning for climate resilience is a relatively new concept, the City of South Portland's significant

investment in its sewer and stormwater infrastructure over the past few decades have effectively reduced flooding and increased sewer and stormwater capacity for new and redevelopment. Since the late 1980s, South Portland has invested more than \$42 million in collection system separations, pump station renovations, and upgrades to its wastewater treatment plant. These infrastructure upgrades, including the elimination of 24 out of 28 combined sewer overflows, have reduced flooding events and improved water quality.

While these investments have positioned the City of South Portland well for near-term impacts, we know that future projections for sea level rise and intensified storm surges reveal new vulnerabilities that South Portland will need to plan for and adapt to.

These interventions for both cities represent the very beginning of a more significant effort to prepare our communities for the anticipated impacts of climate change.

This vulnerability assessment identifies significant infrastructural, environmental, social, and economic impacts from sea level rise, changes in precipitation, more intense storms, as well as higher temperatures—all of which will provide the groundwork for action in the One Climate Future Plan.

SECTION ONE ENDNOTES

- 1 ISO New England. (2019). Energy Security Improvements. ISO Discussion Paper, April 2019 – Version 1. Holyoke, MA.
- 2 Kristin Kelleher. (2019). Businesses Acting on Rising Seas. Climate Action Business Association. Boston, MA.
- 3 Comes, T., & Van de Walle, B. (2014). Measuring Disaster Resilience: The Impact of Hurricane Sandy on Critical Infrastructure Systems. Proceedings of the 11th International ISCRAM Conference. Hiltz, S.R., Pfaff, M.S., Plotnick, L. & Shih, P.C. eds. Pennsylvania, USA.
- 4 McAlpine, S.A. & Porter, J.R. (2018). Estimating Recent Local Impacts of Sea-Level Rise on Current Real-Estate Losses: A Housing Market Case Study in Miami-Dade, Florida. Population Research and Policy Review. 37(6): 871-895.
- 5 Union of Concerned Scientists. (2018). Underwater: Rising Seas, Chronic Floods, and the Implications for US Coastal Real Estate. Cambridge, MA.
- 6 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.
- 7 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.

2. Climate Hazards

The Cities of Portland and South Portland are already feeling the local effects of global climate change.

Since 1985, average temperatures in Maine have increased 3°F and precipitation has increased by 13 percent. The Gulf of Maine is warming faster than 99 percent of the world's oceans, and sea levels locally have been rising by 0.07 inches per year since 1912. These climate hazards, including warmer air and water temperatures, bigger storms and more precipitation, as well as sea level rise and ocean acidification are all beginning to take a toll on our infrastructure, communities, health, livelihoods, and ecosystems. These hazards are indicators for how our climate is changing now, and for the impacts climate change will continue to bring.

CLIMATE SCENARIOS

While there is no doubt that Portland and South Portland will continue to see changes in the climate through the end of the century, there is a significant amount of uncertainty in how much change we will see.⁸ In addition to the complexities of climate modeling, it is difficult to predict future greenhouse gas emissions, which depend on whether and how quickly communities globally act to prevent climate change.

We thus use a scenario-based approach to look at the range of potential change. These scenarios, known as Representative Concentration Pathways (RCPs), represent possible futures with different levels of greenhouse gas concentrations in the atmosphere. The following three scenarios (RCPs) are used in the International Panel on Climate Change's Fifth Assessment Report⁹ and the Fourth National Climate Assessment.¹⁰

RCP 2.6: *We all act now and drastically reduce emissions.* This scenario represents significant immediate reductions in greenhouse gas emissions, resulting in “net-negative” emissions (more greenhouse gases being drawn from the atmosphere than released into the atmosphere) by 2100. This scenario results in an increase in global mean temperature of 1.9 to 2.3 degrees Celsius by the years 2081–2100 relative to temperatures in 1850–1900.

RCP 4.5: *We all act now, but reduce emissions at a slower pace.* This scenario represents moderate reductions in greenhouse gas emissions, resulting in the stabilization of global emissions by 2050 and a decrease in global emissions afterwards. This scenario results in an increase in global mean temperature of 2.0 to 3.6 degrees Celsius by the years 2081–2100 relative to temperatures in 1850–1900.

RCP 8.5: *We continue business-as-usual.* This scenario represents continued intensive use of fossil fuels and emission of greenhouse gases. This scenario results in an increase in global mean temperature of 3.2 to 5.4 degrees Celsius by the years 2081–2100 relative to temperatures in 1850–1900.

RCP 2.6 represents the pathway required to remain below an increase of 2 degrees Celsius, which has widely been used as a threshold for limiting more significant impacts from climate change. The Fourth National Climate Assessment, however, focuses on RCP 4.5 and RCP 8.5 as “low” and “high” emissions scenarios, respectively, in order to understand the likely potential range of impact due to climate change. Likewise, those two scenarios are primarily used in this Vulnerability Assessment to understand the potential range of climate impacts Portland and South Portland may face in the next thirty years and through the end of the century.

2.1 Changes in Sea Level, Storm Surge, and Tidal Flooding

SEA LEVEL RISE

Global average sea level has increased by roughly seven to eight inches (16 - 21 cm) since the early 1900s, with almost half of that rise occurring since 1993 as land-based ice has melted and oceans have warmed.¹¹ The National Ocean and Atmospheric Administration (NOAA) has three active tide stations for long-term sea level rise monitoring in Maine, one of which is located in Portland. According to data collected at the Portland tide gauge (Station 8418150), local sea levels have been rising at a rate of 0.07 inches (1.9 millimeters) per year since 1912 (**Figure 2.1**).

The 2018 National Climate Assessment suggests that sea levels will continue to rise, and that the pace will likely quicken.¹² In 2017, NOAA conducted a review of sea level rise literature and provided a range of global and regional

THE GIST

Portland and South Portland will experience more intense and frequent flooding due to sea level rise and storm surge. Certain areas that flood now during heavy storm events will likely experience daily flooding at high tide by the end of the century.

Note: Much of the data and projections in this section are drawn from the report *Bayside Adapts Phase 1: Stormwater and Sewer Gap Analysis*. Further details can be referenced in that report.

sea level rise projections based on the three emissions scenarios listed previously (RCP 2.6, 4.5, and 8.5).¹³ The six global mean sea level (GMSL) rise scenarios include an extreme upper-bound (highest potential sea level rise in 2100), a lower-bound (lowest potential sea level rise in 2100), and four intermediate conditions. **Table 2.1**

Relative Sea Level Rise (Measured at Portland, Maine Tide Gauge)

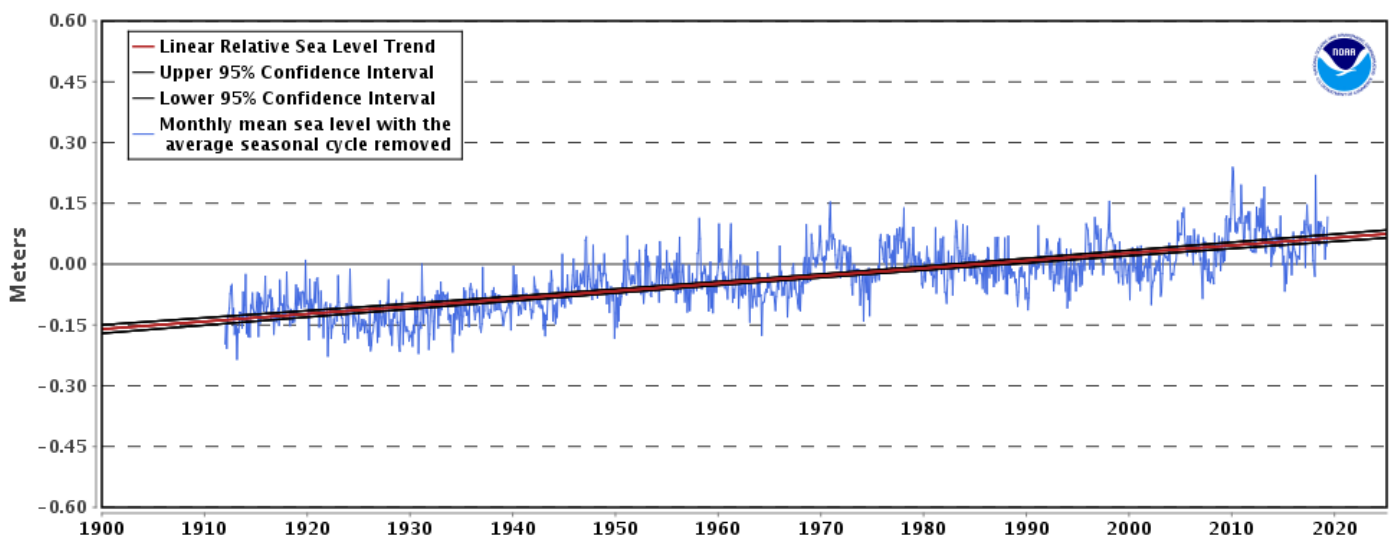


Figure 2.1. The plot shows monthly mean sea level with the regular seasonal fluctuations removed, as well as the long-term linear trend (red line) with its 95% confidence interval. The trend indicates a 1.88 mm per year increase in mean sea level with a 95% confidence interval of ± 0.14 mm per year based on data from 1912 to 2018. Figure source: National Ocean and Atmospheric Administration (NOAA) (2018).²¹

Global Mean Sea Level Rise Scenarios

Scenario	Global Mean Sea Level Rise	Probability of Exceedance
Low	0.3 meters (1 ft)	94 - 100%
Intermediate Low	0.5 meters (1.6 ft)	94 - 96%
Intermediate	1 meters (3.3 ft)	2 - 17%
Intermediate High	1.5 meters (4.9 ft)	0.4 - 1.3%
High	2 meters (6.6 ft)	0.1 - 0.3%
Extreme	2.5 meters (8.2 ft)	0.05 - 0.1%

Table 2.1. Global mean sea level rise scenarios for 2100 with the corresponding probability that sea level rise will exceed the given threshold. The probability is based on the RCP 2.6 to RCP 8.5 scenarios. Table adapted from Bayside Adapts Phase 1 report (2017).²²

summarizes the six global scenarios and, for each, gives the probability that sea levels will surpass that height, based on the three greenhouse gas emissions scenarios. Most notably, NOAA now suggests that a rise in sea level between 2.0 and 2.5 meters is not only plausible but also becoming more likely, based on new research on the instability of the Antarctic Ice Sheet.

Sea level rise will play out differently on a local scale based on a number of factors, including variations in the Earth's gravitational forces, ocean circulation patterns, ice sheet and glacial melt, and vertical movement in the land. To account for this variation, NOAA derived regional relative sea level rises from the global scenarios on a one-degree grid along the US coastline and at tide

gauges, including Portland Station 8418150.¹⁴ **Table 2.2** summarizes the regional relative sea level rise scenarios for 2050 and 2100 for the Greater Portland area, as well as the projections as mean sea level relative to NGVD29 (the cities' preferred vertical datum).¹⁵

With so many potential scenarios, which should we focus on? NOAA provides guidance on choosing planning thresholds based on the likelihood of the scenarios and the level of risk posed. Using this guidance, and referring to the data in **Tables 2.1** and **2.2**, Portland's *Bayside Adapts Phase 1: Stormwater and Sewer Gap Analysis* ("Bayside Adapts") defines "what is most likely to occur" as the intermediate scenario (2-17% probability of exceedance) and "how bad can things

Sea Level Rise Scenarios for Portland and South Portland

Scenario	2050		2100	
	Relative Sea Level Rise (feet)	Mean Sea Level (feet, relative to NGVD29)	Relative Sea Level Rise (feet)	Mean Sea Level (feet, relative to NGVD29)
Low	0.62	1.08	1.12	1.58
Intermediate Low	0.82	1.28	1.53	2.00
Intermediate	1.48	1.94	3.84	4.30
Intermediate High	2.16	2.63	6.00	6.46
High	2.95	3.41	8.72	9.19
Extreme	3.38	3.84	10.79	11.25

Table 2.2. Sea level rise scenarios for 2050 and 2100 in Portland and South Portland. Columns two and four report the regional relative sea level rise (i.e., the magnitude of change) in feet derived by NOAA²³ for Portland, Maine. Columns three and five report the relative sea level rise converted to mean sea level relative to NGVD29, the cities' preferred vertical datum. The conversion was completed as part of the Bayside Adapts Phase 1: Stormwater and Sewer Gap Analysis, based on the methodology presented by NOAA in Sweet et al. (2017).

Mean Sea Level for Portland and South Portland

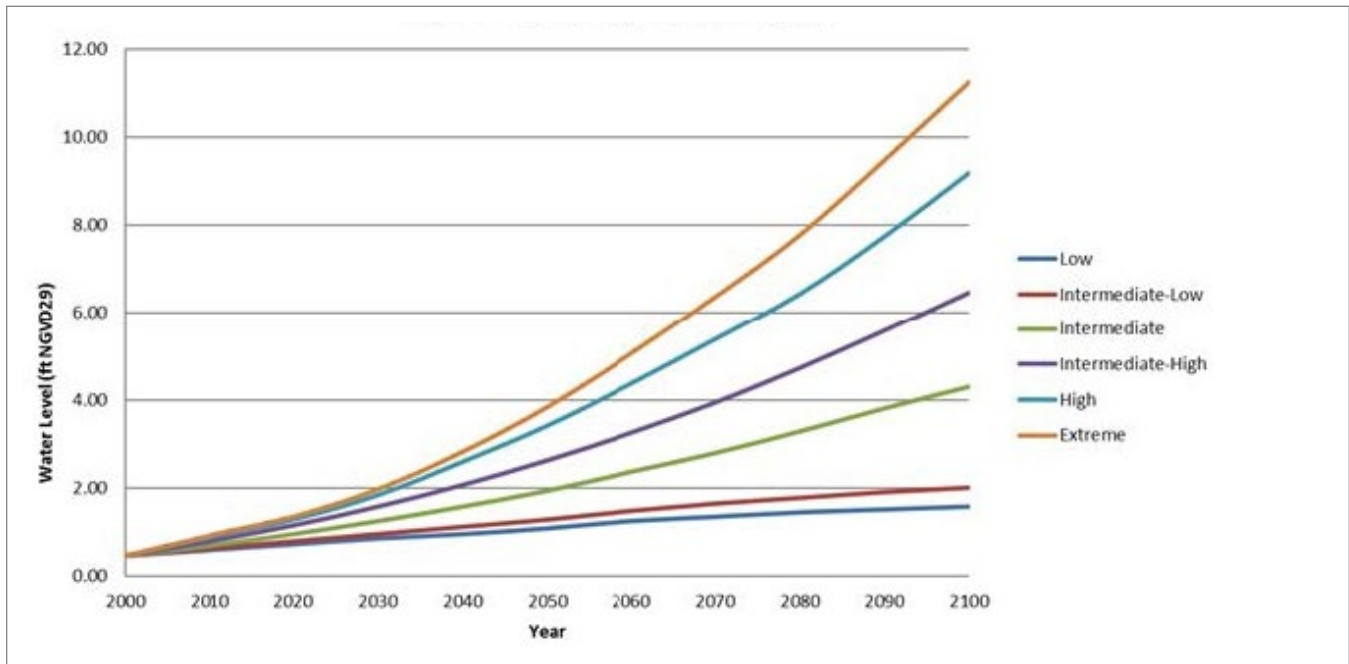


Figure 2.2. Mean sea level over the course of the century, based on Low to Extreme emissions scenarios for Portland and South Portland. Predicted water levels are in feet, relative to NGVD29. Figure source: Bayside Adapts Phase 1 report (2017).²⁴

get” as the extreme scenario (0.05 to 0.1% probability of exceedance, representing a low probability but high consequence event). These thresholds are based on the characteristics of the regional sea level rise scenarios, not characteristics specific to Portland. Therefore, the same planning thresholds also apply to South Portland. It is recommended that Portland and South Portland commit to managing the intermediate scenario (1.48 feet), but be prepared to manage the extreme scenario (3.38 feet) when considering a 2050 planning horizon (**Table 2.3**).

By 2100, the potential levels of sea level rise across the scenarios deviate from each other quite significantly. *Bayside Adapts* recommends committing to managing the intermediate scenario (3.84 feet) for a 2100 planning horizon, being prepared to manage the high scenario (8.72 feet), and being aware of and monitoring for the extreme scenario (10.79 feet). When planning for worst-case scenarios, it is important to consider these projected increases in sea level on top of the highest astronomical tide.

Sea Level Rise Planning Scenarios for Portland and South Portland

Scenario	Relative Sea Level Rise (feet)	
	2050	2100
Low	0.62	1.12
Intermediate Low	0.82	1.53
Intermediate	1.48 – “Commit to manage”	3.84 – “Commit to manage”
Intermediate High	2.16	6.00
High	2.95	8.72 – “Prepare to manage”
Extreme	3.38 – “Prepare to manage”	10.79 – “Be aware of”

Table 2.3. Sea level rise scenarios for 2050 and 2100 in Portland and South Portland, including recommendations for response in city planning. Table adapted from Bayside Adapts Phase 1 report (2017).

HIGH TIDE FLOODING

Due to sea level rise, Portland and South Portland will likely see more flooding on a more regular basis. Tidal flooding, also known as “sunny day flooding” or “nuisance flooding,” is the temporary inundation of low-lying areas during particularly high tides. Tidal flooding is usually not deep enough to cause significant threats to health, safety, or property, but it often causes road closures, disrupts daily activity, adds strain on sewer and stormwater systems, and can lead to minor property and infrastructure damage.¹⁶

NOAA’s National Weather Service (NWS) has defined a series of thresholds for minor, moderate, and major

flooding that are used for issuing flood advisories. The minor level refers to a likely inconvenience or some public threat, but no property damage; the moderate level refers to the likely inundation of roads and buildings, and the potential need for evacuation to higher elevations; and the major level refers to serious and extensive inundation of roads and property, and the need for significant evacuations to higher elevations.

At the Portland Tide Station (8418150), the minor, moderate, and major flooding thresholds are 7.5, 8.5, and 9.5 feet relative to NGVD29, respectively (or 12, 13, and 14 MLLW). These thresholds correspond to documented nuisance flooding in Portland in the Commercial Street

Historic Nuisance Flooding Inundation in Portland

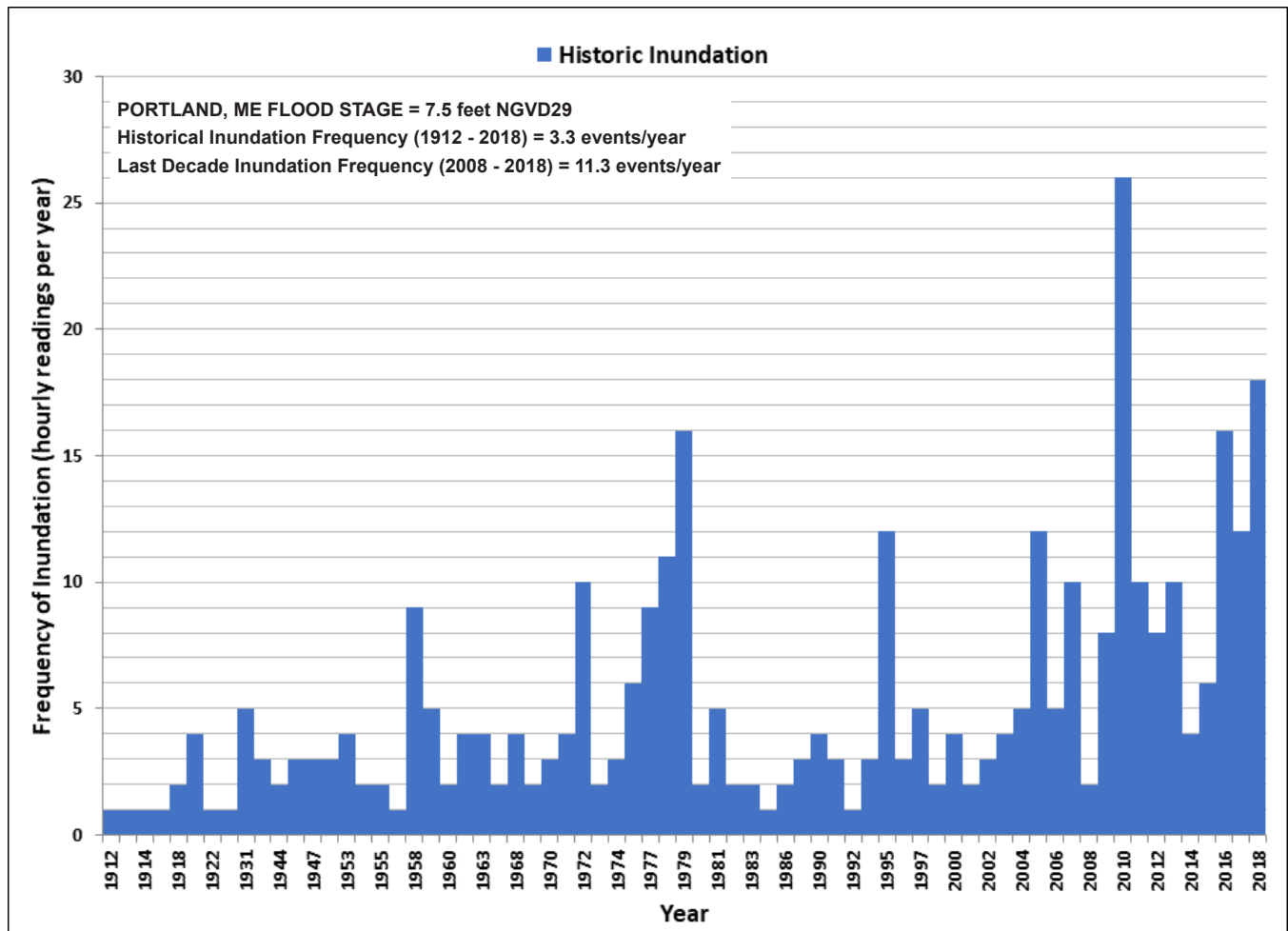


Figure 2.3. The frequency of inundation from nuisance flooding measured in hourly readings per year from 1912 to 2018, based on flood levels at the Portland tide gauge reaching 7.5 feet relative to NGVD29 (12 feet Mean Lower Low Water per NOAA AHPS). Graphic source: Peter Slovinsky, Maine Geological Survey (2019). Portland, ME flood stage from NOAA Advanced Hydrologic Prediction Service; Inundation data from NOAA-COOPS.

and Back Cove areas. To date, South Portland has had minimal coastal flooding, and so corresponding flood thresholds have not yet been defined.

Figure 2.3 shows the frequency of historic inundation from nuisance flooding from 1912 to 2018, based on flood levels at the Portland tide gauge reaching 7.5 feet relative to NGVD29 (the minor flood threshold for Portland). Since 1912, Portland has been flooding 3.3 times per year, on average. Within the last decade, that rate has increased to 11.7 times per year. **Figure 2.4** shows what that frequency of flooding would have looked like with one foot of sea level rise. With only a one-foot increase

in sea level, Portland would have seen nuisance flooding around 50 times per year, and over 130 times per year in the last decade.

Table 2.4 and **Figure 2.5** show what daily high water levels and the highest astronomical tide may look like in 2050 and 2100 under various sea level rise scenarios. Mean Higher High Water (MHHW) is the average height of the highest tide recorded each day during the recording period (the National Tidal Datum Epoch, NTDE) and thus denotes the high water level reached daily. The highest astronomical tide is the highest tide predicted to occur at the station within the NTDE.

Historic Nuisance Flooding Inundation and Inundation with 1 Foot of Sea Level Rise in Portland

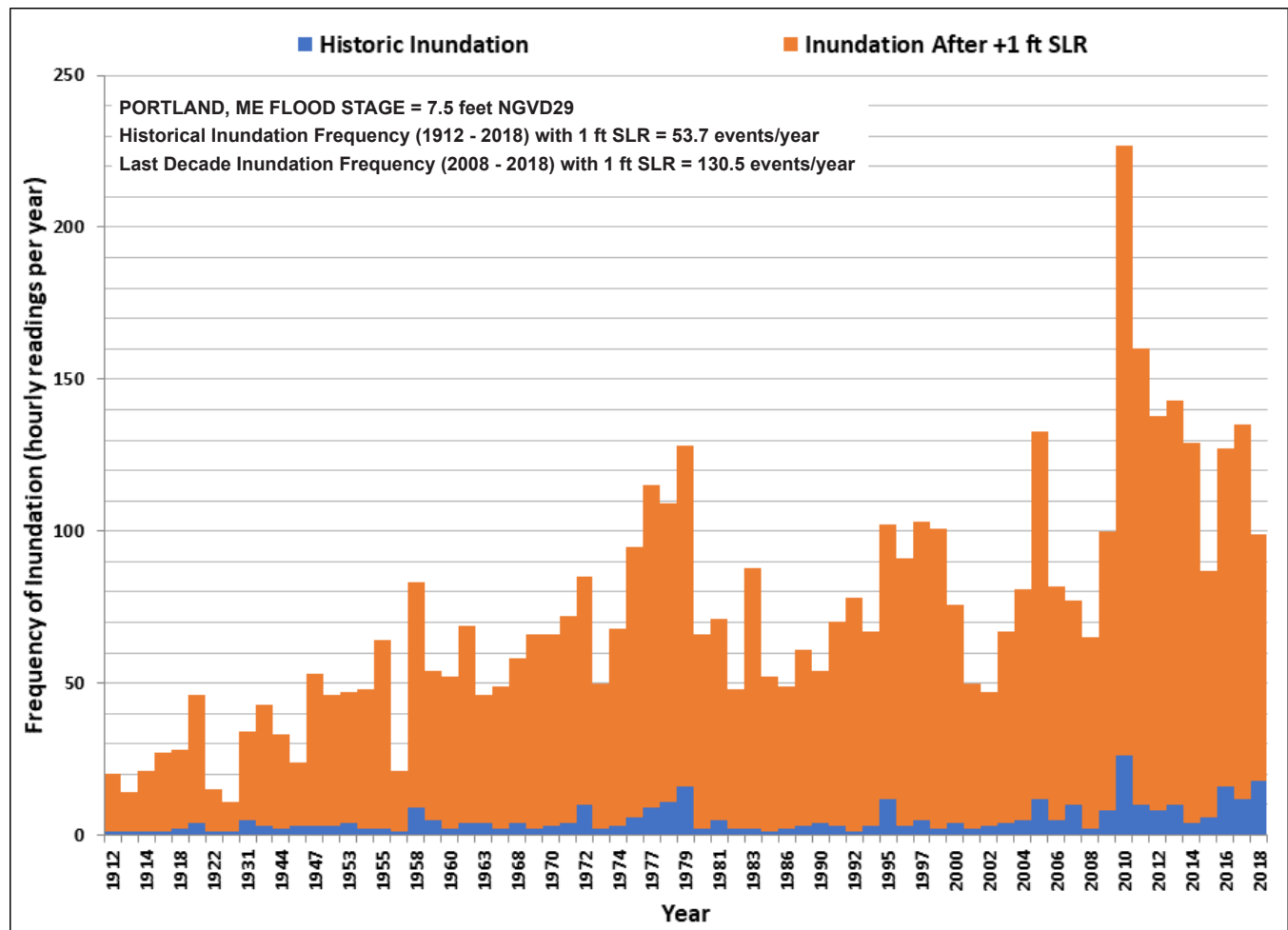


Figure 2.4. The frequency of inundation from nuisance flooding measured in hourly readings per year from 1912 to 2018, based on flood levels at the Portland tide gauge reaching 7.5 feet NGVD29 (12 feet Mean Lower Low Water per NOAA AHPS) (blue), as well as the frequency of historic inundation as it would have occurred over 1912 to 2018 with one foot of sea level rise (orange). Graphic source: Peter Slovinsky, Maine Geological Survey (2019). Portland, ME flood stage from NOAA Advanced Hydrologic Prediction Service; Inundation data from NOAA-COOPs.

Projected Daily High Water Levels and Highest Astronomical Tide

Scenario	2050		2100	
	MHHW (5.38 feet NGVD29)	HAT (7.42 feet NGVD29)	MHHW (5.38 feet NGVD29)	HAT (7.42 feet NGVD29)
Intermediate	6.93	8.97	9.29	11.35
Intermediate High	7.61	9.65	11.45	13.49
High	8.40	10.44	14.17	16.21
Extreme	8.83	10.87	16.24	18.28

YELLOW = Above NWS minor flood threshold (7.5 feet)

ORANGE = Above NWS moderate flood threshold (8.5 feet)

RED = Above NWS major flood threshold (9.5 feet)

Table 2.4. Daily high water (MHHW: Mean Higher High Water) and highest astronomical tide (HAT) projections for 2050 and 2100, based on measurements at the Portland tide gauge. Color designations indicate whether the water level surpasses National Weather Service flood threshold levels for Portland: red indicates major flooding, orange indicates moderate flooding, yellow indicates minor flooding. MHHW and HAT baselines and projections as well as flood threshold values are specified in feet relative to NGVD29. Table adapted from Bayside Adapts Phase 1 report (2017).

Flood Thresholds and Projected Mean Higher High Water

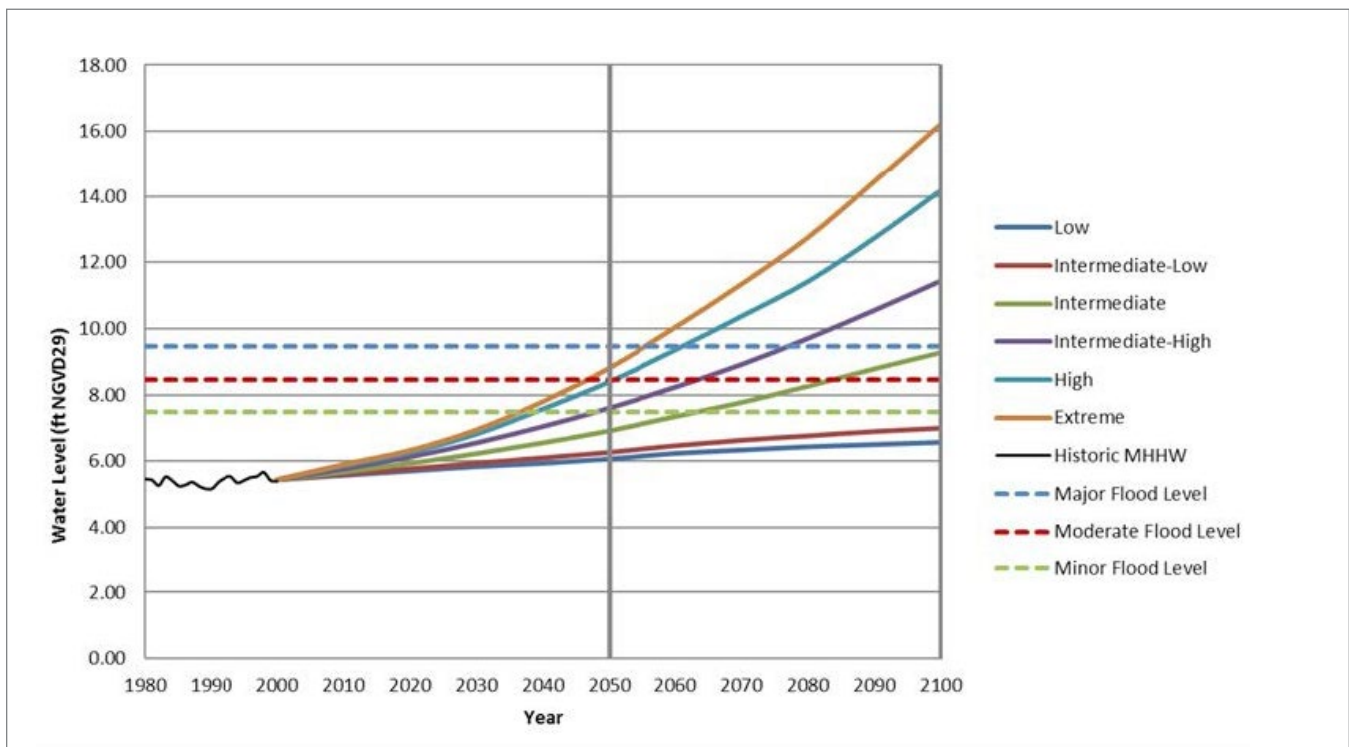


Figure 2.5. Predicted Mean Higher High Water (MHHW) levels from 2000 to 2100 in feet relative to NGVD29 for relative sea level (RSL) rise scenarios for Greater Portland. Dashed lines show major, moderate, and minor flood threshold designations by the NOAA National Weather Service (NWS) for Portland. Figure source: Bayside Adapts Phase 1 report (2017).

The following maps (**Figures 2.6, 2.7, and 2.8**) show potential flooding in Portland and South Portland for the six different scenarios due to sea level rise and/or storm surge on top of the astronomical high tide.¹⁷ All scenarios refer to the inundation we may see in Portland and South Portland by the year 2100.

To achieve the “low” or “low-intermediate” scenarios, we would need to achieve substantial global greenhouse gas emissions reductions (i.e., as aligned with Representative

Concentration Pathways 2.6 and 4.5, respectively).

The “intermediate” scenario represents a case where emissions continue to increase through the end of the century (i.e., as aligned with RCP 8.5). The “extreme” case represents the lowest probability, worst-case scenario (i.e., the upper bound of the model). In the near-term, it is likely that we will see the effects of the “low” scenario by 2030 and the “low-intermediate” scenario by 2050 if we continue on the “business as usual” trajectory.

Extent of Inundation from Projected Sea Level Rise in Portland and South Portland (2100)

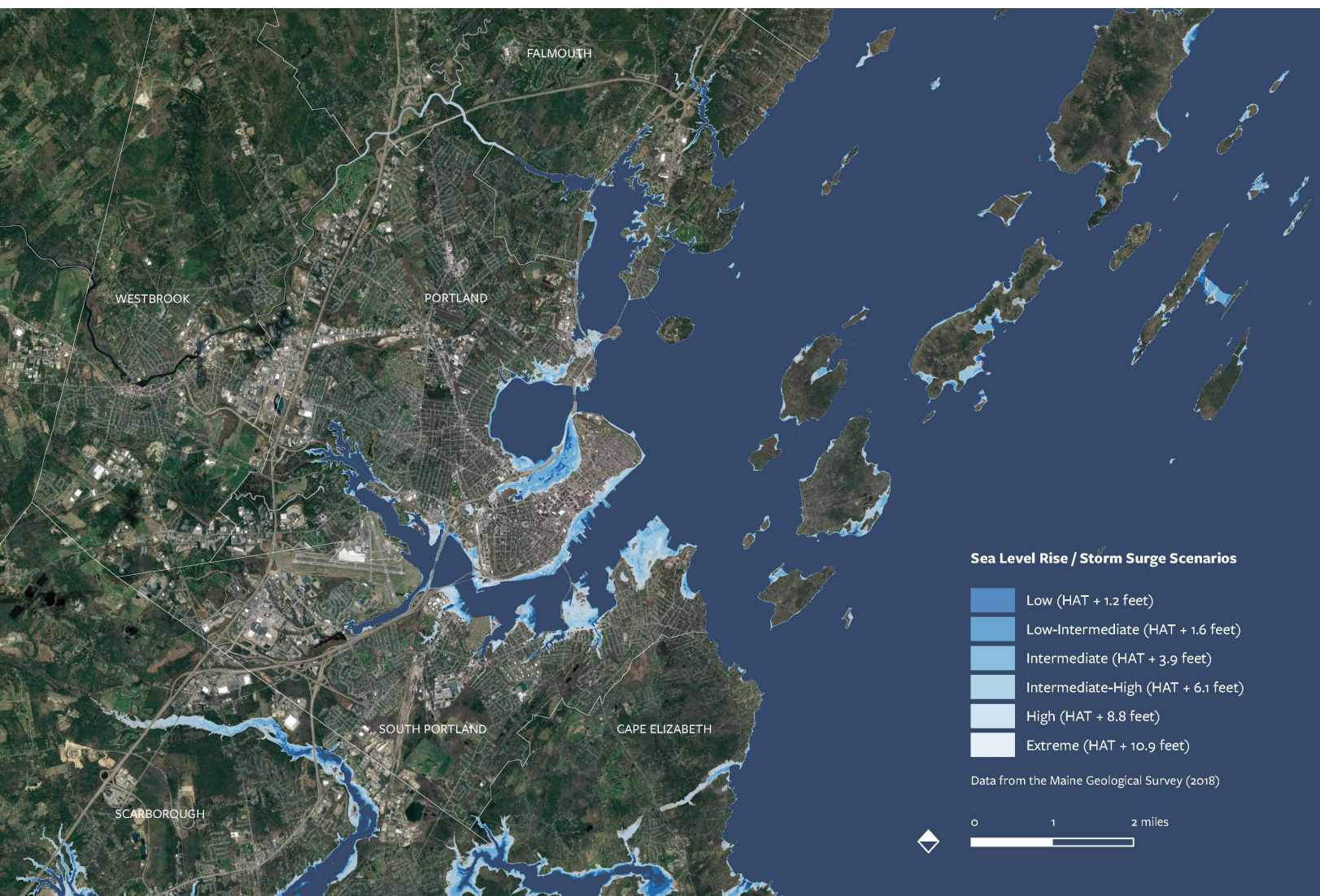


Figure 2.6. Extent of flooding due to sea level rise or storm surge on top of the highest astronomical tide in Portland and South Portland for six scenarios for the year 2100. Scenarios include low, low-intermediate, intermediate, intermediate-high, high, and extreme sea level rise at the 50% confidence interval. Data source: Maine Geological Survey Sea Level Rise/Storm Surge Data (2018).²⁵

Waterfront Inset: Sea Level Rise Scenarios (2100)

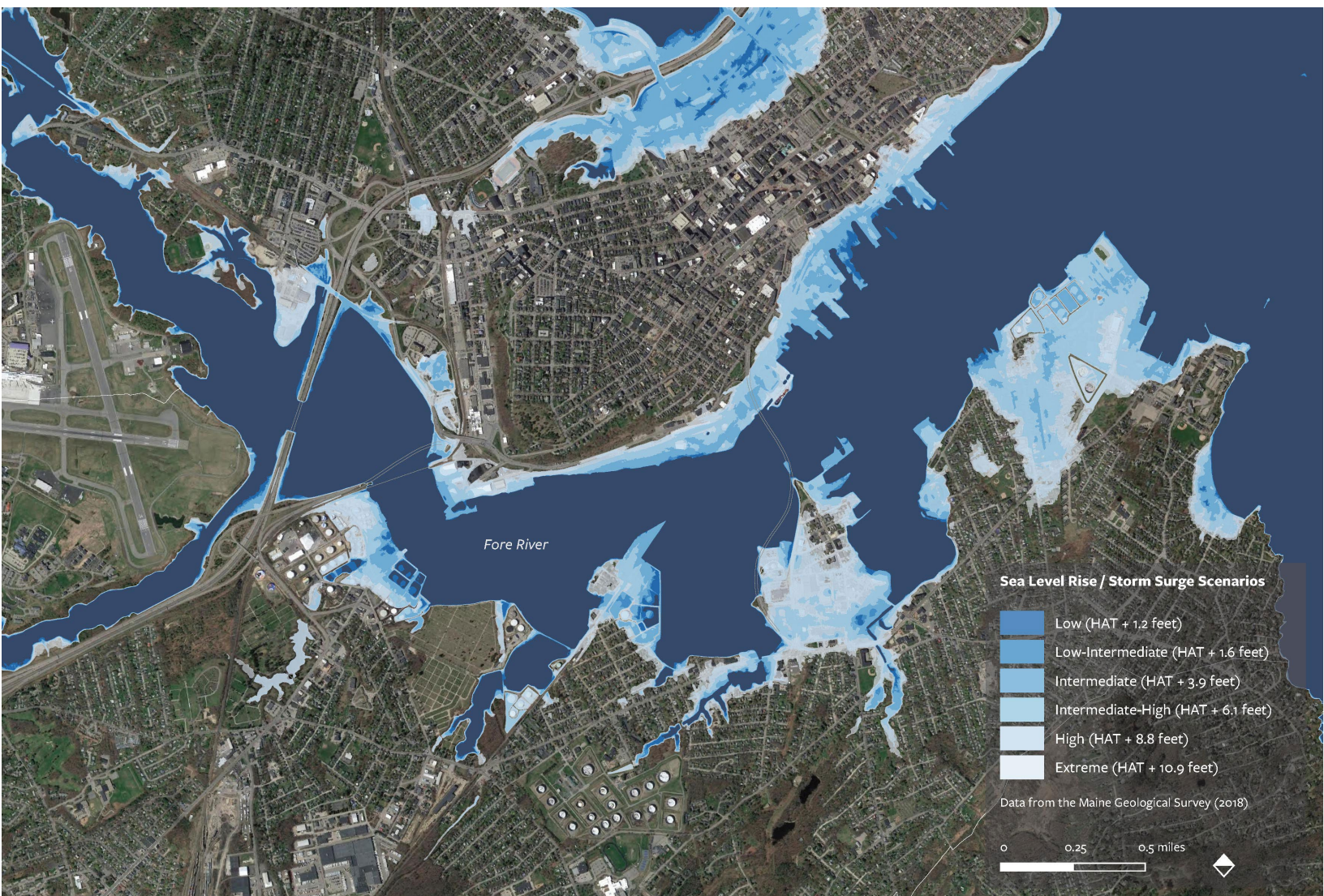


Figure 2.7. Extent of flooding along the Portland and South Portland waterfronts due to sea level rise or storm surge on top of the highest astronomical tide for six scenarios for the year 2100. Data source: Maine Geological Survey Sea Level Rise/Storm Surge Data (2018).

STORM SURGE

Storm surge is the temporary increase in water levels above predicted astronomical tides due to atmospheric pressure changes and strong winds from storms. The *storm tide* specifies the increase in water level from both storm surge and the astronomical tide. As climate change is projected to bring greater storm intensity, sea level rise and potentially greater storm surge compound to create even higher water levels and greater flood risk.

Through the 2015 North Atlantic Comprehensive Coast Study (NACCS), the U.S. Army Corps of Engineers

(USACE) characterized the impact of future storm hazards along the North Atlantic Coast by simulating winds, waves, and water levels based on 1,050 synthetic tropical storms and 100 historical extratropical storms, applied to 96 random tide phases. **Table 2.5** summarizes the 10-year, 20-year, 100-year, and 500-year return period storm tide levels at three of the NACCS stations based in Portland and South Portland and indicates how those are projected to change by 2050 under various sea level rise scenarios. **Table 2.6** summarizes the same information for 2100.

Waterfront Inset: Sea Level Rise Scenarios (2100)

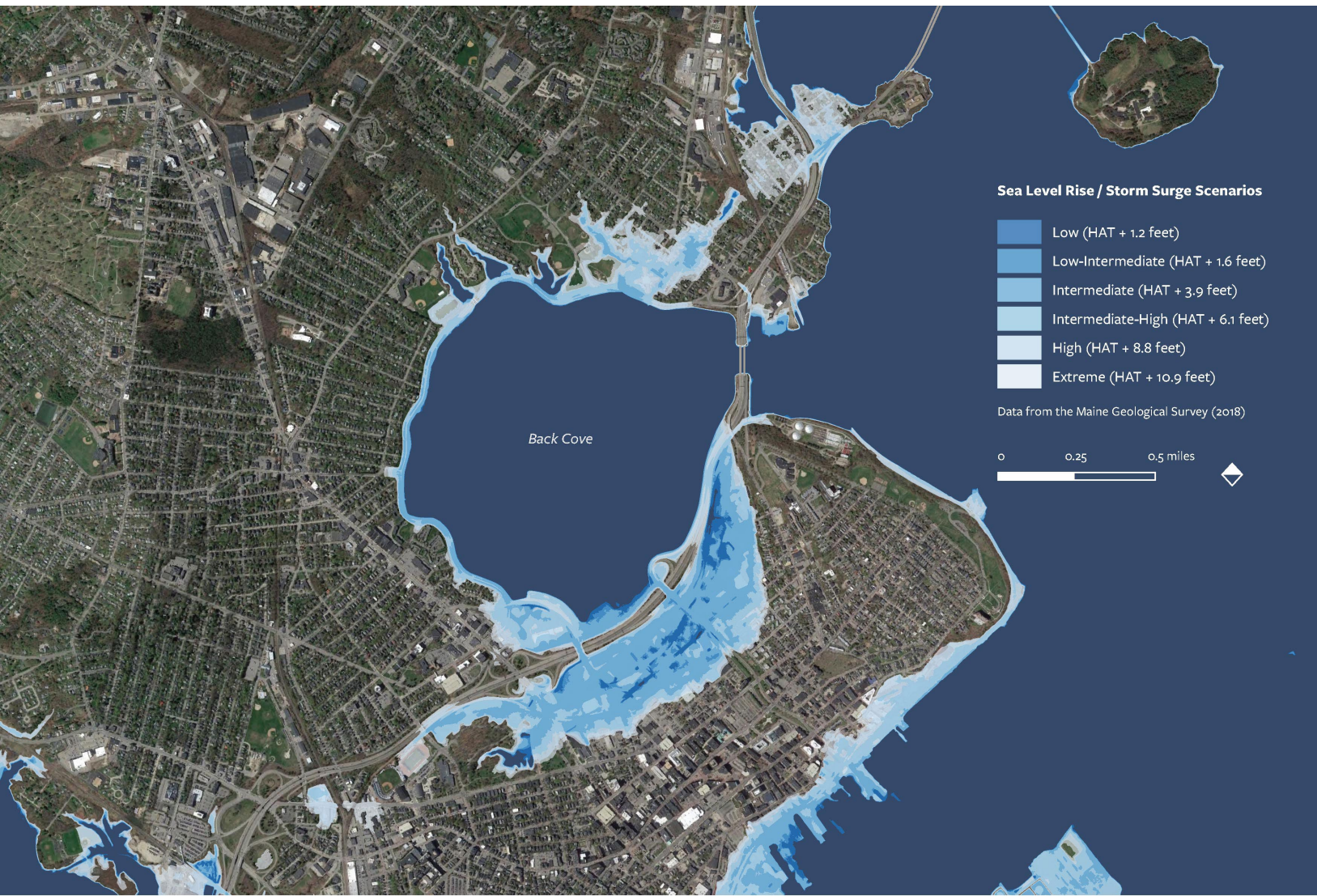


Figure 2.8. Extent of flooding in the Back Cove area of Portland due to sea level rise or storm surge on top of the highest astronomical tide for six scenarios for the year 2100. Data source: Maine Geological Survey Sea Level Rise/Storm Surge Data (2018).

For reference, the Blizzard of 1978 was representative of the 100-year water level for Greater Portland.¹⁸ During that storm, water levels reached 9.6 feet NGVD29, the highest values ever recorded at the Portland Tide Station by almost 0.9 feet. Under the Intermediate sea level rise scenario, similar water levels are projected to occur at a ten-year return period—in other words, ten times as frequently as they currently do today.

Although there is no scientific certainty as to whether climate change will impact the frequency of hurricanes, a number of studies point to the ways climate change will

increase their intensity.¹⁹ Warmer surface waters produce heat and water vapor, which fuel hurricane intensity, and warmer air temperatures can hold more of that available moisture, leading to higher levels of precipitation. These effects are combined with the impact of sea level rise, mentioned above, which amplifies the inland impacts of storm tides. According to NOAA, Maine has been hit by nine hurricanes, with five of those making landfall. All five have been either a category 1 or 2.²⁰

See **Appendix B** for maps of potential inundation from hurricane surge for hurricane categories 1-4.

Storm Surge Applied to Mean Sea Level Rise Scenarios for 2050

NACCS Station	Water Level Return Period	Storm Tide Water Level (Feet)	Storm Tide Water Level with Sea Level Rise (2050)			
			Intermediate Scenario 1.94 MSL, feet NGVD29	Intermediate-High Scenario 2.63 MSL, feet NGVD29	High Scenario 3.41 MSL, feet NGVD29	Extreme Scenario 3.84 MSL, feet NGVD29
Station 7047 (Maine State Pier)	10-year	7.81	9.75	10.43	11.22	11.65
	20-year	8.17	10.11	10.79	11.58	12.01
	100-year	8.89	10.83	11.52	12.30	12.73
	500-year	9.55	11.48	12.17	12.96	13.39
Station 7222 (Veteran's Memorial Bridge)	10-year	7.87	9.81	10.50	11.28	11.71
	20-year	8.27	10.21	10.90	11.68	12.11
	100-year	9.06	11.00	11.69	12.47	12.90
	500-year	9.84	11.78	12.47	13.25	13.68
Station 7221 (Back Cove)	10-year	8.04	9.97	10.66	11.45	11.88
	20-year	8.73	10.66	11.35	12.14	12.57
	100-year	10.73	12.67	13.35	14.14	14.57
	500-year	11.45	13.39	14.08	14.86	15.29

Storm Surge Applied to Mean Sea Level Rise Scenarios for 2100

NACCS Station	Water Level Return Period	Storm Tide Water Level (Feet)	Storm Tide Water Level with Sea Level Rise (2100)			
			Intermediate Scenario 4.3 MSL, feet NGVD29	Intermediate-High Scenario 6.46 MSL, feet NGVD29	High Scenario 9.19 MSL, feet NGVD29	Extreme Scenario 11.25 MSL, feet NGVD29
Station 7047 (Maine State Pier)	10-year	7.81	12.11	14.27	16.99	19.06
	20-year	8.17	12.47	14.63	17.35	19.42
	100-year	8.89	13.19	15.35	18.08	20.14
	500-year	9.55	13.85	16.01	18.73	20.80
Station 7222 (Veteran's Memorial Bridge)	10-year	7.87	12.17	14.33	17.06	19.12
	20-year	8.27	12.57	14.73	17.46	19.52
	100-year	9.06	13.36	15.52	18.25	20.31
	500-year	9.84	14.14	16.30	19.03	21.09
Station 7221 (Back Cove)	10-year	8.04	12.34	14.50	17.22	19.29
	20-year	8.73	13.03	15.19	17.91	19.98
	100-year	10.73	15.03	17.19	19.91	21.98
	500-year	11.45	15.75	17.91	20.64	22.70

Tables 2.5 (top) and 2.6 (bottom). Extreme water levels as derived from the NACCS Study for three stations in Portland and South Portland, combined with mean sea level scenarios for 2050 (top) and 2100 (bottom). Storm tides are relative to MSL. Note that storm tide water levels are highest at the Back Cove station, followed by the Veteran's Memorial Bridge station (located on the South Portland side of the bridge), followed by the Maine State Pier station. Storm tide water levels were also examined for NACCS stations located further out in Casco Bay east of Bug Light and Spring Point; water levels at these sites were lower and within an inch of those reported for the Maine State Pier station. Note that for simplicity these values assume that sea level rise and storm tides can be added; however, in some locations the actual effect on storm surge is non-linear due to local coastal geomorphology.²⁶

2.2 Changes in Precipitation and Storm Patterns

TOTAL PRECIPITATION

As the climate changes, warming ocean surface temperatures lead to higher levels of evaporation and greater moisture in the air—contributing to more precipitation and extreme weather events.²⁷ The average amount of precipitation that Maine sees in a year has increased six inches (13 percent) since 1895.²⁸ **Figure 2.9** illustrates the increase in precipitation specifically in the Greater Portland area over the past 40 years.

This trend is expected to continue, with precipitation in the Portland area projected to increase by 4–5 percent from current totals (defined by a time period from 1995–2014) by 2050.²⁹ **Figure 2.10** shows the total amount of precipitation expected for Portland and South Portland through 2100. Most of the increase is expected to come in the winter and spring, with precipitation in the summer and fall staying relatively constant.³⁰ See **Figure 2.11**

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Portland and South Portland will experience more precipitation on a yearly basis, as well as greater storm intensity. In other words, more precipitation will fall in shorter periods of time, causing strain on stormwater systems and increasing the risk from flooding.

Note: Much of the data and projections in this section are drawn from the report *Bayside Adapts Phase 1: Stormwater and Sewer Gap Analysis*. Further details can be referenced in that report.

for projected change in winter precipitation. Graphs for all seasonal precipitation projections are included in **Appendix C**.

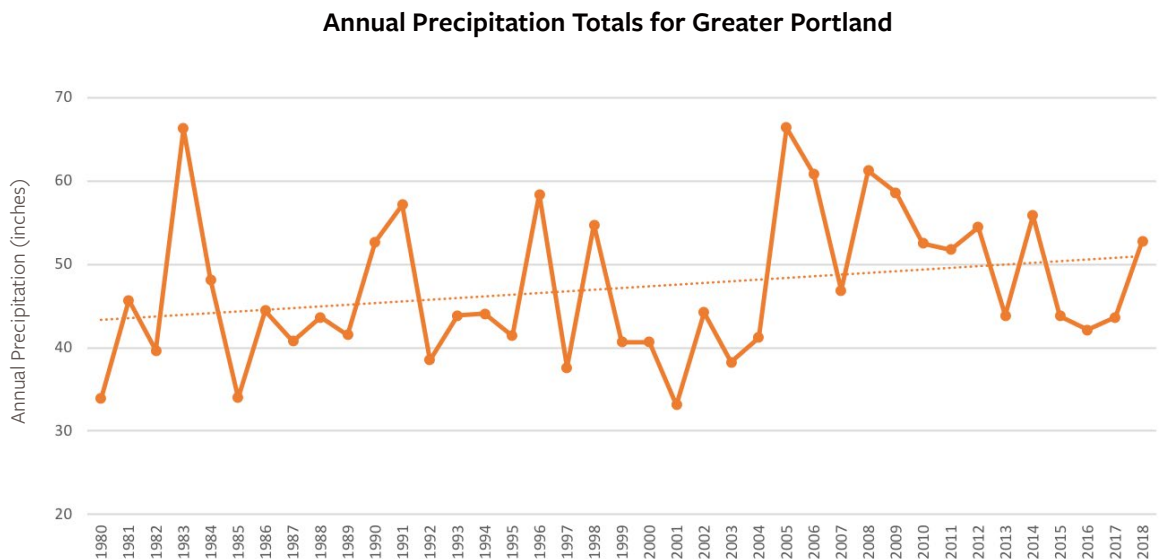


Figure 2.9. Annual precipitation totals from 1980 to 2018, as measured at the Portland International Jetport National Weather Service (NWS) weather station (the National Weather Service forecast area for both Portland and South Portland). The linear trend line fit to the data indicates an increase in total annual precipitation over the last forty years. Data source: NOAA Online Weather Data (NOWData).³⁴

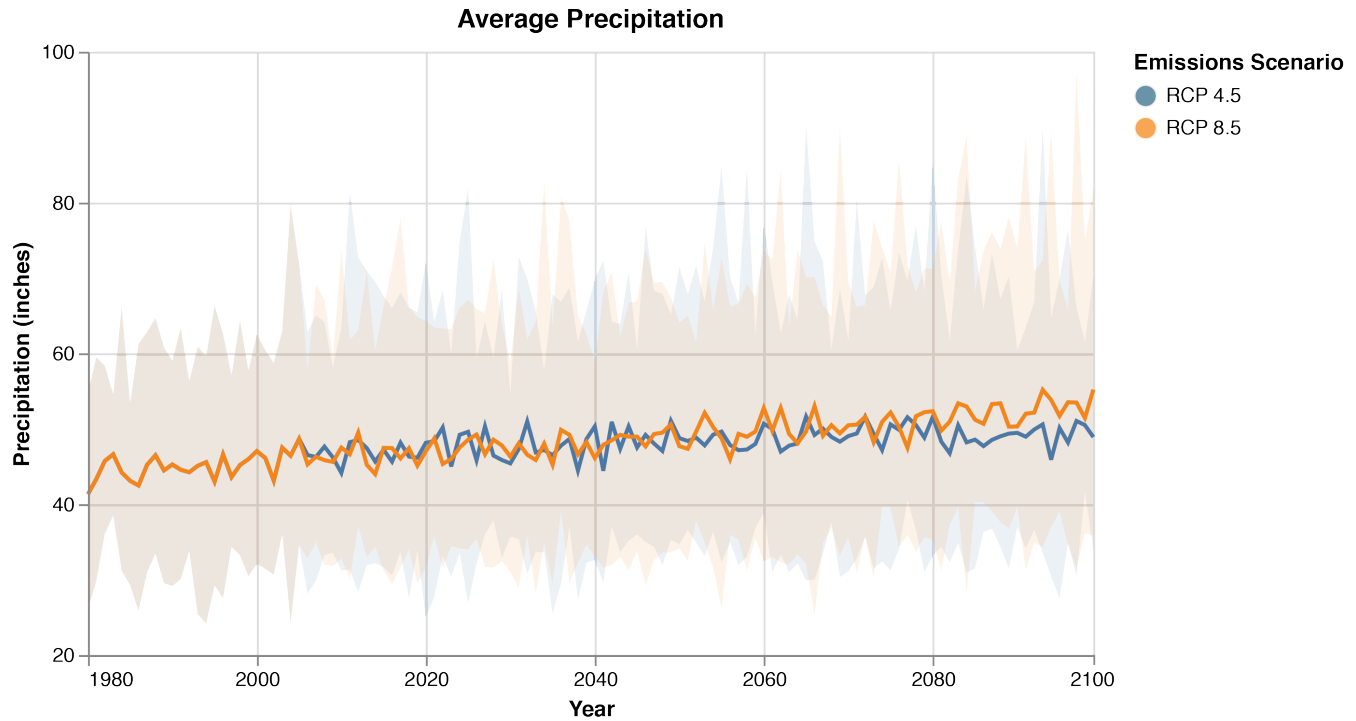


Figure 2.10. Historical simulations (1980–2005) and future projections (2006–2099) in annual averages of precipitation for Portland and South Portland. The orange line represents the business-as-usual high greenhouse gas emissions scenario (RCP 8.5), while the blue line represents a low emissions scenario (RCP 4.5). Average annual precipitation is expected to increase under both scenarios with relatively minimal difference between the scenarios through 2080. Data source: Earth System Research Center/EOS, University of New Hampshire (2019).³⁵

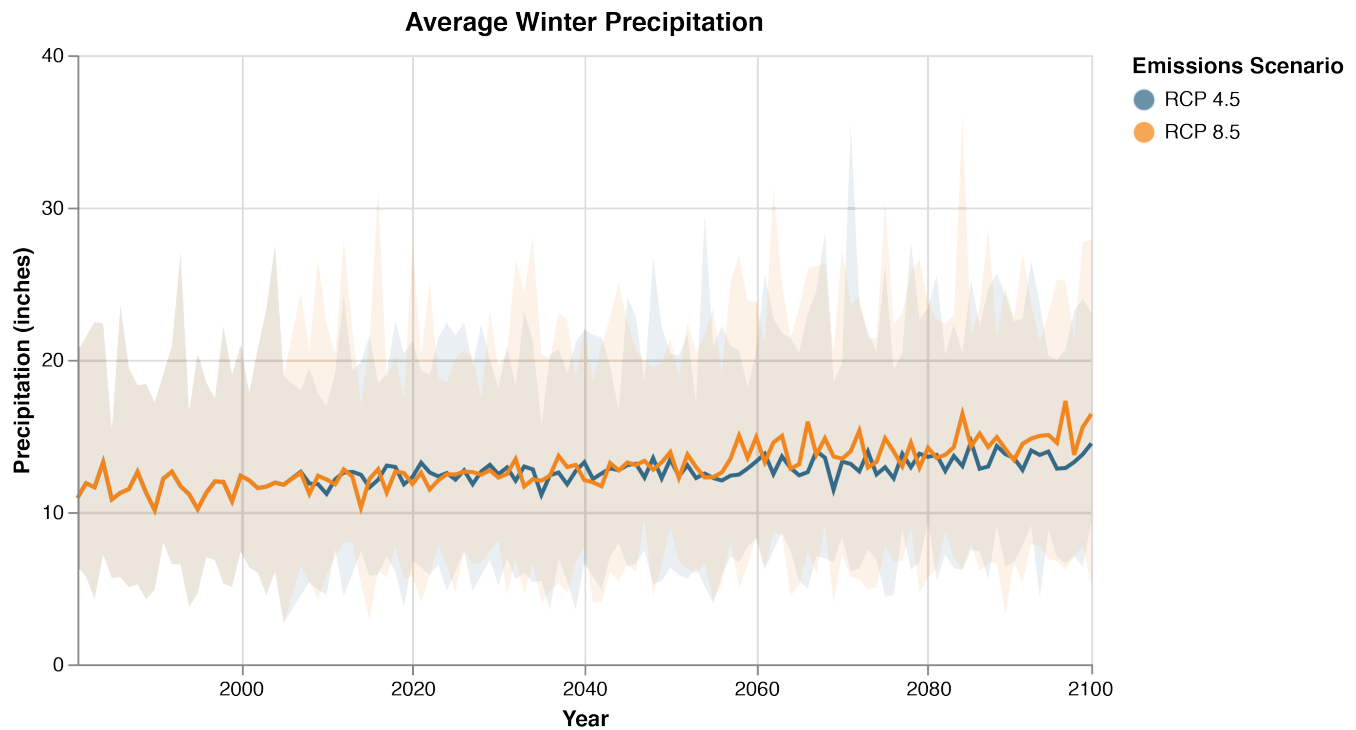


Figure 2.11. Historical simulations (1980–2005) and future projections (2006–2099) in annual averages of winter precipitation for Portland and South Portland. The orange line represents the business-as-usual high greenhouse gas emissions scenario (RCP 8.5), while the blue line represents a low emissions scenario (RCP 4.5). Although there is little difference between the two scenarios in the first half of the century, the two scenarios begin to deviate after 2050. Data source: Earth System Research Center/EOS, University of New Hampshire (2019).³⁶

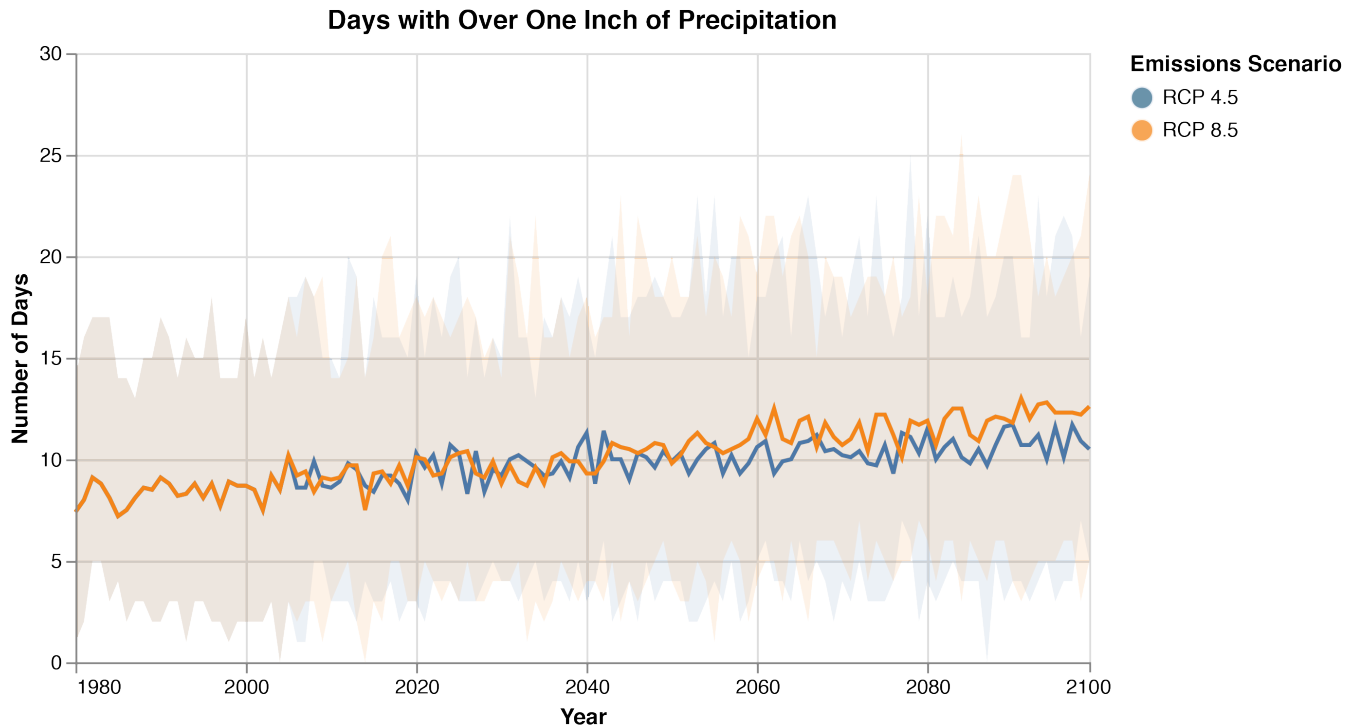


Figure 2.12. Historical simulations (1980–2005) and future projections (2006–2099) for the number of days per year with greater than one inch of precipitation in Greater Portland. The orange line represents the business-as-usual high greenhouse gas emissions scenario (RCP 8.5), while the blue line represents a low emissions scenario (RCP 4.5). Although there is little difference between the two scenarios in the first half of the century, the two scenarios begin to deviate after 2050. Data source: Earth System Research Center/EOS, University of New Hampshire (2019).³⁷

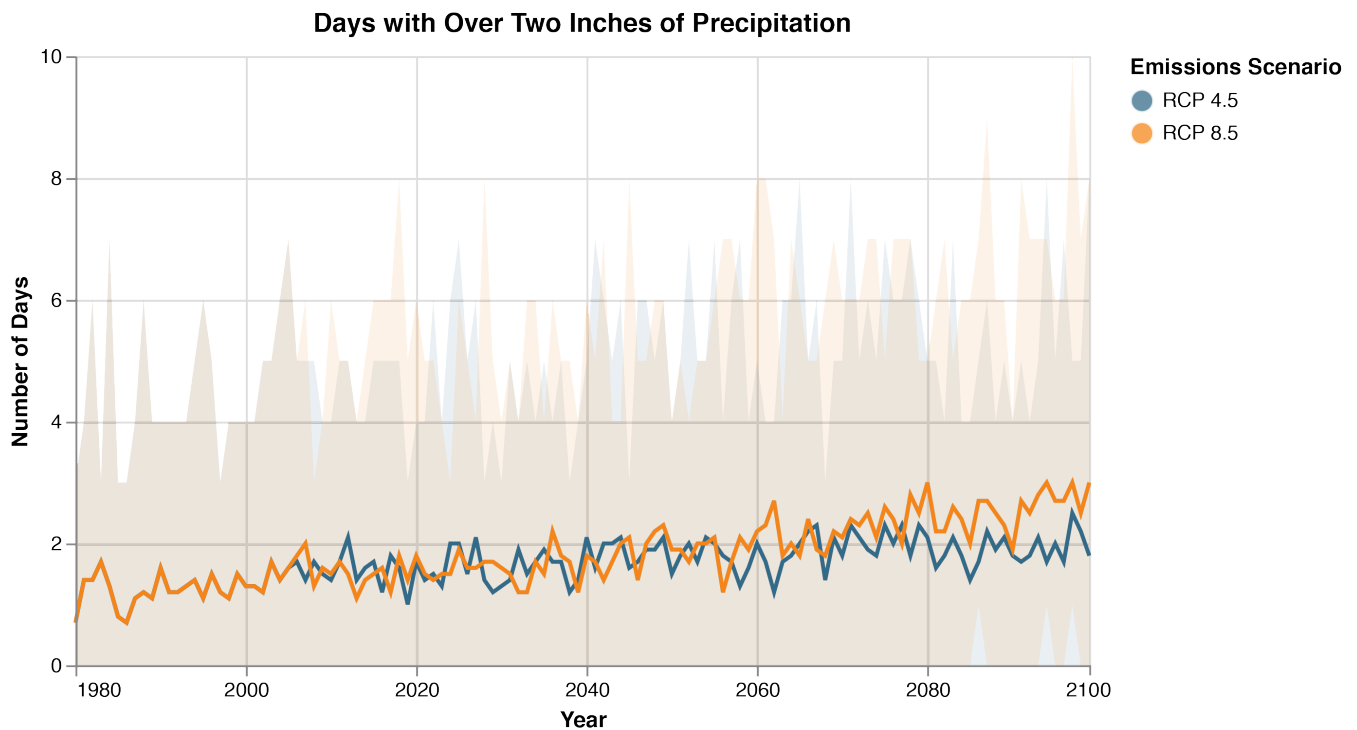


Figure 2.13. Historical simulations (1980–2005) and future projections (2006–2099) for the number of days per year with greater than two inches of precipitation in Greater Portland. The orange line represents the business-as-usual high greenhouse gas emissions scenario (RCP 8.5), while the blue line represents a low emissions scenario (RCP 4.5). Data source: Earth System Research Center/EOS, University of New Hampshire (2019).³⁸

STORM INTENSITY

Not only is the amount of precipitation increasing, but so is the intensity of precipitation events. Between 1958 and 2010, the northeastern United States has seen a 70 percent increase in the amount of precipitation occurring in very heavy rain events (defined as the heaviest 1 percent of all daily events).³¹ Communities in coastal Maine have seen larger increases in total precipitation and extreme precipitation events (greater than two inches of rain in 24 hours) than inland Maine due to the area's closer proximity to Atlantic storm tracks.³²

Figures 2.12 and 2.13 show the projected increase in the number of days per year that receive over one inch and over two inches of precipitation, respectively, for two different greenhouse gas emission scenarios for the Greater Portland area.

The historic and projected precipitation totals for a 24-hour storm for various recurrence intervals are summarized in **Table 2.7**.³³ A recurrence interval, also known as the return period, is the time between two storms of a particular magnitude, estimated through statistics. For example, a significant storm with five inches of precipitation within 24-hours has historically been likely to occur every ten years, as shown in **Table 2.7**. However, by 2100, a storm of that magnitude is roughly equivalent to the five-year storm. In other words, a storm of that size is likely to occur twice as frequently by 2100.

Figure 2.14 further illustrates how the historic 25-year 24-hour storm event is expected to be equivalent to the 16-year storm event in 2050 and to the 13-year in 2100. Likewise, the historic 100-year 24-hour storm is expected to be equivalent to the 52-year in 2050 and to the 42-year in 2100.

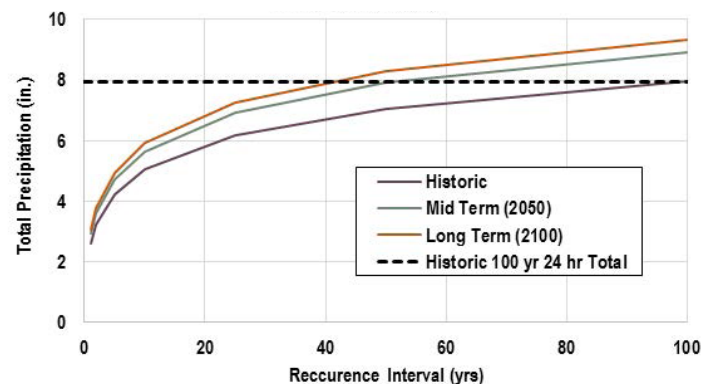
24-Hour Storm Event Precipitation Totals for Historic and Future Recurrence Intervals [Table]

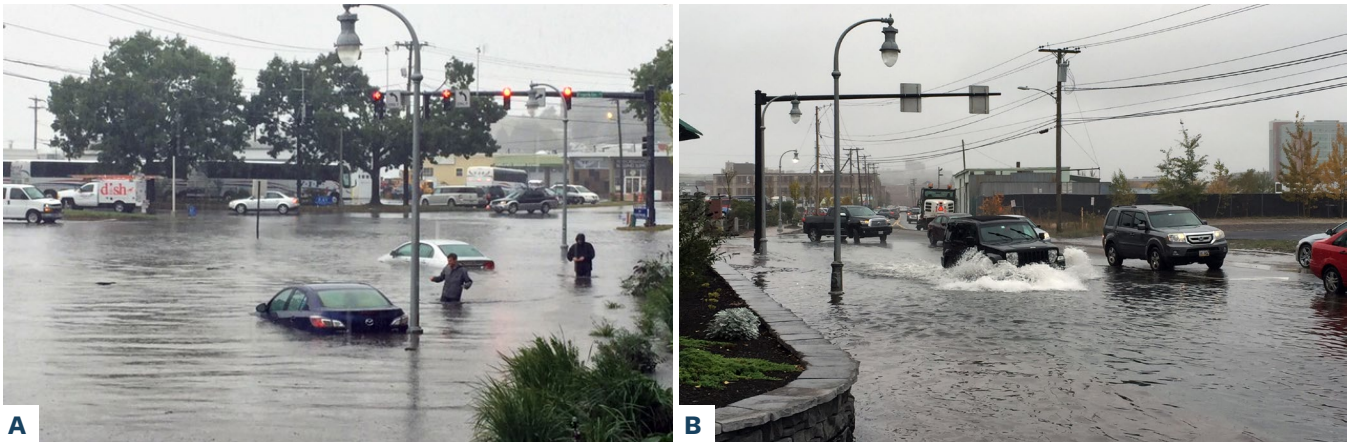
Average Recurrence Interval (ARI) (years)	24-Hour Precipitation Totals (inches)		
	Historic	Mid-Term (2050)	Long-Term (2100)
1	2.62	2.93	3.07
2	3.23	3.62	3.79
5	4.22	4.73	4.95
10	5.05	5.66	5.92
25	6.19	6.93	7.26
50	7.07	7.92	8.29
100	7.95	8.90	9.32

Table 2.7. Historic and projected precipitation totals for a 24-hour storm for various recurrence intervals. Table adapted from Bayside Adapts Phase 1 report (2017).

24-Hour Storm Event Precipitation Totals for Historic and Future Recurrence Intervals [Figure]

Figure 2.14. Precipitation totals for the 24-hr storm event for various recurrence intervals for historic (purple), mid-term (green), and long-term (red) timeframes. The precipitation total for the historic 100-year 24-hour storm (black dashed line) is marked to show how a storm of that magnitude will likely occur at increasing frequencies by 2050 and 2100. Figure source: Bayside Adapts Phase 1 report (2017).





A: Flooding at the intersection of Somerset and Franklin (Portland) during the September 30, 2015 rain event in which 4.8" of rain fell in six hours on top of an 11.6 foot tide and 0.5 feet of surge. Image from Cameron Adams, Maine Geological Survey. **B:** Flooding on Somerset Street (Portland) during the King Tide on October 19, 2016. Image by Abbie Sherwin, Maine Geological Survey / Maine Coastal Program. These images highlight some of the already recurring flooding in Portland, and what the future might hold when all factors combine. South Portland is not currently seeing this level of flooding, but will likely see increasing pressure on its stormwater system and areas along the coast as storm intensity and sea levels continue to rise.

TYPE OF PRECIPITATION

Due to rising temperatures, precipitation in Maine is increasingly falling as rain instead of snow. Since 1895, average annual snowfall in Maine has decreased by about one inch (6.6%) (**Figure 2.15**), and the snowpack duration has decreased by two weeks over the past century.³⁹

The state is expected to see further decreases in total snowfall accumulation, with coastal communities seeing the most significant decreases around 40 percent.⁴⁰ Likewise, the snowpack duration in the state is projected to decrease by another two weeks by 2050. Despite these trends, extreme snowfall events such as strong nor'easters are likely to increase in frequency.

DROUGHT

Although drought risk in Maine is much lower than nearly every other state in the United States, the risk increases with climate change. Despite projections suggesting that average annual precipitation will increase in the coming years, the increase is likely to be more consolidated in the winter and spring. Summer and fall, on the other hand, may have increasing seasonal drought risk. Summer drought threat considers the average monthly soil moisture projections for July, August, and September, and a widespread summer drought is when at least 30 percent of the state's soil is drier than usual. Projections suggest that Maine could see a 70 percent increase in threat from widespread summer drought by 2050.⁴¹

Total Annual Snowfall in Maine (1895-2014)

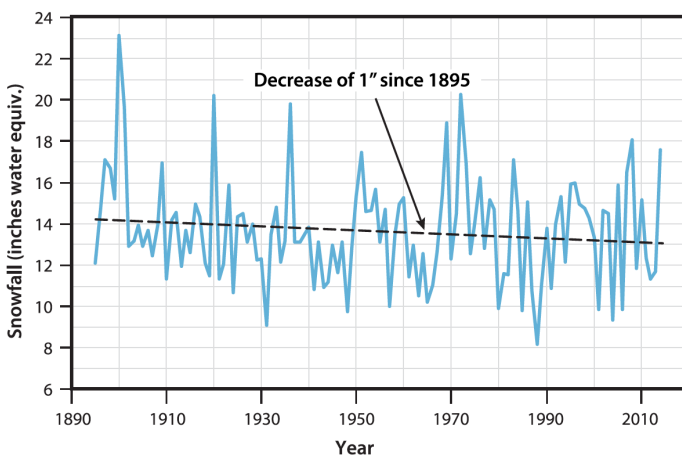


Figure 2.15. Total annual snowfall in Maine from 1895-2014. The linear trend (black dashed line) indicates that snowfall decreased approximately 1.0 inches (6.6%) during the recording period. Figure source: Maine's Climate Future: 2015 Update (2015).

2.3 Changes in Air Temperatures

AVERAGE TEMPERATURES

Average annual temperatures across Maine have increased 3°F since 1895 (**Figure 2.16**).⁴² Along the coast, temperatures are expected to continue to increase another 3.5–4°F by 2050.⁴³ **Figure 2.17** shows the projected increase in maximum annual temperature for a low greenhouse gas emissions scenario (blue) and high scenario (orange) for Greater Portland. Temperature projections remain relatively similar for the two scenarios through 2050, at which point they begin to diverge substantially through 2100.

With this increase in temperature, Maine’s seasons are already shifting. Between the 1900s–2000s, Maine’s “warm season” (when the average daily temperature is above freezing) increased by two weeks.⁴⁴ According to global climate models, the warm season will likely increase by two more weeks by 2050 (**Figure 2.18**).

To date, Maine’s winters have been warming faster than summers. Downscaled climate models for the Portland area, however, indicate that the rate of change will increase for summers, particularly under a business-as-usual, high emissions scenario. See **Appendix C** for projected seasonal temperature changes for the Portland area.

Figure 2.19 illustrates how the annual number of days below freezing in the Portland area has been decreasing since the 1970s and is predicted to continue to decrease through the end of the century. Again, projections show a low greenhouse gas emissions scenario (blue) and high scenario (orange).

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Portland and South Portland will experience warmer average temperatures over the course of the century, including more days of extreme heat and fewer days below freezing. Extreme heat can cause severe health complications, while fewer days below freezing are leading to increases in rates of pest outbreaks and vector-borne diseases, like Lyme disease.

Average Annual Temperature in Maine (1895 - 2014)

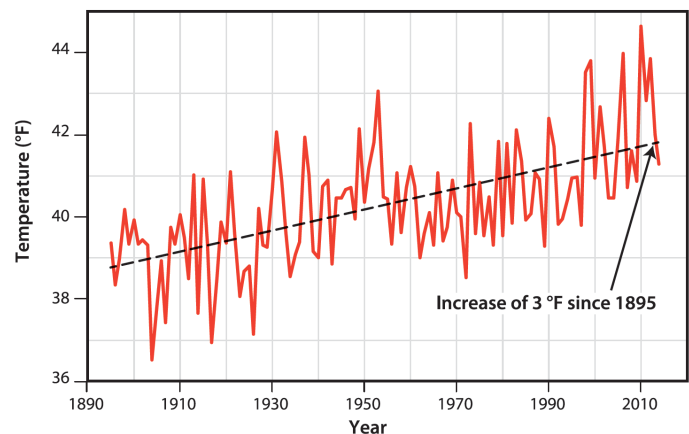


Figure 2.16. Average annual temperatures in Maine from 1895–2014. The linear trend (black dashed line) indicates that temperatures have increased approximately 3.0°F during the recording period. Figure source: Maine’s Climate Future: 2015 Update (2015).

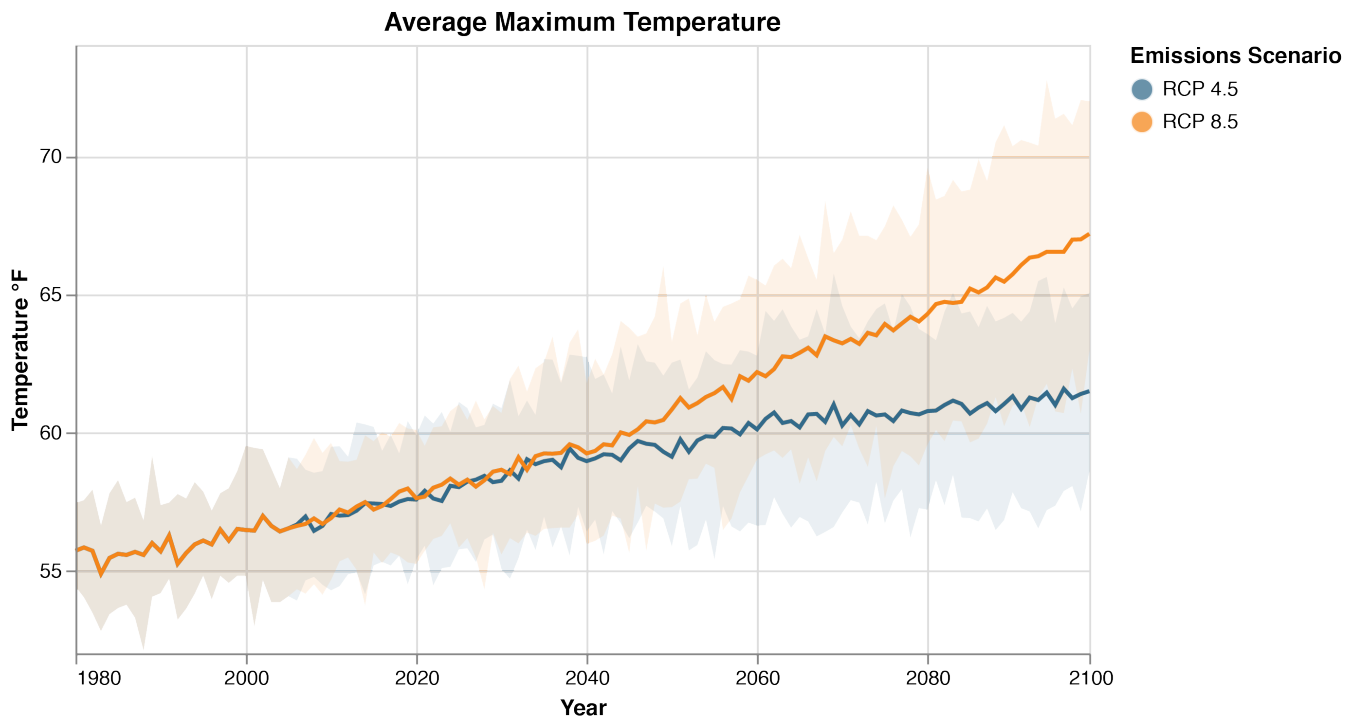


Figure 2.17. Historical simulations (1980–2005) and future projections (2006–2099) for average maximum temperature in Greater Portland. The orange line represents the business-as-usual high greenhouse gas emissions scenario (RCP 8.5), while the blue line represents a low emissions scenario (RCP 4.5). See the appendix for a similar graph of the change in average minimum temperature. Data source: Earth System Research Center/EOS, University of New Hampshire (2019).⁴⁶

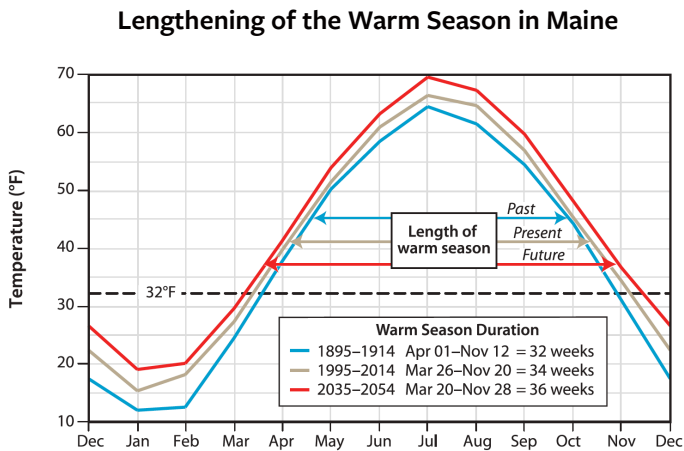


Figure 2.18. Mean monthly temperature for historical (1895–1914), recent (1995–2014), and future (2035–2054) time periods, averaged across Maine. The warm season (defined as when average daily temperature is above freezing) has increased two weeks since the historical period and is predicted to increase two more weeks by 2050. Figure source: Maine's Climate Future: 2015 Update (2015).⁴⁷

EXTREME TEMPERATURES

As temperatures warm, Maine is also seeing more days of extreme heat where temperatures exceed 90°F and 95°F. The combination of heat and high relative humidity can make a hot day feel even hotter. The heat index is therefore a measure that combines heat and relative humidity to give a sense of how hot a day feels. The Portland area has historically experienced four high-heat days a year where the heat index reaches over 95°F. The number of days is expected to reach 13.5 by 2050.⁴⁵

Figures 2.20 and 2.21 show the projected increase in the number of days above 90°F and 95°F, respectively, for a low greenhouse gas emissions scenario (blue) and high scenario (orange) for the Greater Portland area. Whereas the hottest day of the year for the Portland area has historically been around 95°F, the hottest day will likely reach temperatures closer to 100–108°F by 2100 (**Figure 2.22**).

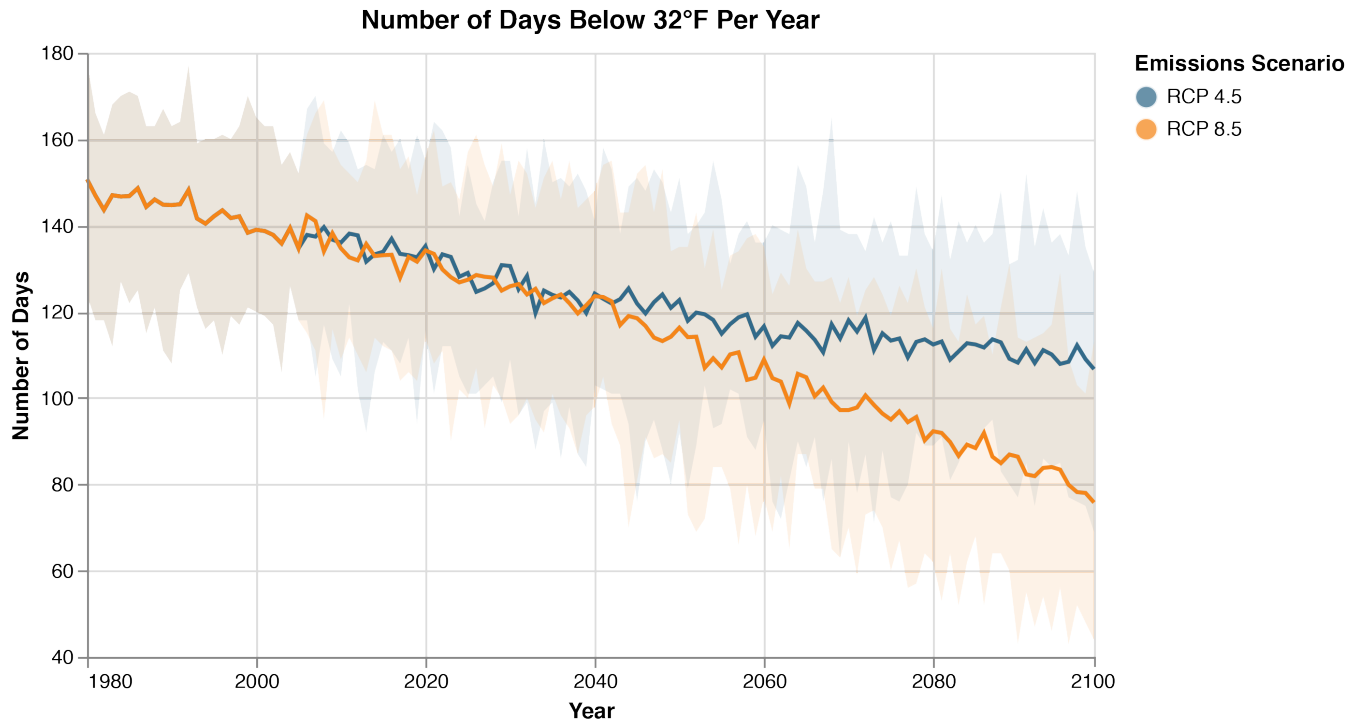


Figure 2.19. Historical simulations (1980–2005) and future projections (2006–2099) for the number of days below 32°F in Greater Portland. The orange line represents the business-as-usual high greenhouse gas emissions scenario (RCP 8.5), while the blue line represents a low emissions scenario (RCP 4.5). See the appendix for a similar graph of the change in the number of days below 0°F. Data source: Earth System Research Center/EOS, University of New Hampshire (2019).⁴⁸

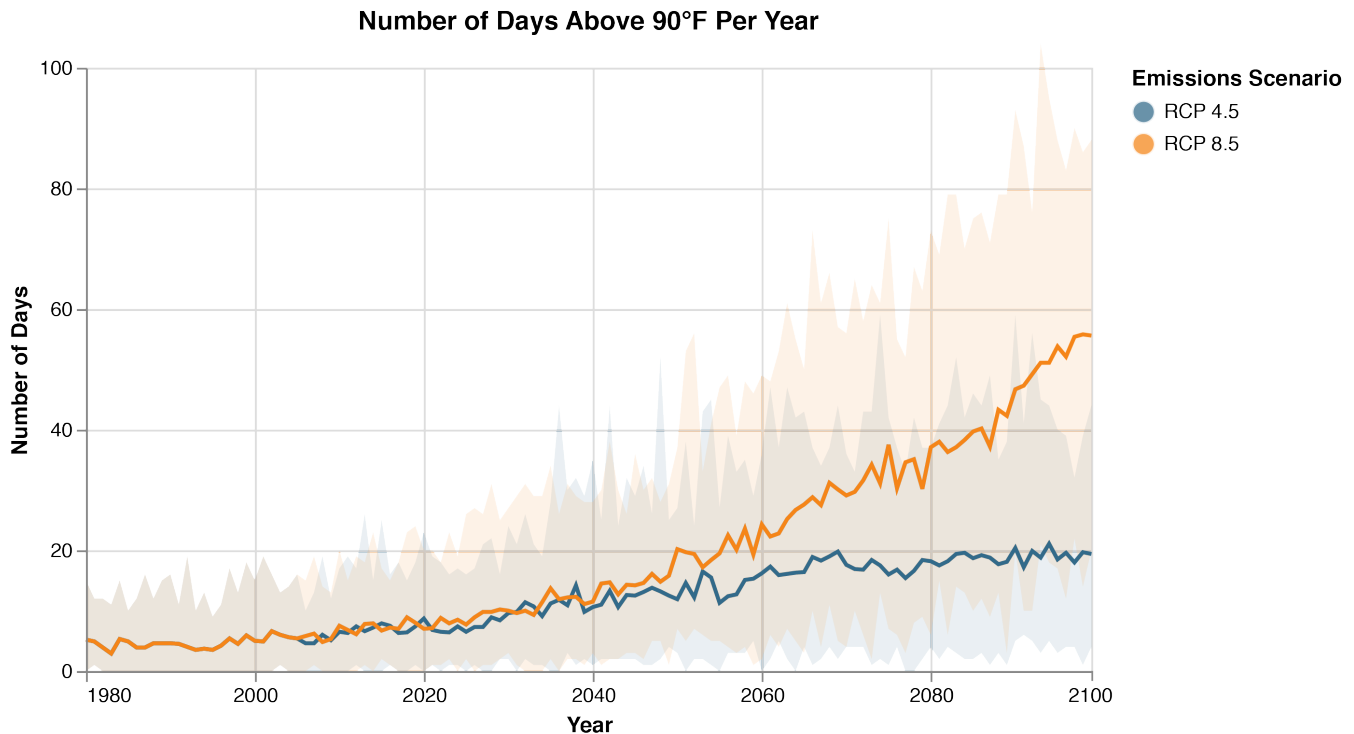


Figure 2.20. Historical simulations (1980–2005) and future projections (2006–2099) for the number of days above 90°F in Greater Portland. The orange line represents the business-as-usual high greenhouse gas emissions scenario (RCP 8.5), while the blue line represents a low emissions scenario (RCP 4.5). Data source: Earth System Research Center/EOS, University of New Hampshire (2019).⁴⁹

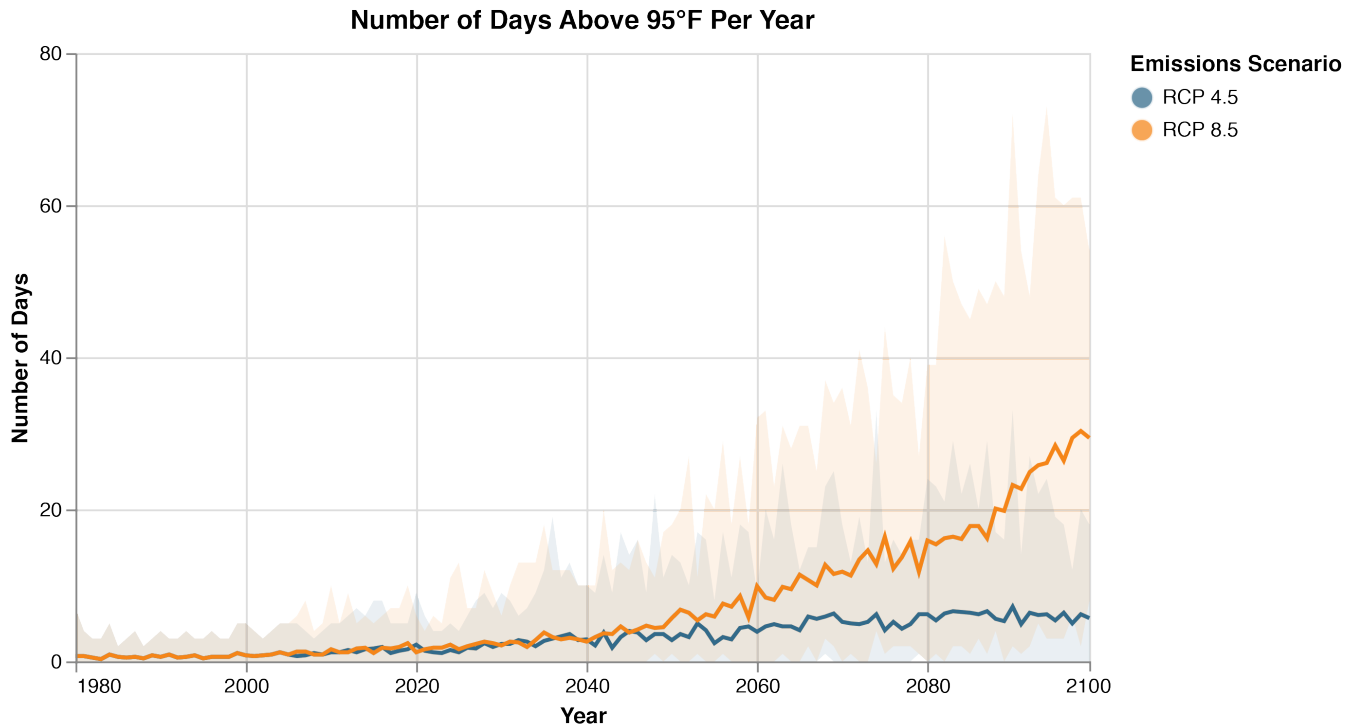


Figure 2.21. Historical simulations (1980–2005) and future projections (2006–2099) for the number of days above 95°F in Greater Portland. The orange line represents the business-as-usual high greenhouse gas emissions scenario (RCP 8.5), while the blue line represents a low emissions scenario (RCP 4.5). Data source: Earth System Research Center/EOS, University of New Hampshire (2019).⁵⁰

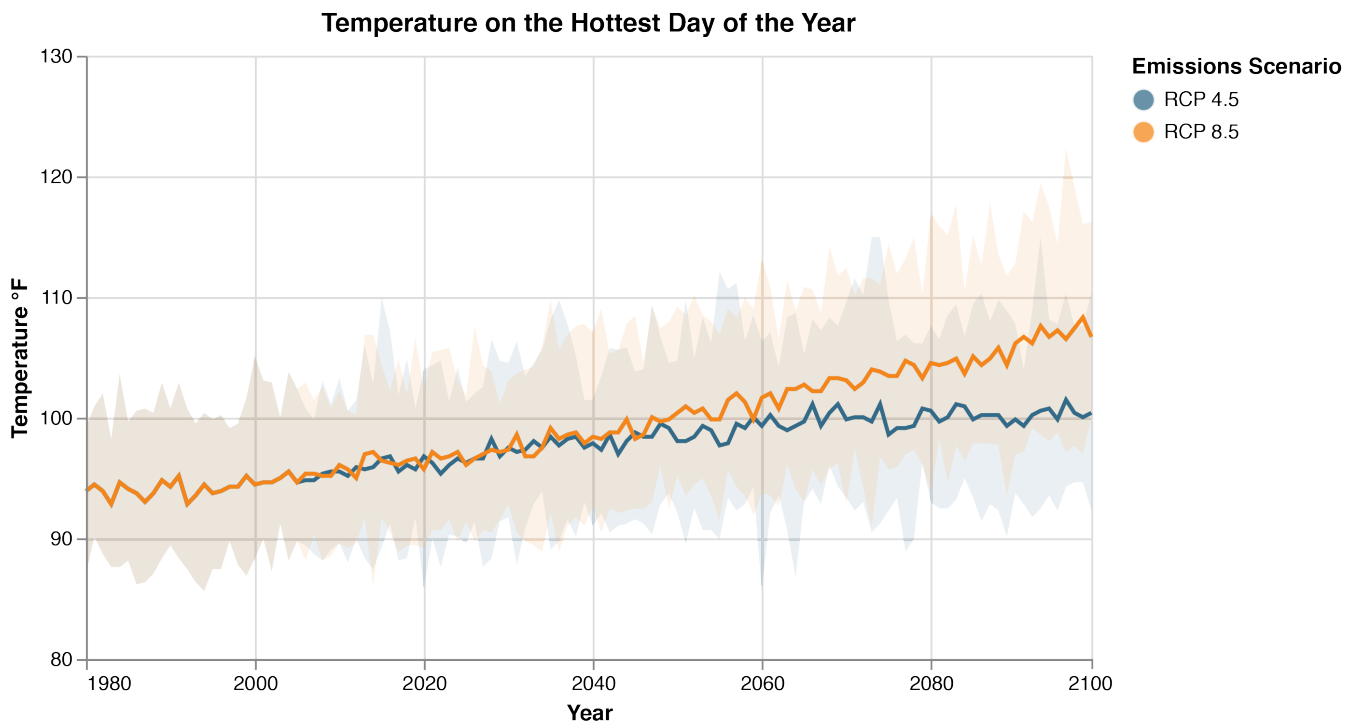


Figure 2.22. Historical simulations (1980–2005) and future projections (2006–2099) for the temperature on the hottest day of the year in Greater Portland. The orange line represents the business-as-usual high greenhouse gas emissions scenario (RCP 8.5), while the blue line represents a low emissions scenario (RCP 4.5). See the appendix for similar graphs for hottest night, coldest day, and coldest night of the year. Data source: Earth System Research Center/EOS, University of New Hampshire (2019).⁵¹

2.4 Changes in Water Temperatures and Acidification

OCEAN WARMING

Ocean temperatures in the Gulf of Maine have been rising, and at an accelerating rate. The Gulf of Maine has warmed three times as fast as the global average over the past three decades, and seven times as fast in just the last fifteen years.⁵² Between 2004 and 2013, the Gulf of Maine warmed 0.41°F (0.23°C) per year, a rate faster than 99 percent of the world's oceans.⁵³ In Casco Bay, specifically, water temperatures have increased about 2.5°F (1.4°C) between 1993 and 2018 (**Figure 2.24**).⁵⁴

While ocean temperatures have a natural cycle of variability, it is becoming increasingly clear that we are

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The Gulf of Maine, including Casco Bay, is warming faster than 99 percent of the world's oceans. At the same time, the Gulf of Maine is particularly susceptible to ocean acidification and its acidity is expected to increase faster than average for oceans globally.

seeing an accelerating, long-term warming trend.⁵⁵ When warmer periods due to natural variability compound with the warming trend, we are likely to see more intense periods of extreme ocean temperatures. For example, the Northwest Atlantic from North Carolina to Iceland underwent an “ocean heat wave” in 2012,

Monthly Sea Surface Temperature Anomaly

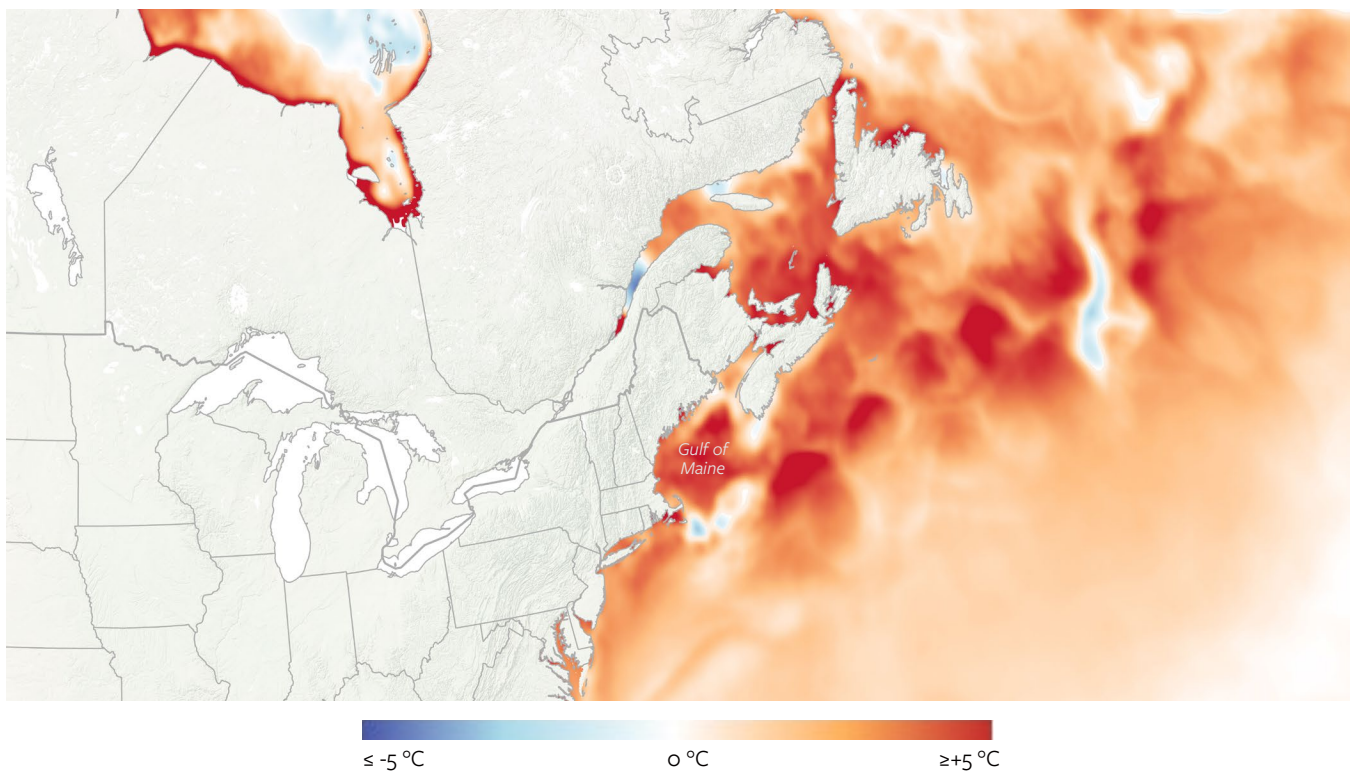


Figure 2.23. The difference in water temperature for the month of August 2018, as compared to average August water temperatures from 1985-2012. Shades of red and blue indicate how much the temperatures were above and below the long-term average, respectively. Figure source: NASA Earth Observatory with sea surface temperature data from Coral Reef Watch (2018).⁶¹

Warming Temperatures in Casco Bay (1993 – 2018)

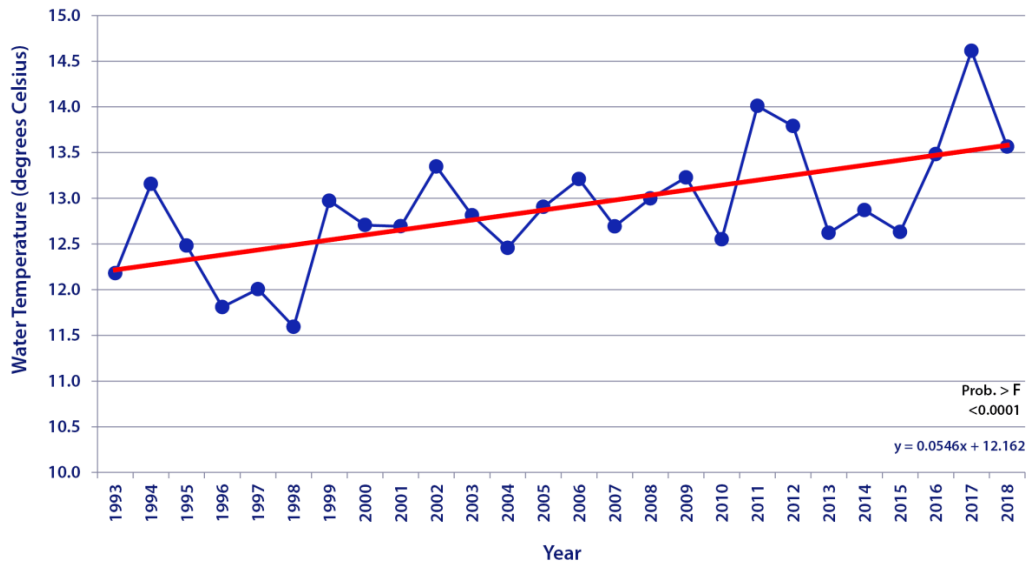


Figure 2.24. Rising water temperatures in Casco Bay, based on May through October annual averages of water sampling measured at the Sentinel Site by Friends of Casco Bay. Water temperatures have increased by 2.5°F (1.4°C) between 1993 and 2018. Graphic source: Friends of Casco Bay Baykeeper (2019).

which was considered the most intense heat wave in three decades—and was felt most acutely in the Gulf of Maine.⁵⁶ Using satellite data and sea-based sensors, scientists measured sea surface temperatures of 68.98 °F (20.55 °C), the warmest ever recorded temperatures for the Gulf of Maine.

The Gulf of Maine has experienced more heat waves since 2012. Oceanographers define marine heat waves as five consecutive days where water temperatures are above the 90th percentile of average temperatures. The Gulf of Maine had 180 days over the 90th percentile in 2018. **Figure 2.23** shows the difference in surface water temperatures for August 2018, compared to the long-term average. On August 8, 2018, the Gulf of Maine hit the second highest temperature ever recorded, just 0.05 °F (0.03 °C) below the record.

Warming ocean temperatures are causing populations of marine species to shift northward, creating repercussions for food webs and other ecosystem dynamics, as well as marine economies. See sections *4.4 Shifting Habitats: New Pests and Invasive Species* and *4.1 Local Economy and Livelihoods* for further details on the impacts to fisheries and marine ecosystems.

OCEAN AND COASTAL ACIDIFICATION

Simultaneously, oceans globally have become 30 percent more acidic (a 0.1 decrease in pH units) in the last 100 years.⁵⁷ This rate is faster than any period in the past million years and is driven by a number of factors. Oceans absorb roughly a quarter of the carbon dioxide added to the atmosphere from human activity (e.g., burning fossil fuels), contributing to global ocean acidification.⁵⁸ At the same time, pollutants from wastewater and stormwater runoff fuel greater net primary production in coastal waters, which leads to higher levels of respiration, increases in carbon dioxide, and thus further coastal acidification.

More annual precipitation and intense storms due to climate change will amplify the amount of pollutants entering marine waters through runoff. In particular, wastewater entering coastal waters from combined sewer overflows (CSOs) during heavy rain events can lead to higher acidities due to high nitrogen concentrations in wastewater. See sections *4.3 Compromised Natural Water Systems* and *4.5 Acidification Impacts on Species Health* for further details.

The Gulf of Maine, in particular, may have a higher susceptibility to ocean acidification because of its relatively low pH and colder waters, which more readily absorb carbon dioxide.⁵⁹ As a coastal area, the Gulf of Maine also has higher levels of freshwater input, which reduces the Gulf's buffering capacity, as well as higher levels of pollutants from stormwater runoff and river discharge. Researchers therefore predict that the acidity

of the Gulf of Maine will continue to increase rapidly in the coming decades and at a pace faster than the global average.⁶⁰ Acidification is expected to harm the health of marine species, particularly shellfish, which will have more difficulty in building shells and skeletons. See 4.5 *Acidification Impacts on Species Health* for further details.

SECTION TWO ENDNOTES

- 8 Fernandez, I.J., Schmitt, C.V., Birkel, S.D., Stancioff, E., Pershing, A.J., Kelley, J.T., Runge, J.A., Jacobson, G.L., & Mayewski, P.A. (2015). *Maine's Climate Future: 2015 Update*. Orono, ME: University of Maine.
- 9 International Panel on Climate Change (IPCC). 2014. *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.). Geneva, Switzerland: IPCC.
- 10 U.S. Global Change Research Program (USGCRP). (2018). *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.). Washington DC: U.S. Global Change Research Program.
- 11 U.S. Global Change Research Program (USGCRP). (2018). *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.). Washington DC: U.S. Global Change Research Program.
- 12 U.S. Global Change Research Program (USGCRP). (2018). *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.). Washington DC: U.S. Global Change Research Program.
- 13 Sweet, W.V., Kopp, R.E., Weaver, C. P., Obeysekera, J., Horton, R. M., Thieler, E.R., & Zervas, C. (2017). *Global and Regional Sea Level Rise Scenarios for the United States*. NOAA Technical Report NOS CO-OPS 83.
- 14 Sweet, W.V., Kopp, R.E., Weaver, C. P., Obeysekera, J., Horton, R. M., Thieler, E.R., & Zervas, C. (2017). *Global and Regional Sea Level Rise Scenarios for the United States*. NOAA Technical Report NOS CO-OPS 83.
- 15 **NOTE:** This conversion was completed as part of the Bayside Adapts Phase 1: Stormwater and Sewer Gap Analysis; see the report for further details. Reference: City of Portland, New England Environmental Finance Center, Woodard & Curran, RPS ASA, and Jordan Environmental Engineering. (2017). *Bayside Adapts Phase 1: Sewer and Stormwater System Data Gap Analysis*. Portland, Maine.
- 16 Moftakhari, H.R., AghaKouchak, A., Sanders, B.F., Allaire, M., & Matthew, R.A. (2018). "What Is Nuisance Flooding? Defining and Monitoring an Emerging Challenge." *Water Resources Research*. 54, no. 7: 4218–27.
- 17 **NOTE:** The sea level rise scenarios were developed by using available long-term sea level rise data from Portland, Bar Harbor, and Eastport tide gauges; the US Army Corps of Engineers Sea-Level Change Curve Calculator (v. 2017.55); and sea level rise scenarios established by NOAA et al. (2017) prepared for the US National Climate Assessment. Potential extents of inundation were developed with a static "bathtub" inundation model, using LiDAR topographic data as a base digital elevation model. For more information, see the Maine Geological Survey site at: www.maine.gov/dacf/mgs/hazards/slr_ss/index.shtml.
- 18 City of Portland, New England Environmental Finance Center, Woodard & Curran, RPS ASA, and Jordan Environmental Engineering. (2017). *Bayside Adapts Phase 1: Sewer and Stormwater System Data Gap Analysis*. Portland, Maine.
- 19 Union of Concerned Scientists (2019). "Hurricanes and Climate Change." Accessed September 2019 at <https://www.ucsusa.org/resources/hurricanes-and-climate-change>
- 20 Maine Geological Survey. (2019). *Potential Hurricane Inundation Mapping - Frequently Asked Questions*. Retrieved from <https://www.maine.gov/dacf/mgs/hazards/slosh/faq.htm>
- 21 National Ocean and Atmospheric Administration (NOAA). (2018). "Relative Sea Level Trend: 8418150 Portland, Maine." *Tides and Currents*. Retrieved from https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8418150.
- 22 Sweet, W.V., Kopp, R.E., Weaver, C. P., Obeysekera, J., Horton, R. M., Thieler, E.R., & Zervas, C. (2017). *Global and Regional Sea Level Rise Scenarios for the United States*. NOAA Technical Report NOS CO-OPS 83.
- 23 Sweet, W.V., Kopp, R.E., Weaver, C. P., Obeysekera, J., Horton, R. M., Thieler, E.R., & Zervas, C. (2017). *Global and Regional Sea Level Rise Scenarios for the United States*. NOAA Technical Report NOS CO-OPS 83.
- 24 City of Portland, New England Environmental Finance Center, Woodard & Curran, RPS ASA, and Jordan Environmental

- Engineering. (2017). Bayside Adapts Phase 1: Sewer and Stormwater System Data Gap Analysis. Portland, Maine.
- 25 Sea level rise scenario data from the Maine Geological Survey (2018).
- 26 City of Portland, New England Environmental Finance Center, Woodard & Curran, RPS ASA, and Jordan Environmental Engineering. (2017). Bayside Adapts Phase 1: Sewer and Stormwater System Data Gap Analysis. Portland, Maine.
- 27 Fernandez, I.J., Schmitt, C.V., Birkel, S.D., Stancioff, E., Pershing, A.J., Kelley, J.T., Runge, J.A., Jacobson, G.L. & Mayewski, P.A. (2015). Maine's Climate Future: 2015 Update. Orono, ME: University of Maine.
- 28 Fernandez, I.J., Schmitt, C.V., Birkel, S.D., Stancioff, E., Pershing, A.J., Kelley, J.T., Runge, J.A., Jacobson, G.L. & Mayewski, P.A. (2015). Maine's Climate Future: 2015 Update. Orono, ME: University of Maine.
- 29 Fernandez, I.J., Schmitt, C.V., Birkel, S.D., Stancioff, E., Pershing, A.J., Kelley, J.T., Runge, J.A., Jacobson, G.L. & Mayewski, P.A. (2015). Maine's Climate Future: 2015 Update. Orono, ME: University of Maine.
- 30 **NOTE:** See Appendix for seasonal precipitation graphs.
- 31 U.S. Global Change Research Program (USGCRP). (2018). Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.). Washington DC: U.S. Global Change Research Program.
- 32 Fernandez, I.J., Schmitt, C.V., Birkel, S.D., Stancioff, E., Pershing, A.J., Kelley, J.T., Runge, J.A., Jacobson, G.L. & Mayewski, P.A. (2015). Maine's Climate Future: 2015 Update. Orono, ME: University of Maine.
- 33 **NOTE:** This table came from the Bayside Adapts report, which also has tables for 3-hour, 6-hour, and 12-hour precipitation durations; see the report for further details. Reference: City of Portland, New England Environmental Finance Center, Woodard & Curran, RPS ASA, and Jordan Environmental Engineering. (2017). Bayside Adapts Phase 1: Sewer and Stormwater System Data Gap Analysis. Portland, Maine.
- 34 NOAA Online Weather Data (NOWData) (n.d.) Northwest Regional Climate Center. Accessed July 2019. Retrieved from <http://www.nrcc.cornell.edu/wxstation/nowdata.html>
- 35 **NOTE:** Historical simulations (1980–2005) and future projections (2006–2099) in annual averages of precipitation from a 29-member, high resolution (4 km) statistically downscaled Coupled Model Intercomparison Project (CMIP5) ensemble mean lower (RCP 4.5 - blue line) and higher (RCP 8.5 - orange line) representative concentration pathway (RCP) emission scenarios. Orange and blue lines for the period 1980–2005 are identical. The light blue (light orange) shading represent the highest and lowest values from the 29 different model RCP 4.5 (RCP 8.5) simulations for each year. Graphs from Elizabeth Burakowski and Cameron Wake, Earth System Research Center/EOS, University of New Hampshire.
- 36 **NOTE:** Historical simulations (1980–2005) and future projections (2006–2099) in annual averages of precipitation from a 29-member, high resolution (4 km) statistically downscaled Coupled Model Intercomparison Project (CMIP5) ensemble mean lower (RCP 4.5 - blue line) and higher (RCP 8.5 - orange line) representative concentration pathway (RCP) emission scenarios. Orange and blue lines for the period 1980–2005 are identical. The light blue (light orange) shading represent the highest and lowest values from the 29 different model RCP 4.5 (RCP 8.5) simulations for each year. Graphs from Elizabeth Burakowski and Cameron Wake, Earth System Research Center/EOS, University of New Hampshire.
- 37 **NOTE:** Historical simulations (1980–2005) and future projections (2006–2099) in days with over one inch of precipitation from a 29-member, high resolution (4 km) statistically downscaled Coupled Model Intercomparison Project (CMIP5) ensemble mean lower (RCP 4.5 - blue line) and higher (RCP 8.5 - orange line) representative concentration pathway (RCP) emission scenarios. Orange and blue lines for the period 1980–2005 are identical. The light blue (light orange) shading represent the highest and lowest values from the 29 different model RCP 4.5 (RCP 8.5) simulations for each year. Graphs from Elizabeth Burakowski and Cameron Wake, Earth System Research Center/EOS, University of New Hampshire.
- 38 **NOTE:** Historical simulations (1980–2005) and future projections (2006–2099) in days with over two inches of precipitation from a 29-member, high resolution (4 km) statistically downscaled Coupled Model Intercomparison Project (CMIP5) ensemble mean lower (RCP 4.5 - blue line) and higher (RCP 8.5 - orange line) representative concentration pathway (RCP) emission scenarios. Orange and blue lines for the period 1980–2005 are identical. The light blue (light orange) shading represent the highest and lowest values from the 29 different model RCP 4.5 (RCP 8.5) simulations for each year. Graphs from Elizabeth Burakowski and Cameron Wake, Earth System Research Center/EOS, University of New Hampshire.
- 39 Fernandez, I.J., Schmitt, C.V., Birkel, S.D., Stancioff, E., Pershing, A.J., Kelley, J.T., Runge, J.A., Jacobson, G.L. & Mayewski, P.A. (2015). Maine's Climate Future: 2015 Update. Orono, ME: University of Maine.
- 40 Fernandez, I.J., Schmitt, C.V., Birkel, S.D., Stancioff, E., Pershing, A.J., Kelley, J.T., Runge, J.A., Jacobson, G.L. & Mayewski, P.A. (2015). Maine's Climate Future: 2015 Update. Orono, ME: University of Maine.
- 41 Climate Central. (n.d.) "Maine Drought." States at Risk, Climate Central. Retrieved July 2019 from <https://statesatrisk.org/maine/drought>
- 42 Fernandez, I.J., Schmitt, C.V., Birkel, S.D., Stancioff, E., Pershing, A.J., Kelley, J.T., Runge, J.A., Jacobson, G.L. & Mayewski, P.A. (2015). Maine's Climate Future: 2015 Update. Orono, ME: University of Maine.
- 43 Fernandez, I.J., Schmitt, C.V., Birkel, S.D., Stancioff, E., Pershing, A.J., Kelley, J.T., Runge, J.A., Jacobson, G.L. & Mayewski, P.A. (2015). Maine's Climate Future: 2015 Update. Orono, ME: University of Maine.
- 44 Fernandez, I.J., Schmitt, C.V., Birkel, S.D., Stancioff, E., Pershing, A.J., Kelley, J.T., Runge, J.A., Jacobson, G.L. & Mayewski, P.A. (2015). Maine's Climate Future: 2015 Update. Orono, ME: University of Maine.

- 45 Fernandez, I.J., Schmitt, C.V., Birkel, S.D., Stancioff, E., Pershing, A.J., Kelley, J.T., Runge, J.A., Jacobson, G.L. & Mayewski, P.A. (2015). *Maine's Climate Future: 2015 Update*. Orono, ME: University of Maine.
- 46 **NOTE:** Historical simulations (1980–2005) and future projections (2006–2099) in average maximum temperature from a 29-member, high resolution (4 km) statistically downscaled Coupled Model Intercomparison Project (CMIP5) ensemble mean lower (RCP 4.5 - blue line) and higher (RCP 8.5 - orange line) representative concentration pathway (RCP) emission scenarios. Orange and blue lines for the period 1980–2005 are identical. The light blue (light orange) shading represent the highest and lowest values from the 29 different model RCP 4.5 (RCP 8.5) simulations for each year. Graphs from Elizabeth Burakowski and Cameron Wake, Earth System Research Center/EOS, University of New Hampshire.
- 47 **NOTE:** Historical and recent data from the U.S. Climate Divisional Dataset (ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php), and future prediction from an ensemble simulation of the IPCC emissions scenario A2. Reference: Fernandez, I.J., Schmitt, C.V., Birkel, S.D., Stancioff, E., Pershing, A.J., Kelley, J.T., Runge, J.A., Jacobson, G.L. & Mayewski, P.A. (2015). *Maine's Climate Future: 2015 Update*. Orono, ME: University of Maine.
- 48 **NOTE:** Historical simulations (1980–2005) and future projections (2006–2099) in number of days below 32°F per year from a 29-member, high resolution (4 km) statistically downscaled Coupled Model Intercomparison Project (CMIP5) ensemble mean lower (RCP 4.5 - blue line) and higher (RCP 8.5 - orange line) representative concentration pathway (RCP) emission scenarios. Orange and blue lines for the period 1980–2005 are identical. The light blue (light orange) shading represent the highest and lowest values from the 29 different model RCP 4.5 (RCP 8.5) simulations for each year. Graphs from Elizabeth Burakowski and Cameron Wake, Earth System Research Center/EOS, University of New Hampshire.
- 49 **NOTE:** Historical simulations (1980–2005) and future projections (2006–2099) in number of days above 90°F per year from a 29-member, high resolution (4 km) statistically downscaled Coupled Model Intercomparison Project (CMIP5) ensemble mean lower (RCP 4.5 - blue line) and higher (RCP 8.5 - orange line) representative concentration pathway (RCP) emission scenarios. Orange and blue lines for the period 1980–2005 are identical. The light blue (light orange) shading represent the highest and lowest values from the 29 different model RCP 4.5 (RCP 8.5) simulations for each year. Graphs from Elizabeth Burakowski and Cameron Wake, Earth System Research Center/EOS, University of New Hampshire.
- 50 **NOTE:** Historical simulations (1980–2005) and future projections (2006–2099) in number of days above 95°F per year from a 29-member, high resolution (4 km) statistically downscaled Coupled Model Intercomparison Project (CMIP5) ensemble mean lower (RCP 4.5 - blue line) and higher (RCP 8.5 - orange line) representative concentration pathway (RCP) emission scenarios. Orange and blue lines for the period 1980–2005 are identical. The light blue (light orange) shading represent the highest and lowest values from the 29 different model RCP 4.5 (RCP 8.5) simulations for each year. Graphs from Elizabeth Burakowski and Cameron Wake, Earth System Research Center/EOS, University of New Hampshire.
- 51 **NOTE:** Historical simulations (1980–2005) and future projections (2006–2099) in temperature on the hottest day of the year from a 29-member, high resolution (4 km) statistically downscaled Coupled Model Intercomparison Project (CMIP5) ensemble mean lower (RCP 4.5 - blue line) and higher (RCP 8.5 - orange line) representative concentration pathway (RCP) emission scenarios. Orange and blue lines for the period 1980–2005 are identical. The light blue (light orange) shading represent the highest and lowest values from the 29 different model RCP 4.5 (RCP 8.5) simulations for each year. Graphs from Elizabeth Burakowski and Cameron Wake, Earth System Research Center/EOS, University of New Hampshire.
- 52 Carlowicz, M. (2018). Watery heatwave cooks the Gulf of Maine. NASA's Earth Observatory. Retrieved from <https://climate.nasa.gov/news/2798/watery-heatwave-cooks-the-gulf-of-maine/>
- 53 Pershing, A. J., Alexander, M.A., Hernandez, C.M., Kerr, L.A., Le Bris, A., Mills, K.E., Nye, J.A., Record, N.R., Scannell, H.A., Scott, J.D., Sherwood, G.D., Thomas, A.C. (2015). Slow adaptation in the face of rapid warming leads to the collapse of the Gulf of Maine cod fishery. *Science*. 350, no 6262: 809–12.
- 54 Friends of Casco Bay. (2019). Casco Bay Matters: Advancing the conversation—and action—on climate change. Casco Baykeeper. Retrieved from <https://www.cascobay.org/tag/casco-baykeeper/>
- 55 Fernandez, I.J., Schmitt, C.V., Birkel, S.D., Stancioff, E., Pershing, A.J., Kelley, J.T., Runge, J.A., Jacobson, G.L. & Mayewski, P.A. (2015). *Maine's Climate Future: 2015 Update*. Orono, ME: University of Maine.
- 56 Mills, K.E., Pershing, A.J., Brown, C.J., Chen, Y., Chiang, F.S., Holland, D.S., Lehuta, S., Nye, J.A., Sun, J.C., Thomas, A.C., & Wahle, R.A. (2013). Fisheries management in a changing climate: lessons from the 2012 ocean heat wave in the Northwest Atlantic. *Oceanography* 26(2):191–195.
- 57 Fernandez, I.J., Schmitt, C.V., Birkel, S.D., Stancioff, E., Pershing, A.J., Kelley, J.T., Runge, J.A., Jacobson, G.L. & Mayewski, P.A. (2015). *Maine's Climate Future: 2015 Update*. Orono, ME: University of Maine.
- 58 Casco Bay Estuary Partnership, Natural Choices, Waterview Consulting. (2017). *Casco Bay Climate Change Vulnerability Report*. Portland, ME: University of Southern Maine, Muskie School of Public Service, Casco Bay Estuary Partnership.
- 59 Fernandez, I.J., Schmitt, C.V., Birkel, S.D., Stancioff, E., Pershing, A.J., Kelley, J.T., Runge, J.A., Jacobson, G.L. & Mayewski, P.A. (2015). *Maine's Climate Future: 2015 Update*. Orono, ME: University of Maine.
- 60 Casco Bay Estuary Partnership, Natural Choices, Waterview Consulting. (2017). *Casco Bay Climate Change Vulnerability Report*. Portland, ME: University of Southern Maine, Muskie School of Public Service, Casco Bay Estuary Partnership.
- 61 NASA Earth Observatory image by Lauren Dauphin, and sea surface temperature data from Coral Reef Watch.

3. Infrastructural Exposure, Risk, and Vulnerability

Climate change can create cascading impacts across Portland and South Portland's energy, transportation, water, and communication infrastructure.

CONTEXT FOR INFRASTRUCTURE VULNERABILITY

Portland and South Portland rely on a complex network of infrastructure to provide power, water and sewer, communication, and transportation capabilities to residents, businesses, and visitors. There are also unique components, like the working waterfront, that the two cities rely on to support the local, regional, and state economy. Climate hazards like heavy precipitation, sea level rise, storm surge, and extreme heat are causing damage to infrastructure including roads, buildings, and utilities (water, sewer, energy, communications). Much of the existing infrastructure currently in place was not built to handle the climate conditions that we are beginning to see and that we anticipate seeing by the end of the century. In addition to disruptions in these infrastructure systems, climate hazards increase the risk of exposure and transport of hazardous material currently stored in above and below ground containments and built up in soils. Identifying these vulnerabilities presents both challenges and opportunities for increasing the resiliency of these systems in Portland and South Portland.

THE INTERCONNECTEDNESS OF SYSTEMS

While each of these infrastructure systems are discussed individually in the sections below, it is critical to consider the significant interconnectedness and interdependencies of infrastructure systems in the two cities. This interdependence is both scalar (e.g., local distribution lines rely on regional high voltage transmission lines) and crosses systems (e.g., sewer/

stormwater pump stations rely on electrical power). Furthermore, infrastructure systems are often collocated, meaning telecommunications lines, water mains, and transportation infrastructure such as bridges are usually clustered alongside each other. This design strategy results in specific corridors that, if compromised, could lead to the failure of a number of systems simultaneously. The collocated telecommunications infrastructure on Pan Am rail bridges is one prime example.⁶²

Likewise, the interdependency of infrastructure systems can lead to “cascading failure,” whereby the failure of one system triggers secondary and tertiary (and often ongoing) system interruptions. During Hurricane Sandy, for example, widespread power outages compromised operations for oil terminals, pipelines, storage facilities, and filling stations. Only a few installations had access to backup power generation, and long-term recovery challenges led to gas shortages.⁶³ Limitations on gasoline distribution further hampered backup generation capacity across other sectors, as well as impacted transportation systems. Obstructed roadways further affected transportation systems, and collectively the gas shortages and blocked routes led to slower repair and recovery of the other systems. This case study points to the ways in which the resilience of one infrastructure system must rely on the resilience of multiple systems. Studies suggest that power disruptions are most frequently the root cause of cascading failures, and thus prioritizing vulnerabilities in power supplies, distribution systems, and the power-dependence of other infrastructures can help contain risk. Considering the power reliance of each of the infrastructure systems discussed below is one critical way to consider system interdependency.

A NOTE ON FLOOD VULNERABILITY ASSESSMENT

In several of the following sections, two sets of flood risk data were used to provide complementary assessments of flood risk. The first investigation looks at FEMA Flood Rate Insurance Maps (FIRMs), which depict areas that are vulnerable to inundation by the 1% annual chance flood, formerly referred to as the 100-year flood. In other words, areas designated on the map have a 1% chance of being flooded by a storm every year. FIRMs are based on existing shoreline characteristics and historic recurrence intervals for wave and storm dynamics, and do not project effects from climate change. Nevertheless, they offer an indication of flooding associated with a particular level of storm, and a relative probability of occurrence. It is important to note that by 2050 with climate change and sea level rise, we will likely see water heights equivalent to the 1% annual chance storm nearly ten times as frequently, or every ten years (based on an “Intermediate” emissions scenario).

Three types of FEMA flood zone designations are included on the maps in this assessment, which are summarized in **Table 3.1**. While there are differences between the zones, all three zones represent the 1% annual chance flood and are considered “high-risk areas.”

The second investigation uses geospatial data from the Maine Geological Survey, which shows relative levels

of inundation from sea level rise or storm surge for the Maine coast for the year 2100 under six scenarios. These sea level rise scenarios were constructed based on long-term sea level rise data from Portland, Bar Harbor, and Eastport tide gauges, the US Army Corps of Engineers Sea-Level Change Curve Calculator (v. 2017.55), and sea level rise scenarios established by NOAA et al. (2017), in alignment with the Fourth US National Climate Assessment. The scenarios selected for this analysis include 1.6, 3.9, 6.1 and 8.8 feet of sea level rise on top of the highest astronomical tide (HAT), which correspond to the Low-Intermediate, Intermediate, Intermediate-High and High scenarios for 2100, respectively. Under the Intermediate scenario, we would expect to see 1.48 feet of relative sea level rise by 2050 for the Greater Portland Area—or up to 3.38 feet under the Extreme scenario. For the sake of visualization, these 2050 thresholds roughly correspond with the lower two thresholds for 2100 (1.6 and 3.9-foot rise above HAT).

For reference, the Bayside Adapts report recommends “committing to manage” the Intermediate scenario for the Portland area, which corresponds to 1.48 feet of relative sea level rise (RSLR) by 2050, and 3.84 feet RSLR by 2100. It likewise recommends “preparing to manage” the Extreme scenario by 2050 (3.38 feet RSLR) and the Intermediate-High Scenario by 2100 (8.72 feet RSLR).

FEMA Flood Zone Descriptions

Zone	Description
AE	Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. This is the base floodplain where base flood elevations are provided.
A	Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. No depths or base flood elevations are shown within these zones, because detailed analyses have not been conducted for these zones.
VE	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. No base flood elevations are shown within these zones.

Table 3.1. Descriptions for FEMA 1% annual chance flood zones A, AE, and VE. Table adapted from FEMA, “Definitions of FEMA Flood Zone Designations” (n.d.).⁷⁵

3.1 Energy Infrastructure

Energy systems across New England are increasingly vulnerable to climate change, with both direct and indirect impacts threatening the efficiency of the system and the reliability of supply. Extreme weather events, including high winds, heavy precipitation, storm surge, and flooding, may increasingly damage or disrupt electrical power plants, petroleum and natural gas storage, pumping facilities, and other energy production and distribution facilities. The projected temperature changes may change patterns in energy use, while also threatening system reliability and capacity. The energy systems that provide service and economic opportunities in Portland and South Portland are all interconnected in broader regional systems. Understanding local infrastructure connections in the context of both the regional systems and climate hazards is necessary to determine potential actions for risk mitigation.

The main energy infrastructure components evaluated in this section include: electric transmission and distribution, municipal solar arrays, petroleum, and natural gas. It is important to note that this assessment is looking at the vulnerability of *current* energy systems within the context of *future* climate projections out to the year 2100. As advanced through the One Climate Future planning process, both Portland and South Portland intend to transform their energy systems and move away from the use of fossil fuels within that time period. Therefore it will be important to re-evaluate vulnerability as these systems transition.

ELECTRIC TRANSMISSION AND DISTRIBUTION

Central Maine Power is the electric utility for Portland and South Portland as well as the majority of southern Maine. There are over 25,000 miles of transmission and distribution lines and 280 substations in the Casco Bay Region (**Figure 3.1**). Higher temperatures, increased

Regional Electrical Power Infrastructure

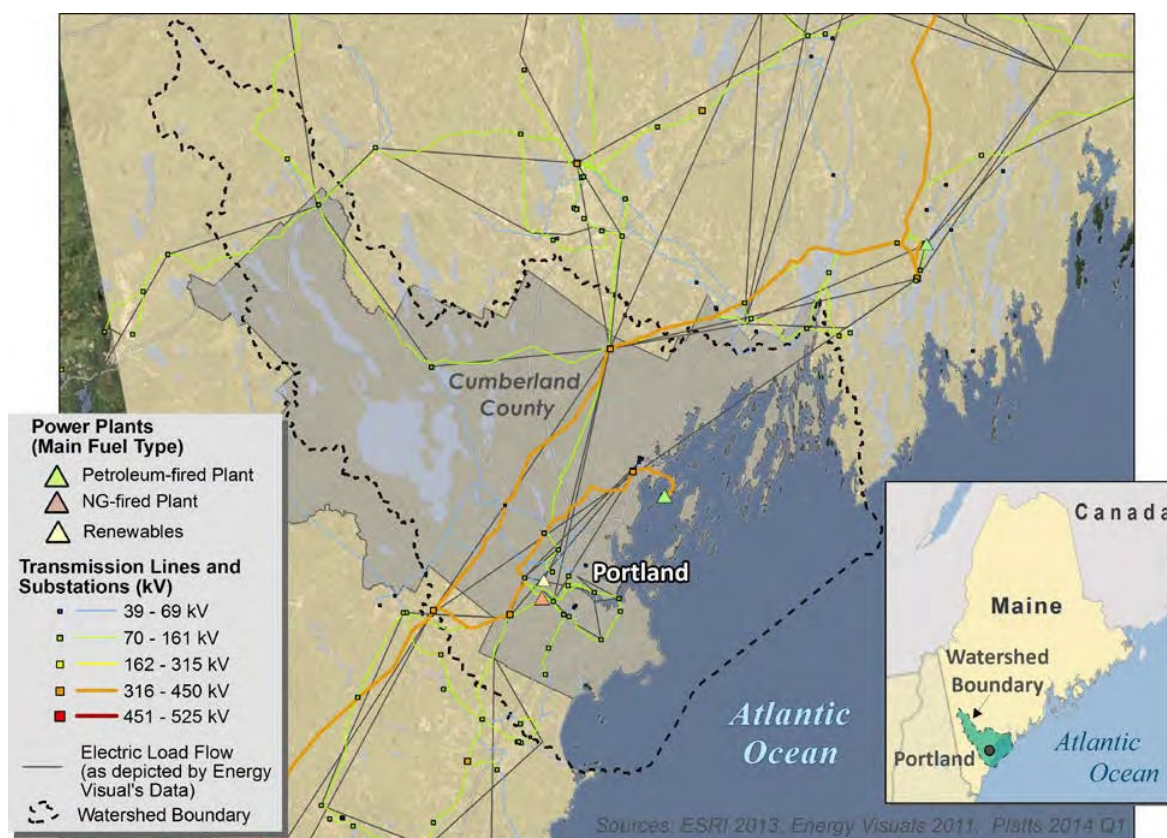


Figure 3.1. Regional electrical power infrastructure in the Cumberland County area. Figure source: U.S. Department of Homeland Security, (2016).⁷⁶

Climate Impacts to Electric Transmission and Distribution Infrastructure

Climate Hazard	Key Impacts
Increased Temperatures	• Lower generation efficiency • Decreased solar PV efficiency • Reduced carrying capacity and increased losses in lines and transformers • Increased demand for cooling
Increased Precipitation	• Damaged power lines from snow and ice • Flooding of underground infrastructure • Damaged towers due to erosion
Sea Level Rise	• Flood damage to coastal and/or low-lying infrastructure
Severe Storms	• Damaged infrastructure from wind and extreme weather • Disruption of supply chains at the local and regional level • Damage to facilities due to erosion

Table 3.2. Potential impacts to electric transmission and distribution infrastructure from climate hazards. Table adapted from Burillo, (2018).⁷⁷

precipitation, sea level rise, and storm surge due to climate change are all expected to hamper the function of the region's electric transmission and distribution system. **Table 3.2** summarizes some of the key issues for electric transmission and distribution systems.

In 2016, the U.S. Department of Homeland Security (DHS) conducted a study as part of the Regional Resiliency Assessment Program (RRAP) that looked at the effects of a category 2 hurricane along the coast of Maine. The study found that thirteen power plants (with a total generating capacity of 311 megawatts) and fifteen substations could be inundated by hurricane surge, reducing active electric generation in the state by 14 percent. This generation loss is unlikely to lead to power outages directly,⁶⁴ but localized power failures are probable during such a storm due to associated impacts on the distribution system.

The same study suggests that increases in average maximum temperature in Maine through 2050 could decrease overall plant generation output by 73 megawatts and decrease transmission line capacity by an average 8 percent. At the same time, electric power demand is expected to increase in the summers due to higher needs for cooling.⁶⁵

In the Northeast, there is a need for investment in the grid in order to continue to meet demand, reliability, resilience, and decarbonization goals. In 2018, AVANGRID Inc., the parent company of Central Maine Power, announced a plan to spend \$2.5 billion to improve the resiliency of the power grid that serves Maine, Connecticut, and New York to minimize the potential impacts of severe storms in the future. AVANGRID anticipates replacing aging infrastructure such as telephone poles, evaluating options and weighing costs

Portland and South Portland Municipal Solar Arrays

Facility	Community	Details
Riverside Golf Course	Portland	23 KW, Installed in 2018
Ocean Avenue Solar	Portland	1 MW, Installed in 2018
Portland International Jetport	Portland	450 KW, Installed in 2018
Landfill Solar (929 Highland Avenue)	South Portland	1 MW, Installed in 2017
Planning and Development Office	South Portland	18 KW, Installed 2012

Table 3.3. Municipal solar arrays in Portland and South Portland.

for hardening electrical infrastructure or installing microgrids, aggressively tree trimming, and targeting distribution system upgrades.

MUNICIPAL SOLAR ARRAYS

Portland and South Portland have developed solar projects on municipal properties to create locally generated renewable energy (**Table 3.3**). The existing solar arrays are not located in floodplains and are not currently projected to be impacted by sea level rise. Other climate hazards that may impact the arrays include heavy winds or precipitation, but major damage is unlikely.

PETROLEUM

Petroleum is a widely used resource in Maine, used both for heating and transportation fuel. As of 2016, petroleum supplied half of the energy consumed in the

state,⁶⁶ and 50 percent of the petroleum consumed in Maine entered through the Port of Portland.⁶⁷ The terminal infrastructure at the port, located in South Portland, plays a significant role in the state's petroleum supply chain, with seven terminals and a total storage capacity of 8.6 million barrels.⁶⁸ Refined products arriving at the port are transported within the state via the 124-mile Buckeye Pipeline, running from the port to the Buckeye Terminal in Bangor. There is also a pipeline from South Portland to Canada that has transported foreign crude oil since World War II, but which has largely been dormant since 2016 due to market competition from the Canadian tar sands.

The critical infrastructure associated with receiving and distributing petroleum is located in Portland Harbor at the mouth of the Fore River. Sea level rise and heavy storms projected with climate change may impact the

Petroleum Infrastructure Inundation Areas

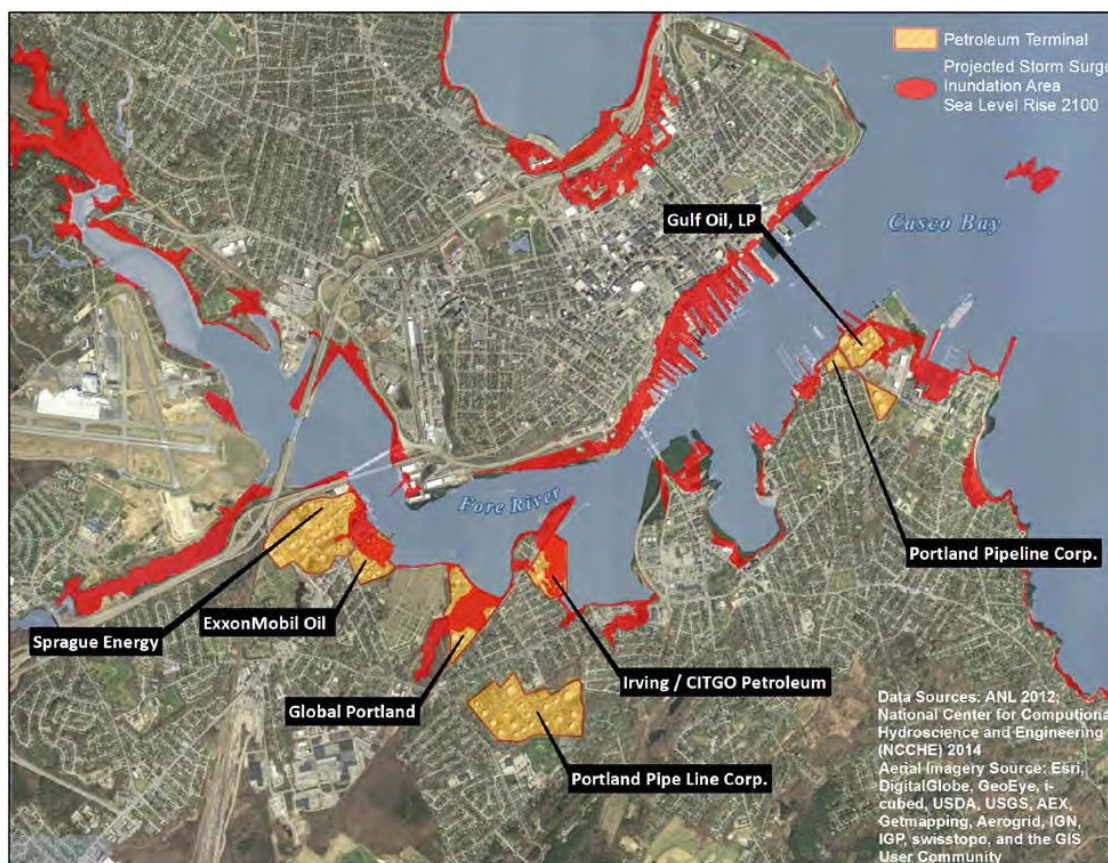


Figure 3.2. Petroleum terminals (2016) and areas projected to be inundated by sea level rise and storm surge based on a scenario of 38.6 inches of sea level rise by 2100. Figure source: Department of Homeland Security, (2016).⁷⁸

terminals and storage areas associated with petroleum operations, as well as the ability of oil tankers to utilize land-side infrastructure to distribute petroleum. An analysis completed by the US Department of Homeland Security (DHS) during the Regional Resiliency Assessment Program for Casco Bay shows significant inundation across the Portland and South Portland waterfront under a global sea rise scenario of 38.6 inches (3.2 feet) by 2100 (**Figure 3.2**). See section 3.5 *Impacts to Sites of Contaminated Soil and Hazardous Waste Storage* for a further assessment of the flood vulnerability of petroleum facilities along the Fore River.

Any disruption in the petroleum supply chain—including damage to terminals, transport interruptions, price spikes, and/or other obstructions—may have immediate implications for the state. The DHS Regional Resiliency Assessment for Casco Bay highlights the region’s limited

fuel reserves. As of 2016, a typical January-February inventory for stored distillate fuel oil can only meet two to four weeks of demand. Likewise, a typical January-February inventory is only able to meet an eight to twelve days of transportation-related fuel demand.⁶⁹ Furthermore, petroleum is distributed from terminals to retailers and homes primarily by truck in Maine, making the petroleum supply chain not only dependent on adequate driving conditions and unobstructed roads, but also on petroleum fuels for completing deliveries.

NATURAL GAS

In Maine, there are three interstate pipelines that provide natural gas for industrial, commercial, and residential use and electricity generation. The Maritime and Northeast Pipeline (M&NP) and the Portland Natural Gas Transmission System (PNGTS) import gas from Canada, with the former transporting natural gas southward to

Natural Gas Infrastructure in Greater Portland

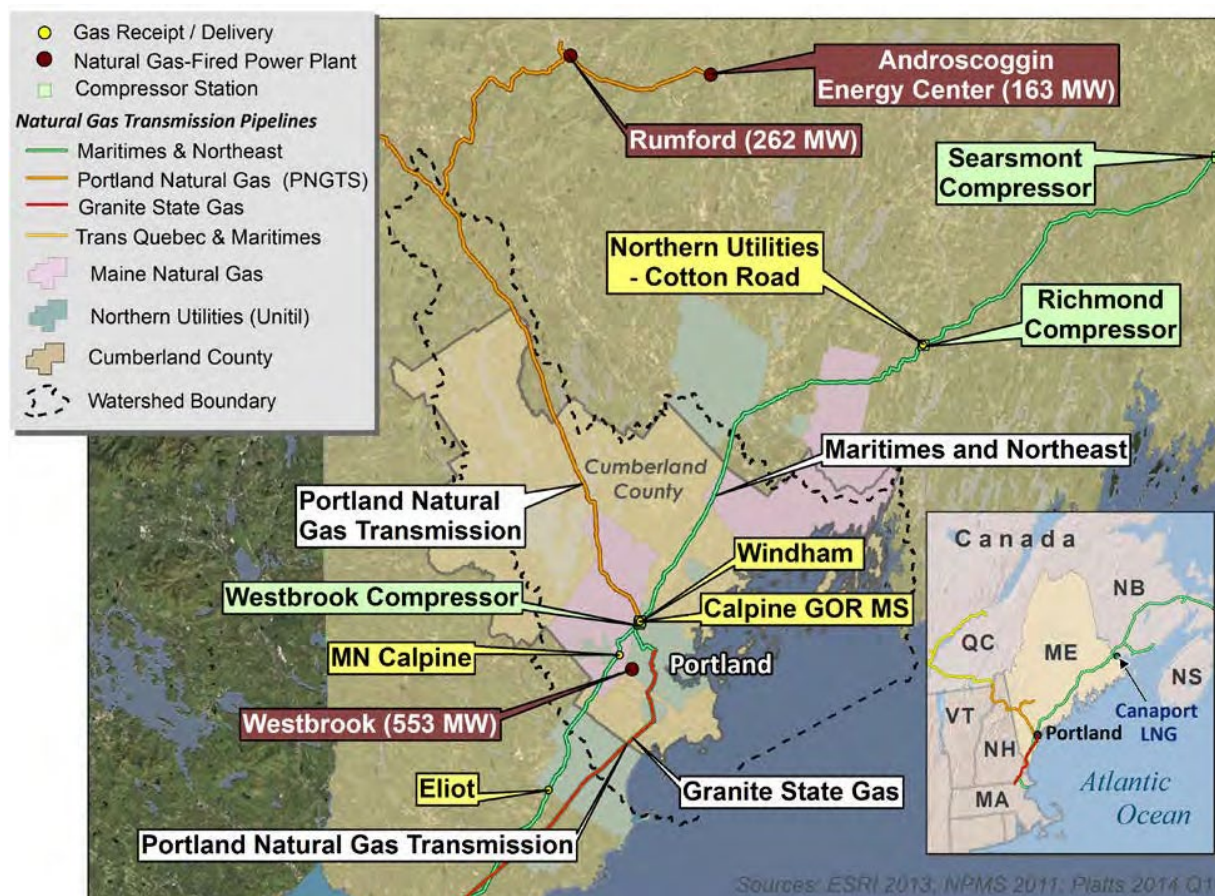


Figure 3.3. Natural gas transmission and power plant infrastructure (2016) in the Casco Bay region. Figure source: Department of Homeland Security (2016).⁷⁹

other US markets (**Figure 3.3**). Four local distribution companies further supply natural gas to Central and Southern Maine. Portland and South Portland are served by Northern Utilities (Unitil). Granite State Gas Transmission, which can be seen in **Figure 3.3**, is a subsidiary of Unitil.

Throughout the United States, natural gas is expected to provide the majority of electricity by 2050.⁷⁰ This is due to the increase in domestic supply, partially as a result of fracking drilling techniques and its increasing cost-competitiveness compared to other energy sources. The use of natural gas for residences, businesses, and electrical generation continues to grow, which places increased pressure to upgrade and expand the pipelines serving Maine. While considerations for changes or upgrades to natural gas systems need to consider climate resilience, any significant investment must also consider that improving natural gas infrastructure is a divergence in reaching carbon neutrality goals.

Because the region's primary natural gas infrastructure is located further inland, sea level rise and storm surge presents less of a risk for this system. Nevertheless, localized flooding caused by heavy precipitation or hurricanes remain a concern, particularly for the compressor stations that maintain the necessary pipeline pressure to move natural gas through the system. The DHS Regional Resiliency Assessment for Casco Bay further highlights the lack of redundancy in the region's natural gas system. Because M&NP and PNGTS each operate single pipelines, disruptions in these mainlines would cut off natural gas to the rest of the system. Maine, along with much of New England, has also seen recurring natural gas shortages and price spikes in association with extreme cold temperatures.

3.2 Water and Wastewater Infrastructure

Water and wastewater infrastructure in Portland and South Portland are critical assets. Protecting reliable drinking water, stormwater, and wastewater systems and services, as well as their associated public health, water quality, and economic benefits, has tremendous value locally, regionally, and statewide. Current and projected changes in the climate require altering how this infrastructure is being planned for, maintained, and upgraded.

DRINKING WATER

Portland and South Portland receive their drinking water from Sebago Lake. The Sebago Lake watershed is approximately 282,000 acres, extending from Standish to Bethel, Maine (**Figure 3.4**). Much of the watershed surrounding Sebago Lake is undeveloped forested land, which contributes to the superior quality of the drinking water. Sebago Lake is so clean that it requires no filtration before it is disinfected and distributed—

something that only 50 surface water suppliers out of 13,000 in the country can claim.⁷¹

Water Source — To date, the forestland in the Sebago Lake Watershed has maximized the removal of sediment and pollutants from water as it moves through the watershed to the lake. More recently, development pressure, deforestation, stormwater pollution and population growth have created concerns for maintaining this high water quality, and climate change exacerbates this risk. The Portland Water District, the region's water supplier, makes an intentional effort to invest in natural infrastructure to help support and prioritize clean water in Sebago Lake through land conservation and conservation easements.

For the Sebago Lake watershed, climate hazards will pose new challenges to maintaining water quality, particularly due to increases in nonpoint source pollution from heavy rain events and warmer waters which can encourage bacterial and algal growth. (See section 4.3 *Compromised Natural Water Systems* for further discussion of this

impact.) Beyond impacts on water quality, water quantity can be impacted by changes in seasonal, annual, or multi-year precipitation totals. For example, in 2016 much of Maine had lower than usual rainfall, and southern coastal Maine experienced severe drought conditions. Although Sebago Lake water levels were at a 10-year low, the Portland Water District affirmed that water supplies remained sufficient for all 54,000 customers.

Water Distribution — The Portland Water District maintains a water distribution network of 1,000 miles of water mains, pump stations, and reservoirs that bring water from Sebago Lake to its customers. Two large water mains run from the treatment facility to Westbrook and Portland, which allow for redundancy in the system.

Variations in water flow combined with the condition of the pipe network throughout the cities can cause early pipe failure. Climate hazards including extreme precipitation events, periods of drought, and sea level rise have the potential to exacerbate failure by increasing the likelihood of pipe breaks and distribution system damage for some of the following reasons:

- Frequent freeze and thaw cycles cause movement in the ground, resulting in strain on distribution system pipes;
- Increases in groundwater salinity in coastal areas due to sea level rise or coastal flooding can cause corrosion, which can weaken metal pipes, cause water mains to break, and result in saltwater intrusion into the water supply;
- Drought conditions may impact groundwater levels and cause movement in the ground as settling occurs; and
- Drought conditions can cause tree roots to grow into water lines as they seek a water source, eventually cracking the pipe or pipe joints.

All pipe failures and disruption to water service risk leading to loss of public trust, economic costs, and public health repercussions. The vulnerability of specific drinking water assets was not assessed in this study; Data related to such assets were not available for use due to homeland security concerns.

SEWER AND STORMWATER

The sewer and stormwater system plays a key role in treating and managing “used” water (wastewater) and rainwater that enters the cities, protecting the health of water systems, and mitigating flooding. The evaluation in this section assesses the vulnerability of wastewater and stormwater structures to sea level rise and storm surge in Portland and South Portland, including pump stations (PS), manholes (MH), sewer/stormwater pipe networks, and combined sewer overflows (CSOs). The potential sea level rise and storm surge impacts not only affect the structural integrity and design capacity of the infrastructure system, but also pose a threat to essential operation and maintenance (O&M) necessary of a combined sewer system as it begins to age.

Sebago Lake Watershed

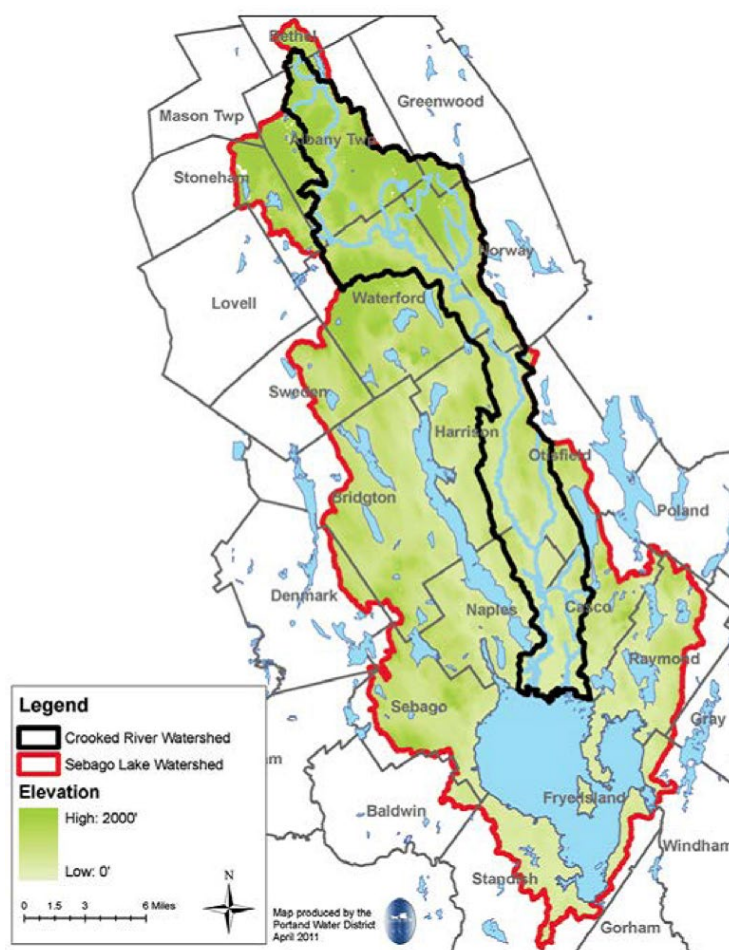


Figure 3.4. Sebago Lake Watershed. Figure source: Portland Water District (2011).⁸⁰

As outlined in the introduction of the Infrastructure section (page 34), two sets of flood risk data were used in this analysis, which provide complementary assessments of flood risk. The first investigation looks at FEMA Flood Rate Insurances Maps (FIRMs), which depict areas that are vulnerable to inundation by the 1% annual chance flood. (See page 35 for descriptions of the flood zone designations.)

The second investigation uses geospatial data from the Maine Geological Survey, which shows relative levels of inundation from sea level rise or storm surge for the Maine coast for the year 2100 under six scenarios. The specific scenarios selected for this analysis include 1.6, 3.9, 6.1 and 8.8 feet of sea level rise on top of the highest astronomical tide (HAT), which correspond to the Low-Intermediate, Intermediate, Intermediate-High and High scenarios for 2100, respectively. By 2050, we would expect to already see 1.48 feet of relative sea level rise under the Intermediate scenario, or 3.38 feet under the Extreme scenario specifically for the Greater Portland area. (See page 35 for further details.) The vulnerability of infrastructure assets within the cities was determined based on a visual assessment of asset locations, flood zones, and the sea level rise data under each of the four separate sea level rise scenarios to determine which assets fall within the projected boundaries of flood risk.

The data utilized for the following analysis were provided by the City of Portland, the City of South Portland, and the Portland Water District (PWD). The sewer and stormwater data for both cities were last updated between 2017 and June 2019. The observations about the sewer and stormwater systems in Portland and South Portland were based on the GIS data that were received from the cities and PWD, and may not directly coincide with results produced by other recent reports or analyses, depending on the version of the dataset used for those studies. In order to have consistency across our analysis, GIS sewer or stormwater structures identified in the data sources provided by the Cities in 2019 are the basis upon which results and conclusions were determined and presented in this section. Again, only sewer and stormwater assets (not drinking water assets) were included in this assessment.

Portland

System Overview

The City of Portland owns and maintains water, sewer, and stormwater infrastructure and is responsible for the cost of its maintenance, improvements, and expansion, as well as for the associated bonds and revenues. The City of Portland sewer system includes an estimated 270 miles of sanitary sewer and combined sanitary and storm sewers along with 24 pump stations, 15 of which are owned and operated by the Portland Water District. City of Portland pump stations are shown in **Figure 3.5**.

In addition to operating 15 pump stations, the Portland Water District owns and manages the treatment of the city's water and wastewater. The East End Wastewater Treatment Facility (WWTF) is located on a site adjacent to the Eastern Promenade and treats approximately 20 MGD of dry-weather flow, and is designed to treat 80 MGD during peak weather events. This facility is key to protecting the Casco Bay Watershed and has been upgraded and modified since it opened in 1979 to handle more wastewater.⁷² The Portland Water District also operates the Peaks Island WWTF, which serves 500 residents on the island, and treats 0.2 MGD of dry-weather flow and 0.61 MGD at peak flow.

The flood risk assessment also looks at Combined Sewer Overflows (CSOs), which occur when untreated wastewater is directed into streams, rivers, and oceans as a result of heavy rain events that cause the system's capacity to be exceeded. The City of Portland CSO Master Plan from 1993 identified 42 CSOs in the city. The current City GIS data includes 41 structures. Of the 41 structures, 30 are currently active CSOs according to the most recent Maine DEP Maine Pollutant Discharge Elimination System (MEPDES) Permit Renewal dated February 2019. These are currently being addressed through CSO separation efforts in the city. Some active CSOs are owned by the City and some are owned by Portland Water District. For the purpose of this analysis, all 41 structures in the City's GIS database have been analyzed for flooding and sea level rise impacts. Structures that were once active CSOs and are now closed should not discharge during rainfall events. However, unless the structure has been properly inspected, it is unknown if the structure is fully sealed when exposed to flooding and predicted sea level

rise. Although inactive structures may not be actively discharging during wet weather events, infiltration and inflow may still pose a threat to the sewer and stormwater network. Therefore all 41 structures within the City's GIS data were evaluated for impacts under the flooding conditions and the four sea level rise scenarios.

These structures are identified as CSOs for mapping purposes. It is recommended that the City of Portland inspect all inactive structures and active CSOs exposed to flood risk. Additionally, it is recommended that the City update the GIS inventory to match the DEP MEPDES Permit Renewal dated February 2019.

Portland City-Owned Pump Station Locations

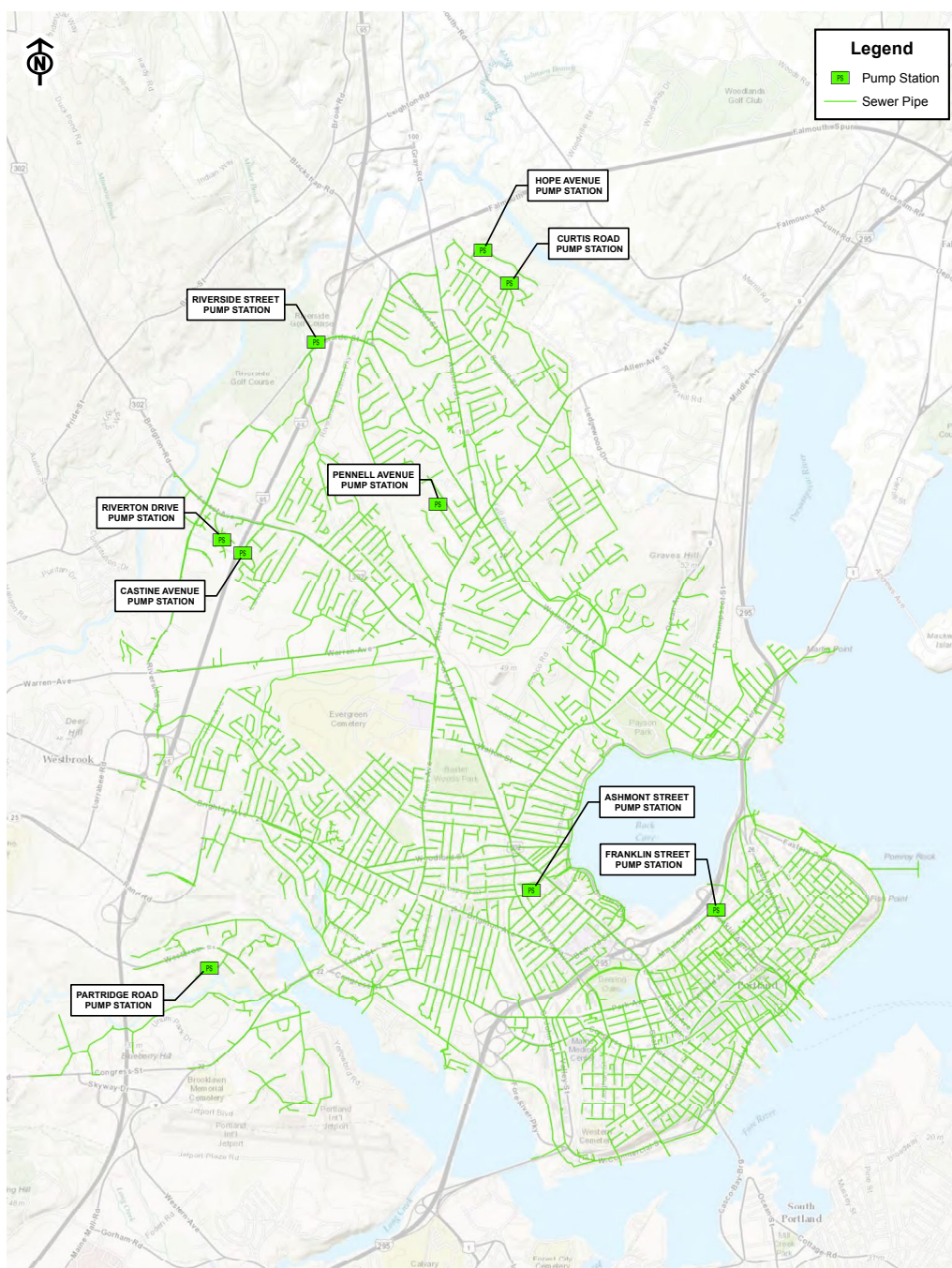


Figure 3.5. Locations of city-owned pump stations in Portland. Figure source: Woodard & Curran (2013).⁸¹

Vulnerable Assets

Table 3.4 summarizes the sewer and stormwater infrastructure in Portland that is vulnerable to flooding based on the 1% annual chance flood. Assets are tallied across three types of flood zones: VE zones are coastal, high velocity zones where flooding and wave action can be anticipated, AE zones are the base floodplain where base elevations have been provided, and A zones are areas where base flood elevations have not been determined. (See page 35 for these descriptions). All zones represent inundation areas associated with the 1% annual chance flood and are considered high risk areas.

Table 3.5 summarizes the sewer and stormwater infrastructure in Portland that are vulnerable to flooding based on four sea level rise scenarios. Based on both sets of flood risk data, sewer and stormwater infrastructure

in Back Cove, Bayside, and Commercial Street face the greatest vulnerability to flooding. Specific areas and vulnerable assets are discussed in more detail in the following sections.

A) Pump Stations — The East End Beach Pump Station is located in the FEMA VE flood zone; the Westbrook Pump Station, Riverside Street Pump Station, and Great Pond Pump Station are located in the AE flood zone; and the Blueberry Road Pump Station is located in the A flood zone (**Figure 3.6**). All five stations are vulnerable to the 1% annual chance flood, with the pump station in the VE zone being most vulnerable due to additional high velocity wave action. Any damage to the stations from flooding would disrupt the overall function of the wastewater collection system and lead to loss of service to customers.

Portland Sewer and Stormwater Structures in FEMA Flood Zones

Item	FEMA Flood Zones					
	VE Flood Zone		AE Flood Zone		A Flood Zone	
	Total	Percent	Total	Percent	Total	Percent
Pump stations (number)	1	4%	3	13%	1	4%
Manholes (number)	6	< 1%	270	3%	14	< 1%
CSOs (number)	2	5%	4	10%	0	0%
Pipe network (linear feet)	27,220	< 1%	152,930	3%	6,100	< 1%

Table 3.4. Sewer and stormwater structures in Portland that are located in VE, AE, and A FEMA preliminary flood zones (2018). Infrastructure in all flood zones is vulnerable to the 1% annual chance flood; infrastructure in the VE zone may also be exposed to wave action.

Portland Sewer and Stormwater Structures Vulnerable to Sea Level Rise

Item	Sea Level Rise Scenarios							
	HAT + 1.6 Feet		HAT + 3.9 Feet		HAT + 6.1 Feet		HAT + 8.8 Feet	
	Total	Percent	Total	Percent	Total	Percent	Total	Percent
Pump stations (number)	1	4%	4	17%	4	17%	11	46%
Manholes (number)	100	1%	403	4%	663	7%	835	9%
CSOs (number)	0	0%	0	0%	15	37%	18	44%
Pipe network (linear feet)	78,994	2%	169,606	4%	230,320	5%	281,190	6%

Table 3.5. Sewer and stormwater structures in Portland that are vulnerable to sea level rise based on four sea level rise scenarios for 2100. Inundation from each of the scenarios is based on sea level rise on top of the highest astronomical tide (HAT).

Portland Pump Stations Vulnerable to the 1% Annual Chance Flood

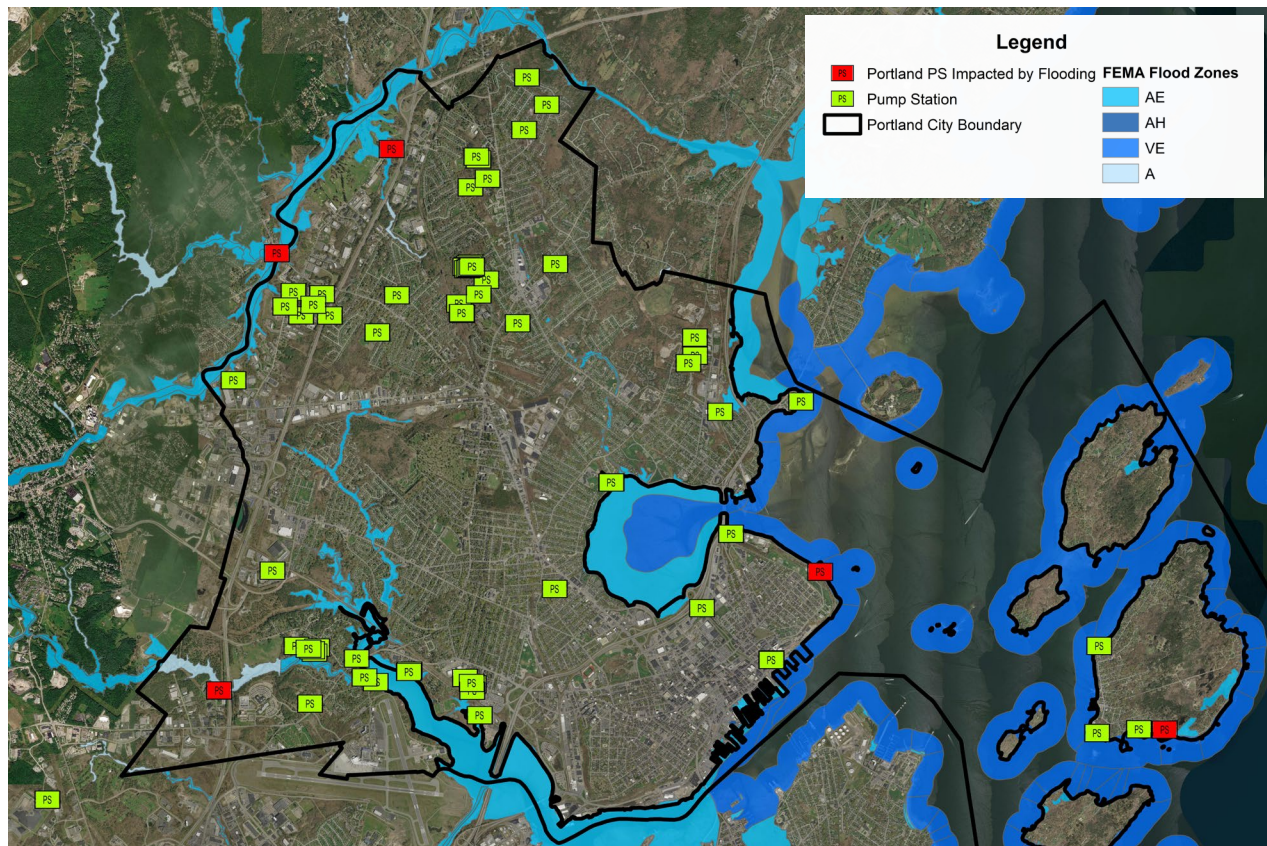


Figure 3.6. Pump stations in Portland that are vulnerable to the 1% annual chance flood. Included on this map are private pump stations which were in the GIS data provided by the City of Portland GIS Department. No private pump stations are predicted to be vulnerable to the 1% annual chance flood. Data from the City of Portland and Portland Water District and FEMA preliminary flood zones (2018).

Portland Pump Stations Vulnerable to Sea Level Rise

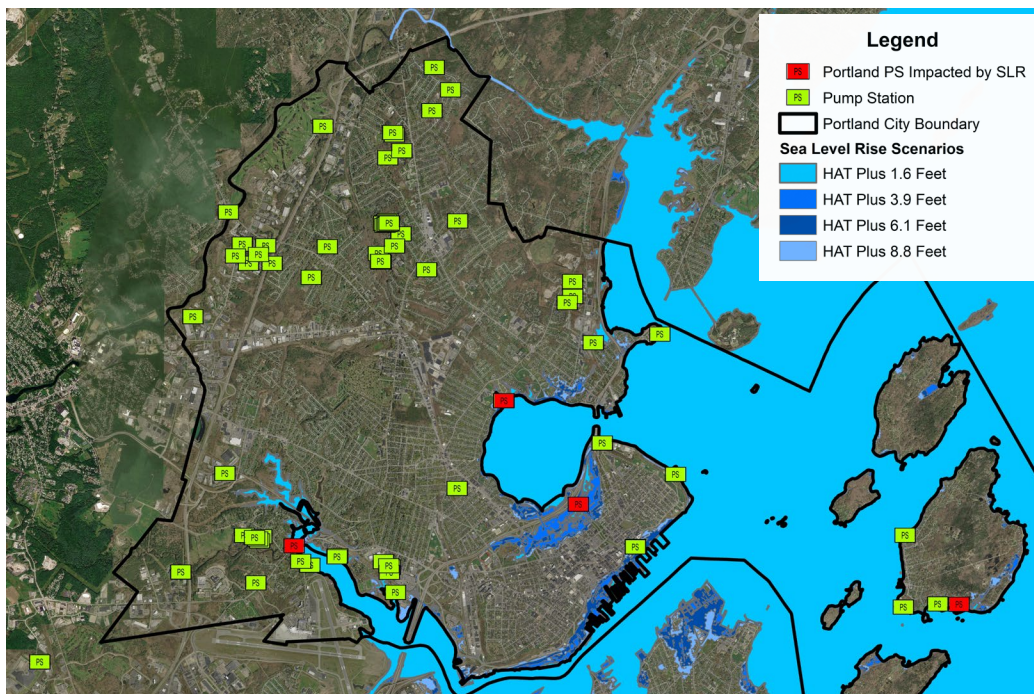


Figure 3.7. Pump stations in Portland that are vulnerable to flooding based on four sea level rise scenarios. Data from the City of Portland and Portland Water District and Maine Geological Survey Sea Level Rise/Storm Surge Scenarios.

Of the 24 pump stations operated by the City and the Portland Water District (PWD), 3.9 feet of sea level rise on top of the astronomical high tide will impact four pump stations: Baxter Street Pump Station, Commercial Street Pump Station, Franklin Street Pump Station, and Great Pond Pump Station (**Figure 3.7**). Franklin Street Pump Station is city-owned and operated and the remaining three are owned and operated by the Portland Water District.

B) Wastewater Treatment Facilities — The Portland wastewater treatment facility in the East End does not show significant vulnerability to the 1% annual chance flood, nor any of the four sea level rise scenarios. It is likely, however, that the city would lose access to the facility due to inroads being inundated both in the 1% annual chance storm and in a scenario where sea levels reach HAT + 6.1 feet or higher (**Figure 3.8**). The Peaks Island WWTF is not located in a FEMA Flood Zone and is not projected to be impacted by sea level rise. However, both facilities are still at risk of climate hazards concurrent to sea level rise, such as more frequent and more powerful storms. As they are situated on the shoreline, it is certainly possible that during a violent coastal storm, these WWTF could be at risk from water or storm damage.

C) Manholes — Six manholes in Portland are within the FEMA VE high risk coastal flood zone (less than 1 percent of all sewer and stormwater manholes in the city); 270 manholes are located in AE flood zones (approximately 3 percent of all manholes) and 14 manholes are located in A flood zones (less than 1 percent). Particularly vulnerable areas of concern include Back Cove, Commercial Street, and the Fore River area near Stroudwater (**Figure 3.9**). The implications of manholes that are located in an area at risk for flooding is that non-watertight manholes allow floodwaters to infiltrate the sewer system.

Approximately 1 percent of all sewer and stormwater manholes are predicted to be impacted by 1.6 feet of sea level rise above the astronomical high tide (a threshold that could likely be seen by 2050), which is an estimated 100 manholes out of 9,326 sewer and stormwater manholes included in the GIS data provided. Approximately 4 percent of all manholes (an estimated 403 manholes) are predicted to be impacted by 3.9 feet of sea level rise on top of the astronomical high tide. Although locations with affected manholes are widespread throughout the city, four primary areas of concern have been established: Back Cove, Bayside, Fore River, and Commercial Street.

Portland WWTF Flood Vulnerability

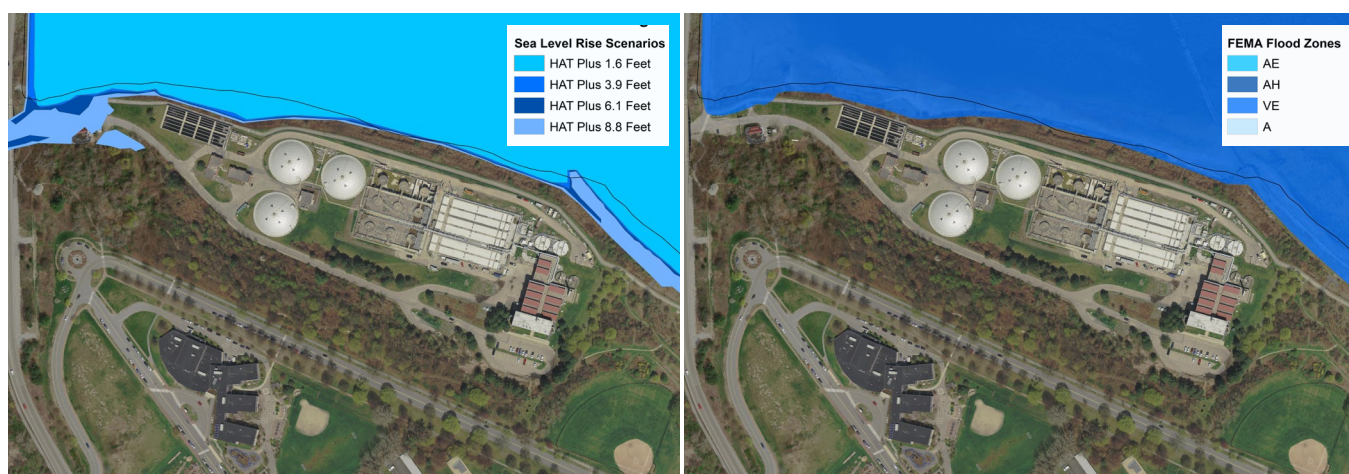


Figure 3.8. Extent of vulnerability of the East End wastewater treatment facility in Portland to flooding from four scenarios of sea level rise (left) and the 1% annual chance flood (right). Data from FEMA preliminary flood zones (2018), and Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

Portland Manholes and Pipe Network Vulnerable to the 1% Annual Chance Storm

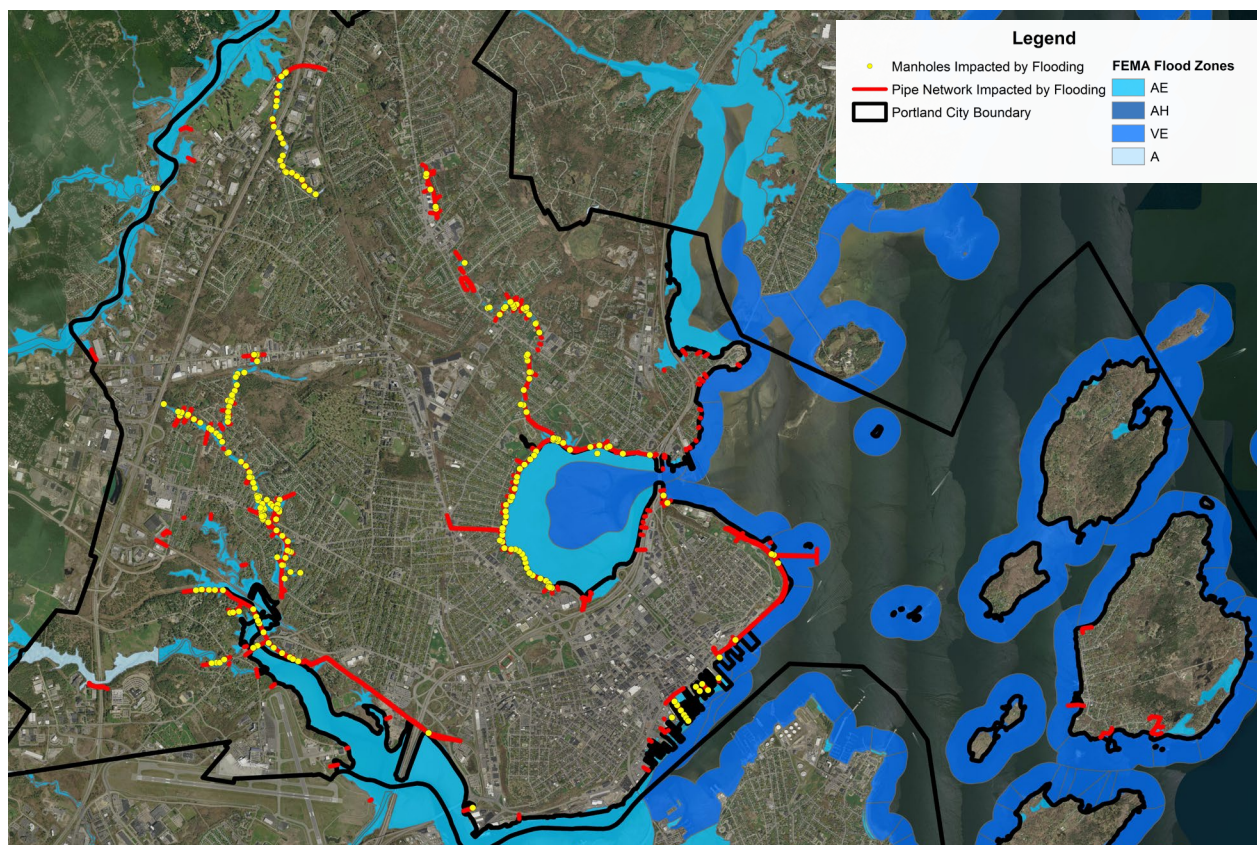


Figure 3.9. Manholes and pipe network segments in Portland that are vulnerable to the 1% annual chance flood. Data from the City of Portland and Portland Water District and FEMA preliminary flood zones (2018).

D) Pipe Network — The Portland pipe network that was evaluated for flood risk includes sewer gravity mains, sewer force mains, and stormwater mains. Less than 1 percent of the city’s pipe network will be impacted by flooding within the VE FEMA flood zone, or approximately 27,220 linear feet of pipe, according to the data provided by the City of Portland GIS department and the Portland Water District. Approximately 152,930 linear feet (3 percent of the pipe network) is vulnerable to flooding in the AE flood zone and approximately 6,100 linear feet (less than 1 percent of the pipe network) is located in the A flood zone. The at-risk sewer and stormwater pipe network assets are primarily within the Back Cove, Commercial Street, and Fore River or Stroudwater Areas.

Based on the 3.9-ft sea level rise scenario, sea level rise will impact approximately 169,606 linear feet (4

percent) of the pipe network. High-risk areas include Back Cove, Bayside, and Commercial Street. Increases in groundwater salinity due to sea level rise or coastal flooding can lead to pipe corrosion, which weakens metal pipes and leads to pipe main breaks. Inundation of the sewer and stormwater pipe network also leads to higher volume and frequency of combined sewer overflows, discussed in the following section.

E) Combined Sewer Overflows — Portland’s pipe network is subject to Combined Sewer Overflows (CSOs), which occur when heavy rain events overwhelm the capacity of the pipe network, and as a result, untreated wastewater is directed into streams, rivers, and oceans. CSOs pose a significant threat to the water quality along Portland’s coast, creating health concerns for water recreation and impacting ecologically sensitive areas. Higher-intensity precipitation events are likely to

cause capacity issues and the potential for larger and more frequent CSOs for the system in its current state.

For the purpose of this analysis, all 41 structures (active and inactive CSOs) in the City's GIS database have been analyzed for flooding and sea level rise impacts, based on the reasoning described on page 42. Of these 41 structures, none are vulnerable to sea level rise based on the HAT + 1.6-ft or HAT + 3.9-ft sea level rise scenarios. Vulnerability significantly jumps when assessing sea level rise based on the HAT + 6.1-ft rise scenario, with 15 structures predicted to be impacted (approximately 37 percent). A total of 18 structures could be impacted under the HAT + 8.8-ft sea level rise scenario (the High scenario for 2100). Vulnerable areas include the north and south side of Back Cove and Commercial Street.

Six structures are vulnerable to the 1% annual chance storm, two of which (approximately 5 percent) are located in the VE flood zone, and four of which (approximately 10 percent) are located in the AE flood zone.

South Portland

Overview

The City of South Portland sewer system includes an estimated 170 miles of sanitary sewer and stormwater pipes in the network and over 6,000 stormwater and wastewater structures.⁷³ The South Portland wastewater treatment plant (WWTP) is located in Knightville just east of the Casco Bay Bridge with a design capacity of 9.3 MGD of dry-weather flow, and is designated to treat 22.9

South Portland City-Owned Wastewater Pump Stations

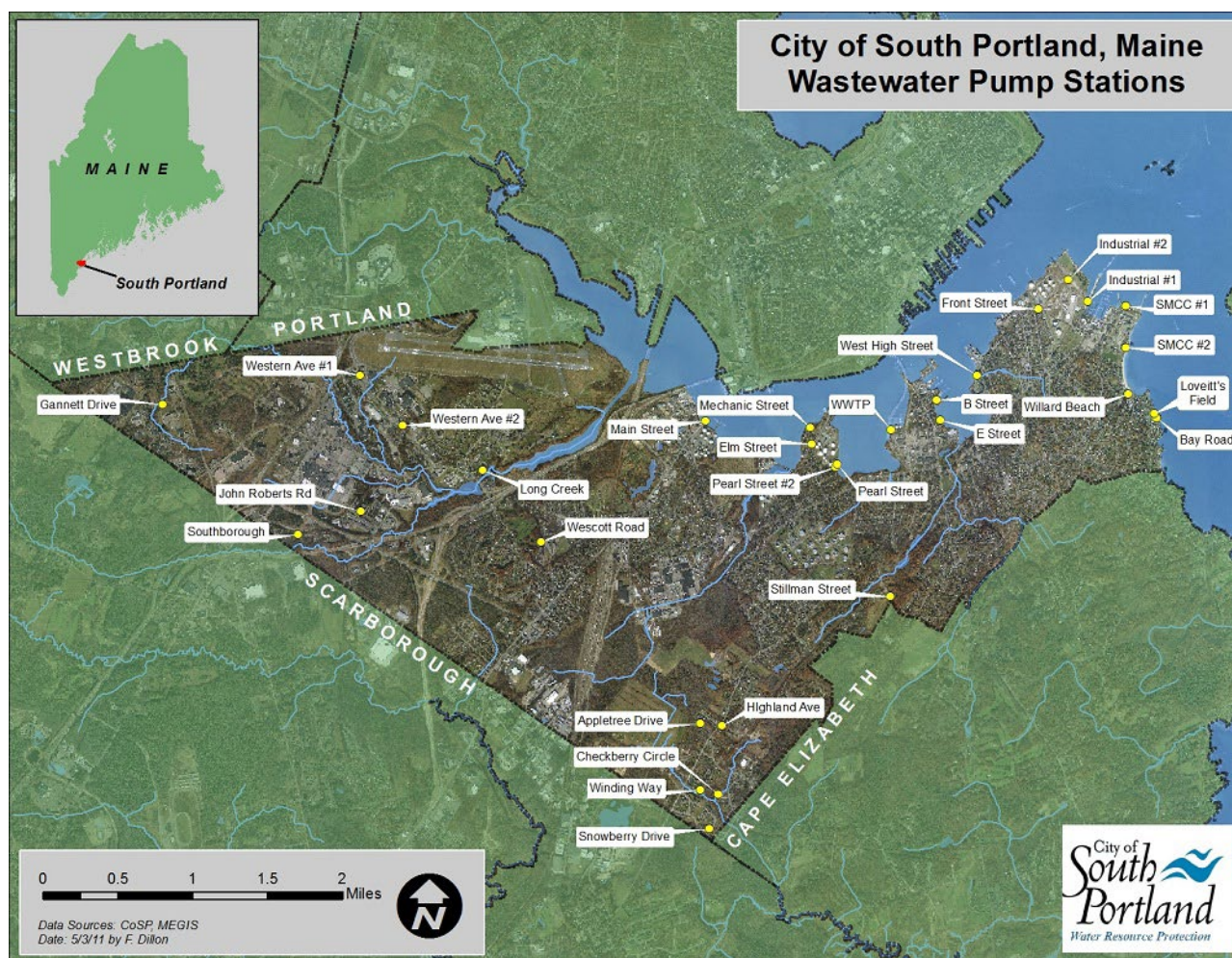


Figure 3.10. Locations of city-owned pump stations in South Portland. Figure source: City of South Portland, Water Resource Protection (2011).⁸²

MGD during peak weather events. Originally constructed in 1977, the most recent major upgrade to the WWTP was in 1995.⁷⁴ Based on City of South Portland GIS data, there are 34 pump stations in the city; **Figure 3.10** shows the locations of 30 pump stations operated by the South Portland Treatment Systems Division (2011). The city also currently has six Combined Sewer Overflow (CSO) sites, which were also evaluated for flood risk.

Data used for this analysis was received from the City of South Portland Water Resource Protection department. The sewer and stormwater infrastructure data were last updated between 2016 and 2018. Vulnerable assets and high-risk areas for the City of South Portland are discussed in the following section.

Vulnerable Assets

Table 3.6 summarizes the sewer and stormwater infrastructure in the City of South Portland that is vulnerable to flooding based on the 1% annual chance flood. Assets are tallied across three types of flood zones: VE zones are coastal, high velocity zones where flooding and wave action can be anticipated, AE zones are the base floodplain where base elevations have been provided, and A zones are areas where base flood elevations have not been determined. (See page 35 for these descriptions). All zones represent inundation areas associated with the 1% annual chance flood and are considered high risk areas.

Table 3.7 summarizes the sewer and stormwater infrastructure in the City of South Portland that is vulnerable to flooding based on four sea level rise

South Portland Sewer and Stormwater Structures in FEMA Flood Zones

Item	FEMA Flood Zones					
	VE Flood Zone		AE Flood Zone		A Flood Zone	
	Total	Percent	Total	Percent	Total	Percent
Pump stations (number)	2	6%	4	12%	0	0%
Manholes (number)	28	< 1%	65	1%	2	< 1%
CSOs (number)	0	0%	0	0%	0	0%
Pipe network (linear feet)	4,510	1%	16,310	3%	1,002	< 1%

Table 3.6. Sewer and stormwater structures in South Portland that are located in VE, AE, and A FEMA flood zones. Infrastructure in all flood zones is vulnerable to the 1% annual chance flood; infrastructure in the VE zone may also be exposed to wave action.

South Portland Sewer and Stormwater Structures Vulnerable to Sea Level Rise

Item	Sea Level Rise Scenarios							
	HAT + 1.6 Feet		HAT + 3.9 Feet		HAT + 6.1 Feet		HAT + 8.8 Feet	
	Total	Percent	Total	Percent	Total	Percent	Total	Percent
Pump stations (number)	0	0%	5	15%	9	27%	13	38%
Manholes (number)	16	< 1%	105	2%	292	6%	484	11%
CSOs (number)	0	0%	1	17%	1	17%	4	67%
Pipe network (linear feet)	7,896	1%	23,273	4%	44,244	7%	61,415	10%

Table 3.7. Sewer and stormwater structures in South Portland that are vulnerable to sea level rise based on four sea level rise scenarios for 2100. Inundation from each of the scenarios is based on sea level rise on top of the highest astronomical tide (HAT).

scenarios. Based on both sets of flood risk data, sewer and stormwater infrastructure in Knightville, Ferry Village, Simonton Cove, and Cushing Point face the greatest vulnerability. In South Portland, the pipe network and associated structures are dependent on each other for the operation of an efficient collection system, making it essential that vulnerable assets are managed proactively and properly to prevent system failure.

A) Pump Stations — Based on City GIS data, there are 34 pump stations in the City of South Portland. **Figure 3.11** displays the pump stations that may be inundated by the 1% annual chance flood. The Bay Road Pump Station and Loveitt's Field Pump Station are located in the FEMA VE flood zone. These pump stations are connected to sewer and stormwater pipes also vulnerable to flooding in this area near Willard Beach. Four additional pump stations are located in the AE flood zone:

- Pearl Street Pump Station
 - Willard Beach Pump Station
 - "Industrial Area 1" Pump Station*
 - "SMTC 1" Pump Station*
- *as described in the GIS data provided

Figure 3.12 displays the pump stations that may be affected by sea level rise. Five of South Portland's pump stations (approximately 15 percent) are predicted to be impacted at 3.9 feet of sea level rise on top of the highest astronomical tide. These include:

- Pearl Street Pump Station
 - Elm Street Pump Station
 - Front Street Pump Station
 - "Industrial Area 1" Pump Station*
 - "Industrial Area 2" Pump Station*
- *as described in the GIS data provided

South Portland Pump Stations Vulnerable to the 1% Annual Chance Flood

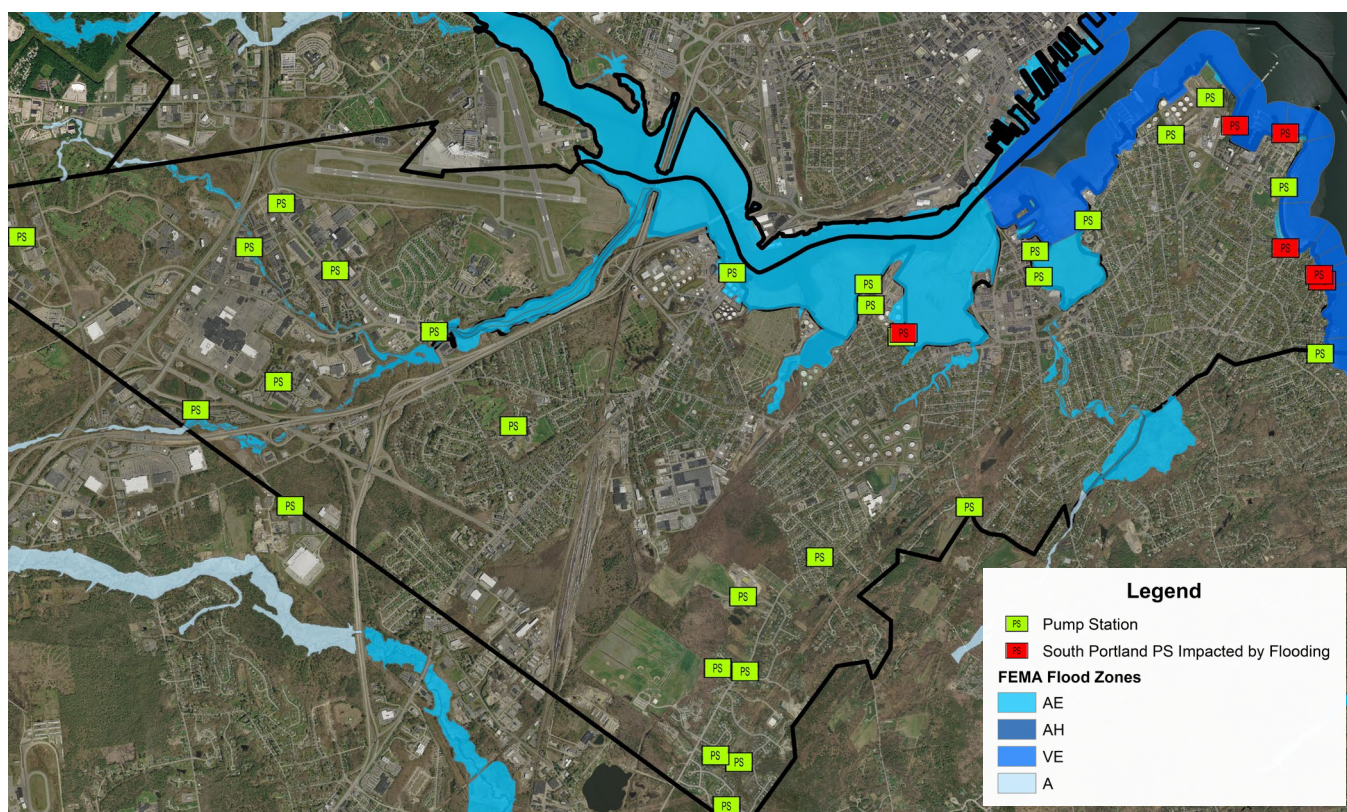


Figure 3.11. Pump stations in South Portland that are vulnerable to the 1% annual chance flood. Data from the City of South Portland and FEMA preliminary flood zones (2018).

South Portland Pump Stations Vulnerable to Sea Level Rise

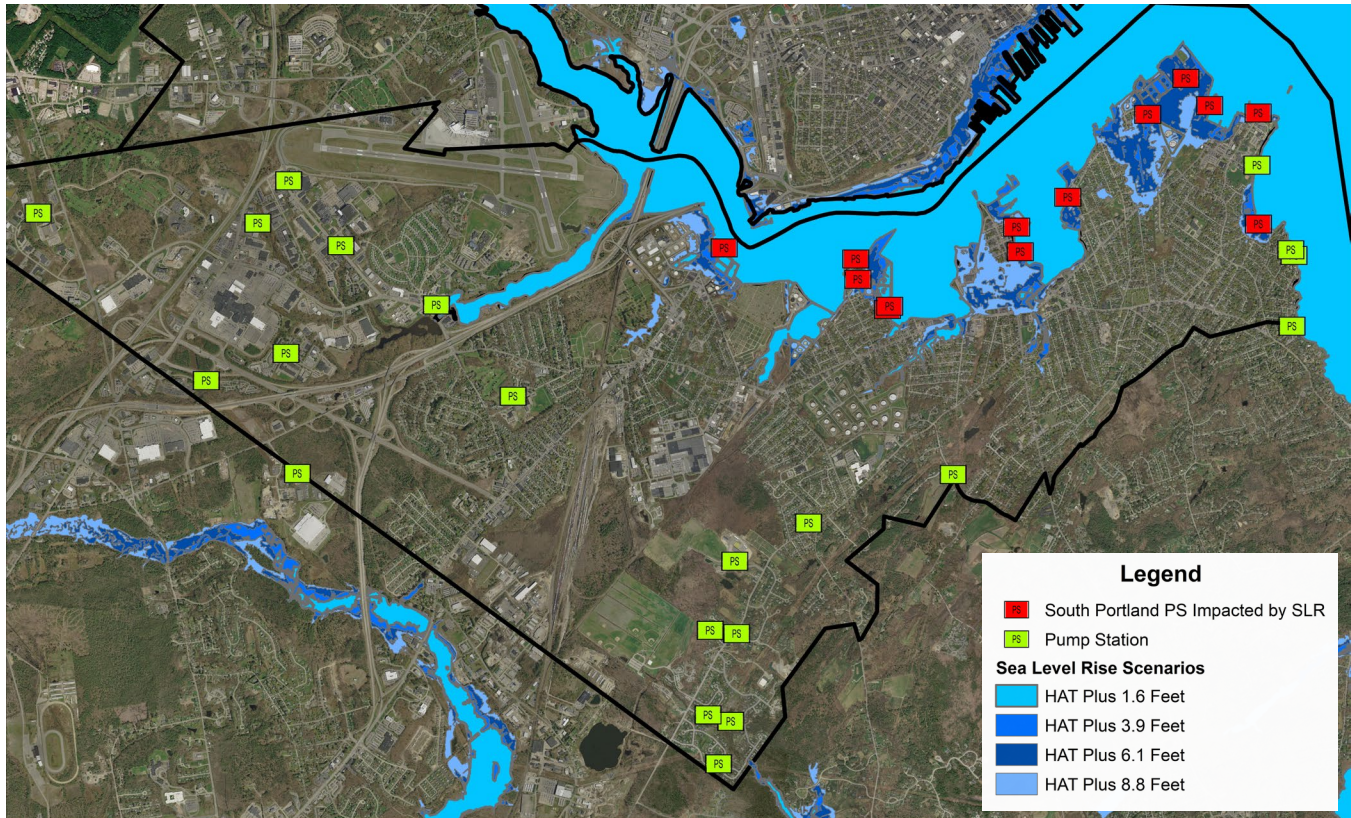


Figure 3.12. Pump stations in South Portland that are vulnerable to sea level rise based on four sea level rise scenarios for 2100. Data from the City of South Portland and Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

South Portland WWTF Flood Vulnerability

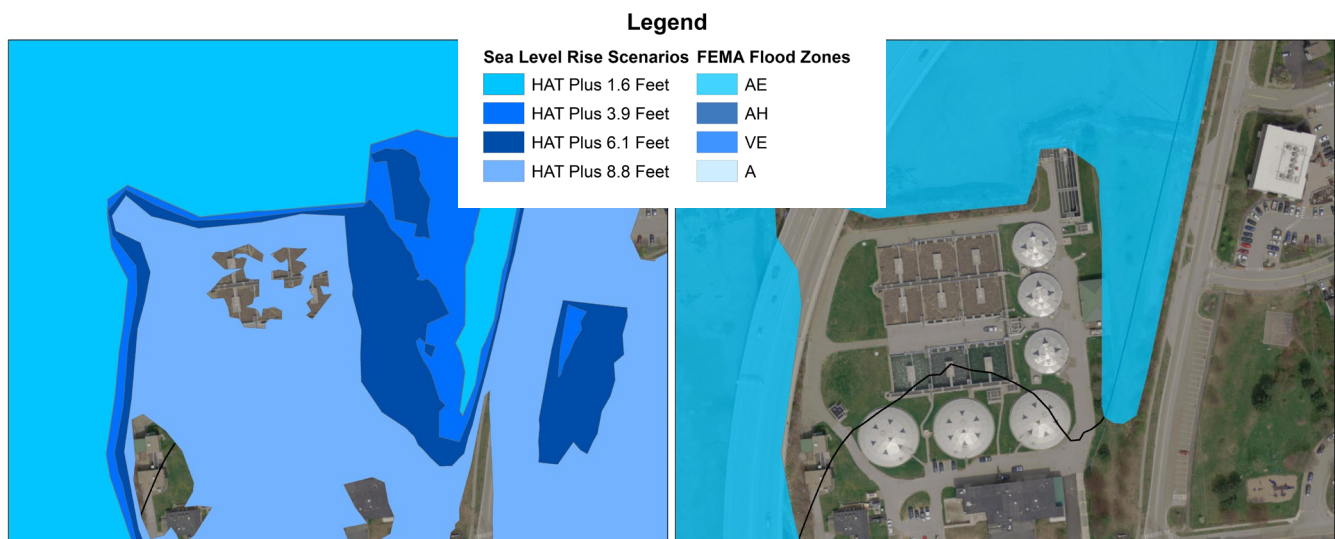


Figure 3.13. Extent of vulnerability of the wastewater treatment facility in South Portland to flooding from four scenarios of sea level rise (left) and the 1% annual chance flood (right). Data from FEMA preliminary flood zones (2018) and Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

B) Wastewater Treatment Facility — The South Portland wastewater treatment plant is currently technically outside the 1% annual chance flood zone; however, the site is projected to be partially or fully inundated by sea level rise by 2100 under an Intermediate-High or High scenario, respectively (**Figure 3.13**). The facility could experience structural damage or failure due to loads from wave action and water inundation, impact from moving debris in a violent flood, or corrosion from salt exposure.

C) Manholes — Approximately 95 stormwater and sewer manholes are exposed to high flood risk based on the 1% annual chance flood. Approximately 28 manholes (less than 1 percent of all manholes in South Portland) are located within the FEMA VE flood zone; 65 manholes (approximately 1 percent) are located within the FEMA AE flood zone; and two manholes are located in the

FEMA A flood zone. Primary areas that are projected to be affected include Ferry Village, Simonton Cove, and Cushing Point.

Only 2 percent of stormwater and sewer manholes in South Portland are vulnerable to 3.9 feet of sea level rise on top of the highest astronomical tide; however, this vulnerability increases to over 10 percent under the HAT + 8.8-ft scenario. Highly impacted areas in South Portland include Knightville, Trout Brook south of Meetinghouse Hill, Cushing Point, and Simonton Cove.

D) Pipe Network — Approximately 21,822 linear feet of pipe in the South Portland sewer/stormwater pipe network are exposed to high flood risk based on the 1% annual chance flood (**Figure 3.14**). Of that total, roughly 4,510 linear feet (less than 1 percent) of the pipe network are in the VE flood zone; 16,310 linear feet are in

South Portland Pipe Network Vulnerability to the 1% Annual Chance Flood

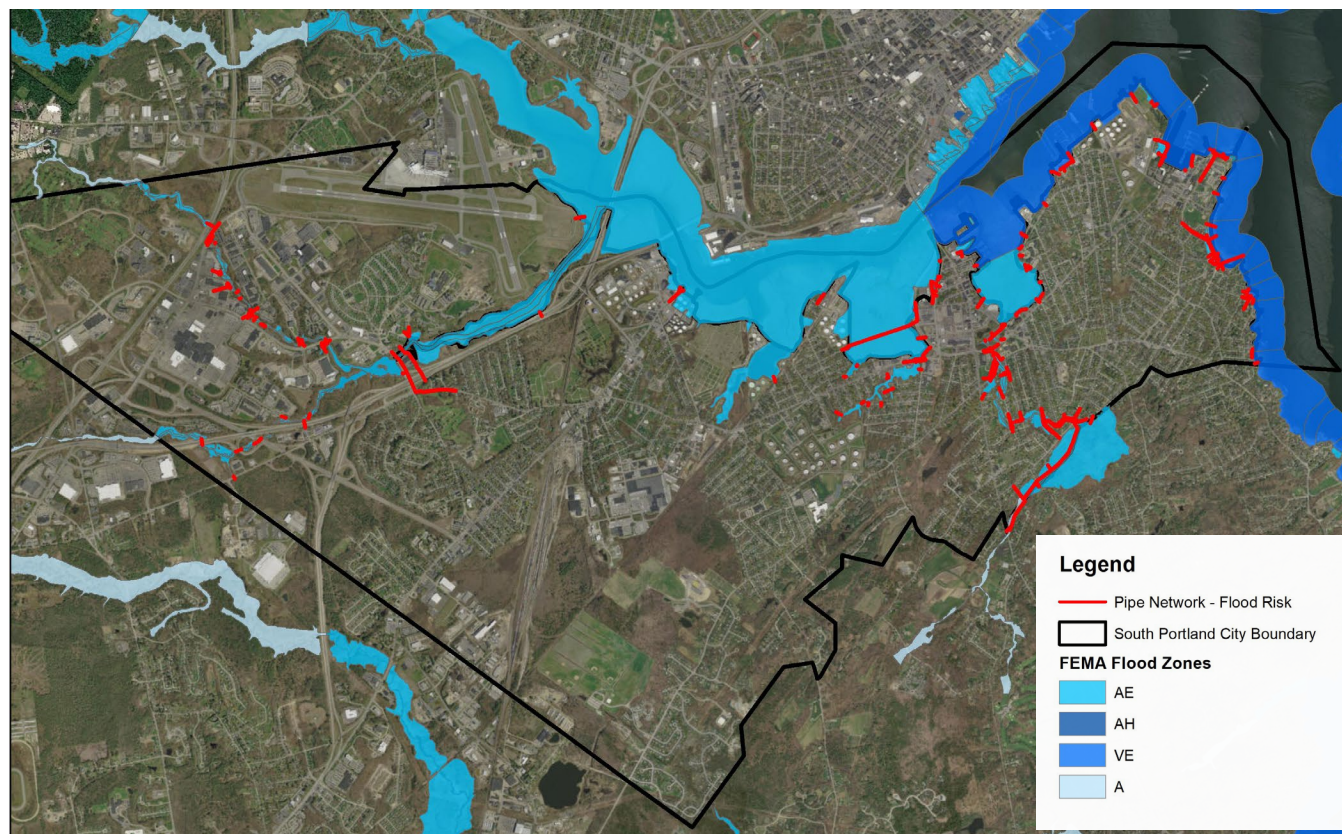


Figure 3.14. Pipe network segments in South Portland that are vulnerable to the 1% annual chance flood. Data from the City of South Portland and FEMA preliminary flood zones (2018).

the AE flood zone (approximately 3 percent of the pipe network); and roughly 1,002 linear feet are in the A flood zone (less than 1 percent of the pipe network). Areas of vulnerable pipe network are primarily along the coast and Fore River shoreline, Long Creek, and Trout Brook.

At a sea level rise scenario of HAT + 3.9 feet, approximately 4 percent of the overall South Portland pipe network will be vulnerable to inundation. The high-risk areas include Knightville, Ferry Village, Cushing Point, and Simonton Cove. In addition to the inundation of pipe networks from flooding, pipes will be increasingly subject to structural damage by more intense freeze-thaw cycles and increased groundwater salinity.

E) Combined Sewer Overflows (CSOs) — Based on the flood risk assessment, none of the six existing CSO

locations in South Portland are predicted to be impacted by flooding from the 1% annual chance flood. Of the six CSO sites, one is vulnerable to sea level rise based on the HAT + 3.9 feet scenario. This impacted CSO site is located in Ferry Village. In total, there could be four active CSO sites impacted under 8.8 feet of sea level rise on top of the highest astronomical tide. See **Figure 3.15** for locations of the four impacted CSOs.

High Priority Areas

Through this evaluation, the areas included in **Figure 3.16** were identified as high priority vulnerable areas. **Table 3.8** summarizes areas of Portland and South Portland's wastewater system that will be impacted by the 1% annual chance flood and/or the sea level rise scenarios that were discussed in this section. These areas are labeled in **Figure 3.16**.

South Portland CSO Sites Vulnerable to Sea Level Rise

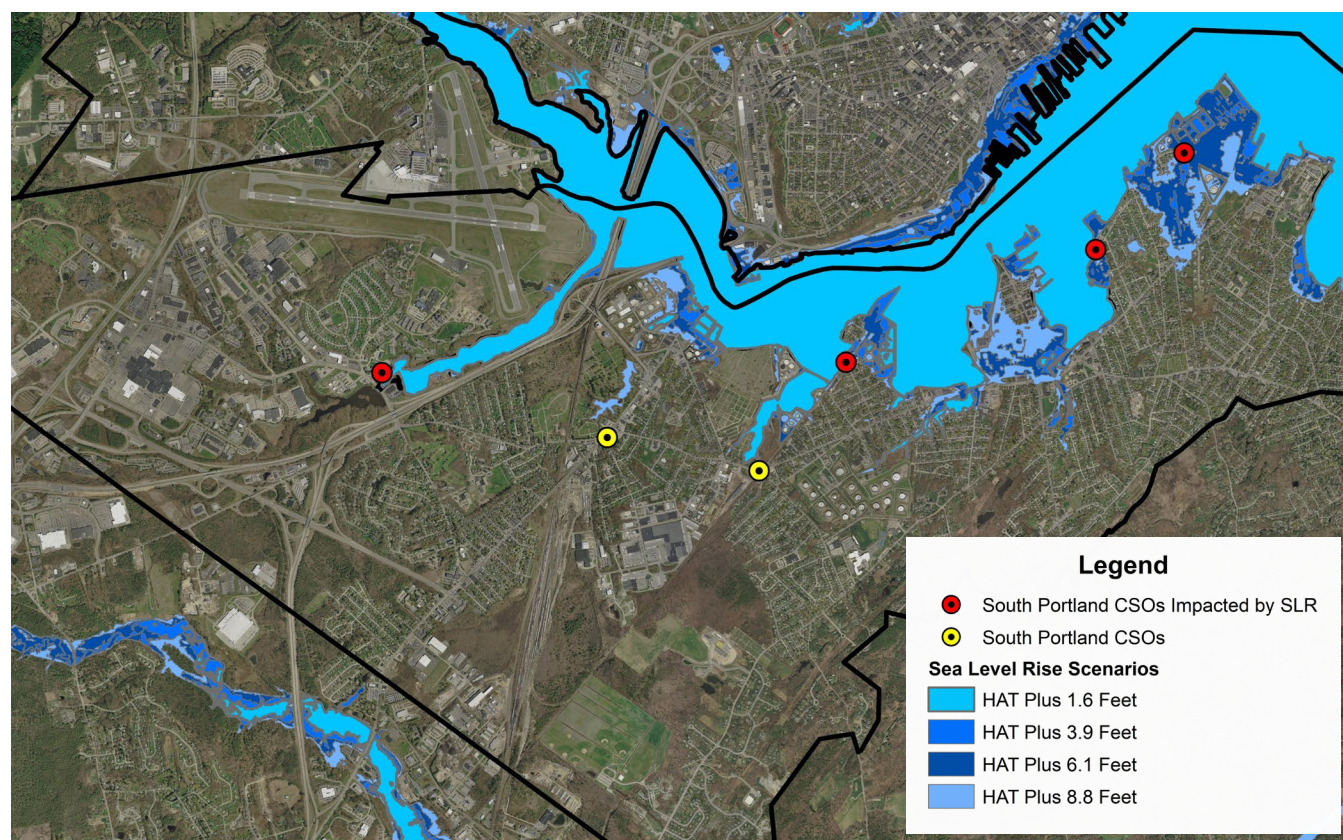


Figure 3.15. CSO locations in South Portland that are vulnerable to flooding based on four sea level rise scenarios. Data from the City of South Portland and Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

Wastewater Infrastructure Impact Summary by Area

Area	City	Pump Station(s)	CSO Site(s)	Manholes	Pipe Network	WWTF
Back Cove	Portland	X	X	X	X	
Bayside	Portland	X	X	X	X	
East End	Portland	X			X	
Riverton	Portland	X				
Peaks Island	Portland	X				
Commercial Street	Portland		X	X	X	
Stroudwater	Portland	X		X		
Simonton Cove	South Portland	X		X	X	
Ferry Village	South Portland	X	X		X	
Cushing Point	South Portland	X		X	X	
Knightville	South Portland	X		X	X	X
Turner Island	South Portland	X	X	X		

Table 3.8. Summary of affected infrastructure in high priority areas in Portland and South Portland that have large numbers of stormwater and sewer infrastructure assets vulnerable to the 1% annual chance flood and/or sea level rise.

Reference Map for High Priority Areas in Table 3.8

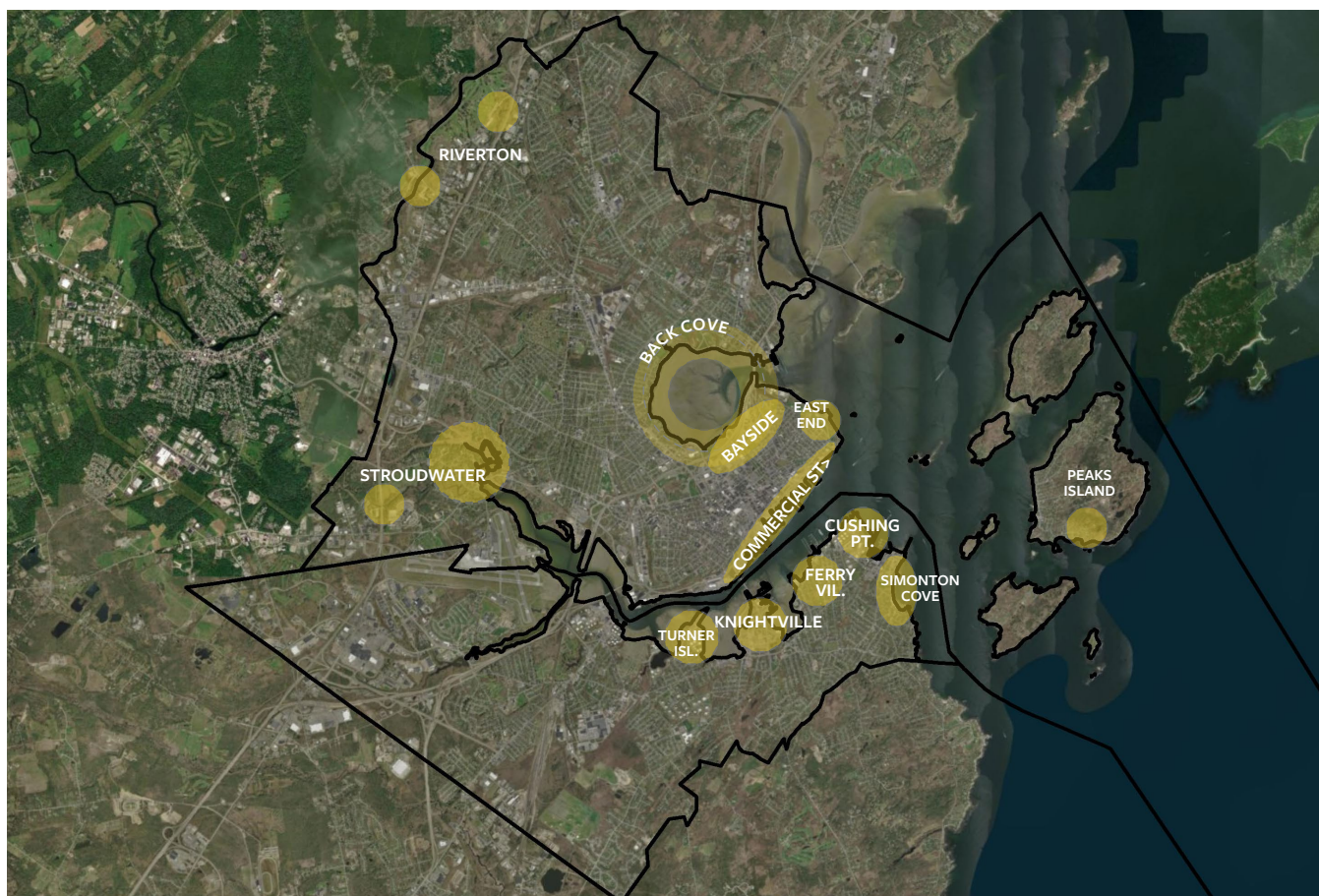


Figure 3.16. High priority areas in Portland and South Portland that have large numbers of stormwater and sewer infrastructure assets vulnerable to the 1% annual chance flood and/or sea level rise.

3.3 Transportation Infrastructure

Portland and South Portland are fortunate to have a multi-modal transportation network serving residents, businesses, visitors, and key economic sectors. The various transportation systems are designed to consider some weather interruptions; however, climate change is expected to increase the frequency, intensity, and duration of the extreme weather events, while also causing long-lasting change to the cities through sea level rise. Transportation infrastructure may face acute or chronic damage, disruption, or delay, or complete long-term loss of capacity depending on location. Adaptation will be necessary to ensure the ongoing reliability, safety, and efficiency of the local and regional transportation system. Major transportation assets in the two communities include:

Roads — Interstate highways I-95 and I-295; US Routes 1 and 302; State and local roadway networks

Air — Portland International Jetport (passenger and freight)

Rail — Pan Am Railways, St. Lawrence and Atlantic Railroad Co. (freight rail); Turner Island LLC (freight terminal and switching); Amtrak Downeaster (passenger rail); Portland Transportation Center (passenger train and bus station)

Bus — Greater Portland Transit District METRO (local bus service); South Portland Bus Service (local bus service); Shuttlebus-Zoom (local bus service); Lakes Region Explorer and Paratransit (local bus service); Concord Coach Lines (regional bus service); Greyhound Bus Lines (regional bus services); Portland Transportation Center (passenger train and bus station); Greyhound Bus Station (passenger bus station); South Portland Bus Transit Hub (passenger bus station)

Marine — Casco Bay Lines (passengers and freight ferry service); Portland OceanTerminal (passenger and freight ferry terminal); Ocean Gateway Terminal (international ferry and cruise ship terminal); International Marine Terminal (international marine freight terminal); Merrill Marine Terminal (private marine freight terminal); Many private petroleum storage and distribution terminals

Bike and Pedestrian — Networks of bike lanes, shared use pathways, neighborhood byways, sidewalks, and trails

INTERSTATES AND ROADWAYS

Activity in Portland and South Portland relies on extensive road networks, including interstates, arterials, collectors, and local roads. Arterials are high-capacity roads that transport traffic between major destinations and to interstates or highways. A collector road connects traffic between local and arterial roads. Local roads are the most common; they have high accessibility to abutting land uses and connect to collector and arterial roads. Obstructions or closures will create different types of vulnerabilities depending on the road type. Closures or obstructions of arterial roads could be considered more acute—they would quickly affect a larger number of people and make evacuation more difficult during emergency situations. Impacts to collector and local roads, however, would affect the ability of drivers to access specific areas, business, and services.

Assessment of Highway Corridor Priority Areas

As part of the Maine DOT highway asset management program, highway assets are categorized into six levels known as Highway Corridor Priorities (HCP), used for monitoring roadway conditions and prioritizing investment. Highway Corridor Priorities were set by Maine DOT based on several factors including the function of the roadway and its contribution to the overall economic health of the state. This assessment looks at the flood vulnerability of HCP categories 1 through 4 as a means for understanding the climate vulnerability of the major road networks in Portland and South Portland. Categories 1 through 4 are defined as:

- Priority 1 – Includes the Maine Turnpike, interstate system, and key principal arterials
- Priority 2 – High-value arterials
- Priority 3 – Remaining arterials and significant major collector highways
- Priority 4 – Remaining major collector highways, and minor collector highways

As outlined in the Introduction of the Infrastructure Section, two sets of flood risk data were used in this analysis, which provide complementary assessments of flood risk. The first investigation looks at FEMA Flood Rate Insurances Maps (FIRMs), which depict areas that are vulnerable to inundation by the 1% annual chance flood. (See page 35 for descriptions of the flood zone designations.) The second investigation uses geospatial data from the Maine Geological Survey, which shows relative levels of inundation from sea level rise or storm surge for the Maine coast for the year 2100 under six scenarios. The specific scenarios selected for this analysis include 1.6, 3.9, 6.1 and 8.8 feet of sea level rise on top of the highest astronomical tide (HAT), which correspond to the Low-Intermediate, Intermediate, Intermediate-High and High scenarios for 2100, respectively. By 2050, we would expect to already see 1.48 feet of relative

sea level rise under the Intermediate scenario, or 3.38 feet under the Extreme scenario specifically for the Greater Portland area. (See page 35 for further details.) The Maine DOT data for High Corridor Priorities were updated as of July 2019.

Portland — HCP roadways in the vicinity of Back Cove that may be impacted by the current 1% annual chance flood include Route 1 at Martin's Point (priority 3), and Baxter Boulevard on the north side of Back Cove (priority 4) (**Figure 3.17**). Although I-295 crosses an AE flood zone north of Back Cove and a VE flood zone at Tukey's bridge, the FEMA maps suggest that the roads are elevated enough in both locations so as not to be affected. Other HCP roadways in Portland that may be affected by the 1% annual chance flood include Congress Street (priority 2) where the route crosses the Fore

Highway Corridor Priority Roadways and FEMA Flood Zones – Back Cove



Figure 3.17. Highway Corridor Priority (HCP) areas in Portland's Back Cove overlaid with FEMA flood zones for the 1% annual chance flood. HCP roadways in the Back Cove vicinity that may be impacted include Route 1 at Martin's Point (priority 3), and Baxter Boulevard on the north side of Back Cove (priority 4). Data from Maine DOT and FEMA preliminary flood zones (2018).

River, as well as potentially a couple small pinch points on Brighton Ave (priority 2) and Capisic Street (priority 4) where the routes cross the Capisic Brook and Capisic Pond, respectively. However, culverts in both locations may prove sufficient.

With sea level rise up to 3.9 feet above the highest astronomical tide (HAT), the highest priority roads in Portland that are expected to be affected include I-295 exits 7 and 6A (priority 1); Franklin Street, State Street, High Street, Commercial Street, and Congress Street where it crosses the Fore River (priority 2); Marginal Way, Preble Street, and Elm Street (priority 3); and Baxter Boulevard and Forest Ave (priority 4). A number of additional priority roads would be potentially inundated

if sea levels reach 8.8 feet above the astronomical high tide—most critically I-295 (priority 1), as well as Fore River Parkway and Washington Ave (priority 2) (**Figures 3.18 and 3.19**). Interstate and high-value arterials tend to accumulate higher volumes of traffic on a daily basis and provide more direct routes for drivers, which makes closures on these routes most problematic.

South Portland — Based on the information available in the assessment, no High Corridor Priority roadways in South Portland are vulnerable to the 1% annual chance flood. HCP roadways also show very little vulnerability to inundation up through 3.9 feet of sea level rise on top of the astronomical high tide. Broadway where the route crosses Anthoine Creek and the Mill River (priority 2)

Highway Corridor Priority Areas Vulnerable to Sea Level Rise – Back Cove



Figure 3.18. Highway Corridor Priority (HCP) areas in Portland's Back Cove area that are vulnerable to flooding based on four sea level rise scenarios. Data from Maine DOT (HCP areas) and Maine Geological Survey (sea level rise inundation).

Highway Corridor Priority Areas Vulnerable to Sea Level Rise – Commercial Street



Figure 3.19. Highway Corridor Priority (HCP) areas in Portland's Commercial Street area that are vulnerable to flooding based on four sea level rise scenarios. Data from Maine DOT and Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

Portland Highway Corridor Priority Roadways Impacted by Sea Level Rise

Road Segment	Ranking	Area	Note
I-295	Priority 1	Back Cove	I-295 is a major highway corridor through the City of Portland and heavily traveled. The roadway provides access to and from the City of Portland.
Franklin Street	Priority 2	Back Cove	Franklin Street connects I-295 and the waterfront, and provides access to downtown.
Washington Ave	Priority 2	Back Cove	Washington Ave provides access to the northwest side of the city (East and North Deering), and connections between I-295 and areas to access I-95.
State Street / High Street / Forest Ave	Priority 2	Back Cove	The State Street / High Street / Forest Ave intersection provides access to and from I-295 and to the waterfront through downtown Portland.
Marginal Way	Priority 3	Back Cove	Marginal Way parallels I-295, provides access to a number of the highway on-ramps, as well as area businesses.
Preble Street / Elm Street	Priority 3	Back Cove	Preble Street / Elm Street provide connections between Back Cove / Baxter Boulevard and downtown Portland.
Baxter Boulevard	Priority 4	Back Cove	Baxter Boulevard is a frequently used scenic roadway that provides access between the downtown peninsula and western portions of the city.
Commercial Street	Priority 2	Waterfront	Commercial Street is the main roadway serving the waterfront.
Fore River Parkway	Priority 2	Waterfront	Fore River Parkway provides direct access to the downtown area of the city as well as the Casco Bay Bridge which serves South Portland.

Table 3.9. Maine Department of Transportation Highway Corridor Priority (HCP) Roadways (priority categories 1-4) in the City of Portland that are projected to be impacted by sea level rise based on four sea level rise scenarios for 2100.

Highway Corridor Priority Areas Vulnerable to Sea Level Rise – Knightville and Ferry Village

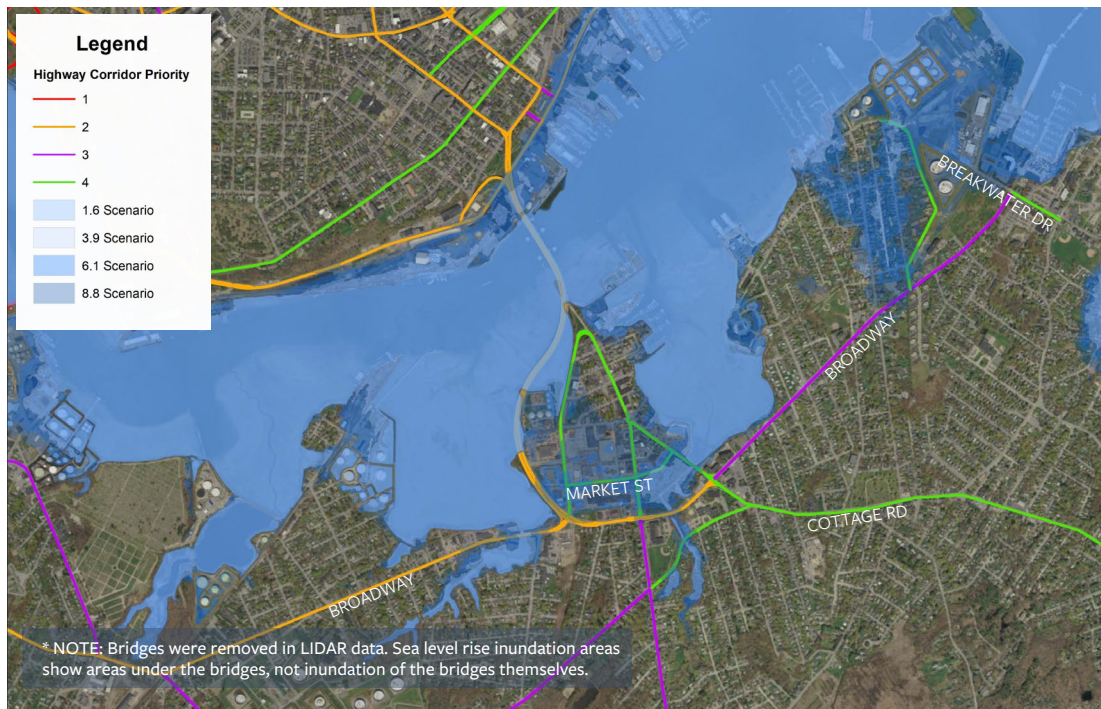


Figure 3.20. Highway Corridor Priority (HCP) areas in South Portland’s Knightville and Ferry Village neighborhoods that are vulnerable to flooding based on four sea level rise scenarios. Data from Maine DOT and Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

South Portland Highway Corridor Priority Roadways Impacted by Sea Level Rise

Road Segment	Ranking	Area	Note
Casco Bay Bridge	Priority 2	Knightville	The impacts will be to the roadway from Casco Bay Bridge as it turns into Broadway, or the approach to the bridge, not to the actual Casco Bay Bridge roadway itself.
Broadway	Priority 2	Knightville	Broadway in Knightville is a heavily traveled roadway that provides access to Casco Bay Bridge, the Mill Creek shopping area and the wastewater treatment plant.
Broadway	Priority 3	Ferry Village	Broadway in Ferry Village provides access to residential, recreation, marina, commercial, retail, restaurant, and industrial uses.
Waterman Drive	Priority 4	Knightville	Waterman Drive provides access to the wastewater treatment plant, Thomas Knight Park, and South Port Marine. This area of the city also has residential, commercial, restaurant, and retail uses.
Ocean Street	Priority 4	Knightville	Ocean Street provides access to residential, commercial, and retail uses.
Hinkley Drive & Market Street	Priority 4	Knightville	Hinkley Drive / Market Street provide access between Cottage Road and Waterman Drive through the Mill Creek shopping area.
Cottage Road	Priority 4	Knightville	Cottage Road provides access to the Mill Creek shopping area and connector roads to the wastewater treatment plant.
Highland Avenue	Priority 4	Knightville	Highland Avenue provides a connection to and from South Portland to roadways leading to Cape Elizabeth and residential neighborhoods in South Portland.
Henley Street	Priority 4	Ferry Village	Henley Street provides local access to the Portland Pipeline and Gulf Oil terminals.
Preble Street	Priority 4	Ferry Village	Preble Street provides local access to the Portland Pipeline and Gulf Oil terminals.

Table 3.10. Maine Department of Transportation Highway Corridor Priority (HCP) Roadways (priority categories 1-4) in the City of South Portland that are projected to be impacted by sea level rise based on four sea level rise scenarios for 2100.

show potential vulnerable pinch points. With sea level rise up to 8.8 feet on top of the highest astronomical tide (HAT), affected HCP roadways in South Portland include Broadway near Knightville and at the junction to the Casco Bay Bridge (priority 2); Broadway at Ferry Village (priority 3); as well as Waterman Drive, Ocean Street, Market Street, Cottage Road (in Knightville), and Preble Street (in Ferry Village) (priority 4). This level of inundation cuts off access to the City's wastewater treatment plant (via Waterman Drive) (**Table 3.10**).

Annual Average Daily Traffic

Further evaluation of roadway vulnerability for Portland and South Portland was completed through the review of annual average daily traffic (AADT) data collected by Maine DOT. AADT is the accumulation of daily traffic volume measurements over the course a year, then divided by 365 to calculate an average per day. The use of AADT data is a best practice for determining the volume of traffic a road experiences and how it should be planned for, designed, or maintained.

This assessment was completed to understand which high-volume roadways are vulnerable to flooding. There is no specific threshold by which roadways are categorized as either low-volume or high-volume; this cutoff varies state-to-state. Based on the AADT data for Portland and South Portland, it was determined that any road with an AADT equal to or greater than 5,000 would be assessed for flood risk to determine high-volume roadways of concern. AADT data is based on road

High-Volume Roadways Vulnerable to the 1% Annual Chance Flood in Portland

Road Type	Miles Impacted	% of Total Miles (AADT >5000)
Interstate	2.11	5.6%
Major Collector	0.95	2.5%
Minor Arterial	0.30	0.8%
Local	0.0	0.0
Other	0.33	0.9%

Table 3.11. Extent of high-volume roadways (annual average daily traffic greater than 5,000) in FEMA A, AE, and VE flood zones in Portland. All zones represent vulnerability to the 1% annual chance flood.

segments; therefore, the maps show segments in which at least a portion of the segment is impacted by flooding.

As used in the analysis of HCP roadways, flood risk was assessed using both the preliminary FEMA flood zone data (2018) for the 1% annual chance flood and Maine Geological Survey data (2018) for four sea level rise scenarios for 2100 (Low-Intermediate, Intermediate, Intermediate-High and High scenarios).

High-Volume Roadways Vulnerable to Inundation from Sea Level Rise in Portland

Road Type	Miles Impacted	% of Total Miles (AADT >5000)
HAT + 1.6 Feet		
Interstate	0.0	0.0
Major Collector	0.0	0.0
Minor Arterial	0.1	0.3%
Local	0.1	0.3%
Other	0.0	0.0
HAT + 3.9 Feet		
Interstate	0.3	0.7%
Major Collector	0.1	0.2%
Minor Arterial	0.1	0.3%
Local	0.1	0.3%
Other	0.0	0.0
HAT + 6.1 Feet		
Interstate	2.8	7.3%
Major Collector	0.9	2.3%
Minor Arterial	1.7	4.4%
Local	0.2	0.5%
Other	0.1	0.3%
HAT + 8.8 Feet		
Interstate	3.2	8.5%
Major Collector	1.0	2.8%
Minor Arterial	2.1	5.5%
Local	0.2	0.5%
Other	0.1	0.4%

Table 3.12. Extent of high-volume roadways (annual average daily traffic greater than 5,000) in Portland that are vulnerable to sea level rise based on four sea level rise scenarios on top of the astronomical high tide (HAT).

Portland — Overall, there are five segments of Interstate and two segments of Major Collector roadways in coastal Portland, and several inland road segments, where some of the roadway is located in FEMA flood zones (**Figure 3.21**). The impacted roadways surrounding Back Cove are considered high-risk areas due to high traffic volumes. **Table 3.11** details the percentage of the heavily traveled roadways in Portland that are in any designated flood zone along with estimated AADT.

Sea level rise will further amplify the flooding experienced during the 1% annual chance storm (**Figure 3.22**). A significant number of road segments are projected to be inundated at the highest astronomical tide under 1.6 feet of sea level rise, a level that is possible for 2050. Results for each sea level rise scenario are presented in **Table 3.12**. Overall, areas of most concern include Back Cove, Bayside, and Commercial Street.

South Portland — The City of South Portland has minimal flooding impacts to high-volume roadways within the city boundary under the 1% annual chance flood (**Table 3.13** and **Figure 3.23**). The areas affected by flooding are somewhat dispersed, but primarily located along Trout Brook and Anthoine Creek.

Sea level rise will create further flood impacts on heavily traveled roadways in South Portland. There are six primary focus areas: the I-295 bridge crossing, Veterans Memorial Bridge, Pleasantdale, Knightville, Ferry Village, and Simonton Cove/Willard's Beach area (**Figure 3.24**).

High-Volume Roadways Vulnerable to the 1% Annual Chance Flood in South Portland

Road Type	Miles Impacted	% of Total Miles (AADT >5000)
Interstate	1.34	1.2%
Major Collector	0.33	0.2%
Minor Arterial	0.87	0.2%
Local	0.00	0.0
Other	0.95	0.3%

Table 3.13. Extent of high-volume roadways (annual average daily traffic greater than 5,000) in FEMA A, AE, and VE flood zones in South Portland. All zones represent vulnerability to the 1% annual chance flood.

The areas affected will likely cause bottlenecks and access issues in the roadway system. Roadways affected by the various sea level rise scenarios are presented in **Table 3.14**. No high-volume roadways will be impacted by the 1.6-ft and 3.9-ft sea level rise scenarios.

High-Volume Roadways Vulnerable to Inundation from Sea Level Rise in South Portland

Road Type	Miles Impacted	% of Total Miles (AADT >5000)
HAT + 1.6 Feet		
Interstate	0.0	0.0
Major Collector	0.0	0.0
Minor Arterial	0.0	0.0
Local	0.0	0.0
Other	0.0	0.0
HAT + 3.9 Feet		
Interstate	0.0	0.0
Major Collector	0.0	0.0
Minor Arterial	0.0	0.0
Local	0.0	0.0
Other	0.0	0.0
HAT + 6.1 Feet		
Interstate	0.0	0.0
Major Collector	0.3	1.5%
Minor Arterial	0.2	1.1%
Local	0.0	0.0
Other	0	0.0
HAT + 8.8 Feet		
Interstate	0.0	0.0
Major Collector	0.5	2.1%
Minor Arterial	0.4	1.9%
Local	0.04	0.2%
Other	0.0	0.0

Table 3.14. Extent of high-volume roadways (annual average daily traffic greater than 5,000) in South Portland that are vulnerable to sea level rise based on four sea level rise scenarios on top of the astronomical high tide (HAT).

Portland High-Volume Roadways Vulnerable to the 1% Annual Chance Flood

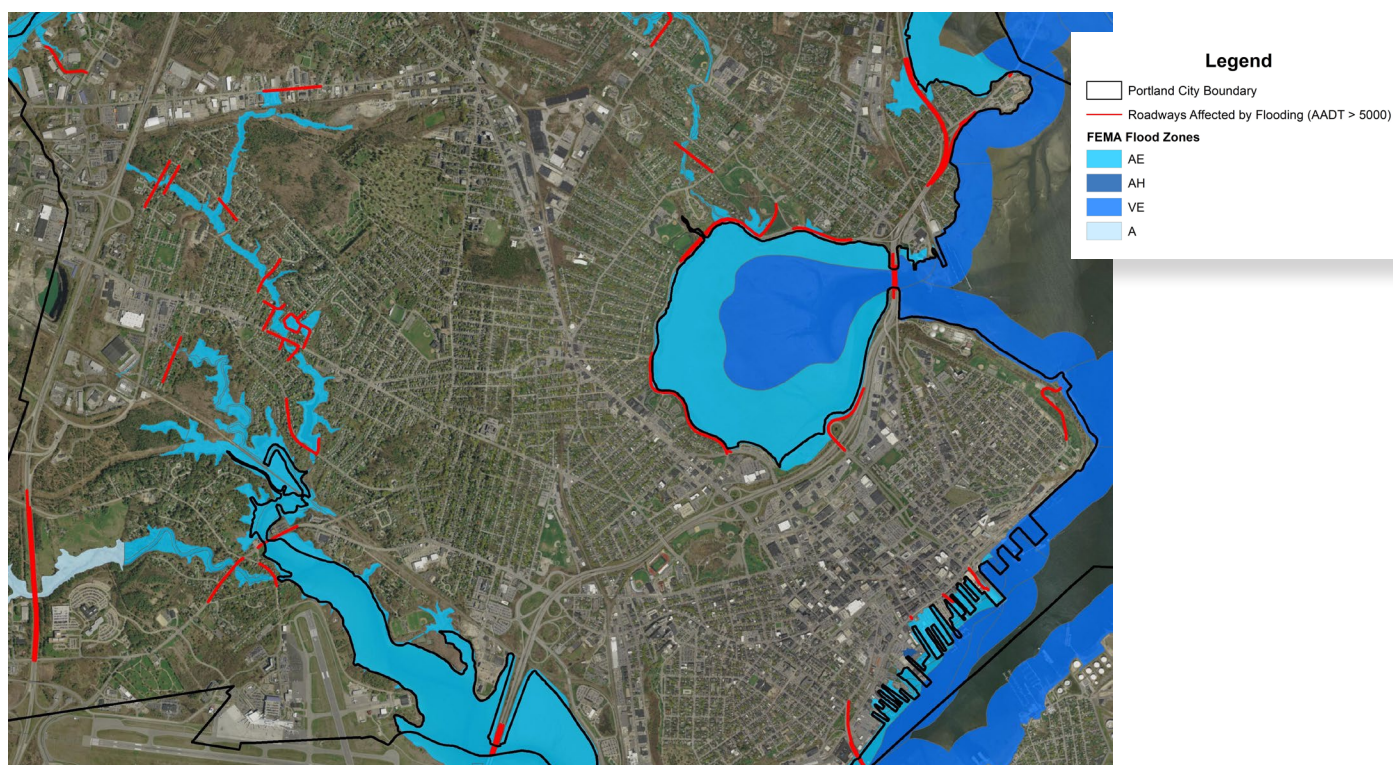


Figure 3.21. High-volume roadways (annual average daily traffic greater than 5,000) in Portland that are vulnerable to flooding from the 1% annual chance flood. Data from Maine DOT and FEMA preliminary flood zones (2018).

Portland High-Volume Roadways Vulnerable to Flooding from Sea Level Rise

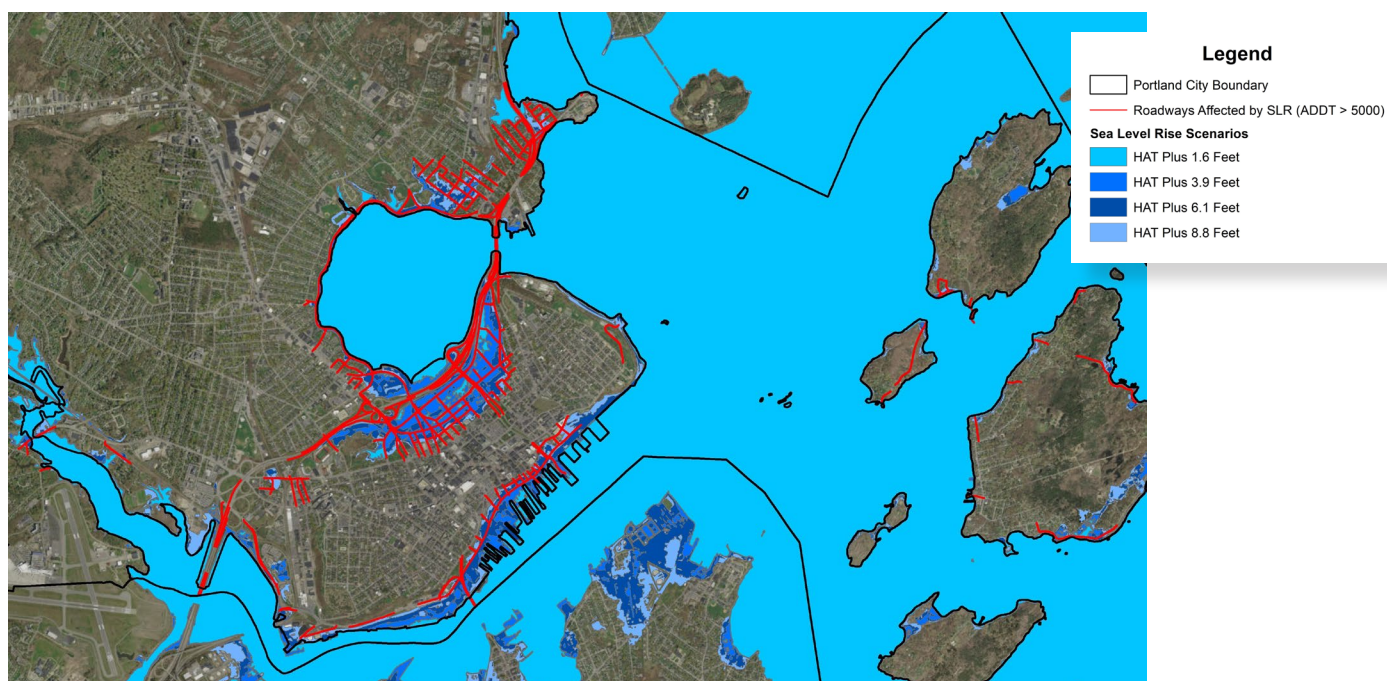


Figure 3.22. High-volume roadways (annual average daily traffic greater than 5,000) in Portland that are vulnerable to flooding based on four sea level rise scenarios. Data from Maine DOT and Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

South Portland High-Volume Roadways Vulnerable to the 1% Annual Chance Flood

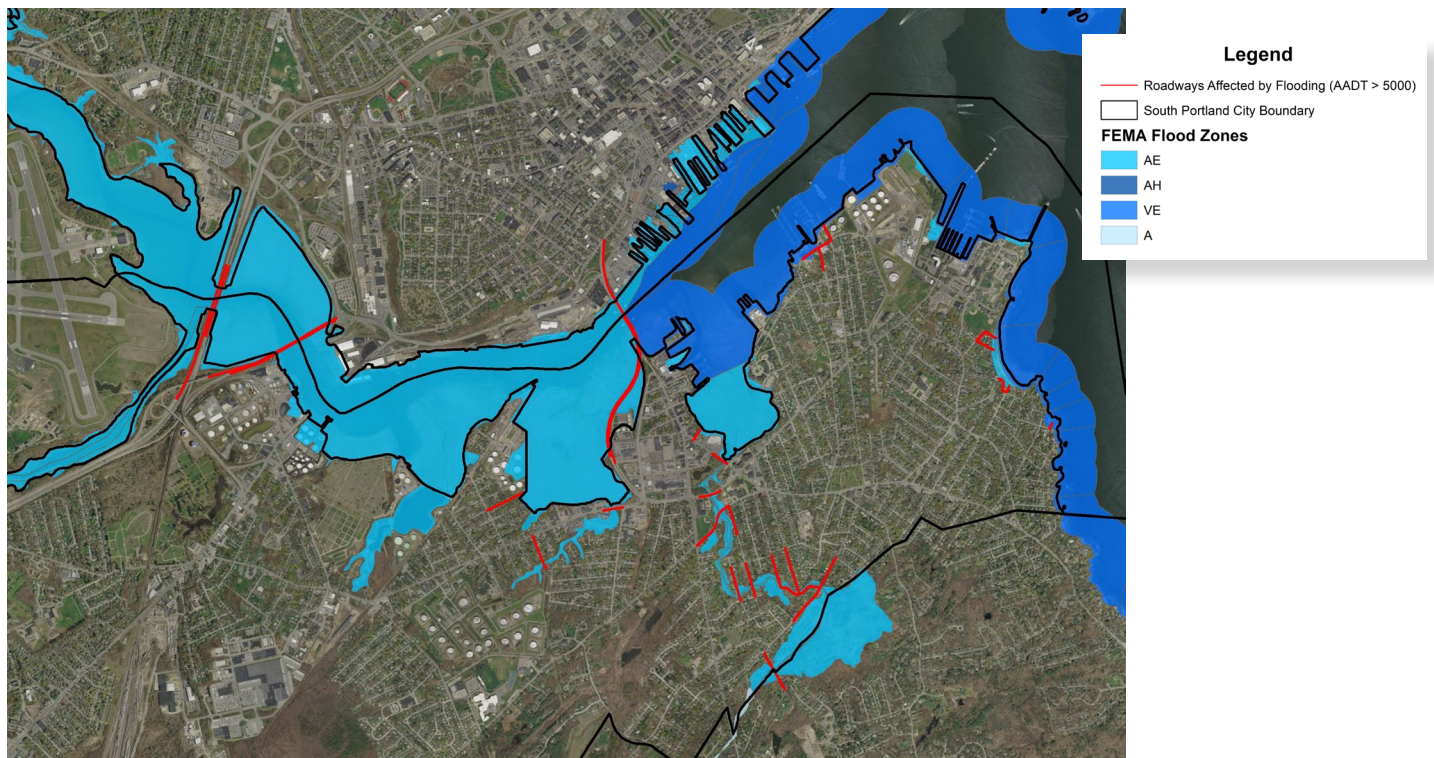


Figure 3.23. High-volume roadways (annual average daily traffic greater than 5,000) in South Portland that are vulnerable to flooding from the 1% annual chance flood. Data from Maine DOT and FEMA preliminary flood zones (2018).

South Portland High-Volume Roadways Vulnerable to Flooding from Sea Level Rise

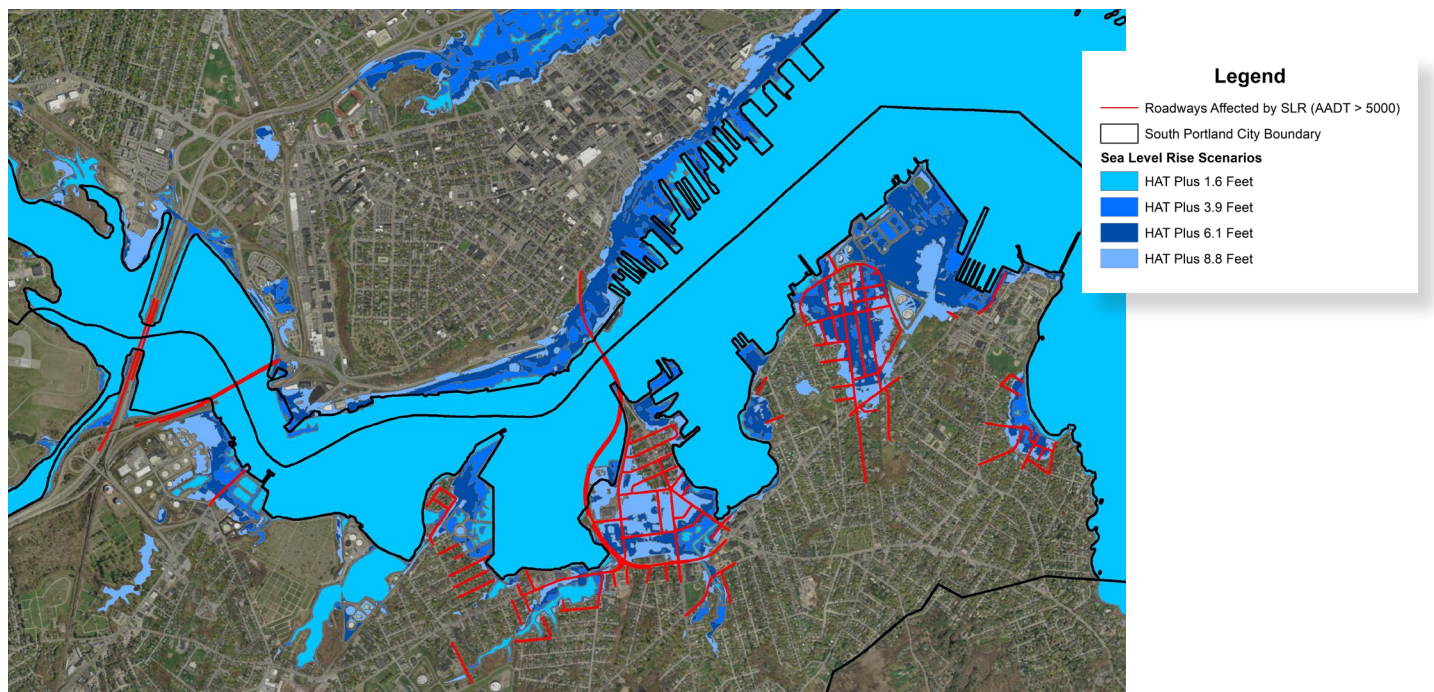


Figure 3.24. High-volume roadways (annual average daily traffic greater than 5,000) in Portland that are vulnerable to flooding based on four sea level rise scenarios. Data from Maine DOT and Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

AIR TRANSPORTATION INFRASTRUCTURE

The Portland International Jetport is a small commercial airport located near the Fore River in Portland and South Portland. The Jetport has two intersecting runways and a passenger terminal, and accommodates shipping goods by air such as freight and mail. Only a portion of the Jetport's property adjacent to the Fore River is located in a FEMA 1% annual chance flood zone (**Figure 3.25**) and sea level rise is not anticipated to have direct impacts on the runways or passenger terminal. The roadway that serves the airport may be impacted near the Stroudwater area portion of Congress Street. Alternate routes, however, would be available. Potential other climate-related impacts to the Jetport may include schedule disruptions or increased turbulence due to severe storm events or wind pattern changes.

BUS TRANSPORTATION INFRASTRUCTURE

The Greater Portland METRO Bus Service and South Portland Bus Service may experience service interruptions during severe storms or a flooding event, depending on bus routes. Regional bus systems that have bus depots in Portland are Concord Coach, which is located at the Portland Transportation Center on Thompson's Point, and Greyhound, which is located at the corner of Congress Street and St. John Street. Neither of these stations are in the FEMA 1% annual chance flood zones or are projected to be impacted by sea level rise. Although stations are "fixed nodes" in a bus system, routes will likely change over time based on demand and other factors, which also means bus networks will have a level of adaptability to adjust their routes to contend with the effects of climate change.

Portland International Jetport and FEMA Flood Zones

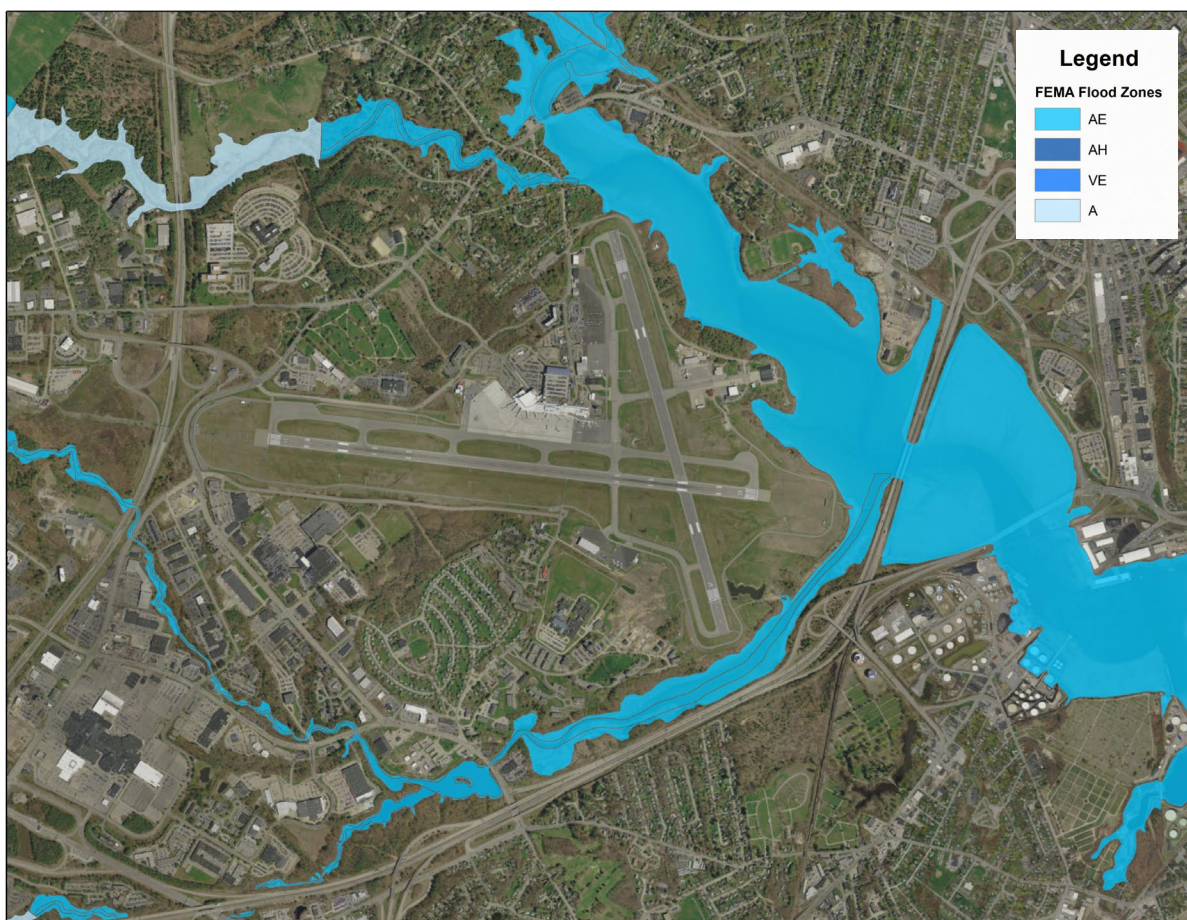


Figure 3.25. Portland International Jetport overlaid with FEMA flood zone data. Neither the passenger terminal nor the runways show vulnerability to the 1% annual chance flood. Data from FEMA preliminary flood zones (2018).

MARINE TRANSPORTATION INFRASTRUCTURE

The Portland Ferry Terminal, Ocean Gateway Terminal, International Marine Terminal, and Merrill Marine Terminal support a mix of passenger and/or freight transit services. The Portland Ferry and Ocean Gateway terminals are located in the FEMA 1% annual chance flood zone and all four terminals are projected to see impacts from sea level rise, which could alter how these services are offered in the future or require relocation or significant upgrades to the docks and terminal buildings.

This marine infrastructure provides a link to land-based infrastructure systems for passengers and the movement of goods. Therefore, without re-engineering these connections across the waterfront, the link to associated parking, trucking, or rail systems would also remain vulnerable. Direct rail connections for moving bulk cargo and container freight are particularly important for the Merrill Marine Terminal (near Veterans Memorial Bridge) and the International Marine Terminal (adjacent to the Casco Bay Bridge). In addition to the marine transportation assets listed above, private shipping terminals in the two cities, and in particular many of the South Portland terminals associated with petroleum storage and transport, are likewise vulnerable to sea level rise and storm surge. (See sections 3.1 *Energy Infrastructure* and 3.5 *Impacts to Sites of Contaminated Soil and Hazardous Waste Containment* for further details.) Extreme weather and flooding may increasingly have the following impacts:

- Interruptions or temporary closures in operations;
- Damage to property (docks, wharves), cargo (containers), or equipment;
- Increased costs from maintenance or repair;
- Need for reconfiguration of operational areas (cargo storage, docks, berths, piers, etc.);
- Increased corrosion or oxidation of equipment, tanks, and pipelines; and
- Spills or accidents that could discharge pollutants into Casco Bay.

For all marine transportation infrastructure, extreme weather may affect shipping conditions, creating greater hazards to navigation, ship, cargo, and crew that could also alter the way these facilities operate. Rising temperatures in the Arctic are likely to make new shipping lanes increasingly navigable, which may create

both new opportunities and risks for shipping transport into the Port of Portland.

RAIL TRANSPORTATION INFRASTRUCTURE

The freight and passenger rail services in the Greater Portland area serve as important transportation connections throughout Maine and New England. Greater Portland has three major freight rail operators:

- Pan Am Railways – This operator runs a line from South Berwick, ME through Portland into Penobscot County and is a primary connection to the rest of the country.
- St. Lawrence & Atlantic Railroad Co. – This operator runs a line from Portland north to Montreal.
- Turners Island LLC – This is a terminal operator connecting Pan Am to the shipping facility in South Portland.

In addition to freight rail lines, the Downeaster passenger rail travels a route covering 143 miles between Boston and Brunswick, ME, and makes round trips from Portland to Boston numerous times per day.

Railways generally are sensitive to extreme weather. Flooding and heavy precipitation can accelerate wear on rail lines and cause erosion resulting in instability around rail tracks. Steel tracks are designed to operate in a narrow range of temperatures, based on the climate where (and when) the track was originally installed. Temperatures significantly above the optimal operating temperature can cause the metal to expand and buckle, creating what are called “sun kinks.” More days of extreme heat increase the chance of rail line failure, and train travel must be reduced or put on hold until temperatures drop to reduce stress on the tracks. Recent studies estimate that these delays will have significant economic repercussions throughout the United States, including for routes in Maine.⁸³

The rail lines serving Portland and South Portland also have portions of their tracks located in FEMA flood zones and areas that may be impacted by sea level rise. These conditions have and will cause infrastructure damage, service disruption, and wide scale ripple effects in rail transit. **Figure 3.26** displays the active rail lines in Portland and South Portland, overlaid with the FEMA flood zones and the sea level rise scenarios.

Active Rail Lines in Portland and South Portland Vulnerable to the 1% Annual Chance Flood (top) and to Sea Level Rise (bottom)

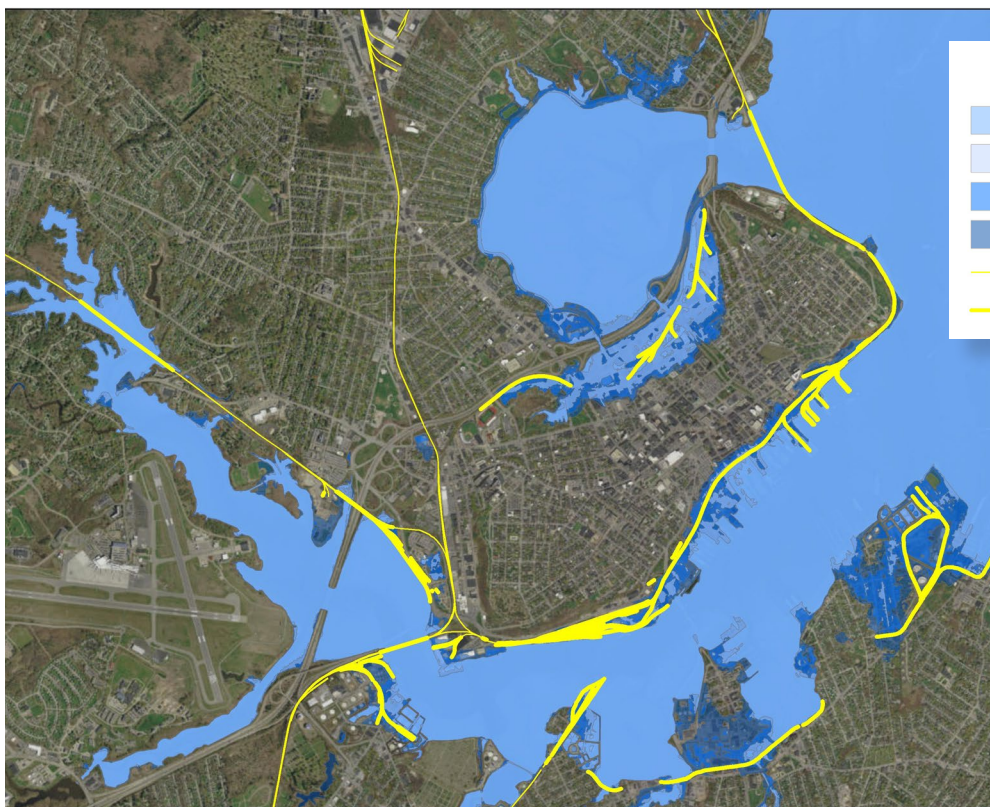


Figure 3.26. Active rail lines in Portland and South Portland that are vulnerable to flooding from the 1% annual chance flood (top), and vulnerable to flooding based on four sea level rise scenarios (bottom). Data from Maine DOT, FEMA preliminary flood zones (2018), and Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

Legend

FEMA Flood Zones

- AE
- AH
- VE
- A
- MaineDOT Active Railroads
- Active Railroads Impacted by FEMA Flood Zones



Legend

- 1.6 Scenario
- 3.9 Scenario
- 6.1 Scenario
- 8.8 Scenario
- MaineDOT Active Railroads
- Active Railroads Impacted by SLR

3.4 Communication Systems Infrastructure

Information and Communications Technology (ICT) systems include cell towers and facilities, fiber lines, telephone networks, data centers, and other related infrastructure. Each of these components have a service life, which has implications for how we think about the vulnerability of these components to climate hazards.

Figure 3.27 indicates that end user and system devices will likely reach their useful service life before we see the more significant impacts from climate change. Depending on the location, data center and transmission infrastructure installed today may be affected by sea level rise and storm surge seen between now and 2050. However, because their service lives are still relatively short, these systems are better able to incrementally adapt. Infrastructure with significantly longer service lives, such as copper or fiber optic cabling or buildings, will need installation and maintenance plans that consider climate hazards projected for the end of the century.

Table 3.15 summarizes the potential impacts climate change will increasingly have on ICT infrastructure. In particular, the DHS Climate Change Resiliency Assessment for Casco Bay highlighted the risk of severe storms with high winds damaging cellular and microwave towers, higher temperatures affecting electronic equipment, and flooding from heavy precipitation, storm surge, and sea level rise drowning network cables or other equipment.⁸⁴

There are two data centers located in Portland, GWI and FirstLight Portland, and none in South Portland. Both data centers are in downtown Portland near Congress Street, making flooding or sea level rise issues less of a concern. While the data centers generally have diverse underground power feeds and backup generators, potential impacts underground could occur from damage to roadways or land subsidence issues. Above ground, impacts could result from heavy precipitation or high wind events depending on what infrastructure is in place. Wireless, radio or satellite services could be impacted by temperature changes.

Service Life of ICT Infrastructure and Climate Change Impacts

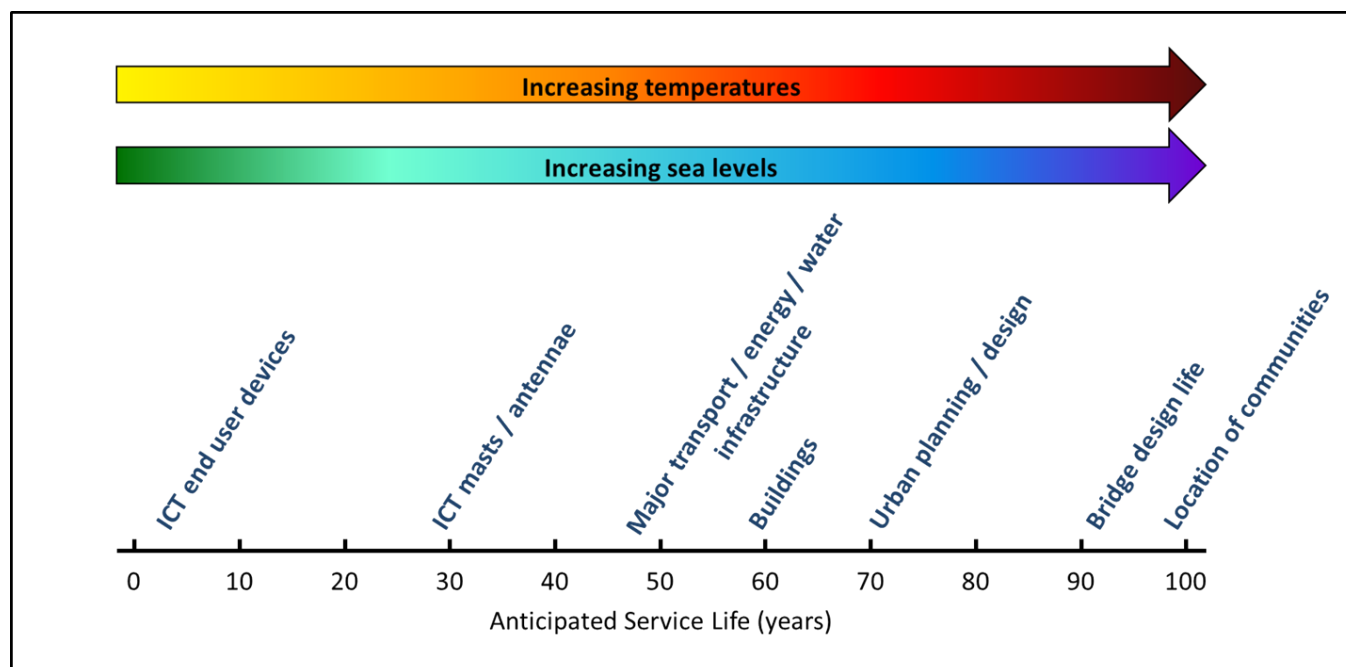


Figure 3.27. Service life of information and communications technology infrastructure with respect to climate change impacts. Source: USAID, Addressing Climate Change Impacts on Infrastructure, (2013).⁹²

Climate Change Impacts on ICT Infrastructure and Services

Climate Change Impact	Transmissions Infrastructure	Wireless Signals	Buildings and Equipment
Temperature Change	Increased heat-related health and safety risks for maintenance workers	Decreased range of wireless signal transmission, resulting in the location/density of wireless masts becoming sub-optimal	- Overheating of data centers, exchanges, base stations, etc. - Increased air-conditioning requirements and costs - Decreased heating requirements and costs
Precipitation Change	- Increased flooding of low-lying/ underground infrastructure and access points, particularly in coastal areas and floodplains - Exposed cables/trunk routes due to erosion or damage of transportation infrastructure	Reduced quality and strength of wireless service due to increased rainfall	Changes in requirements to maintain internal environments of system devices due to changes in humidity
Sea Level Rise and Increased Storm Surge	Increased flooding and salt water corrosion of infrastructure in low-lying/coastal areas	Changes in reference datum for telecommunication and satellite transmission calculations	Closure or reduced access to low-lying coastal buildings due to permanent or temporary flooding
Changes in Extreme Storms and Wind	- Fallen cell towers or telephone poles from high winds or fallen trees - Increased damage to above-ground infrastructure	Minimal Impact	Minimal Impact

Table 3.15. Potential climate change impacts on information and communications technology infrastructure and services. Table adapted from USAID, Addressing Climate Change Impacts on Infrastructure, (2013).⁹³

Any impacts to ICT infrastructure tend to be amplified due to interdependencies between infrastructure systems. ICT networks rely heavily on the power grid, and when there are service interruptions, back-up power is usually provided by petroleum generators. In order to have fuel for the generators, the transportation sector must be functioning. Similarly, infrastructure systems are usually colocated, meaning fiber and telecommunications lines are usually clustered alongside transportation infrastructure. Therefore, a bridge failure may disrupt transportation as well as ICT networks. The colocated telecommunications infrastructure on Pan Am rail bridges is one prime example.⁸⁵

3.5 Impacts to Sites of Contaminated Soil and Hazardous Waste Storage

Historically, the coastal areas of Portland and South Portland served as a home for shipping, fishing, commerce, travel and industrial uses. Portland's industrial revolution from the mid- to late-nineteenth century led to a boom in industries that produced unnatural compounds and introduced them to the environment without restriction—in particular, tanneries, paint factories, shipyards, metal foundries, railroad yards, and a coal-gas plant were the burgeoning Portland-area industrial sites that had the largest environmental impact in that time.⁸⁶

Research commissioned by the Casco Bay Estuary Partnership found that historic development in the Portland and South Portland areas closely reflected the layout of watersheds, as these industries were often reliant on water for processes, power transport, and waste removal (**Figure 3.28**). Although heavy industry is no longer the backbone of the Portland and South Portland economies, the petroleum tanks that were first established in South Portland in the 1920s have continued to make South Portland a regional hub for petroleum transportation. Strict environmental regulations now prevent pollution from the tank farms from entering the bay, and yet the historic and present-day uses of the area have led to a higher concentration of contaminated sites and hazardous material storage facilities in these areas (**Table 3.16**).

Climate hazards pose a significant threat of transporting these materials. Shoreline retreat due to sea level rise could submerge hazardous material sites currently in the floodplain, expose them to wave action, and incorporate new sites into floodplain areas. More frequent extreme weather events could likewise expose these sites to wind and wave action, and higher, salt-containing water tables, which can transport soil-bound pollutants and compromise subsurface containment systems.

Historic Development Areas in 1800s Portland and South Portland



Figure 3.28. Historic development areas in Portland and South Portland that correspond with higher levels of contaminants and hazard storage facilities based on their historic and present uses. Figure source: Hawes, E. (2014).⁹⁴

Historic Uses Associated With Development Areas in Figure 3.28

Development Area	Historic Use
Railroad Triangle	Railroad yards with machine shops, slaughterhouses, soap factory, brickyard.
West Back Cove/Deering	Tanneries, varnish and paint factory, foundry, stoneware factory, brickyard.
North Back Cove/East Deering	Pewter and Britannia metal shops, tanneries, book bindery, can factory, galvanizing and plating shop, possible brickyard.
South Back Cove/Munjoy Hill	Tannery, dump, fill at East Promenade.
South Back Cove/Industrial	Considerable filling of the cove, railroad repair yard, Portland Stove Works, machine shops and metalworking facilities.
Grand Trunk Area	Smelter, cemetery, shipyard, rail yard with machine shop, metal shops, metalworking facilities, major foundry, lead paint factory.
Central Commercial Street	Paint factory, canneries, machine shops and small foundries, galvanizing operations, boat landings.
West Commercial Street	Match factory, sugar refinery, railroad yards, gas works, hat factory, petroleum storage/distribution.
Spring Point	Military bases.
Ferry Village	Shipyard, metalworking facilities.
Knightville/Mill Cove	Dry dock, brewery, and shipyards.
Turner's Island/Pleasantdale	Heavy landfilling, cemetery, rail yard and repair facility.
Rolling Mills/Ligonis	Substantial landfilling, cemeteries, large iron rolling and fabrication facility, acid chemicals plant, kerosene refinery, paint and varnish factory.

Table 3.16. Historic uses associated with development areas in Figure 3.28. Table adapted from Hawes, E. (1994).⁹⁵

CURRENT SITES OF CONTAMINATED SOIL AND HAZARDOUS WASTE STORAGE

Today, the Maine Department of Environmental Protection (DEP) tracks data associated with water quality and potential and actual sources of contamination to groundwater in Maine. The data is referred to as the Environmental and Geographic Analysis Database (EGAD).⁸⁷ This database also includes biological and surface water sampling sites. DEP and staff from the Bureau of Remediation and Waste Management and the Bureau of Water Quality use this information to assess trends in regional surface and groundwater quality and quantity. The EGAD data was used for this vulnerability assessment to identify hazardous waste sites in Portland

and South Portland that might be of particular concern when considered with climate hazards either for the type of contamination, their location, or both. **Table 3.17** indicates the different types of sites that are included within the EGAD data and how those sites are defined by DEP.

The site types in **Table 3.17** relevant to Portland and South Portland can be grouped into two categories:

1. Sites of confirmed or suspected soil contamination, and
2. Hazardous material storage areas.

EGAD Site Type Definitions

Site Type	Definition
Large Bulk Fuel Storage/ Distribution Facility	A group of large above-ground storage tanks (ASTs) usually used to store petroleum products, (i.e., marine terminals, petroleum distribution facilities), with a total facility volume greater than 1,320 gallons.
Leaking Above-ground Storage Tank	(LAST). A container, 90% or more of which is above the ground, which is used to hold oil and other petroleum derived products. It is considered to be leaking if there is some evidence that it has released some of its contents to the environment.
Leaking Underground Storage Tank	(LUST). A container, 10% or more of which is beneath the surface of the ground, which is used to hold oil and other petroleum derived products. It is considered to be leaking if there is some evidence that it has released some of its contents to the environment.
RCRA Large Quantity Generator	A Resource Conservation and Recovery Act (RCRA) Fully Regulated Generator that generates more than 1,000 kilograms (2,205 lbs) of hazardous waste per month. Hazardous waste cannot be stored more than 90 days from date of generation.
RCRA Medium Quantity Generator	A Resource Conservation and Recovery Act (RCRA) generator that generates between 100 and 1,000 kilograms (220-2,205 lbs) of hazardous waste per month, either on average per month or exceeding 100 kg in any one month.
RCRA Small Quantity Generator	A Resource Conservation and Recovery Act (RCRA) generator that generates less than 100 kilograms (220 lbs) of hazardous waste per month AND accumulates no more than 55 gallons (1 drum; ~208 kg) of hazardous waste per month.
Sand/Salt Storage	An area at which salt, or sand-and-salt, are stored in preparation for road and highway deicing.
Sanitary & Industrial WWTF	A wastewater treatment facility (WWTF) used for treating sanitary or industrial wastewater. This may include spray irrigation sites, aerated lagoons, stabilization ponds, polishing ponds, sand filters, and other similar structures used for that purpose.
Surface Spill	A site where oil has been released onto the ground, not caused by a leak from a storage tank. Common examples include heating oil and gasoline tank overfills, tanker truck accidents, and releases from gasoline tanks mounted on vehicles.
Uncontrolled Site, All Other	An uncontrolled hazardous substance site. A location at which hazardous substances came to be located, where the site poses a threat or hazard to any person or the natural environment and requires action to abate.

Table 3.17. Environmental and Geographic Analysis Database (EGAD) site type definitions. Table adapted from Maine Department of Environmental Protection (2019).⁹⁶

Each of these site types is vulnerable in different ways due to climate hazards such as increased precipitation, extreme weather, and sea level rise. While the specific climate vulnerabilities of these sites will be touched on throughout the discussion of their locations, the vulnerabilities are more thoroughly summarized in **Table 3.18**. The sites of confirmed or suspected soil contamination in Portland and South Portland include the sites of former LASTs, LUSTs, surface spills, and salt storage, as well as uncontrolled sites. The sites of hazardous material storage include the RCRA waste generators, as they are permitted to store material on

site subject to various restrictions; the large bulk fuel storage facilities; and the one wastewater treatment facility identified as being vulnerable to the sea level rise scenarios used for this discussion. It is important to keep in mind throughout this discussion that the EGAD data identifies single points, such as the location of a tank farm, that may contain multiple hazards, such as multiple tanks.

The EGAD data was analyzed along with the Maine Geological Survey (MGS) Sea Level Rise/Storm Surge data (2018). As mentioned in the introduction to the

Impacts of Climate Hazards on Vulnerable Hazardous Material Sites

Climate Hazard	Vulnerable Site Type	Potential Effect
Changes in water tables and increased groundwater salinity	Contaminated Soil	Mobilization of contaminants (e.g., from vadose zone to groundwater) → Higher contaminant concentration/export, overpowering significant degradation rate in groundwater zone could remove natural protective barriers Altered salinity → Altered degradation rates (physical, microbial)
	Hazardous Material Storage	Higher groundwater levels → Structural damage to subsurface containments due to increased hydrostatic pressures Altered salinity → Damage to clay containing layers
Sea level rise	Contaminated Soil	Tidal erosion → Damage to site integrity, mobilization of soils Site inundation → Increased mobilization of contaminants, increased bioavailability of contaminants
	Hazardous Material Storage	Tidal erosion → Damage to containment structure integrity due to saltwater corrosion or hydrostatic loads of inundation Site inundation → Containment structure overflow, floating or spilling of improperly secured containers
Extreme weather	Contaminated Soil	Wind/wave action; surface water flow velocity → Scouring, mobilization of soils Flooding → Contaminant export
	Hazardous Material Storage	Wind/wave action; surface water flow velocity → Structural damage to containment structures by wind and hydrodynamic loads as well as debris Flooding → Structural damage to containment structures by hydrostatic loads

Table 3.18. Impacts of climate hazards on vulnerable hazardous material sites. Table adapted from Maco, et al. (2018);⁹⁷ with information from Flynn, T.J. et al. (n.d.).⁹⁸

Infrastructure Section of this report, the MGS sea level rise scenarios selected correspond with the Low-Intermediate, Intermediate, Intermediate-High, and High scenarios for 2100. Under the Intermediate scenario, we would expect to see 1.48 feet of relative sea level rise by 2050 for the Greater Portland area—or up to 3.38 feet under the Extreme scenario. For the sake of visualization, these 2050 thresholds roughly correspond with the

lower two thresholds for 2100 (1.6 and 3.9-foot rise above HAT). An overview of the sites identified within the EGAD dataset that may be specifically impacted by sea level rise is presented in **Figure 3.29**.

Vulnerabilities identified within the 1.6-ft scenario include two RCRA Small Quantity Generators (SQGs) in the Central Waterfront District of Portland, a site of

Vulnerable Hazardous Waste Sites in Portland and South Portland

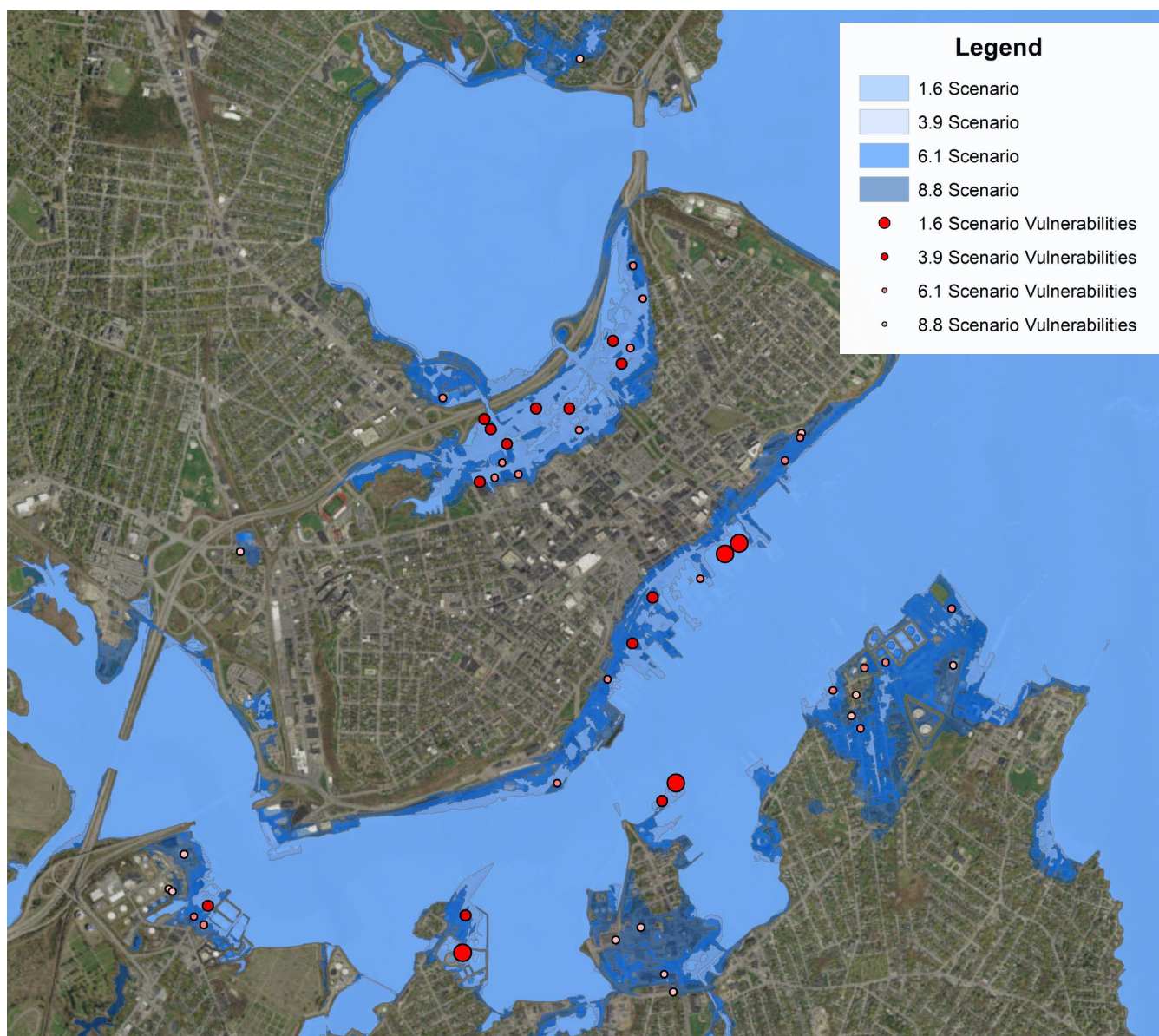


Figure 3.29. Vulnerable hazardous waste sites in Portland and South Portland based on four scenarios of sea level rise (1.6, 3.9, 6.1, and 8.8 feet on top of the highest astronomical tide). Data sources: Maine Department of Environmental Protection, EGAD (2019); Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

petroleum waste sludge buried on Turner Island and potentially contained by a suspected clay layer below (considered Large Bulk Fuel Storage in the EGAD data), several aboveground storage tanks (ASTs) also on Turner Island, and an AST in the Knightville area of South Portland (**Figure 3.30** and **Table 3.19**).

According to Maine DEP, SQGs may accumulate hazardous waste on site for 180 days, though this quantity may never exceed 440 pounds or 55 gallons.⁸⁸ The EPA regulates that the waste must be managed in tanks or containers, and an emergency coordinator must always be available to respond in an emergency,

but SQGs are not required to have a written contingency plan.⁸⁹ In a worst-case scenario, a severe flood event could hit at a time when vulnerable SQGs are storing the maximum amount of waste permitted.

All 1.6-ft Sea Level Rise Vulnerabilities by Type

Vulnerability Type	Number of Sites
Large Bulk Fuel Storage	3
Small Quantity Generators	2

Table 3.19. Vulnerable hazardous waste sites in Portland and South Portland based on inundation from 1.6 feet of sea level rise on top of the highest astronomical tide (HAT).

Selected 1.6-ft Sea Level Rise Vulnerabilities



Figure 3.30. Vulnerable hazardous waste sites in Portland and South Portland based on 1.6 feet of sea level rise on top of the highest astronomical tide. Data sources: Maine Department of Environmental Protection, EGAD (2019); Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

In the case of a 1.6-ft tide increase, the three sites of above-ground storage—the two SQGs and the AST—could be subject to wave action and corrosion by saltwater. Should there be a violent storm and flooding, these tanks would be the first to be subjected to damage or dislodgement by forceful wave action, or hydrostatic pressures should they be submerged.

As sea levels rise, so do groundwater levels, and the buried petroleum waste sludge may become vulnerable to migration.⁹⁰ Increased saltwater content in the groundwater could potentially allow water to permeate the clay layer suspected to contain the waste, which is normally impervious to freshwater, subjecting the waste to solution and migration.⁹¹

The vulnerabilities within the 3.9-ft scenario include four sites with contaminated soils, including the site of a former salt pile, several large ASTs, and a number of Small, Medium and Large Quantity Generators. The

All 3.9-ft Sea Level Rise Vulnerabilities by Type

Vulnerability Type	Number of Sites
Soil Contamination	5
Small Quantity Generator	4
Medium Quantity Generator	5
Large Quantity Generator	1

Table 3.20. Vulnerable hazardous waste sites in Portland and South Portland based on inundation from 3.9 feet of sea level rise on top of the highest astronomical tide (HAT).

Selected 3.9-ft Sea Level Rise Vulnerabilities



Figure 3.31. Selected vulnerable hazardous waste sites in Portland and South Portland based on 3.9 feet of sea level rise on top of the highest astronomical tide. Data sources: Maine Department of Environmental Protection, EGAD (2019); Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

majority of these vulnerabilities are concentrated in the low area of Portland's Bayside area along Back Cove (**Figure 3.31** and **Table 3.20**).

According to Maine DEP, MSQs may not accumulate more than 1,320 pounds of hazardous waste on site and may store this amount for up to 180 days. LQGs do not have a limit on the amount of hazardous waste accumulated onsite, but they may only accumulate material for 90 days. LQGs must have a written contingency plan and an emergency coordinator available at all times. The vulnerable sites shown in **Figure 3.31** are largely MQGs, in addition to the two SQLs, two contaminated soil sites, and a former salt pile that are brought into the 3.9-ft HAT rise. These sites are subject to the same considerations discussed in the previous section, including damage to storage mechanisms and transport of pollutants. In addition, 7 of the 13 large

storage tanks near Bug Light, depicted in **Figure 3.32**, fall within low-lying, vulnerable areas with 3.9 feet of sea level rise. The berms will likely protect the tanks from wave action and corrosion on a regular basis, but these areas could be inundated if back-up pumps were to fail.

The particularly high density of ASTs in the Portland and South Portland area, and their vulnerability to sea level rise, is particularly evident when looking at the number of these tanks within a quarter mile of the South Portland's Fore River coastline to the east of the Veterans Memorial Bridge—there are approximately 100 ASTs in this zone, and by the time of the 6.1-ft HAT rise, 37 will be in low-lying areas that could be vulnerable to the highest astronomical tide. As previously stated, it is important to keep in mind that each point represents a site in the EGAD data that Maine DEP tracks, but each site may consist of multiple storage tanks. In **Figure 3.33**, the

Storage Tanks near Bug Light with Exposure to Sea Level Rise



Figure 3.32. Seven of thirteen storage tanks near Bug Light show vulnerability under the 3.9-foot sea level rise scenario. Tanks are protected by berms and not directly exposed to tides, but are in low-lying areas that may be vulnerable to flooding if protection systems were to fail. Data sources: Maine Department of Environmental Protection, EGAD (2019); Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

large number of ASTs within the quarter mile buffer are evident, despite there being only a few points from the EGAD data, as compiled in **Table 3.21**. In addition to the ASTs, the vulnerabilities within the 6.1-ft scenario include eight contaminated soil sites, including a former salt pile, and several SQGs and MQGs.

The South Portland WWTF located at 111 Waterman Drive could experience structural damage or failure due to loads from wave action and water inundation, impact from moving debris in a violent flood, or corrosion from salt exposure. The East End and Peaks Island Wastewater Treatment Facilities, while included in the EGAD data, are at elevations such that they are not vulnerable to the sea level rise scenarios modeled. However, they are still at risk of climate hazards concurrent to sea level rise, such as more frequent and more powerful storms. As they are situated on the shoreline, it is certainly possible that during a violent coastal storm, these other treatment plants could be at risk of similar threats.

At the sites with contaminated soils, pollutants could be transported through the ground by the higher groundwater levels that would result from higher sea levels, and damage due to wave action or flooding could completely remove and transport contaminated soil layers. With respect to the many above-ground storage

All 6.1-ft Sea Level Rise Vulnerabilities by Type

Vulnerability Type	Number of Sites
Soil Contamination	8
Large Bulk Fuel Storage	3
Small Quantity Generator	8
Medium Quantity Generator	2
Wastewater Treatment Facility	1

Table 3.21. Vulnerable hazardous waste sites in Portland and South Portland based on inundation from 6.1 feet of sea level rise on top of the highest astronomical tide (HAT).

Selected 6.1-ft Sea Level Rise Vulnerabilities

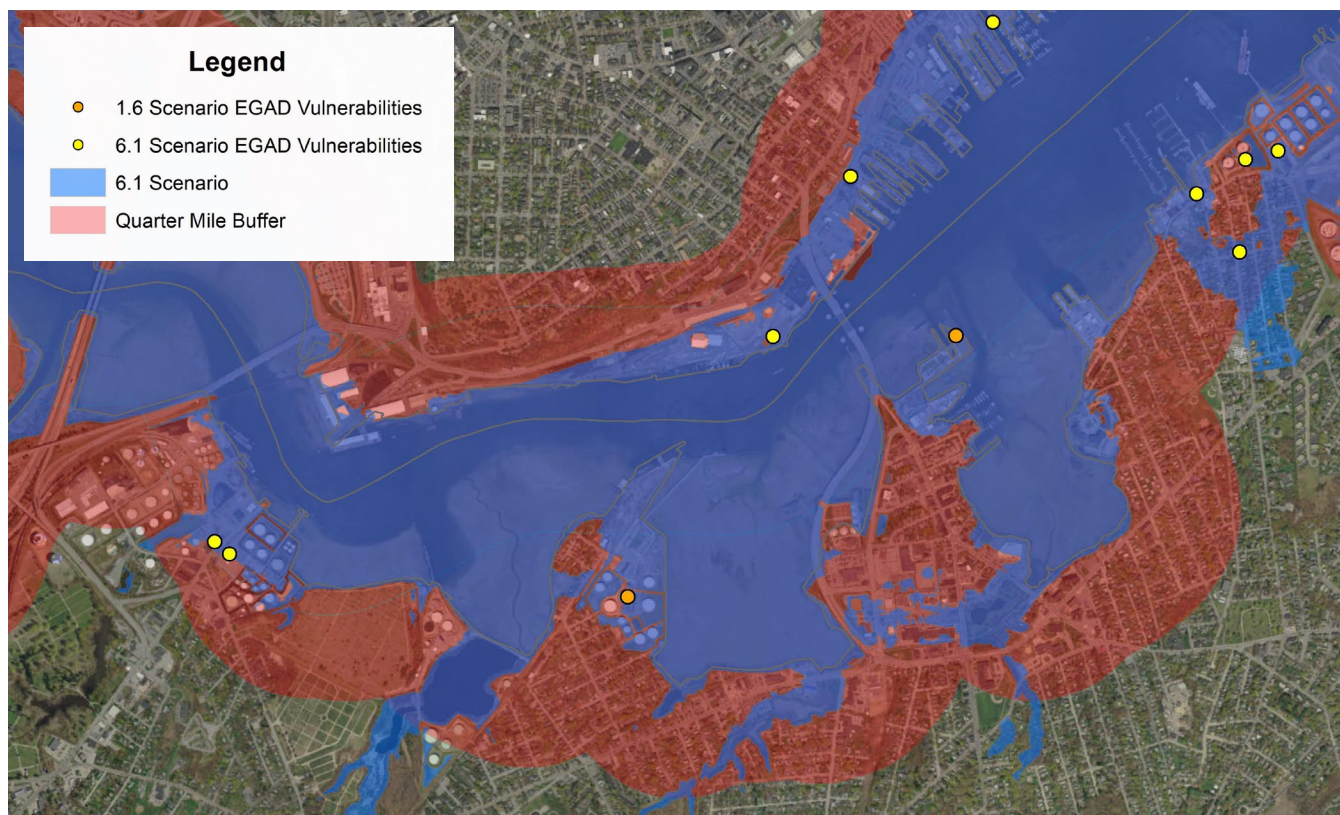


Figure 3.33. Selected vulnerable hazardous waste sites in Portland and South Portland based on 6.1 feet of sea level rise on top of the highest astronomical tide. Data sources: Maine Department of Environmental Protection, EGAD (2019); Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

tanks identified within the 8.8-foot rise, tanks could be structurally damaged by debris, wave and hydrostatic pressures, and corrosion, or could even be dislodged by wave action and spill.

The vulnerabilities within the 8.8-ft scenario include 38 additional storage tanks along the South Portland coastline discussed previously, as well as several RCRA generators and sites of contaminated soils, depicted in **Figure 3.34** and listed in **Table 3.22**. The 8.8-ft scenario vulnerabilities in Portland are largely the contaminated sites and waste generators, while the vulnerabilities in South Portland are largely storage tanks.

All 8.8-ft Sea Level Rise Vulnerabilities by Type

Vulnerability Type	Number of Sites
Soil Contamination	5
Large AST	2
Small Quantity Generator	4
Medium Quantity Generator	3

Table 3.22. Vulnerable hazardous waste sites in Portland and South Portland based on inundation from 8.8 feet of sea level rise on top of the highest astronomical tide (HAT).

Selected 8.8-ft Sea Level Rise Vulnerabilities



Figure 3.34. Selected vulnerable hazardous waste sites in Portland and South Portland based on 8.8 feet of sea level rise on top of the highest astronomical tide. Data sources: Maine Department of Environmental Protection, EGAD (2019); Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

PRIORITY AREAS

Based on the assessment above, there appear to be two most critical areas for all the projected scenarios:

- Portland's Bayside area along Back Cove, and
- The low-lying areas of South Portland along the Fore River with a high concentration of large bulk storage tanks.

The most critical vulnerable sites are the hazardous material storage areas; in particular, the Large ASTs and Medium and Large Quantity Generators. For this reason, the Fore River Shoreline appears to be of highest concern. All the ASTs in this area, along with the 8.8-ft scenario for reference, are highlighted in **Figure 3.35**.

For the Low-Intermediate sea level rise scenario, relevant to 2050, the most critical vulnerability appears to be the ASTs that enter into the inundation area for the 1.6-

foot rise in HAT along the Fore River, but even the sites that are not brought into the tidal zone are subject to the impacts of extreme weather. For the Intermediate scenario, more ASTs along the Fore River shoreline are brought into the tidal zone, as well as some MQGs and an LQG, and these are the most critical areas of concern.

There are many contaminated soil sites in the Portland and South Portland area monitored by Maine DEP and included in the EGAD data, as well as the many more that likely exist as a result of the areas' industrial past. Most of the soils in the area are held in place by development, and the transport of their contaminants would not be as acute a threat as the potential transport of the huge volumes of hazardous materials stored in containment systems along the Fore River shoreline in South Portland and, to a lesser extent, those materials potentially stored by RCRA Generators in the Bayside Area of Portland.

ASTs Along the Fore River Shoreline

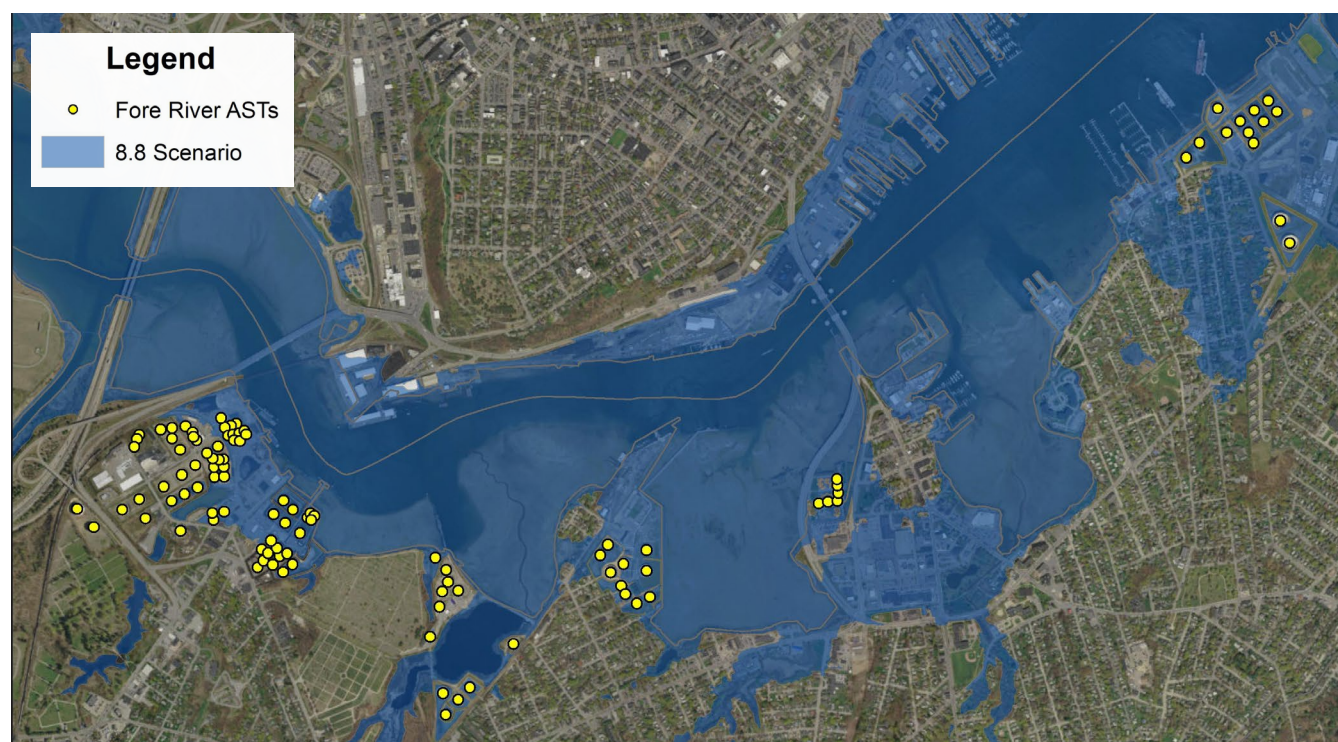


Figure 3.35. Above ground storage tanks (ASTs) along the Fore River shoreline overlaid with projected inundation from 8.8 feet of sea level rise on top of the astronomical high tide. A portion of the ASTs are far enough inland and/or protected by berms so as not to be directly affected by tidal inundation. Further hydrological study is necessary, however, to assess the flood risk of these tanks, particularly in low-lying areas. Data sources: Maine Department of Environmental Protection, EGAD (2019); Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

SECTION THREE ENDNOTES

- 62 U.S. Department of Homeland Security. (2016). Casco Bay Region Climate Change Resiliency Assessment. Regional Resiliency Assessment Program.
- 63 Comes, T., & Van de Walle, B. (2014). Measuring Disaster Resilience: The Impact of Hurricane Sandy on Critical Infrastructure Systems. Proceedings of the 11th International ISCRAM Conference. Hiltz, S.R., Pfaff, M.S., Plotnick, L. & Shih, P.C. eds. Pennsylvania, USA.
- 64 Local energy systems expert, GridSolar. (2019). Portland, ME.
- 65 U.S. Department of Homeland Security. (2016). Casco Bay Region Climate Change Resiliency Assessment. Regional Resiliency Assessment Program.
- 66 U.S. Energy Information Administration. (2016). State Energy Data System, Table C1. Energy Consumption Overview: Estimates by Energy Source and End-Use Sector.
- 67 U.S. Department of Homeland Security. (2016). Casco Bay Region Climate Change Resiliency Assessment. Regional Resiliency Assessment Program.
- 68 City of Portland. (2017). Portland's Plan 2030. Portland, ME.
- 69 U.S. Department of Homeland Security. (2016). Casco Bay Region Climate Change Resiliency Assessment. Regional Resiliency Assessment Program.
- 70 Union of Concerned Scientists. (2014). The Climate Risks of Natural Gas. Retrieved from https://www.ucsusa.org/sites/default/files/legacy/assets/documents/clean_energy/Climate-Risks-of-Natural-Gas-Full-Infographic.pdf
- 71 Portland Water District. (2019.) Annual Water Quality Report. Retrieved from https://www.pwd.org/sites/default/files/annual_water_report_2019.pdf.
- 72 City of Portland. (2017). Portland's Plan 2030. Portland, ME.
- 73 City of South Portland (2019). Water Resources Protection Department.
- 74 City of South Portland. (2019). Wastewater Plant O&M. Retrieved from <https://www.southportland.org/departments/water-resource-protection/treatment-systems/pump-station-o-m/>
- 75 FEMA (n.d.) "Definitions of FEMA Flood Zone Designations." FEMA Map Service Center. Retrieved from <https://snmapmod.snco.us/fmm/document/fema-flood-zone-definitions.pdf>
- 76 U.S. Department of Homeland Security. (2016). Casco Bay Region Climate Change Resiliency Assessment. Regional Resiliency Assessment Program.
- 77 Burillo, D. (2018). Effects of Climate Change in Electric Power Infrastructures. Retrieved from 10.5772/intechopen.82146
- 78 U.S. Department of Homeland Security. (2016). Casco Bay Region Climate Change Resiliency Assessment. Regional Resiliency Assessment Program.
- 79 U.S. Department of Homeland Security. (2016). Casco Bay Region Climate Change Resiliency Assessment. Regional Resiliency Assessment Program.
- 80 Portland Water District (2017). Sebago Lake Watershed Map. As cited in Sebago Clean Waters. Retrieved from <https://www.sebagocleanwaters.org/watershed-map>
- 81 Woodard & Curran. (2013). CMOM Assessment and Corrective Action Plan Report. Retrieved from <https://www.portlandmaine.gov/DocumentCenter/View/13789/20131118-CMOM-Report>
- 82 City of South Portland. (2019). Wastewater Plant O&M. Retrieved from <https://www.southportland.org/departments/water-resource-protection/treatment-systems/pump-station-o-m/>
- 83 Chinowsky, P., Helman, J., Sahil, G., Neumann, J., & Martinich, J. (2019). Impacts of climate change on operation of the US rail network. Transport Policy. 75: 183-191.
- 84 U.S. Department of Homeland Security. (2016). Casco Bay Region Climate Change Resiliency Assessment. Regional Resiliency Assessment Program.
- 85 U.S. Department of Homeland Security. (2016). Casco Bay Region Climate Change Resiliency Assessment. Regional Resiliency Assessment Program.
- 86 Hawes, E. (1994). The Dirty History of Portland Harbor. Casco Bay Estuary Partnership, Muskie School of Public Service, University of Southern Maine. Portland, ME. Retrieved from <https://www.cascobayestuary.org/wp-content/uploads/2018/02/2006-Dirty-History-Fact-Sheet-1994-reprint.pdf>, 1994.
- 87 Maine Department of Environmental Protection. (2019). EGAD (Environmental and Geographic Analysis Database). Retrieved from <http://www.maine.gov/dep/maps-data/egad/>
- 88 Maine Department of Environmental Protection. (2018). Handbook for Hazardous Waste Generators. Retrieved from <https://www.maine.gov/dep/waste/hazardouswaste/documents/hazardous-waste-handbook-2018.pdf>
- 89 U.S. Environmental Protection Agency (EPA). (2019). Categories of Hazardous Waste Generators. Retrieved from www.epa.gov/hwgenerators/categories-hazardous-waste-generators.
- 90 Flynn, T.J., Walesh, S.G., Titus, J.G., & Barth, M.C. (n.d.) Implications of Sea Level Rise for Hazardous Waste Sites in Coastal Floodplains. Retrieved from <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.391.7715&rep=rep1&type=pdf>
- 91 Kebede, A.S. (2009). Assessing Potential Risks of Impacts of Climate Change on Coastal Landfill Sites: A Case Study of Pennington Landfill Site - Hampshire, United Kingdom. (Unpublished master's thesis). University of Southampton, Southampton, England.
- 92 USAID. (2013). Addressing Climate Change Impacts on Infrastructure: Preparing for Climate Change. Washington DC.
- 93 USAID. (2013). Addressing Climate Change Impacts on Infrastructure: Preparing for Climate Change. Washington DC.

- 94 Hawes, E. (1994). The Dirty History of Portland Harbor. Casco Bay Estuary Partnership, Muskie School of Public Service, University of Southern Maine. Portland, ME. Retrieved from <https://www.cascobayestuary.org/wp-content/uploads/2018/02/2006-Dirty-History-Fact-Sheet-1994-reprint.pdf>, 1994.
- 95 Hawes, E. (1994). The Dirty History of Portland Harbor. Casco Bay Estuary Partnership, Muskie School of Public Service, University of Southern Maine. Portland, ME. Retrieved from <https://www.cascobayestuary.org/wp-content/uploads/2018/02/2006-Dirty-History-Fact-Sheet-1994-reprint.pdf>, 1994.
- 96 Maine Department of Environmental Protection. (2019). EGAD (Environmental and Geographic Analysis Database). Retrieved from <http://www.maine.gov/dep/maps-data/egad/>
- 97 Maco, B. et al. (2018). Resilient remediation: Addressing extreme weather and climate change, creating community value. Remediation. Retrieved from <https://onlinelibrary.wiley.com/doi/abs/10.1002/rem.21585>
- 98 Flynn, T.J., Walesh, S.G., Titus, J.G., & Barth, M.C. (n.d.) Implications of Sea Level Rise for Hazardous Waste Sites in Coastal Floodplains. Retrieved from <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.391.7715&rep=rep1&type=pdf>

4. Environmental Exposure, Risk, and Vulnerability

Portland's and South Portland's ecosystems are already changing in response to climate change.

ENVIRONMENTAL CONTEXT

The Casco Bay Watershed spans nearly 1,000 square miles in southern Maine. It is rich with forests, soils, and wetlands that support wildlife, filter air and water, help to buffer extreme temperatures, and enhance our quality of life. The water from snowmelt, streams, rivers, and rainwater collect and travel through 42 communities within the watershed, running into Casco Bay and the broader Gulf of Maine. The Gulf of Maine and Casco Bay are closely intertwined, exchanging nutrients and marine life that are collectively impacted by the acidity, temperature, and salinity conditions of these environments.

Portland and South Portland's connection to water resources serves as a defining feature for both cities. Portland and the majority of South Portland sit within the far eastern edge of the Casco Bay Watershed, where the watershed meets the bay (**Figure 4.1**). (The southern edge of South Portland sits within the Saco River Watershed, which drains into Saco Bay.) The Fore, Presumpscot, and Stroudwater Rivers, as well as numerous other freshwater streams that run into the Fore River, serve as some of the cities' primary water conduits. Both the Fore River and Back Cove—Portland's large tidal basin—offer important habitat for estuary ecosystems. Likewise, Casco Bay and the Gulf of Maine support abundant marine species, many of which generate key value to the coastal economy.

Despite being urban in nature, Portland and South Portland also have important land-based environmental

Casco Bay Watershed

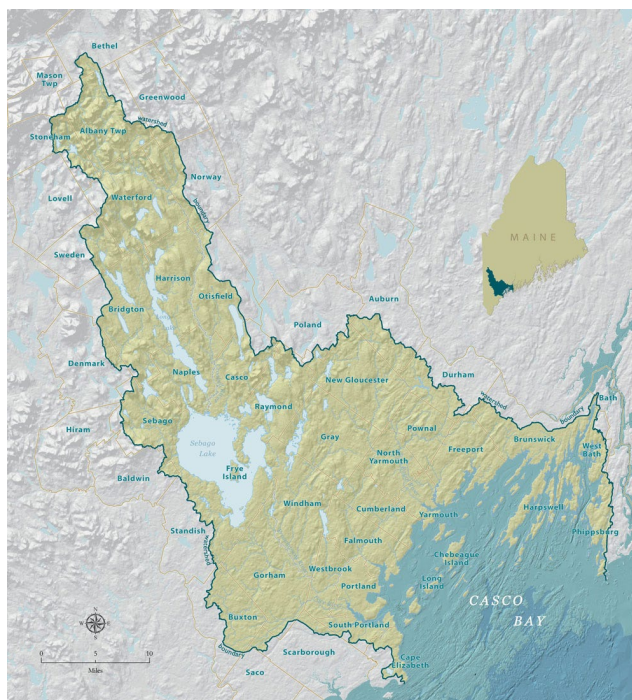


Figure 4.1. Map of the Casco Bay Watershed. Figure source: Casco Bay Estuary Partnership (2017).

resources. Roughly 4 percent of Portland's area is made up of parks, land bank properties, and Portland Trail networks;⁹⁹ likewise, roughly 4 percent of South Portland's area includes city-managed parks, fields, and open space,¹⁰⁰ and roughly 400 acres in South Portland are conservation land.¹⁰¹ Although few areas are undisturbed or contiguous, these spaces provide habitat for small animals and plant life. Portland, in particular, highlights its native, old-growth tree stands—most notably Deering Oaks and Baxter Woods. These resources, including the parks, multiuse trails, passive open spaces, and water access points, play a role in creating healthy and thriving places to live, work, and play.

Climate change has already begun to create strain on ecosystems and has the potential to lead to long-term impacts to the cities' critical environmental resources. While the cities' water ecosystems provide significant assets to the cities, they in particular show significant vulnerability. Five specific environmental issues are highlighted in this section:

- Marsh Migration
- Coastal Erosion
- Compromised Natural Water Systems
- Shifting Habitats, Pests, and Invasives
- Species Health Impacts from Ocean and Coastal Acidification

Understanding how and where the environment is vulnerable will help inform the necessary choices and strategies for ensuring the cities' environmental resources remain healthy despite a changing climate.

4.1 Marsh Migration

Climate hazards, and in particular sea level rise, are known to impact sensitive tidal areas including marshes and wetlands. These coastal ecosystems provide tremendous benefit to wildlife, plant species, and the surrounding built environment by serving as habitat and a protective barrier against storm surge and rising sea levels by buffering wave action. Marshes also have the natural ability to filter various types of pollution and slow the impacts of erosion, which can cause property damage in developed areas. In Maine, marshes are a unique resource since much of the coastline has a steep topography. Preserving and protecting marsh and wetland areas are of interest to many coastal communities due to the benefits they provide.

In mostly urban environments such as Portland and South Portland, marshes have already been significantly reduced or degraded from development and from pollution from stormwater runoff.¹⁰² Infrastructure, including roads, bridges, dams, and railroads that cross tidal wetlands interfere with the way water exchanges from one side of the infrastructure to the other, and can

increase water flow velocity, create scour, and undermine the resilience of the marshes. As sea levels rise, marshes will continue to lose suitable habitat, particularly at these points.

The process by which tidal marshes gradually shift inland onto formerly dry land or nontidal areas as sea levels rise is known as marsh migration. Migration is possible where there are not constraints from the developed environment or steep slopes. In areas where marshes are buffered by the built environment, shifting may not be possible. Losing these critical marsh ecosystems will impact the plant and animal habitats that thrive there as well as decrease natural flooding buffers, making the areas further inland more vulnerable to storm surge.

In 2013, the Casco Bay Estuary Partnership (CBEP) looked at the impacts of sea level rise on wetlands throughout Casco Bay. The study specifically identified four primary areas in Portland and three in South Portland where marsh migration is likely to occur due to sea level rise, and where these areas may come into conflict with existing development:

- Upper Fore River Area (**Figure 4.2**)
- Back Cove Area (**Figure 4.3**)
- Commercial Street Area (**Figure 4.4**)
- East Deering Area (**Figure 4.5**)
- Bug Light and Southern Maine Community College Area (**Figure 4.6**)
- Mill Creek and Turner Island Area (**Figure 4.7**)
- Forest City Cemetery Area (**Figure 4.8**)

For each site, CBEP assessed the marsh migration driven by one foot and three feet of sea level rise. Flood extents are determined by static inundation modeling based on storm tide levels overlaid with LIDAR data. The figures for three feet of sea level rise are included below. To see the analysis at one foot, see the Portland and South Portland editions of *Sea Level Rise and Casco Bay's Wetlands: A Look at Potential Impacts* (2013).¹⁰³

Upper Fore River Area – A portion of the Upper Fore River is shown in **Figure 4.2**. A three-foot rise in sea level would lead to marsh migration inland in a number of directions, and would likely result in conflicts with

existing infrastructure and developed areas. Potential instances where marsh migration comes into conflict with the built environment include:

- Stroudwater Village Causeway
- Low-lying areas of Stroudwater Village including portions of outer Congress Street
- Three culverts where the railroad tracks cross the Fore River Sanctuary
- Developed areas associated with Starbird Lane, Winding Way, Meadowbrook Lane, Frost Street, Cliff Street, Yellowbird Road

The points where marshes are impeded by infrastructure and development creates heightened risk for losing wetland ecosystems. In the upper Fore River this vulnerability is mitigated slightly by the Fore River Sanctuary where the natural area and elevations are suitable in some spots for inland marsh migration.

Back Cove Area – Figure 4.3 shows potential marsh migration in Back Cove, driven by three feet of sea level rise. Baxter Boulevard and the Bayside area are at elevations where marsh migration would “naturally” occur, yet the land use precludes marsh migration. The brooks near Back Cove Estates and Payson Park allow

Potential Marsh Migration: Upper Fore River

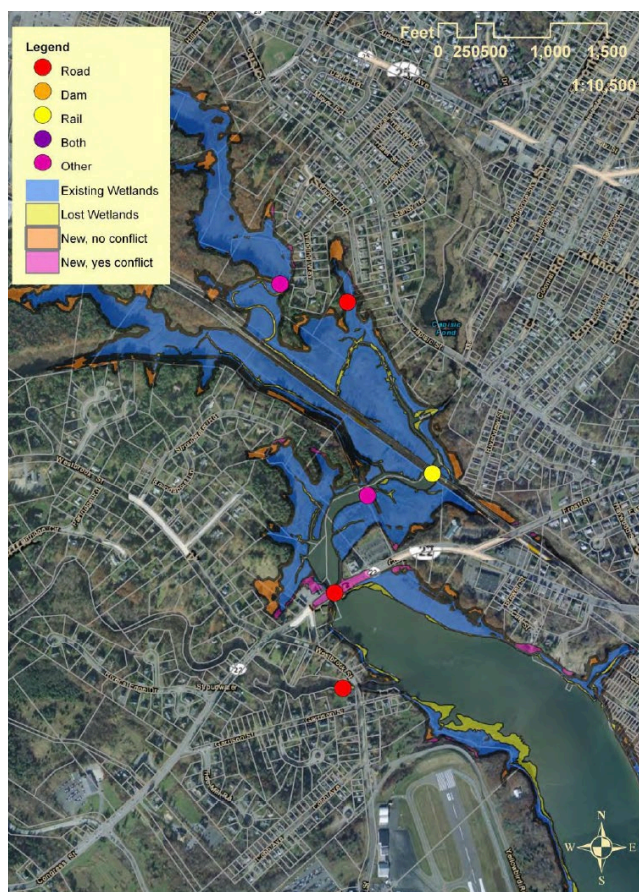


Figure 4.2. Potential marsh migration and areas of conflict in the Upper Fore River (Stroudwater) under 3 feet of sea level rise. Yellow areas represent existing wetlands that will be lost, and pink areas represent areas where wetlands would naturally migrate, but are prevented due to development. Dots specify conflict points between marshes and infrastructure. Figure source: Casco Bay Estuary Partnership (Bohlen et al., 2013).

Potential Marsh Migration: Back Cove



Figure 4.3. Potential marsh migration and areas of conflict in Back Cove under 3 feet of sea level rise. Yellow areas represent existing wetlands that will be lost, and pink areas represent areas where wetlands would naturally migrate, but are prevented due to development. Dots specify conflict points between marshes and infrastructure. Figure source: Casco Bay Estuary Partnership (Bohlen et al., 2013).

for more natural tidal movement, already support marsh ecosystems, and would likely be places for further marsh migration; However, the road crossings and culverts create limitations for this movement. The current edge of Back Cove, including the small freshwater brooks by Back Cove Estates, are within the City's Shoreland Overlay Zone, which offers some protection from development.

Commercial Street Area – Only small patches of wetland exist around the piers in the Commercial Street Waterfront, some of which will likely be lost with three feet of sea level rise (**Figure 4.4**, yellow areas). There are

few suitable areas for marsh migration at this edge of the waterfront. The primary possible area surrounds the current location of Portland Yacht Services.

East Deering Area (Martin's Point) – A thin band of wetlands currently stretches around Martin's Point, and into the cove on the western side of Interstate 295. These wetlands are vulnerable to the effects of sea level rise, and their area will likely be significantly reduced under a three-foot scenario (**Figure 4.5**). The I-295 road crossing that mediates the water exchange between the bay and the cove is suggested to further hinder the health of the marshes.

Potential Marsh Migration: Commercial Street

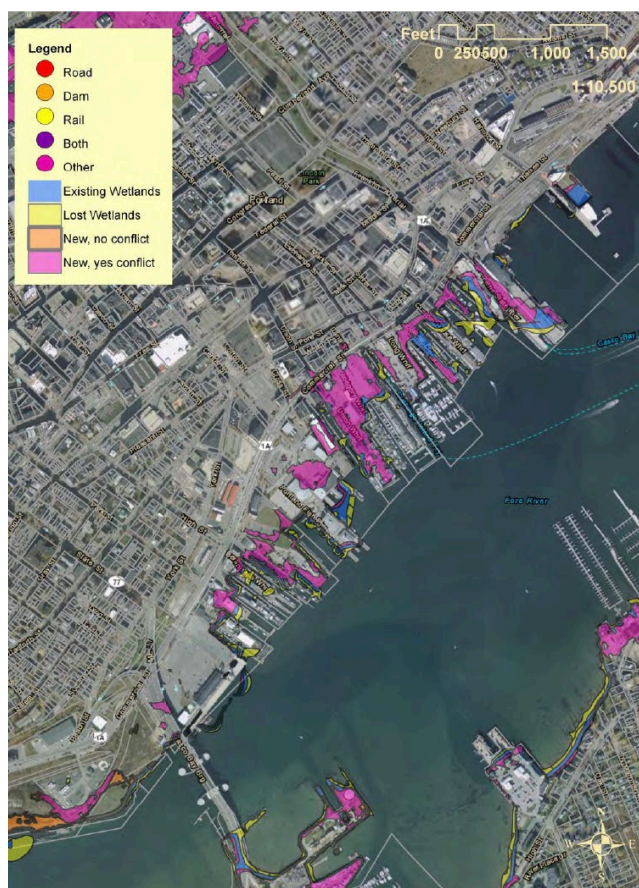


Figure 4.4. Potential marsh migration and areas of conflict in the Commercial Street area under 3 feet of sea level rise. Yellow areas represent existing wetlands that will be lost, and pink areas represent areas where wetlands would naturally migrate, but are prevented due to development. Figure source: Casco Bay Estuary Partnership (Bohlen et al., 2013).

Potential Marsh Migration: East Deering



Figure 4.5. Potential marsh migration and areas of conflict in the East Deering area under 3 feet of sea level rise. Yellow areas represent existing wetlands that will be lost, and pink areas represent areas where wetlands would naturally migrate, but are prevented due to development. Dots specify conflict points between marshes and infrastructure. Figure source: Casco Bay Estuary Partnership (Bohlen et al., 2013).

Bug Light and Southern Maine Community

College Area – A ring of marshland surrounds the coast around Bug Light Park, Simonton Cove, and the adjacent industrial and marine waterfronts. **Figure 4.6** illustrates where these marshes will likely be lost with three feet of sea level rise. This area has very little room for marsh migration, impeded by industrial, commercial, and residential development. Losing some of these marshlands may make this area's waterfront uses, including Willard Beach, increasingly vulnerable to storm surge and erosion.

Potential Marsh Migration: Bug Light & SMCC

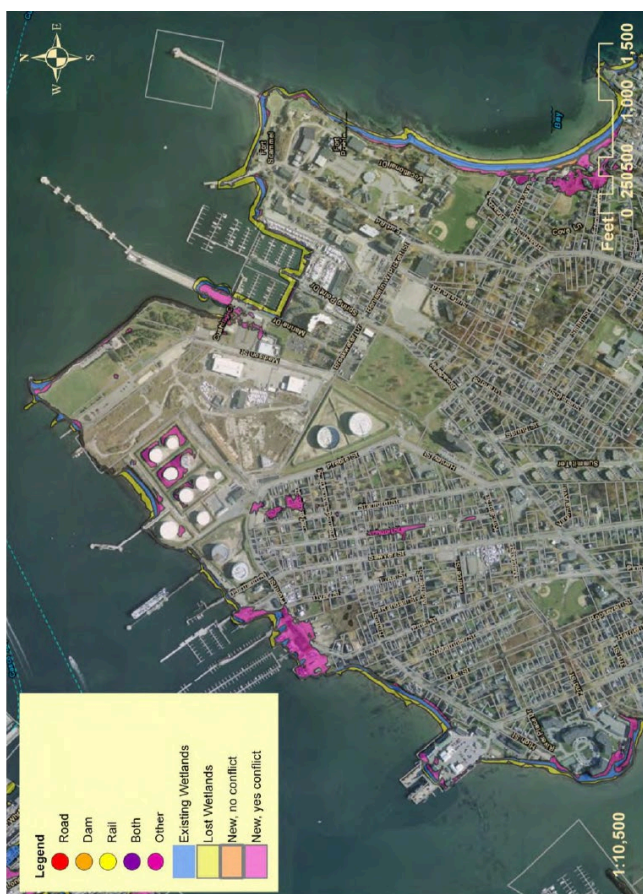


Figure 4.6. Potential marsh migration and areas of conflict in the Bug Light and Southern Maine Community College (SMCC) area under 3 feet of sea level rise. Yellow areas represent existing wetlands that will be lost, and pink areas represent areas where wetlands would naturally migrate, but are prevented due to development. Figure source: Casco Bay Estuary Partnership (Bohlen et al., 2013).

Mill Creek and Turner Island Area – The area spanning Turner Island and Mill Creek (Knightville) includes a number of small creeks that run into the Fore River, creating estuaries with substantial stretches of existing wetlands. Under three feet of sea level rise, this area is likely to lose marshes at the edges of the coves, particularly at the mouths of these creeks (**Figure 4.7**). Unlike many other areas along Portland and South Portland's coasts, however, this area does offer some areas for marsh migration—notably within Mill Creek. (The map also captures the area across the Fore River in Portland, adjacent to Portland Yacht Services, which was a previously mentioned area for potential marsh

Potential Marsh Migration: Mill Creek & Turner Island



Figure 4.7. Potential marsh migration and areas of conflict in the Mill Creek and Turner Island area under 3 feet of sea level rise. Yellow areas represent existing wetlands that will be lost, and pink areas represent areas where wetlands would naturally migrate, but are prevented due to development. Dots specify conflict points between marshes and infrastructure. Figure source: Casco Bay Estuary Partnership (Bohlen et al., 2013).

migration.) A number of road crossings over both Mill Creek and Anthoine Creek, however, are likely to degrade the health of marshes in these locations and amplify their vulnerability to sea level rise.

Forest City Cemetery Area – The outfall of Barberry Creek is a significant site for existing wetlands, and the CBEP studies suggest this site has little vulnerability to sea level rise up to three feet (**Figure 4.8**). The primary losses for wetlands in the Forest City Cemetery area are projected to occur along the coast of the cemetery. Industrial uses on both the South Portland and Portland side of the Fore River in this area prevent any significant space for new marsh migration. Consequently, three feet

4.2 Coastal Erosion

Portland and South Portland are both susceptible to coastal or shoreline erosion. Coastal erosion is a process where events including severe storms, flooding, storm surge, sea level rise and human-related activities wear away beaches and dunes over time. Erosion can occur due to an acute weather-related event or a long-term change in the coastline as waves or currents remove sand or rocks from the shoreline. Erosion can result in a reduction in the storm buffering capacity of beaches and dunes, and habitat loss for sensitive coastal ecosystems. Coastal erosion thus also becomes a threat to adjacent properties and infrastructure, as changes in the shoreline leave them more vulnerable to other severe storms or weather patterns. Shoreline erosion is partially driven by the elevation of high tides, which will continue to increase as sea levels rise.

In the recent 2017 Cumberland County Hazard Mitigation Plan, coastal erosion was included as one of the five highest priority natural hazards impacting communities in this region, including Portland and South Portland. In the two communities, the area of most concern for coastal erosion is Willard Beach in South Portland (**Figure 4.9**). The beach is approximately four acres, located between Fisherman's Point and Southern Maine Community College, and used extensively for recreational activities. Historically, South Portland has protected the sand dunes at Willard Beach through a proactive beach management initiative, which has allowed the city to avoid any beach nourishment efforts for decades. The size of the dunes and beach will fluctuate year to year, and different areas of the beach will grow and erode depending on given forces. As a whole, Willard Beach has been accretive with a mean dune change rate of +1.3 ft/yr over the period from 2007-2019 due to management efforts.¹⁰⁴ Dry beach width (DBW), the distance between the mean high water line and the dunes or seawall, is a good indicator of the buffering capacity of the beach to storms. DBW declined slightly between 2018 and 2019, particularly in the southern half of the beach.¹⁰⁵ Although these

Potential Marsh Migration: Forest City Cemetery

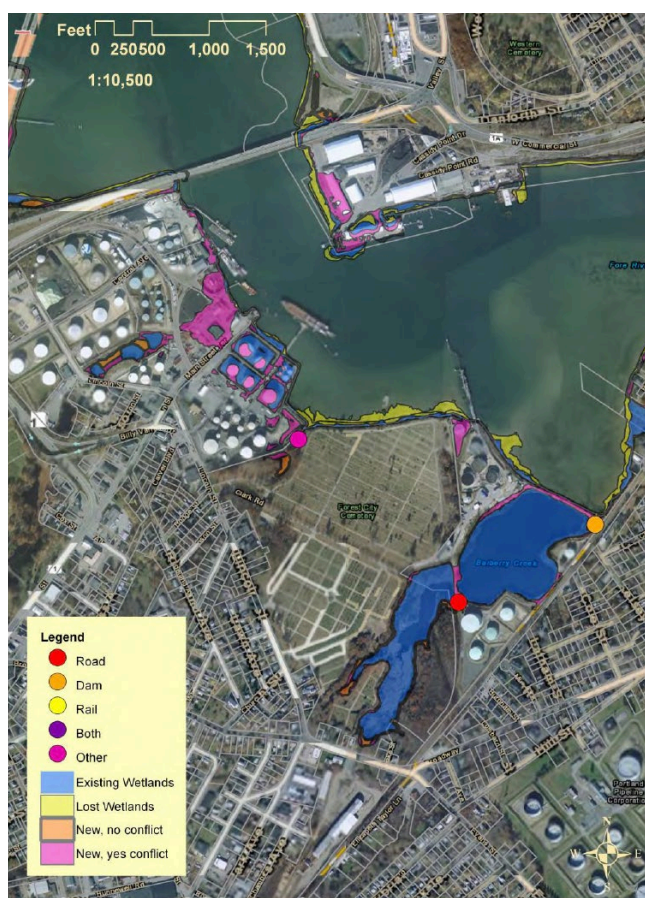


Figure 4.8. Potential marsh migration and areas of conflict in the Forest City Cemetery area under 3 feet of sea level rise. Yellow areas represent existing wetlands that will be lost, and pink areas represent areas where wetlands would naturally migrate, but are prevented due to development. Dots specify conflict points between marshes and infrastructure. Figure source: Casco Bay Estuary Partnership (Bohlen et al., 2013).

dimensions tend to fluctuate, attendees at the Resilience Workshop held in May 2019 voiced concern in continuing to keep erosion at bay at Willard Beach, specifically highlighting the increasing risk sea level rise and storm surge would create for beach erosion.

Other areas of Portland and South Portland that are also vulnerable to erosion and that could affect critical infrastructure include the Stroudwater Area of Congress Street (a heavily traveled roadway), Back Cove Pump Station, and the South Portland Wastewater Treatment Plant. Ecological impacts from coastal erosion can result in habitat loss as the natural coastal wetlands and beach areas deteriorate.

Willard Beach Erosion Hazard Area



Figure 4.9. Willard Beach and the surrounding residential areas. “D1” (Dune 1) marks the frontal dune closest to the water; “D2” (Dune 2) marks the back dunes that lie inland of the frontal dune. The area marked with red hatch delineates the Erosion Hazard Area (EHA), which includes “any portion of the coastal sand dune system that can reasonably be expected to become part of a coastal wetland in the next 100 years” due to a number of forces including long-term erosion or short-term erosion from the 100-year storm. Areas vulnerable to storm surge with two feet of sea level rise, or otherwise included in the AO zone in FEMA flood maps are included in the EHA.²⁶

4.3 Compromised Natural Water Systems

Both freshwater and saltwater systems in the Casco Bay Watershed are increasingly affected by climate change, particularly heavy rainfall and higher temperatures. Increased precipitation duration and intensity will create more stormwater runoff, which can deliver larger quantities of pollutants into streams, rivers, estuaries, and the bay. Higher temperatures further degrade water quality, primarily through facilitating algal blooms.

STORMWATER POLLUTION

Stormwater runoff is often contaminated by nutrients, sediment, bacteria, or even trash, which accumulates as it enters source waters. In Casco Bay, many of the stormwater contaminants are from nonpoint sources such as pet waste, failing septic systems, fuel spills from boats, pesticides washing off lawns, or oil leaking from cars. In particular, the Casco Bay Estuary Partnership has identified high levels of polycyclic aromatic hydrocarbons (PAHs), which are primarily from the combustion of fossil fuels.¹⁰⁶ PAHs accumulate in sediment, as well as travel up the food chain through bottom dwellers, to fish, and to mammals including humans.

A greater volume of stormwater amplifies the pollution entering water bodies particularly when it overwhelms undersized or aging stormwater controls. Overwhelmed controls are especially problematic for cities with combined sewer systems, which carry all collected sewage and stormwater in the same pipe network and transport it to the treatment plant where it is treated and discharged into a water body. When heavy precipitation or snowmelt increases the amount of stormwater in the system and it exceeds the capacity of the pipes, all effluent is dumped directly into the ocean untreated, causing a combined sewer overflow.

NUTRIENT LOADING AND ALGAL BLOOMS

Water quality data collected by the Friends of Casco Bay show that nitrogen concentrations are notably high in parts of Casco Bay.¹⁰⁷ Stormwater carrying fertilizers and pet waste, as well as sewage and air pollutants can contribute to elevated nitrogen levels. Excessive nutrient

levels, including high levels of nitrogen, make Casco Bay increasingly susceptible to harmful algal blooms, or the rapid increase in a population of algae. Algal blooms decrease water quality, lower dissolved oxygen, and lead to potential plant and wildlife die-offs.

In recent years, there have been documented algal blooms in both Back Cove in Portland and Mill Cove in South Portland. This issue can be exacerbated by not only excess nitrogen, but also warmer ocean temperatures and higher levels of carbon dioxide absorbed from the atmosphere, which further increase the vulnerability of Casco Bay to algal blooms.

IMPACTS ON AQUATIC ECOSYSTEMS

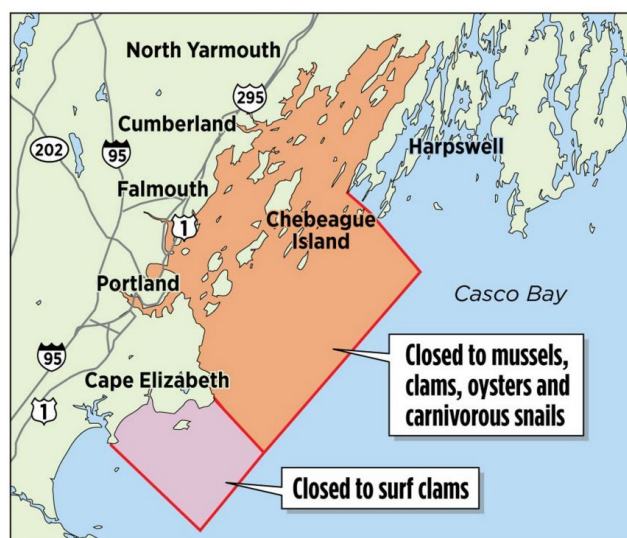
Pollutants and nutrient loading from stormwater runoff have a wide range of negative effects on water quality and on freshwater and saltwater ecosystems.¹⁰⁸ Some of these cascading impacts include:

- Coastal acidification;
- Low or reduced dissolved oxygen levels, resulting in fish die-offs;
- Toxic algal blooms;
- Closure of areas of Casco Bay to shellfishing;
- Loss of eelgrass beds;
- Damage to aquatic habitats;
- Loss of ecological diversity and changes to ecosystem function.

The shellfish industry in Casco Bay, and specifically surrounding Portland and South Portland, has seen repeated and continuous closures due to related water quality challenges, all driven by factors that show potential to worsen with climate change. As mentioned previously, stormwater runoff, often in areas with combined sewer systems, can lead to higher bacteria levels. The Maine Department of Marine Resources has five shellfish classification categories that reflect water quality. The area of Casco Bay around Portland and South Portland is classified as prohibited which means closed to shellfish harvest at all times when water quality testing either shows elevated levels of fecal bacteria or when an area is near a wastewater treatment plant outfall or another source of pathogens.

In adjacent areas where shellfishing is not prohibited, the industry has still experienced closures due to toxic algal blooms. In winter of 2017, a harvesting ban stretched from Portland to Harpswell when shellfish showed elevated domoic acid levels, a biotoxin produced by a large phytoplankton bloom (**Figure 4.10**).¹⁰⁹ Likewise, as of July 2019, Maine DMR had issued a red tide closure for mussels, oysters, clams and snails for an area of Casco Bay including Portland and South Portland.¹¹⁰ These closures impact shellfish harvesting, fisheries operations, local jobs and the economy. Rising temperatures from climate change are expected to make similar toxic algal blooms increasingly hard to contain.

Shellfish Closures in 2017 due to Biotoxin Levels



SOURCE: Department of Marine Resources STAFF GRAPHIC | MICHAEL FISHER

Figure 4.10. Shellfish harvesting closures in 2017 due to elevated levels of the biotoxin domoic acid caused by a large phytoplankton bloom. Domoic acid is known to make people sick, and can induce brain damage. Figure source: Department of Marine Resources, as reported in the Portland Press Herald (2017).

4.4 Shifting Habitats: New Pests and Invasive Species

Portland and South Portland are likely to see substantial changes to ecosystems both on land and in water as climate change brings more precipitation and warmer air and water temperatures. While climate change impacts on habitats and species are not fully understood, it is known that habitats will shift or redistribute. Climate change will provide opportunities for invasive species that may never have survived in this area in the past a chance to thrive, grow, reproduce and survive in environmental conditions that were not previously known to this area. In addition to the introduction and expansion of invasive species, a decline in native species can be expected that may have favored past climate conditions which no longer exist (or that have shifted further north). The interactions of climate change with other related stressors and human activities has the potential to magnify the impacts and threats to marine and terrestrial ecosystems.

Casco Bay Estuary Partnership has specifically identified impacts and key potential areas of concern associated with shifting habitats, new pests, and invasive species as the following:

- Warmer ocean water temperatures cause shifts in species' geographic ranges and the community structure of Casco Bay's ecosystem, leading to declines in some existing fisheries, resources, and increases in some invasive species, pathogens, pests, and disease vectors.
- Climate change leads to changes in marine and coastal food webs, altering species composition, making coastal ecosystems less resilient to other stressors like invasive species, elevated nutrients and habitat destruction, and raising chances of the ecosystem hitting a tipping point.
- Sea level rise and altered hydrology in tidal wetlands (due to multiple climate stressors) shifts species composition, causes both gains and losses of tidal wetland area, and makes the wetlands more susceptible to invasion by invasive plants.

MARINE ECOSYSTEMS

Invasive Species – Casco Bay's marine ecosystems are vulnerable to the threat of invasive species, which are species that tend to spread to the point that they can cause harm to ecosystems. Research completed by Casco Bay Estuary Partnership on invasive species in Casco Bay found that at two specific locations studied in 2013, between one-fifth and one-third of all identified marine species were not native.¹¹¹ Some of these species¹¹² that are known marine invasives include:

- Asian Shore Crab
- European Green Crab
- Dead Man's Fingers
- Lacy Crust Bryozoan
- Hairy-Clawed Shore Crab
- Chinese Mitten Crab
- Common Periwinkle
- Rapa Whelk

One example documented by CBEP is associated with a decline in eelgrass beds, which is a native seagrass that provides critical habitat and food for other marine species. Eelgrass plays a valuable role in maintaining healthy water quality by managing nutrients in the water and stabilizing sediment. It can also sequester carbon at a high rate, which is beneficial when there is excess in the water. Among other environmental stressors, eelgrass stands are declining due to the European green crab, a species whose population has exploded in Casco Bay in recent years due in part to warming waters.

Figure 4.11 shows areas of Portland and South where there has been a change in eelgrass distribution over time.¹¹³ While pockets around the islands have seen some growth in density, the eelgrass area adjacent to the East End Beach has seen a loss in density and extent, while most of the areas at South Portland's water edge have seen either no change or a loss in extent. According to CBEP, between 2001/2002 and 2013, Casco Bay lost more than half of its eelgrass beds.¹¹⁴

Shifting Native Habitats – Changes in climate will shift habitats in Casco Bay, affecting ecosystems, species distributions, as well as the marine resource economy. One such concern is the susceptibility of Maine's lobster

Change in Density and Extend of Eelgrass Beds (1997 – 2010)



Figure 4.11. Change in eelgrass distribution (density and extent of beds) in the Portland Harbor between 1997 and 2010. Figure source: Maine Department of Marine Resources, Historical Eelgrass Coverage Viewer (n.d.).

fishing industry to warming water temperatures. Like much of southern New England, Maine's lobster industry could see a decline or a shift in habitat northward as the ocean continues to warm. **Figure 4.12** illustrates how the density of lobster catches has already shifted significantly since 1970. Recent research predicts that lobster populations are likely to shift 200 miles further north as a result of climate change.¹¹⁵

In addition to lobster, increasing ocean temperatures are resulting in a shift to the north for a number of other species in the Gulf of Maine. The timeframe for species shifting their habitats will depend on the pace of climate change and the adaptability of an individual species.¹¹⁶ Atlantic Cod populations in the Gulf of Maine, in particular, have been declining since before 1990, and recent research suggests that the remaining habitat for the species in the North Atlantic could shrink by over

90 percent by 2100 due to warming waters.¹¹⁷ The same study suggests that scallops, shrimp and groundfish—all significant species in Maine—could shift northward to waters in Canada if ocean temperatures continue to rise. In the meantime, the Gulf of Maine is likely to see increases in other species that are more accustomed to warmer waters. In particular, the Gulf is seeing increasing Black Sea Bass populations.

TERRESTRIAL ECOSYSTEMS

Invasive Species – Climate change can both inhibit and facilitate growth of invasive plant species. Widespread impacts and changes are not understood but as with other environmental systems, the range and abundance of invasive plants are likely to change. Invasive plants tend to be better able to tolerate or adjust to new climates than native species, outcompeting native species for nutrients, water, sunlight, or pollinators.

Changing Density of Lobster Catch (1970 - 2017)

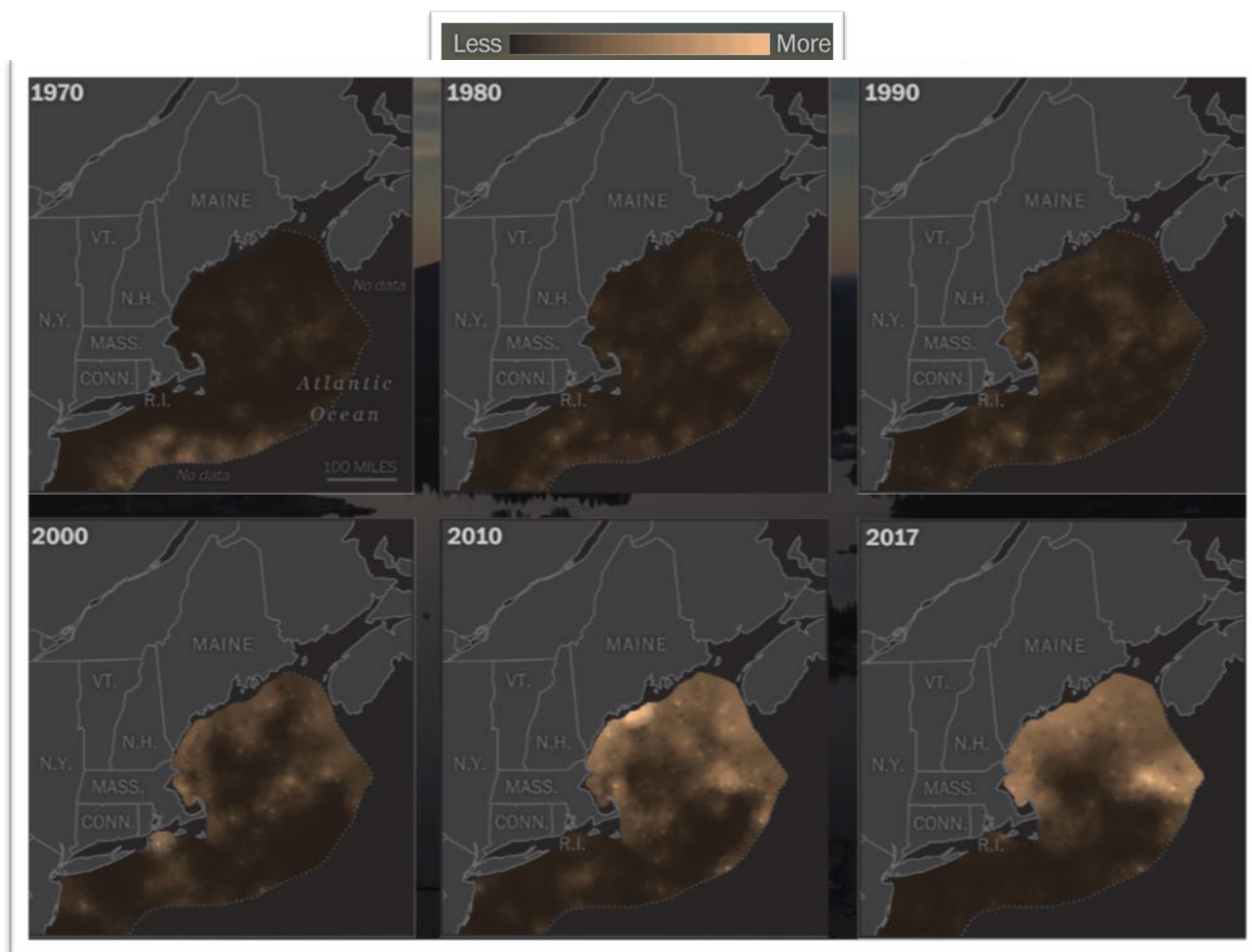


Figure 4.12. Changing density of lobster catches off the coast of Northern New England from 1970 to 2017. Lobster catches have shown a distinctive shift northward, suggesting that the population will continue to shift northward as oceans continue to warm. Source: The Washington Post, “Gone in a Generation” (2019).¹²⁷

Invasive plant species are disrupting ecosystems in Maine by developing self-sustaining populations that are dominant or disruptive to native species. The aggressive growth of invasive plants can affect forest regeneration and reduce the value of habitat for other species. After habitat loss, invasive species are the second most critical threat to ecosystem diversity. Invasive plant species in Maine with wide distribution are listed in **Table 4.1**.¹¹⁸

In particular, longer warm seasons and earlier springs have provided an advantage for the growth of purple loosestrife, a plant introduced from Europe that now chokes wetland habitats by overtaking cattails and

other marsh plants that support wetland wildlife. Purple loosestrife has been able to respond quicker to warming temperatures, and is blooming several weeks earlier than its native competitors.¹¹⁹

Forest Pests – Pests are insects or animals that cause destruction to plant species. Throughout the Northeast, pests have caused significant damage to native tree species, as well as forest ecosystems. Climate change has the potential to amplify this impact, by expanding the range and the intensity of pest infestation. **Table 4.2** catalogs pests that have already started impacting the forest ecosystems in Maine.¹²⁰

Widespread Invasive Plant Species in Maine

Norway Maple	Garlic Mustard	Japanese Barberry
Asiatic Bittersweet	Autumn Olive	Winged Euonymus
Japanese Knotweed	Glossy Buckthorn	Dame's Rocket
Yellow Iris	Morrow's Honeysuckle	Tatarian Honeysuckle
Purple Loosestrife	Black Locust	

Table 4.1. Fourteen of the most widespread invasive plant species in Maine. Source: Maine Department of Agriculture, Conservation, and Forestry (2017).

Invasive Pest Species in Maine

Emerald Ash Borer	Brown Spruce Longhorn Beetle
Asian Longhorn Beetle	Winter Moth
Hemlock Woolly Adelgid	European Wood Wasp
Elongate Hemlock Scale	

Table 4.2. Seven of the most invasive pest species affecting trees and forest ecosystems in Maine. Source: University of Maine, Maine Invasive Species Network (n.d.).

In particular, Portland and South Portland have seen evidence of Hemlock Woolly Adelgid (HWA) outbreaks, a pest that infests hemlock trees throughout the northeast and up the southern Maine coastline. Nearly all hemlock trees infested with HWA eventually die, creating broader ecosystem repercussions, such as loss of primary habitat for the blue-headed vireo and Blackburnian warbler, and the replacement of hemlocks with black oaks, black birch and other hardwoods.¹²¹ There is a significant risk that warming temperatures will allow this pest to expand in distribution, including inland and further up the coastline. Likewise, warmer winters are likely to expand the tree decimation cause by winter moth and emerald ash borer, which currently affect areas within Portland and South Portland and/or in neighboring municipalities.

Vector-borne Diseases – Rising temperatures can lengthen breeding seasons and expand the distribution of insects carrying vector-borne diseases, such as Lyme disease and West Nile Virus. For further details on the risk and health impacts from vector-borne disease see section 5.4 *Health*.

4.5 Acidification Impacts on Species Health

Broadly defined, ocean acidification is caused by the release of carbon dioxide into the atmosphere from burning fossil fuels (cars, buses, homes, industries) and when the carbon dioxide mixes with water, it becomes more acidic. The Friends of Casco Bay have documented a rise in the acidity of Casco Bay over the past 15 years.¹²²

Coastal acidification is driven by freshwater runoff from streams, rivers, and stormwater that have high levels of nutrients, such as nitrogen from pet waste, fertilizer, and wastewater, entering coastal waters. The excess nitrogen results in algal blooms and when they die, the process of bacterial decomposition consumes oxygen and releases carbon dioxide, creating unnatural acidic conditions for coastal habitats and wildlife. See Section 3: *Compromised Water Systems* for further details on algal blooms.

Coastal and ocean acidification can result in the inability of species that live in Casco Bay to survive and flourish due to two simultaneous factors: an increase in acidity and a decrease in carbonate availability.

Marine species with hard protective shells, including clams, lobsters, mussels, shrimp, oysters, scallops, sea urchins, and cold water coral, combine calcium and carbonate found in seawater in order to build calcium carbonate shells. Higher levels of carbon dioxide decrease the carbonate ion concentration in the water, making it difficult for marine life to grow healthy shells. As a result, these species have slower growth, thinner shells, and their mortality rates rise.¹²³

In Maine, 87 percent of the landings value of harvested or grown species comes from organisms that make calcium carbonate shells, suggesting that acidification may have significant ramifications for the health of Maine fisheries.¹²⁴ **Figure 4.13** shows recent data from

the Friends of Casco Bay indicating that levels of calcium carbonate, or shell building material, in Casco Bay are already not sufficient enough for organisms to build and maintain their shells. Under severe conditions, high acidity can dissolve calcium carbonate shells at a faster rate than they can be formed.

Additionally, more acidic marine environments compromise the health and life stages of many marine organisms. Many types of fish and invertebrate larvae are unable to develop properly or lose capacity to avoid predators under more acidic conditions.¹²⁵ Stunted growth or survival at the larval stage will eventually constrict the growth of adult populations.

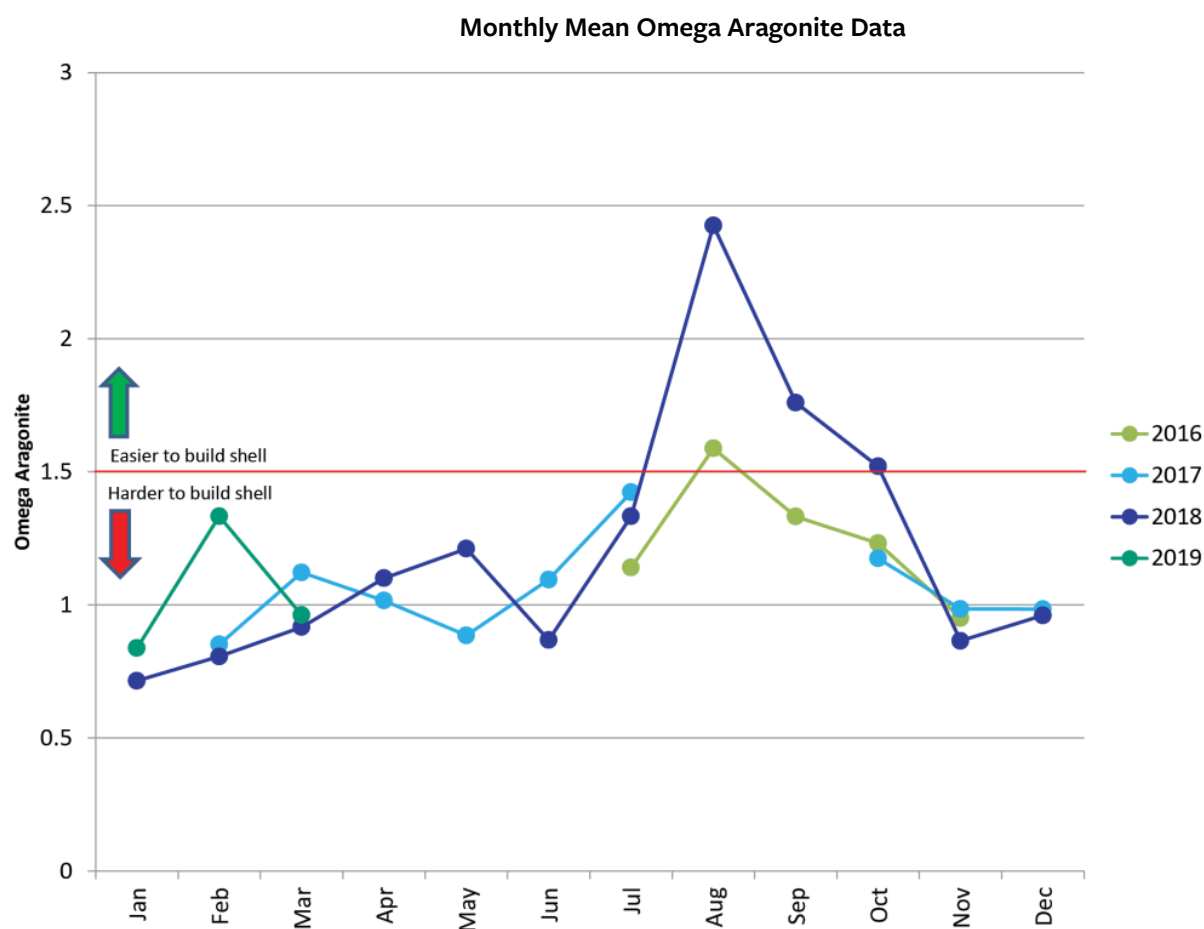


Figure 4.13. Monthly mean omega aragonite, the scientific term for the calcium carbonate saturation state, in Casco Bay from January 2016 through March 2019. Other than a few months in 2018, calcium carbonate has not been readily available for shell-building species. Source: Friends of Casco Bay, Casco Baykeeper (2019).¹²⁸

SECTION FOUR ENDNOTES

- 99 City of Portland. (2016). Portland Open Space Vision and Implementation Plan. Portland, ME.
- 100 City of South Portland. (n.d.) Parks Department. Retrieved from <https://www.southportland.org/departments/parks-recreation-aquaticspool/parks-department/>
- 101 South Portland Land Trust (n.d.) Mission. Retrieved from <https://www.southportlandlandtrust.org/what-we-do>
- 102 Bohlen, C., Stelk, M., Craig, M., & Gerber, C. (2013). Sea Level Rise and Casco Bay's Wetlands: A Look at Potential Impacts ([South] Portland Edition). Casco Bay Estuary Partnership, Muskie School of Public Service, University of Southern Maine. Portland, ME.
- 103 Bohlen, C., Stelk, M., Craig, M., & Gerber, C. (2013). Sea Level Rise and Casco Bay's Wetlands: A Look at Potential Impacts ([South] Portland Edition). Casco Bay Estuary Partnership, Muskie School of Public Service, University of Southern Maine. Portland, ME.
- 104 Slovinsky, P. (2019). State of Maine's Beaches in 2019. Maine Geological Survey. Augusta, ME.
- 105 **NOTE:** The Maine Beach Mapping Program provides updated shoreline data on changes in beach, dune, and dry beach dimensions. See the following reference for further details: Maine Geological Survey (2019). Maine Beach Mapping Program Shoreline Changes. Retrieved from https://www.maine.gov/dacf/mgs/hazards/beach_mapping/index.shtml
- 106 Casco Bay Estuary Partnership. (2015). State of the Bay 2015 Report. Portland, ME.
- 107 Casco Bay Estuary Partnership. (2015). State of the Bay 2015 Report. Portland, ME.
- 108 Bohlen, C., Blair, M., Boundy, V., Freshley, C., Sands, K. (2019). Nutrient Pollution in Casco Bay, Maine. Casco Bay Estuary Partnership, Muskie School of Public Service, University of Southern Maine. Portland, ME.
- 109 McGuire, P. (2017). Late-season toxic algae bloom closes most shellfishing areas in Casco Bay. Portland Press Herald. Retrieved from <https://www.pressherald.com/2017/12/06/toxic-bloom-closes-casco-bay-shellfish-industry/>
- 110 Breton, R. (2019). Longer 'red tide' outbreak impacting Maine shellfish industry. News Center Maine. Retrieved from <https://www.newscentermaine.com/article/news/longer-red-tide-outbreak-impacting-maine-shellfish-industry/97-f3421fa7-e4c7-4ced-a0c3-e63b20cd1130>
- 111 Casco Bay Estuary Partnership. (2015). State of the Bay 2015 Report. Portland, Maine.
- 112 University of Maine. (n.d.) Maine Invasive Species Network. Retrieved from <https://extension.umaine.edu/invasivespecies/>
- 113 Maine Department of Marine Resources. (n.d.) Historical Eelgrass Coverage Viewer. Retrieved from <https://maine.maps.arcgis.com/apps/MapSeries/index.html?appid=ac2f7b3d29b34268a230a060d6b78b25>
- 114 Casco Bay Estuary Partnership. (2015). State of the Bay 2015 Report. Portland, Maine.
- 115 Morley, J.W., Selden, R.L., Latour, R.J., Frolicher, T.L., Seagraves, R.J., Pinsky, M.L. (2018). Projecting shifts in thermal habitat for 686 species on the North American continental shelf. PLoS ONE. 13(5).
- 116 Kleisner, K.M., et al. (2017). Marine species distribution shifts on the U.S. Northeast Continental Shelf under continued ocean warming. Progress in Oceanography. 153: 24-36.
- 117 Morley, J.W., Selden, R.L., Latour, R.J., Frolicher, T.L., Seagraves, R.J., Pinsky, M.L. (2018). Projecting shifts in thermal habitat for 686 species on the North American continental shelf. PLoS ONE. 13(5).
- 118 Maine Department of Agriculture, Conservation, and Forestry (2017). Terrestrial Invasive Plant List. Retrieved from <https://www.maine.gov/dacf/php/horticulture/invasiveplants.shtml>
- 119 Nijhuis, M. (2013). How Climate Change is Helping Invasive Species Take Over. Smithsonian Magazine. Retrieved from <https://www.smithsonianmag.com/science-nature/how-climate-change-is-helping-invasive-species-take-over-180947630/>
- 120 University of Maine. (n.d.) Maine Invasive Species Network. Retrieved from <https://extension.umaine.edu/invasivespecies/>
- 121 US Environmental Protection Agency. (2016). What Climate Change Means for Maine. Retrieved from <https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-me.pdf>
- 122 Casco Bay Estuary Partnership. (2015). State of the Bay 2015 Report. Portland, ME.
- 123 U.S. Environmental Protection Agency. (n.d.). Effects of Ocean and Coastal Acidification on Marine Life. Retrieved November 2019 from <https://www.epa.gov/ocean-acidification/effects-ocean-and-coastal-acidification-marine-life>
- 124 Maine State Legislature; Maine Office of Policy and Legal Analysis; Bentley, Curtis; and Schneider, D. (2015). Report of the Commission to Study the Effects of Coastal and Ocean Acidification and its Existing and Potential Effects on Species that are Commercially Harvested and Grown Along the Maine Coast.
- 125 U.S. Environmental Protection Agency. (n.d.). Effects of Ocean and Coastal Acidification on Marine Life
- 126 Slovinsky, P.A. & Dickson, S.M. (2011). Coastal Sand Dune Geology: Willard Beach, South Portland, Maine. Maine Geological Survey. Augusta, ME.
- 127 Murphy, Z. et al. (2019). "Gone in a Generation." Huffington Post. Retrieved from https://www.washingtonpost.com/graphics/2019/national/gone-in-a-generation/?utm_term=.452f1f2ceo6d#lobster
- 128 Friends of Casco Bay. (2019). Casco Bay Matters: Advancing the conversation—and action—on climate change. Casco Baykeeper. South Portland, ME.

5. Socioeconomic Exposure, Risk, and Vulnerability

Climate hazards will likely create repercussions for our local economy, livelihoods, housing security, food security, and public health.

As adjacent coastal cities in Cumberland County, Portland and South Portland are closely connected in many ways by their populations, economies, institutions, and organizations. The two cities make up the two largest cities in the Greater Portland Metropolitan Area (**Figure 5.1**)—an area comprising of three counties and nearly half the state’s population. While South Portland’s demographics more closely resemble Maine’s as a whole,

both cities’ populations continue to shift towards what you typically see in urban areas: younger, more educated, and more racially and ethnically diverse (**Table 5.1**).

Both Portland and South Portland have vibrant and diverse economies. The number of jobs in Portland now exceeds its population, making up 39 percent of jobs in Cumberland County, 12 percent of jobs in Maine, and overall a significant economic driver for the region.¹²⁹ Portland’s leading sectors by number of jobs include healthcare and social assistance; finance and insurance; and professional, scientific, and technical services, followed closely by accommodation and food services. Likewise, South Portland’s leading sectors include

Population Density in the Greater Portland Area

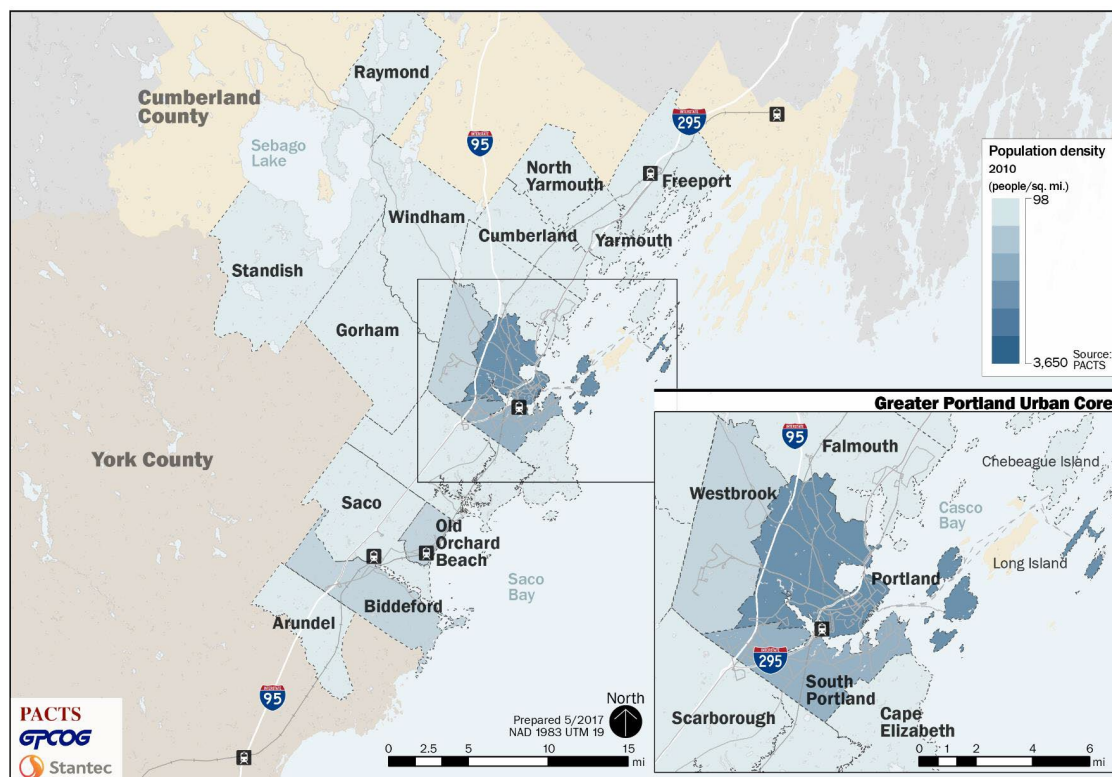


Figure 5.1. Population density in the Greater Portland area (2010). Figure Source: PACTs, GPCOG & Stantec (2017).¹⁸⁴

retail; healthcare and social assistance; and finance and insurance, also followed closely by accommodation and food services. Despite robust economies, both cities have seen the proportion of households living below the poverty rate roughly double since 2000.¹³⁰

Climate hazards not only bring risks to Portland and South Portland's built and natural environments, but are also likely to create repercussions on these social and economic aspects—including the local economy, livelihoods, housing security, food security, and public health. Sea level rise and storm surge may inundate some of the cities' commercial and industrial areas; affect the cost of doing business; influence both property values

and housing affordability; and create challenges in food access. Likewise, higher temperatures, vector-borne diseases, and poor air quality may further affect our public health.

The potential impacts, outlined in the following sections, cross regional, local, household, and individual scales. It is important to note that the burden climate change brings on these many facets will not necessarily be felt equally. How we can continue to strive towards social equity in our communities thus becomes an increasing concern. Our quality of life and ability to grow into even more vibrant, prosperous, and equitable cities will require addressing the potential impacts in the following section.

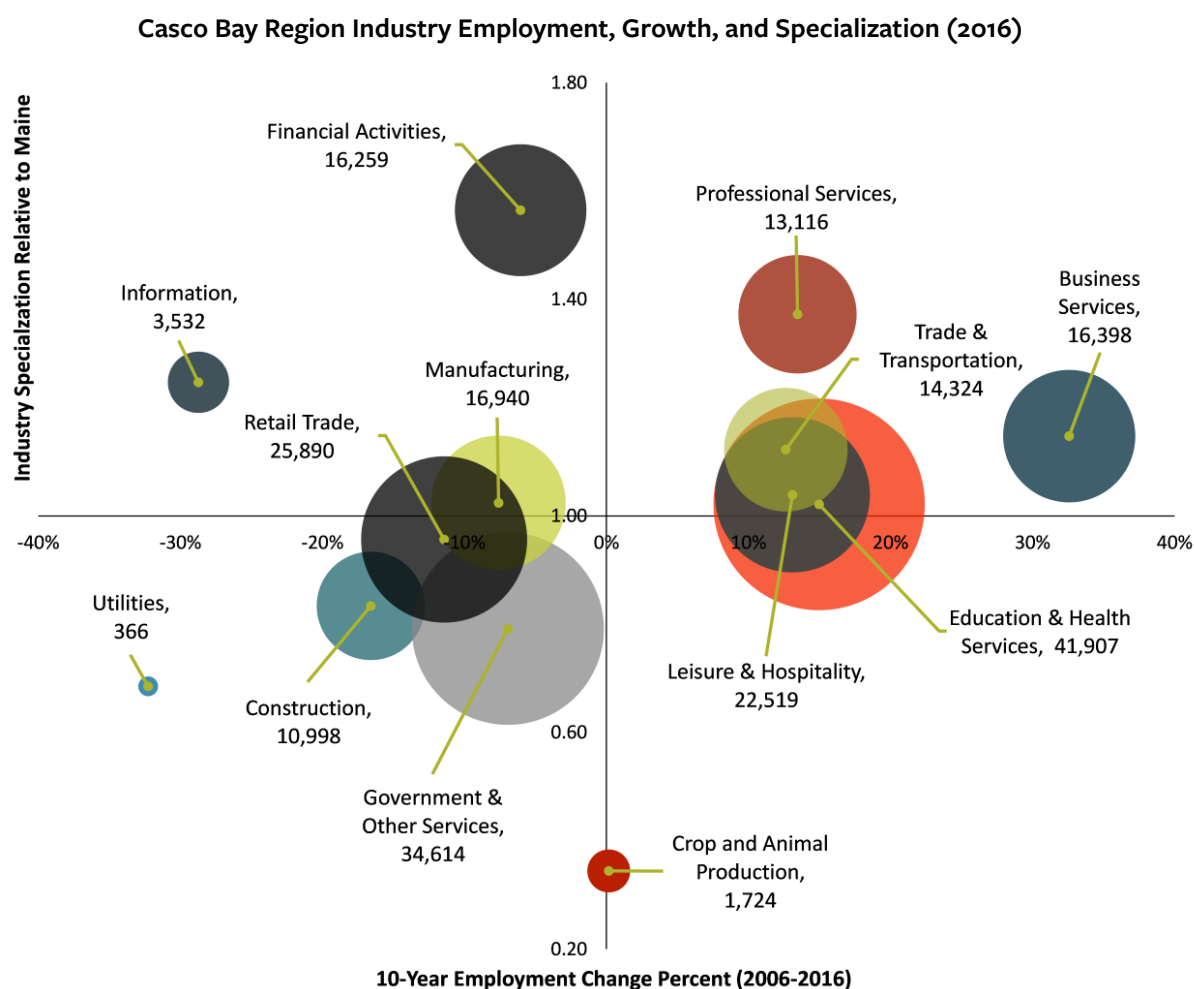


Figure 5.2. Industry employment, growth, and specialization for the Casco Bay region (2016). The bubble size is proportional to the amount of employment. The X-axis plots the 10-year percent change in employment. The Y-axis plots specialization, which is measured relative to the state of Maine and expressed as a location quotient. A value greater than 1 indicates specialization in the region and a value less than 1 indicates a smaller relative share of the industry in the region. Figure source: Maine Center for Business and Economic Research and rbouvier consulting (2017).¹⁸⁵

Population Characteristics

Characteristic	Portland	South Portland	Maine
Population	66,417	25,606	1,338,404
Population Density (people per square mile)	3,107	2,086	43
Median Age	36	40.8	44.6
Percent People Over Age 65	13.7%	15.4%	20.6%
Percent People Under Age 18	16.5%	18.3%	18.7%
Percent People of Color	18.9%	7.5%	6.9%
Percent Foreign-Born	13.4%	5.7%	3.6%
Percent with Bachelor's Degree or Higher	47.6%	42.9%	30.3%
Median Household Income	\$51,430	\$59,515	\$53,024
Median Property Value	\$261,100	\$235,700	\$179,900
Percent Homeowners	44%	62%	72%
Poverty Rate	18.3%	12.4%	11.1%

Table 5.1. A selection of population characteristics for Portland, South Portland, and Maine.¹⁸⁶

5.1 Local Economy and Livelihoods

The impact climate change will have on regional or local economies is difficult to predict—particularly when tied to global markets and supply chains. Climate change is expected to impact the growing capacity of a large range of natural resources globally, thereby affecting the price of feedstocks, fodder, and food, and in turn altering the decision-making calculus for a number of industries. Likewise, disruptions in IT systems, transactions, and product distribution due to power outages, flooding, or road closures has significant economic costs. The Maine Department of Transportation reports that a trucker incurs \$350 of added cost for every hour of unscheduled delay, and on average, poor roads in Maine cost motorists \$263 million per year on average (2009 USD).¹³¹

IMPACT TO ECONOMIC SECTORS

While the impact of climate change on most economic sectors in Portland and South Portland remains unknown (and is outside the scope of this assessment), the impact on the “ocean economy” has been explored for the Casco Bay region. The ocean economy—which includes species harvesting and processing, marine transportation, marine construction, ship and boat building, and tourism

and recreation—accounts for an estimated 4 percent of gross regional product (GRP) in the Casco Bay watershed region, and 8.4 percent of total employment.¹³²

Harvesting, Processing, and Packaging – Harvesting, processing, and packaging of marine species accounts for 11 percent of the Casco Bay ocean economy GRP (\$76 million in 2016), and approximately 1,139 jobs. Although this sector makes up a small portion of the full economy of the Casco Bay region, it holds strong social and cultural importance, including a draw for coastal tourism.

The extensive number of feedback loops and uncertainties in ecosystem dynamics make it largely infeasible to model the impact of climate change on individual commercial marine species. Nevertheless, scientists from the National Oceanic and Atmospheric Administration (NOAA) have published a recent assessment of the climate exposure, biological sensitivity, and potential change in species distribution for a number of marine invertebrates and vertebrates.¹³³ Twelve of the species evaluated are of commercial significance to Casco Bay, and ten of those are predicted to have an overall negative response to climate change within the Northeast Atlantic region. The Maine Ocean and Coastal Acidification Partnership (MOCA) has been

further working to expand the state's understanding of the effects of ocean acidification, in particular, on commercially viable species. See *Section 3: Environmental Exposure, Risk, and Vulnerability* for further details.

If populations begin to collapse, growth rates shift, or species distributions change, fisheries will need to alter management regimes to adapt. If supply decreases for particular species, landing prices will likely increase to compensate. Likewise, higher safety costs from more extreme storms, rising fuel prices, and needing to travel further distances to reach new locations for their catch can all contribute to these rising costs. Although consumers may pay higher prices, they may also switch to alternative species (or alternative proteins), leading to a decrease in revenue for these industries. There is also the risk that a particular stock and fishery would collapse altogether, resulting in loss of jobs and revenue if substitution was not readily feasible.

Wallace et al. (2017). also highlight the equity implications of changes in the harvesting and processing sector due to climate change: more minimally-equipped, smaller operations that have less flexibility in their fishing operations will not fare as well as larger, more mobile operations that have greater access to financial capital and substitute fisheries. This may lead to the consolidation and dominance of fewer, larger operations.¹³⁴

Other Marine Industry – Marine transportation, which primarily consists of shipping and warehousing, makes up 18 percent of the gross regional product (GRP) of the Casco Bay ocean economy, followed by marine construction of port-related infrastructure (1%) and ship and boat building (0.4%). Of these three sectors, marine transportation is likely to be most impacted by climate change. As the polar ice cap continues to melt, new shipping lanes in the Arctic may become increasingly navigable, particularly in summer months. Using the Northwest passage as opposed to the Panama Canal will make the trip from Asia to Europe over a week shorter, with Portland the first port on that course.¹³⁵ With these new routes come substantial new risks and uncertainties.

Additionally, stronger weather patterns, sea level rise, and storm surge will likely have a significant effect on marine industries. Large storms will likely lead to

disruptions in shipping routes and delays in transit, leading to increased costs. Likewise, a substantial amount of coastal infrastructure—including industrial or commercial shipping and storage, passenger and recreational transport facilities, as well as boat engineering, fabrication, and assembly facilities—may need to be restructured to accommodate for rising sea levels. **Figure 2.7** shows the projected impact of sea level rise on Portland and South Portland's waterfronts, including inundation of the Portland piers and the areas surrounding South Portland's petroleum terminals.

Tourism and Recreation – Tourism and recreation makes up 70 percent of the gross regional product of the ocean economy in Casco Bay.¹³⁶ Studies suggest that tourism and recreation will likely be affected both positively and negatively due to climate change—with more out-of-state visitors traveling to Maine to escape increasingly uncomfortable summer weather. Besides effects from crowding, tourism may be impacted by degradation of coastal infrastructure from sea level rise and storm surge, beach erosion and decreased water quality (although Willard Beach and the East End Beach are predominantly utilized by residents), as well as decreases in recreational fishing due to the decline in cold water recreational fishing species.

IMPACT TO COMMERCIAL AREAS

A number of commercial and industrial areas within Portland and South Portland are particularly vulnerable to climate impacts. In Portland, businesses and the waterfront industry along Commercial Street and the piers/wharfs are particularly vulnerable to sea level rise and storm surge, as are the businesses and industry located in the Bayside area (**Figures 2.7** and **2.8**). See section *Section 5.2 Housing and Built Environments* for further analysis of the impacts to these areas specifically. In South Portland, land surrounding the oil terminals is most vulnerable to sea level rise and storm surge in the near term, along with small portions of commercial activity in Knightville, particularly around Thomas Street and the South Port Marina, and along the waterfront in Ferry Village. Any commercial activity in Ferry Village will become increasingly vulnerable to sea level rise and storm surge towards the end of the century.

The vulnerability of these areas will likely increase overhead, operations, and maintenance expenses for

businesses and industries, making it more costly to operate in these specific areas. Any businesses that choose to close or relocate outside the cities will create repercussions for the cities' immediate job markets, economic vibrancy, and tax base.

In addition to the localized impacts from sea level rise and storm surge, the increasing risk of power failures—from high winds, storms, flooding, or high heat—will have cascading economic impacts for businesses across the two cities. Whereas large institutions, such as Maine Medical Center, are equipped with backup generators, most businesses will face significant economic costs from IT disruptions, lost transactions, and temporary business closures. This impact is particularly acute for the cities' restaurants and food industry due to the perishable nature of their inventory.¹³⁷ In a Massachusetts-based study, 70 percent of over 900 businesses interviewed across 20 municipalities voiced concern about the reliance of the power grid and the risk of power failures for their business.¹³⁸ Businesses in Portland and South Portland are similar in profile to those in the study, and are exposed to similar power failure risk from storms. Extreme weather will also have a detrimental impact for commercial businesses reliant on pedestrian traffic.

LIVELIHOOD VULNERABILITY

Residents whose livelihoods rely on the sectors discussed above—specifically marine species harvesting, processing, and packaging, as well as marine transportation—may experience some of highest livelihood vulnerability tied to a specific sector. Changes in species distribution and abundance, as well as added operations and maintenance costs for waterfront infrastructure may create long-term impacts that lead to closures or consolidation. In a better case scenario, climate change may alter the scope of these industries (as well as tourism and recreation, and marine construction) without leading to any job loss for individuals working in these sectors.

More significant risks will come for small business owners who are unable to weather severe impacts from inventory or property loss, as well as self-employed individuals who may lose substantial income if a climate hazard prevents working for a period of time. A significant number of employees within Portland and South Portland commute into the cities on a daily basis (**Figure 5.3**), increasing the risk that any road closures

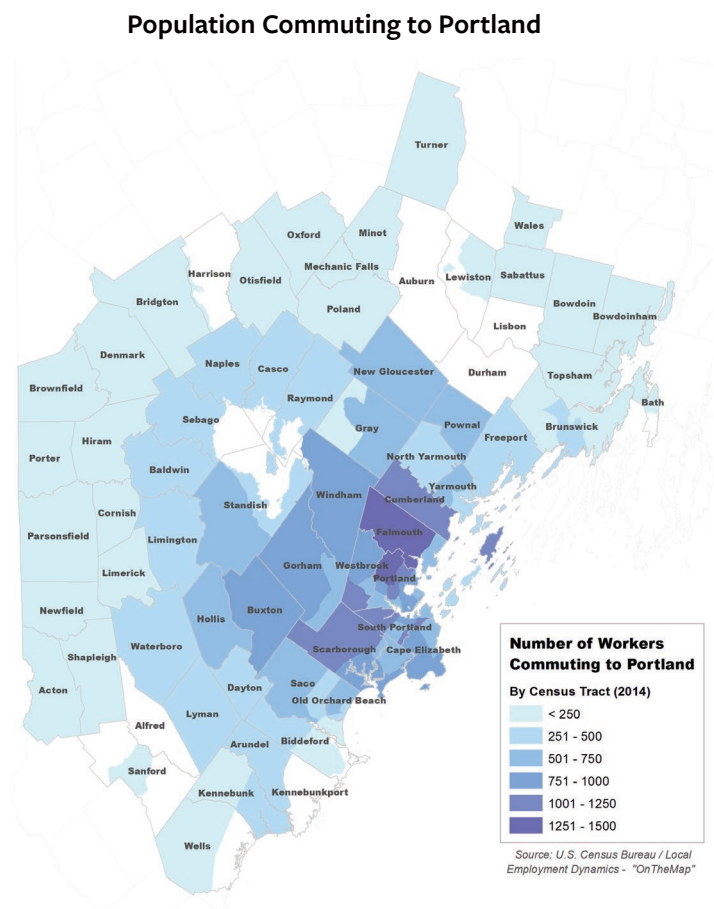


Figure 5.3. Number of workers commuting to Portland. Figure source: Portland's Plan 2030 (2017).

will affect business continuity. Business closures, road closures, and interruptions in public transportation can in particular lead to significant loss of income for residents relying on hourly wages and/or tips. Employees who work in Portland's large food services industry may be particularly hard hit in these scenarios.

5.2 Housing and Built Environments (Economic and Social Implications)

The real estate market, housing affordability, and the quality of the cities' housing stock are all likely to be affected by climate change. Cities have begun documenting the ways in which property values have already begun to shift, creating higher demand for land

at higher elevations and an increasing need for higher density to compensate for lower elevations that may be consumed by frequent flooding. Any substantial loss or damage to the cities' housing stocks due to storms or flooding will ultimately compound with ongoing stresses for housing security, affordability, and quality which may become increasingly important concerns over the course of the next thirty years.

Participants in the One Climate Future Resilience Workshop, hosted in April 2019, highlighted that a large number of Portland's public and subsidized housing units, in particular, are located in the Bayside neighborhood, which is likely to see increasing risk of flooding in the coming years. All but a few Portland Housing Authority (PHA) properties and their adjacent access roads are at elevations safe from flooding up to 3.3 feet of sea level rise, and PHA is working to increase the resilience of its portfolio through federal repositioning programs.¹³⁹ Nevertheless, in addition to 1,000 units of PHA housing, PHA supports another 2,000 families through Housing Choice Vouchers. These families must find housing in the market place—a process that becomes increasingly difficult if sea level rise constricts the housing market, availability drops, and prices rise. Families that can no longer afford to live in Portland or South Portland will be driven further outside the cities, limiting job access, requiring higher commuting costs (in both direct expenses and time), and creating greater vulnerability for climate-related transportation interruptions. Maintaining housing security, affordability, and quality within the cities thus becomes a priority for the region's resilience.

DIRECT ECONOMIC COSTS FROM PROPERTY DAMAGE

Flooding, predominantly from sea level rise and storm surge, poses the most direct economic impacts to Portland and South Portland through infrastructure, building, and property damage. A number of studies have attempted to quantify this impact.

In 2013, Catalysis Adaptation Partners modeled the economic vulnerability of Portland's Commercial Street waterfront area using the COAST (COastal Adaptation to Sea level rise Tool) approach and software. This methodology calculated potential building damage over time, assuming a scenario of two feet of sea level rise by 2050 and four feet of sea level rise by 2100. **Table 5.2** summarizes the expected damage costs to buildings from the 100-year storm in the given year, as well as the accumulated costs for buildings and improvements from all storms (due to sea level rise and storm surge) between 2013 and the given year. Modeling suggests that based on the 2013 buildout of the Commercial Street waterfront area, Portland is projected to see \$26.4 million in damages to buildings in that area from a single 100-year storm in 2100. Furthermore, at the time of the modeling \$46.4 million in building value was located on parcels that are predicted to be permanently inundated by the daily high tide (MHHW) if no action is taken.

Likewise, in 2012 the New England Environmental Finance Center at the University of Southern Maine used the COAST approach and software to model the impact of sea level rise and storm surge on real estate in Portland's

Estimated costs of building damage: Commercial Street Waterfront

Year	Damage from a single 100-year storm	Cumulative damage from all storms 2013 – given year	Value of buildings on permanently inundated parcels
2050	\$16.0 million	\$32.9 million	\$8.7 million
2075	\$25.2 million	\$69.6 million	\$11.9 million
2100	\$26.4 million	\$111.5 million	\$46.4 million

Table 5.2. COAST model output for the Portland Commercial Street waterfront area. Data show the estimated costs of potential building damage for the 100-year storm in 2050, 2075, and 2100; the cumulative damage from all storms from 2013 to the designated year; and the value of buildings on permanently inundated parcels by the given year if no action is taken. All modeling assumes a scenario of four feet of sea level rise by 2100 above 2013 mean higher high water (MHHW). For further details see Catalysis Adaptation Partners (2013).¹⁸⁷

Back Cove area. Based on a 2012 buildout of the Back Cove area, the study suggested that Portland could see \$447 million to \$3.68 billion in damage to Back Cove real estate from a 100-year storm with 1.6 feet of sea level rise and 5.9 feet of sea level rise above MHHW, respectively.¹⁴⁰

While looking thirty to eighty years into the future, the modeling underscores the sheer magnitude of the economic impact and how that cost will accumulate over time if no action is taken. Many studies have begun emphasizing the intergenerational environmental justice concerns of a “wait and see” approach, stressing that any tax dollars saved now for avoided capital investments will ultimately lead to larger and more simultaneous costs for future generations that could be financially catastrophic.

IMPACTS ON PROPERTY VALUES, TAX BASE, AND MUNICIPAL FUNDING

New research from Columbia University underpins the impact that frequent flooding may have on the decline of property values. For properties in the southeast United States that were expected to flood completely during a tidal flood (king tide) in the next fifteen years, the study shows their property values already declining by \$3.08 per square foot annually.¹⁴¹ Homes within a quarter mile of a road that will flood completely in 15 years had likewise begun to decline in value by \$3.71 per square foot annually—roughly \$5,565 per year for a 1,500 square foot home. First Foundation and Columbia University have since applied the methodology to eighteen states, with results suggesting that properties in Portland and South Portland have lost a total of \$701,833 and \$460,033, respectively, between 2005 and 2019.¹⁴² These losses are from years with relatively minimal nuisance flooding when compared to expected future flooding.

High-risk properties are also more likely to be put on the market with each passing year, and the study notes the trend in which the purchase price continues to decline as fewer people want to buy high-risk properties. While wealthier homeowners, businesses, or neighborhoods may have more cumulative value to lose, those with more limited financial means risk losing a much larger portion of their wealth. Lower income homeowners become forced to weigh the tradeoff between costly flood-proofing investments (as discussed in the next section) and defaulting on loans, and homeowners with

rapidly devaluing properties can be left with mortgages that exceed the value of their homes.¹⁴³ Financial risk is then extended to lenders, particularly small local banks concentrated in coastal areas who carry a large number of these risky mortgages. Real estate investors and developers can also risk insolvency if a large portion of their portfolios are on the coast.

In many more ways, changes in property value have implications beyond the individual property (**Figure 5.4**). Neighborhoods in affected areas can begin to lose value as residents move out or adjacent properties decline in quality or value. In Portland and South Portland, it will be important to consider the ways in which these trends increase market affordability in specific areas, but in doing so may exacerbate patterns where residents with fewer financial resources increasingly live in areas with higher flood risk. Furthermore, full communities

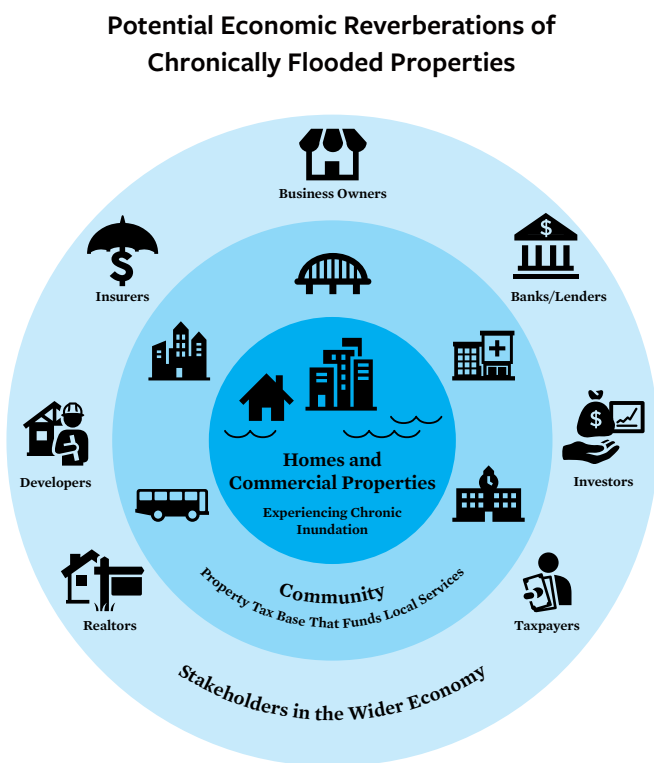


Figure 5.4. Properties lose direct value with chronic flooding, but the economic implications affect the broader community. Municipalities lose tax base to fund public services and many other sectors such as banks/lending institutions, developers, and insurance companies—as well as tax payers—may feel the economic repercussions. Figure source: Union of Concerned Scientists (2018).¹⁸⁸

feel the impact of declining property values when municipalities are forced to either raise tax rates to compensate for lower tax bases, or reduce public funding for transportation, schools, emergency services, or other public goods. Residents who most rely on these public services will be disproportionately affected.

Lastly, the ability of the cities to access additional capital, specifically through bond markets, will depend on municipal credit ratings—a factor that is affected by both the cities’ financial health and exposure to risk. If the financial health of the cities were to decrease as exposure to chronic flooding increases, the cities may face more limited options for financing resilience investments, a vicious circle that could leave the cities increasingly vulnerable to flood risk.

ADDED HOUSEHOLD COSTS

A number of factors driven by climate change will likely increase household costs for both renters and homeowners. Rising costs for flood insurance contribute to higher household costs for homeowners in flood risk areas. The average yearly flood insurance premium in Maine under the National Flood Insurance Program (NFIP) is \$1,065, 52 percent higher than the national average due to the relative higher risk that many Maine communities face. Recent updates to FEMA floodplain designations in Maine communities have indicated potential increases in insurance rates for many homeowners, if and when adopted. While the NFIP risk rating system is currently under revision, it is unclear the average effect it will have for Maine homeowners when the new system rolls out in October 2020.¹⁴⁴

While flood insurance premiums are an added expense, so too are building retrofits and repairs. Many home and business owners are choosing to elevate or increase the freeboard on their buildings, as well as invest in other forms of wet and dry floodproofing, both to decrease insurance premiums and to reduce the risk from flood damage in the future. Damage to buildings from floods, as well as high winds in heavy storms, are expected to increase household financial burden due to climate change. Residents have expressed concern that extreme weather and flooding are already beginning to drive up the costs for buildings to operate effectively.¹⁴⁵ They further note that most older buildings—without investing

in retrofits—lack the capacity to maintain habitable indoor temperatures in cold weather or high heat during an extended power outage.

Based on 2013-2017 data, roughly 11% of homeowners and 24% of renters across Portland and South Portland are “extremely cost-burdened” by housing costs, meaning such costs are 50% or more of household income.¹⁴⁶ (Roughly 28% of homeowners and 48% of renters pay 30% or more in housing costs.) These residents are likely to be most vulnerable in facing higher housing expenses, and least able to retrofit their homes to accommodate increased climate risk.

5.3 Community Resources and Food Security

Portland and South Portland have a wealth of social service organizations, healthcare facilities, mental health services, community centers, places of worship, public libraries, and City services that support the health and wellbeing of residents in a wide number of ways. Such formal resources, as well as the informal social networks fostered in formal and informal gathering spaces, prove crucial to supporting the resilience of any community.

Increasing stresses from climate change—whether financial, physical, or emotional—will likely expand the need for social services and resources in the coming years. Residents likewise point to the fact that Portland and South Portland may continue to become a settlement location for refugees, and in particular climate refugees, as people are displaced due to climate hazards nationally and globally.¹⁴⁷ Organizations and City services risk becoming overstrained and ineffective without deliberate strategies to consider this expanded need.

While increasing this need, climate hazards may simultaneously limit residents’ ability to access services and resources. **Table 5.3**, for example, documents the number of addresses that become inaccessible to emergency medical service providers at various scenarios of sea level rise. The table also documents the estimated extent of investment needed to road infrastructure to maintain accessibility.

Inaccessible Addresses and Costs for Road Upgrades

Sea Level Rise	Number of Inaccessible Addresses		Costs to Upgrade Roads (MM USD)	
	Portland	South Portland	Portland	South Portland
2 feet	43	0	\$2.85	\$0.05
3.3 feet	126	40	\$8.41	\$0.71
6 feet	697	373	\$23.72	\$8.71

Table 5.3. Number of addresses that are inaccessible to emergency medical service providers under various sea level rise scenarios, and the estimated costs to upgrade roads to prevent inaccessibility. Inaccessible addresses are those adjacent to roads that are inundated by any depth of water at the particular sea level increase on top of the highest annual tide. While roads will not be completely impassable in every case, the data suggests the extent of roads that have a high risk of being impassable. Data from the Maine Coastal Risk Explorer Project.¹⁸⁹

Challenges to emergency response highlight a direct and immediate vulnerability in thinking about climate hazards. Storms, flooding, and even high heat can also limit our ability to access resources that ensure health and wellbeing on a day-to-day basis—whether that’s healthy food, childcare, routine health services, a sustainable income, or a sense of community and support. Participants in the One Climate Future Resilience Workshop, for example, voiced concern that much of Portland’s social service network that supports some of Portland’s lowest income households is also located in Bayside, an area vulnerable to sea level rise and flooding.¹⁴⁸

The full scope of resources and services that residents depend on varies greatly based on the context of the

neighborhood and each household. The case study included below begins to scratch the surface in terms of understanding how community assets in the Bayside area may be affected by flooding, and the compounded impact of assets being affected simultaneously.

While outside the scope of this assessment, this exploratory case study could benefit from being carried out in further depth and for neighborhoods across both cities—and ideally through a process led by residents who could discuss and describe the formal and informal resources they rely on. Visualizing this network and understanding potential gaps and vulnerabilities could help inform how resource “nodes” (or “resilience hubs”) can support and augment the formal and informal resources currently in neighborhoods across both cities.

Case Study: Bayside Community Assets

The social and economic impact of a climate hazard tends to be additive, or even multiplicative, when full neighborhoods (or furthermore, cities or regions) are affected simultaneously. The extent of impact comes not only from direct property or infrastructure damage, but also through the immediate and longer-term loss of access to resources, services, social networks, or other community assets that support health and

wellbeing. The full extent of this impact in any event is complex and nuanced, and yet looking at the types of community resources within an impacted area can give a sense of how impacts to certain properties may create more permeating challenges for neighborhoods and communities. The following case study looks at Portland’s Bayside area in a flood scenario with 3.3 feet of sea level rise—a level that is possible by the year 2050.

Figure 5.4. shows the roads in the Bayside area that would be “inundated” by any amount of water covering the surface of the road at 3.3 feet on top of the highest annual tide (red dashed lines). While not all of these road segments would be impassable, the map identifies the segments that are most likely to be obstructed under such conditions, which most significantly include Marginal Way, Somerset Street, Fox Street, Anderson Street, and the connection between Franklin and I-295. **Figure 5.4** also highlights the buildings that would be impacted by this level of flooding (yellow building outlines). It likewise notes the number of addresses

in each Census block group that would lose access to emergency medical service (EMS) providers, and notes the estimated cost to upgrade roads to ensure that access for EMS providers can be maintained. Collectively, **Figure 5.4** begins to explore the extent of the potential physical impact, as well as how it creates immediate access concerns during emergency response.

In the longer-term aftermath, **Figure 5.5** looks further at sets of community resources within the area—specifically schools, grocery stores, community centers and/or public libraries, government facilities, places of worship, health

Vulnerable Bayside Community Assets - Investigation 1



Figure 5.5. Flood vulnerability in the Bayside area. The map shows roads that would be inundated under 3.3 feet of sea level rise on top of the highest annual tide, as well as properties that may be affected. White circles denote the number of addresses in each Census block that would lose access to emergency medical service providers, as well as the cost required per Census block to upgrade roads to prevent loss of access.¹⁹⁰

facilities, and open space. These resources are often important to a community's fabric, providing access to food and household supplies, healthcare services, access to information, as well as free public spaces that are often key to creating and strengthening social relationships. The loss of a number of these resources in close proximity to each other can exacerbate the harm caused by an extreme event. For example, flooding has the potential to affect access to three grocery stores in the area—which has broader implications for food delivery and access for the city. At the neighborhood scale, residents who do not have access to a private

vehicle may have trouble reaching an alternative grocery store at a further distance. Beyond grocery stores, the mapping exercise highlights a significant number of healthcare and social service locations, as well as a school and community center that may be affected. When daily life becomes significantly disrupted, the support and constancy from neighbors and community resources becomes increasingly important. Losing this social fabric is one of the most significant socioeconomic vulnerabilities associated with climate hazards, and is particularly acute when extreme events lead to community displacement. ■

Vulnerable Bayside Community Assets - Investigation 2



Figure 5.6. Flood vulnerability for a set of community assets in the Bayside area in Portland. Flooding across a neighborhood can have significant repercussions when a number of community resources—such as schools, grocery stores, community centers, health facilities, libraries, and open space—are closed or compromised for an extended period of time.¹⁹¹

FOOD SECURITY

Our access to healthy and affordable food in Portland and South Portland may be increasingly affected by climate change. Food security means that “all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for an active and healthy life,” as defined by the United Nations’ Committee on World Food Security. A city’s food system expands well beyond its borders, and includes the integration of agriculture and food harvesting, production and processing, distribution, as well as food access. A number of studies now point to the ways climate change could drive up global food costs—from damage to crops, new pests, and water scarcity—in addition to higher fuel prices and higher global food demand.¹⁴⁹ The impacts of these higher costs are likely to have rippling effects through global, regional, and local food systems.

Food Sourcing, Growing, and Harvesting – On average, 90 percent of food consumed by Mainers comes from outside the state.¹⁵⁰ At any particular time, certain food sectors may be affected by climate shocks outside Maine; likewise, food shipments into the state can be disrupted from extreme weather. Because of the fragmented nature of supply sourcing, however, it is unlikely that Portland or South Portland would experience comprehensive supply shortages, unless widespread fuel shortages were to occur. Nevertheless, food research groups continue to advocate for strengthening regional food production in Northern New England and Maine as a means to advance both the sustainability and resilience of local food systems.¹⁵¹

Climate change is also expected to impact food grown and harvested locally in Maine. Agriculture, aquaculture, and fisheries contribute to the 10 percent of food sourced within the state—with potatoes, dairy products,

eggs, wild blueberries, apples, lobster, herring, mussels, and farmed salmon being some of the primary food commodities.¹⁵² Roughly 8,000 farms (approximately 700 of which are in Cumberland County) produce 80 different crops. Although many people believe that Maine’s agriculture will benefit from a longer growing season, this opportunity is in many ways countered by detrimental climate impacts. Warmer temperatures bring new pests to Maine and allow current pests to reproduce more within a single growing season.¹⁵³ Temperature increases may also decrease yields for some of Maine’s signature crops that grow best in cooler climates (such as potatoes), and unseasonably warm springs can cause fruit trees and other perennial crops to bloom before the last frost, leading to freeze damage. Apple harvests in 2016 were low, for example, because trees blossomed too early throughout much of Maine.¹⁵⁴ Climate change is also expected to bring heavier, more sporadic rain events that damage crops, increase soil erosion and nutrient runoff, and prevent soil from retaining moisture. A lower capacity to retain water combined with warmer and drier summers can be particularly problematic for much of Maine’s unirrigated cropland. Without new management approaches, these vulnerabilities are likely to strain the economic sustainability of Maine’s farms.

Likewise, rising water temperatures and acidification are impacting the health and distribution of species in the Gulf of Maine, with uncertain implications for fisheries and aquaculture along Maine’s coast. In a recent study conducted by NOAA, ten of twelve marine species with commercial significance to Casco Bay showed an overall negative response to climate change within the Northeast Atlantic region.¹⁵⁵ See sections 4.4 *Shifting Habitats: New Pests and Invasive Species*; 4.5 *Acidification Impacts on Species Health*; and 5.1 *Local Economy and Livelihoods* for further details on climate change impacts to fisheries and aquaculture.

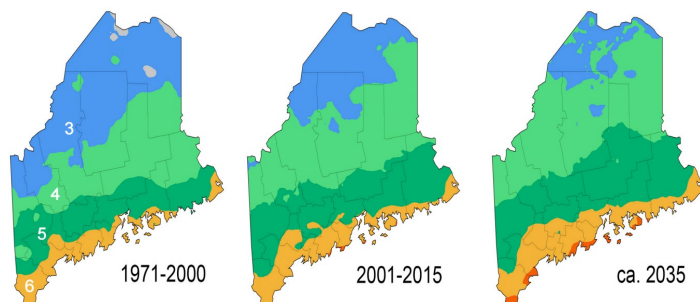


Figure 5.7. Recent, current, and future projected plant hardiness zones, which are shifting northward in Maine due to warmer temperatures. Zones are labeled in the left map. Figure source: University of Maine, Maine Climate and Agriculture Network. Data from PRISM Climate Group, Oregon State University.¹⁹²

Food Processing – The Greater Portland area hosts a significant number of food processing and manufacturing facilities, which make up a sector targeted for further growth. Because most facilities focus on a single product (and most food consumed in Maine is sourced outside the state), interruptions in production or business closures due to climate hazards would have an economic impact for the cities, but create relatively minimal vulnerability for local food availability. Milk processing, however, tends to be one exception. Because of its high level of perishability, milk tends to be sourced primarily from regional processors. Two of Maine’s four milk processing facilities—Oakhurst Dairy and H.P. Hood—are located in Portland. The H.P. Hood facility could be vulnerable to sea level rise or storm surge, but only in very high or extreme scenarios. The Oakhurst Dairy site does not show any notable flood risk.

Food Distribution – A significant number of food wholesalers and distributors are located within the Greater Portland area; most within the two cities, however, are primarily for single products, such as

fish and seafood or beer and wine.¹⁵⁶ Supermarket warehouses and distribution centers are primarily located outside of the two cities, except for the Hannaford Distribution Center at the Rumery Industrial Park in South Portland. This location does not suggest any risk from sea level rise or storm surge. Even if distribution centers are not affected, however, nearly all food products travel to retail locations by truck, and road closures can prevent food delivery. In some cities food distribution trucks are not considered emergency vehicles; case studies illustrate the ways in which these regulations have posed food delivery problems during emergency travel bans or road closures.¹⁵⁷

Portland and South Portland have a wide array of small groceries and food markets, and approximately eleven major stores, or supermarkets, that are over 1,000 square feet. Five of the eleven supermarket locations show vulnerability to sea level rise and storm surge, particularly at Intermediate-High, High, and Extreme scenarios (**Table 5.4**).

Flood Vulnerability of Portland and South Portland Supermarkets

Supermarket	Sea Level Rise Scenario (on top of Highest Astronomical Tide)					
	1.2 ft	1.6 ft	3.9 ft	6.1 ft	8.8 ft	10.9 ft
Hannaford – Riverside (787 Riverside St, Portland)						
Hannaford – Back Cove (295 Forest Ave, Portland)						
Hannaford – Gorham Road (415 Philbrook Ave, S. Portland)						
Hannaford – Mill Creek (50 Cottage Rd, S. Portland)						
Shaw’s – Northgate Plaza (91 Auburn St, Portland)						
Shaw’s – Bradley’s Corner (1364 Congress St, Portland)						
Shaw’s – Mill Creek (180 Waterman Dr, S. Portland)						
Whole Foods – Bayside (2 Somerset St, Portland)						
Trader Joe’s (87 Marginal Way, Portland)						
Save a Lot (268 St John St, Portland)						
Portland Food Coop (290 Congress St, Portland)						

Table 5.4. Five of eleven supermarkets in Portland and South Portland show vulnerability to sea level rise and storm surge. Dark yellow indicates full inundation of the site; medium yellow indicates some flooding of the site; light yellow indicates smaller patches of flooding to the parking lot or adjacent streets.

Food Access – Beyond closures and interruptions to food processing, distribution, and retail, climate change can impact food access at a household level. As of 2017, 12.2 percent of residents in Cumberland County were food insecure, and 16.6 percent of children.¹⁵⁸ Participants in the *One Climate Future* Resilience Workshop emphasized that the South Portland Food Cupboard and area resources are utilized monthly by many residents, in addition to the USDA Supplemental Nutrition Assistance Program (SNAP). If food costs rise, as predicted, this may amplify food insecurity for households across both South Portland and Portland. Likewise, the City of South Portland recently disseminated a survey to understand how people are using the bus system, which illustrated that residents use public transit to get to work, medical services, as well as for groceries. Roughly 5,880 total households across Portland and South Portland (17% of Portland households, and 8% of South Portland households) do not have access to a vehicle. For those who rely on public transit, closures or disruptions in the bus system may create significant limitations in food access, particularly if closer stores temporarily close.

5.4 Health

Extensive research documents the health impacts of climate change across the United States and in Maine.¹⁵⁹ Higher temperatures, more intense storms, flooding, changes in exposure to pathogens, as well as heightened stress are all expected to wear on our immune systems and create new public health concerns. The following sections summarize some of the more significant health impacts that we expect to feel in Portland and South Portland now and in the coming decades.

HEAT STRESS

According to the Environmental Protection Agency (EPA), heat is the leading weather-related cause of death in the United States.¹⁶⁰ Although Maine is not expected to see the same extreme temperatures as other parts of the country, the impact of a high heat day (such as one day over 95° F) or a heat wave (such as three days over 90° F) has a very different impact depending on the region and time of the year. Unseasonably hot days, extreme heat, as well as extended heat waves can have a significant physiological impact on people whose bodies

are less acclimated to warmer weather, which both affects people in historically cooler climates and makes extreme temperatures in the spring more deadly than those later in the summer.¹⁶¹

Likewise, air conditioning is much less prevalent in homes, businesses, and public spaces in northern parts of the United States, including Portland and South Portland. Both due to human physiology and due to infrastructural cooling capacity, cities in cooler climates tend to see more heat-related deaths and hospitalizations.¹⁶² Studies show that human bodies can increase their heat tolerance over time, but in the near-term, public infrastructure that can provide cooling capacity will be a necessary public health intervention.

Health issues from extreme heat most directly stem from the body's inability to regulate internal temperatures, which can lead to heat exhaustion, heat stroke, and hyperthermia. Prolonged exposure to heat also exacerbates asthma, heart disease, and diabetes, leading to more hospitalizations for kidney, cardiovascular, and respiratory disorders. A string of days that also have high minimum temperatures (i.e., hot nights) prevents bodies from being able to recover, amplifying the health risk.

Although all portions of the cities will feel the effects of higher temperatures, residents who live and work in areas with more impervious surfaces and less green space will likely feel high heat more acutely. Impervious surfaces (such as buildings, roads, sidewalks, and parking lots) retain more heat and lead to higher surface temperatures; meanwhile vegetation, and trees in particular, help keep cities cooler both through evapotranspiration and by providing shade. **Figure 5.8** shows the impervious surfaces and green spaces across Portland and South Portland as a proxy for understanding which areas of the cities may feel the effects of extreme heat more than others. Areas with a significant portion of red shading (impervious surfaces)—such as South Portland's West End—will likely feel hotter due to higher surface temperatures.

Residents who work in outdoor occupations, such as construction or landscaping, will have greater vulnerability to periods of high heat. Children, older adults, residents with disabilities, and residents without

Pervious and Impervious Surfaces in Portland and South Portland

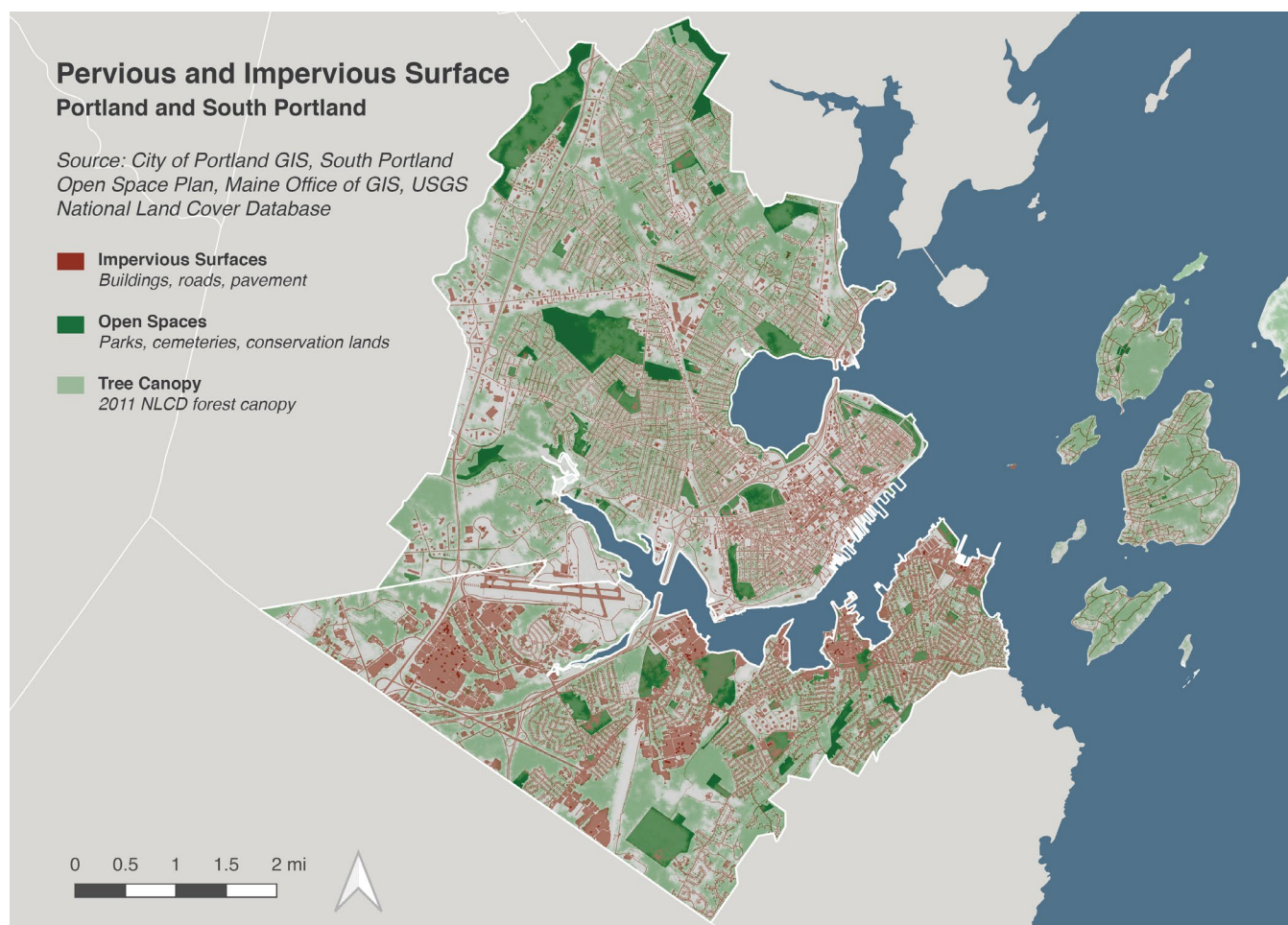


Figure 5.8. Pervious and impervious surfaces across Portland and South Portland. Areas with higher proportions of impervious surfaces will likely feel warmer than other areas on days with high heat.¹⁹³

access to air conditioning will also be more vulnerable. See *Section 5: Social Vulnerability and Adaptive Capacity* for further details on these heightened vulnerabilities.

VECTOR-BORNE DISEASE

Vector-borne diseases are illnesses caused by pathogens that are transmitted from “vectors” such as ticks and mosquitoes. There are fourteen vector-borne diseases that are concerns in the United States, and nine of those diseases (two mosquito-borne and seven tick-borne) have been identified in Maine. Lyme disease, which is spread by black-legged ticks or deer ticks, is the primary and most common vector-borne disease in Maine as of 2019.¹⁶³ Symptoms for Lyme disease in humans usually include a fever, headache, fatigue, and a skin rash called

erythema migrans. If left untreated, the infection can spread, resulting in chronic joint pain and neurological dysfunction.¹⁶⁴

Changes in the climate, including warmer winters, higher humidity, and more precipitation, impact the breeding and survival rates of ticks and mosquitoes, as well as the reproductive rate of the pathogens. Rates of Lyme disease have increased significantly in the past couple decades from less than 100 reported cases in 2000 to 1,373 reported cases in 2018 (280 of which were in Cumberland County).¹⁶⁵ In 2018, Cumberland County also had 71 reported cases of anaplasmosis, 20 cases of babesiosis, 7 cases of ehrlichiosis, and 1 case of Spotted Fever Rickettsiosis. Rates of anaplasmosis and babesiosis,

Reported Lyme Disease Cases in 1996 and 2014

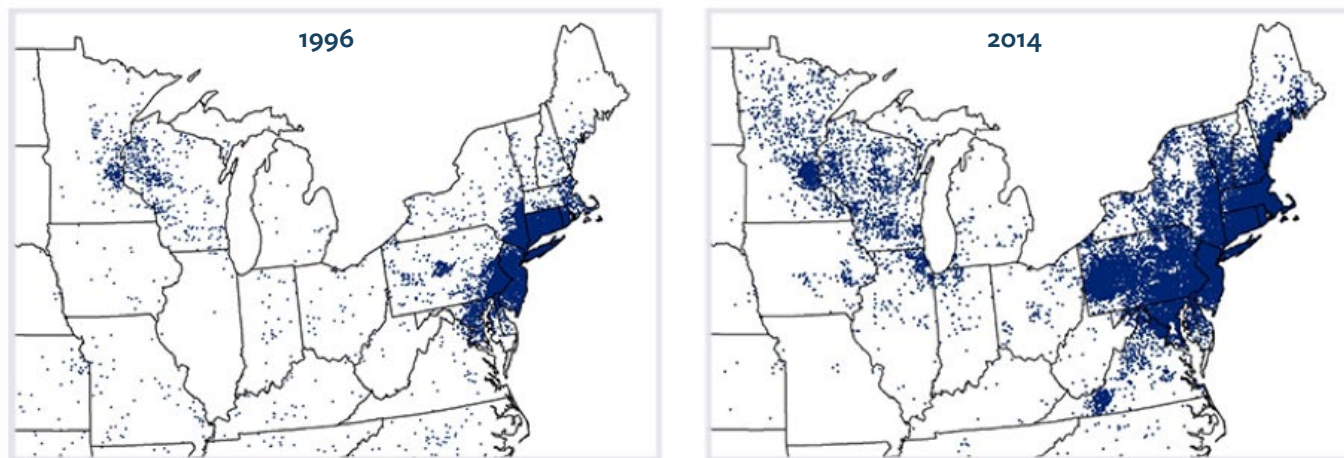


Figure 5.9. The distribution and number of reported Lyme disease cases has increased significantly in the northeast United States over an 18-year timespan from 1996 to 2014. Figure source: Center for Disease Control and Prevention Lyme disease data and statistics (2015).¹⁹⁴

in particular, have increased significantly in Maine in the past ten years.¹⁶⁶ **Figure 5.9** illustrates the drastic increase in reported cases of Lyme disease across the northeast from 1996 to 2014. Southern Maine saw a significant increase in cases over the 18-year timespan.

HEALTH AND SAFETY HAZARDS FROM STORMS AND FLOODING

Major storms, including associated heavy precipitation, high winds, and flooding, bring a wide range of health and safety risks. Most directly, these climate hazards lead to injuries and fatalities due to drowning; blunt injuries from falling objects or debris moving in floodwater currents; electrocution from exposure to electrical systems and electric shocks transmitted through flood waters; as well as vehicle accidents due to slick, eroded, or obstructed roadways.¹⁶⁷

Impaired infrastructure and building damage can likewise lead to cascading health risks through loss or disruption in electricity/power, transportation, communication, and water and sanitation systems. All of these factors in themselves create heightened health risks, which can be amplified by an inability to access medical care, medical equipment, or medications. For example, compromised road and transportation systems restrict access for first responders, and limit access to medical care. Power failures are particularly dangerous for residents who rely

on electric medical equipment such as ventilators or on refrigerated medications. Transportation interruptions and service closures are also hazardous for people reliant on routine medical services such as dialysis, blood transfusions, chemotherapy, or medication treatment for addiction.

Beyond the implications for medical care, power outages create unsafe situations through the loss of lighting, heat, and cooling. Studies show that storms and floods lead to increases in hospital visits and fatalities from carbon monoxide poisoning due to improper use of backup and portable generators as well as combustion appliances (such as charcoal grills or kerosene stoves) intended for outdoor use.¹⁶⁸ Loss of refrigeration—at residential, commercial, and industrial scales—also can compromise food safety and lead to foodborne illnesses.

Likewise, waterborne illness is a major concern stemming from power outages and flooding—both due to risks from contaminated drinking water as well as exposure to contaminated floodwaters. Flooding can lead to both chemical and bacterial water contamination through displaced or overturned chemical storage tanks, bacterial release from sewer systems, or chemical release from waste sites. Exposure to contaminated water can cause gastrointestinal illness as well as irritations and infections of the skin, eyes, nose, and throat.¹⁶⁹

AIR QUALITY AND ALLERGENS

A number of sources including the burning of fossil fuels, wildfires, wood stoves, and agricultural dust contribute to poor air quality by creating smog, particulate matter, and air toxics. A large number of studies now show that climate change will likely exacerbate poor air quality over time. Rising temperatures speed up the chemical reactions that create smog, specifically ground-level ozone. Changes in wind patterns may also result in more stagnant air, which reduces circulation and traps pollution and pollution precursors at ground level. Studies suggest that the northeast will see higher concentrations of ground-level ozone due to both these factors.¹⁷⁰ In 2016, the Portland-South Portland area had 13 days where half or more pollution monitoring locations reported elevated levels of ozone and 17 days with elevated particulate matter (PM_{2.5}).¹⁷¹

While atmospheric ozone is important for protecting us from ultraviolet radiation, ozone at ground level can cause significant public health concerns by causing inflammation in the lungs. This inflammation leads to coughing and throat irritation in the short-term; over the long-term, lung tissues become less elastic, more sensitive to allergens, and more prone to infections—often leading to chronic conditions like asthma.¹⁷² Changes in meteorological factors such as higher humidity and stagnation could also lead to higher levels of particulate matter, which has shown to trigger cardiovascular problems (such as heart attacks, strokes, and congestive heart failure), as well as lead to premature birth, stunted lung development in children, higher rates of asthma, and higher risk of autism and dementia.¹⁷³ As of 2017, Maine had one of the highest asthma rates in the country (11.2% of adults).¹⁷⁴

Likewise, climate change is predicted to exacerbate aeroallergens, which are airborne substances such as pollen and spores that cause allergic reactions. Higher levels of carbon dioxide, higher temperatures, and more precipitation change the quantity, spatial distribution, and seasonal timing of aeroallergens, as well as the intensity of humans' allergic reactions to these substances.¹⁷⁵ With climate changes, we are expected to see earlier flowering, more pollen production, and potentially a longer pollen season, which is predicted to trigger allergic responses, asthma, and other respiratory stress. Studies also suggest that tree species that have more allergenic pollen will

likely fare better than other tree species with climate change.¹⁷⁶ **Figure 5.10** published in a report by the National Wildlife Federation and the Asthma and Allergy Foundation of America illustrates how the distribution of highly allergenic species may expand by 2100 under a high emissions scenario. Maine is highlighted as a “high risk” state for increases in allergenic pollen.

Higher levels of humidity and dampness may also increase mold growth and fungal spores in the air, particularly with increased precipitation, heavy storms, and flooding in indoor spaces.¹⁷⁷ Mold growth has been

Annual Tree Pollen Potential

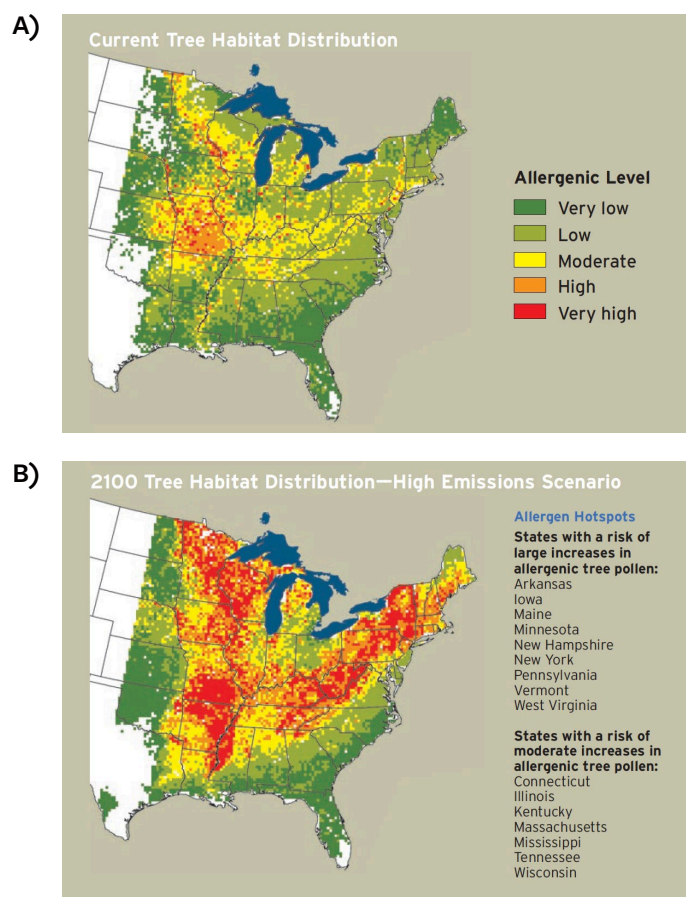


Figure 5.10. Annual allergenic potential from tree pollen from the current distribution of tree species (A) and the potential distribution of tree species under a high greenhouse gas emissions scenario for the year 2100 (B). Maine is listed as a state with “high risk” for increases in allergenic pollen. Figure source: National Wildlife Federation and the Asthma and Allergy Foundation of America (2010).

a particular public health concern in the aftermath of major storms and hurricanes, and is a leading cause for worsened asthma and respiratory infections in the United States.¹⁷⁸ Damp or wet building materials can also lead to higher bacterial growth and elevated off-gassing of volatile organic compounds (VOCs), both of which further exacerbate respiratory stress.¹⁷⁹ Mold growth has recently been highlighted as a concern in the cities, specifically for the South Portland fire station at Cash Corner.¹⁸⁰

MENTAL HEALTH IMPACTS

The health effects of climate change are not only physical, but also mental and emotional. They stem from the immediate trauma from a local climate-related event; from the ongoing emotional toll of processing information about climate change and its consequences; and from stress induced by witnessing changes in the environment and a loss of a sense of place or identity.¹⁸¹

The resulting mental health repercussions range from temporary stress and distress, to extended grief and bereavement, to clinical disorders like post-traumatic stress disorder (PTSD), anxiety, and depression. Data point to higher suicide rates both after catastrophic events, such as major hurricanes and flooding, as well as during “slow” stressors, specifically extended periods of high heat.¹⁸² Climate-related shocks also tend to be followed by higher rates of substance use and misuse, particularly for people with preexisting substance use disorders.

While direct disaster-related factors such as injury, loss of a loved one, loss of possessions or property, and displacement are a primary influence on mental health, other life factors can amplify the mental toll and lingering impacts. These are often compounded by correlated impacts such as losing a job, financial concerns, loss of social networks, or underlying and unrelated sources of family stress. A number of studies show that the mental health toll is particularly acute for people who experience repeated disasters, pregnant and post-partum mothers, emergency responders, elderly, children, economically disadvantaged, people who are homeless, and people with preexisting mental illness—all of whom show higher rates of mental health consequences after extreme events. While most people are able to recover over time

after a traumatic event, roughly 20 percent of individuals show chronic and lasting psychological impacts.¹⁸³ Variations in the extent to which residents may feel the effects of climate change is further explored in *Section 5. Social Vulnerability and Adaptive Capacity*.

5.5 Social Equity

There is a recurring pattern throughout this assessment: climate change will not affect all of us equally. Those of us who rely on lower-wage, hourly employment and public transportation will be more affected by service and business closures; those of us who use food assistance programs will more directly feel rising food costs; and those of us with preexisting health conditions will be more directly affected by high heat. Some of the many factors that tend to increase the impact of climate change on individuals and households are further explored in the following section, *Section 5. Social Vulnerability and Adaptive Capacity*.

A potentially even more significant and related risk, however, is the way in which climate change may drive even greater social inequity. Climate change is expected to impact livelihoods, housing security, food security, and health—thereby enhancing many of the vulnerabilities that make the impacts of climate change more acute for specific individuals and households. In other words, climate change creates a negative feedback loop that creates vulnerability, and with that, more susceptibility to climate impacts.

Portland and South Portland invest greatly in supporting residents with a number of resources and services. These city services are significantly expanded by a vast array of nonprofits and social service organizations that likewise seek to address some of the core roots of poverty, food insecurity, and social marginalization. Supporting and expanding systems for addressing these challenges will be needed in order to address heightened social vulnerability from climate change. Likewise, it will be critical to ensure that equitable processes and outcomes are at the forefront of resilience planning to ensure that further sources of inequity do not become a byproduct of climate change response.

SECTION FIVE ENDNOTES

- 129 City of Portland. (2017). Portland's Plan 2030. Portland, ME.
- 130 Karl F. Seidman Consulting Services & Karp Strategies. (2015). South Portland Economic Development Plan: Positioning South Portland for Balanced and Healthy Growth. South Portland, ME; City of Portland. (2017). Portland's Plan 2030. Portland, ME.
- 131 Maine Department of Transportation & Gates, J. (2009). "Climate Change and Transportation in Maine." Transportation Documents. 58.
- 132 Wallace, R.D., Bouvier, R. Yeitz, L.M., Colgan, C.S. (2017). The Economic Contribution of Casco Bay. Prepared for the Casco Bay Estuary Partnership by the Maine Center for Business and Economic Research at University of Southern Maine and rbouvier consulting.
- 133 Hare, J. A., Morrison, W.E., Nelson, M.W., Stachura, M.M., Teeters, E.J., Griffis, R.B., et al. (2016). A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast US Continental Shelf. PLoS ONE, 11(2).
- 134 Wallace, R.D., Bouvier, R. Yeitz, L.M., Colgan, C.S. (2017). The Economic Contribution of Casco Bay. Prepared for the Casco Bay Estuary Partnership by the Maine Center for Business and Economic Research at University of Southern Maine and rbouvier consulting.
- 135 Wallace, R.D., Bouvier, R. Yeitz, L.M., Colgan, C.S. (2017). The Economic Contribution of Casco Bay. Prepared for the Casco Bay Estuary Partnership by the Maine Center for Business and Economic Research at University of Southern Maine and rbouvier consulting.
- 136 **NOTE:** Tourism and recreation attributed to the Casco Bay ocean economy was calculated as any tourism and recreation within coastal zip codes within the Casco Bay watershed.
- 137 Kristin Kelleher. (2019). Businesses Acting on Rising Seas. Climate Action Business Association. Boston, MA.
- 138 Kristin Kelleher. (2019). Businesses Acting on Rising Seas. Climate Action Business Association. Boston, MA.
- 139 **NOTE:** The Portland Housing Authority's main garage on Anderson Street is at risk, but PHA has plans to expand its garage capacity in other parts of the city. Reference: Cheryl Sessions, Portland Housing Authority (2019).
- 140 Merrill, S., Kirshen, P. Yakovleff, D. Lloyd, S. Keeley, C. & Hill, B. (2012). COAST in Action: 2012 Projects from New Hampshire and Maine. New England Environmental Finance Center. Series Report #12-05. Portland, ME.
- 141 McAlpine, S.A. & Porter, J.R. (2018). Estimating Recent Local Impacts of Sea-Level Rise on Current Real-Estate Losses: A Housing Market Case Study in Miami-Dade, Florida. Population Research and Policy Review. 37(6): 871-895.
- 142 FloodIQ. (n.d.) Retrieved August 2019 from <https://floodiq.com/poi/3be7ca63763c20ed1bc358163a9408c9>
- 143 Union of Concerned Scientists. (2018). Underwater: Rising Seas, Chronic Floods, and the Implications for US Coastal Real Estate. Cambridge, MA.
- 144 Insurance Information Institute. (2019). "Spotlight on: Flood Insurance." Retrieved from <https://www.iii.org/article/spotlight-on-flood-insurance>
- 145 Finding from the One Climate Future Resilience Workshop, South Portland, ME (May 2019).
- 146 **NOTE:** Owner housing costs include mortgage principal payments, interest payments, real estate taxes, property insurance, homeowner fees, condo or coop fees and utilities (not including telephone or cable television). Costs for renters correspond to gross rent, or the contract rent plus the estimated average monthly cost of utilities (Data and definitions from PolicyMap, accessed June 2019).
- 147 Finding from the One Climate Future Resilience Workshop, South Portland, ME (May 2019)
- 148 Finding from the One Climate Future Resilience Workshop, South Portland, ME (May 2019).
- 149 McCabe, M.S. & Burke, J. (2012). "The New England Food System in 2060: Envisioning Tomorrow's Policy Through Assessments." University of New Hampshire School of Law Scholar's Repository. 65 ME. L. REV 549.
- 150 Environment Maine (n.d.) "Local, Sustainable Maine Food." Portland, ME. Retrieved from <https://environmentmaine.org/programs/mee/local-sustainable-maine-food>; H.P. 848 (2019). Resolve, To End Hunger in Maine by 2030. 129th Maine Legislature. Legislative Document No. 1159.
- 151 McCabe, M.S. & Burke, J. (2012). "The New England Food System in 2060: Envisioning Tomorrow's Policy Through Assessments." University of New Hampshire School of Law Scholar's Repository. 65 ME. L. REV 549; Maine Food Strategy. (2016). The Maine Food Strategy Framework: A Tool for Advancing Maine's Food Systems.
- 152 Beck, D.R., Carleton, N., Steinhoff, H., Wallace, D., & Lapping, M. (2011). Maine's Food System: An Overview and an Assessment. Maine Policy Review, 20:1.
- 153 Natural Resources Council of Maine. (n.d). Climate Change Threatens Maine's Farms. Retrieved November 2019 from <https://www.nrcm.org/programs/federal/federal-climate-and-energy-issues/climate-change-threatens-maines-farms/>
- 154 Natural Resources Council of Maine. (n.d). Climate Change Threatens Maine's Farms. Retrieved November 2019 from <https://www.nrcm.org/programs/federal/federal-climate-and-energy-issues/climate-change-threatens-maines-farms/>
- 155 Hare, J. A., Morrison, W.E., Nelson, M.W., Stachura, M.M., Teeters, E.J., Griffis, R.B., et al. (2016). A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast US Continental Shelf. PLoS ONE, 11(2).
- 156 Zeuli, K & Nijhuis, A. (2017). The Resilience of America's Urban Food Systems: Evidence from Five Cities. Initiative for a Competitive Urban City (ICIC). Roxbury, MA.
- 157 Zeuli, K & Nijhuis, A. (2017). The Resilience of America's Urban Food Systems: Evidence from Five Cities. Initiative for a Competitive Urban City (ICIC). Roxbury, MA.

- 158 Feeding America. (2017). Food Insecurity in Cumberland County. Retrieved from <https://map.feedingamerica.org/county/2017/overall/maine/county/cumberland>
- 159 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.
- 160 Environmental Protection Agency. (2016). Climate Change Indicators in the United States: Heat-Related Deaths. Retrieved from www.epa.gov/climate-indicators
- 161 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.
- 162 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.
- 163 Robinson, Sara. (2019). Report to Maine Legislature: Lyme and other Tickborne Illnesses. Maine Department of Health and Human Services, Center for Disease Control and Prevention (Maine CDC). Augusta, ME.
- 164 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.
- 165 Robinson, Sara. (2019). Report to Maine Legislature: Lyme and other Tickborne Illnesses. Maine Department of Health and Human Services, Center for Disease Control and Prevention (Maine CDC). Augusta, ME; Boa, S. (n.d.) Climate Change and Health in Maine. Center for Health and the Global Environment, Harvard Medical School. Cambridge, MA.
- 166 Robinson, Sara. (2019). Report to Maine Legislature: Lyme and other Tickborne Illnesses. Maine Department of Health and Human Services, Center for Disease Control and Prevention (Maine CDC). Augusta, ME.
- 167 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.
- 168 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.
- 169 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.
- 170 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.
- 171 Ridlington, E. & Leavitt, C. (2018). Trouble in the Air: Millions of Americans Breathe Polluted Air. Environment Maine Research and Policy Center, Frontier Group, and US PIRG Education Fund, 55 pp.
- 172 Ridlington, E. & Leavitt, C. (2018). Trouble in the Air: Millions of Americans Breathe Polluted Air. Environment Maine Research and Policy Center, Frontier Group, and US PIRG Education Fund, 55 pp.
- 173 Ridlington, E. & Leavitt, C. (2018). Trouble in the Air: Millions of Americans Breathe Polluted Air. Environment Maine Research and Policy Center, Frontier Group, and US PIRG Education Fund, 55 pp.
- 174 Centers for Disease Control and Prevention. (2019). Most Recent Asthma State or Territory Data. Retrieved from: https://www.cdc.gov/asthma/most_recent_data_states.htm#source
- 175 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.
- 176 National Wildlife Federation & Asthma and Allergy Foundation of America. (2010). Extreme Allergies and Global Warming. Retrieved from <https://www.aafa.org/media/1634/extreme-allergies-global-warming-report-2010.pdf>
- 177 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.

- 178 National Wildlife Federation & Asthma and Allergy Foundation of America. (2010). Extreme Allergies and Global Warming. Retrieved from <https://www.aafa.org/media/1634/extreme-allergies-global-warming-report-2010.pdf>
- 179 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.
- 180 Laaka, Julia. (2018). South Portland fire station mold could cost city \$1.3M. Portland Press Herald.
- 181 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.
- 182 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.
- 183 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.
- 184 PACTs, GPCOG, & Stantec Consulting Services. (2017). Background Analysis: An analysis of existing conditions and background information of the PACTS/GPCOG region and transit operators. Prepared by Stantec for Greater Portland Council of Governments.
- 185 **NOTE:** Data from EMSI, 2017:1 data series. Includes QCEW, non-QCEW, and self-employment. Reference: Wallace, R.D., Bouvier, R. Yeitz, L.M., Colgan, C.S. (2017). The Economic Contribution of Casco Bay. Prepared for the Casco Bay Estuary Partnership by the Maine Center for Business and Economic Research at University of Southern Maine and rbouvier consulting.
- 186 US Census Bureau, American Community Survey (2013-2017); US Census Bureau, Population estimates (2018)
- 187 Catalysis Adaptation Partners. (2013). Executive Summary: Flooding Vulnerability Assessment Using the COAST Tool and Approach for the Portland Society for Architecture and the City of Portland, ME for the Commercial Street Waterfront Area.
- 188 Union of Concerned Scientists. (2018). Underwater: Rising Seas, Chronic Floods, and the Implications for US Coastal Real Estate. Cambridge, MA.
- 189 Coastal Risk Explorer. (2018). Retrieved from <https://maps.coastalresilience.org/maine/>
- 190 **NOTE:** Inundated roads, inaccessible addresses, and costs to upgrade data comes from the Maine Coastal Risk Explorer Project. See the following reference for further details: Johnson, E.S., Bell, J.M., Coker, D., Hertz, E., LaBarge, N., & Blake, G. (2018). A lifeline and social vulnerability analysis of sea level rise impacts on rural coastal communities. Shore & Beach. 86(4). Sea level rise data from the Maine Geological Survey.
- 191 **NOTE:** Community assets data based on Google Maps; Sea level rise data from the Maine Geological Survey (2015).
- 192 Maine Climate and Agriculture Network (n.d.). Farm Response to Changing Weather. University of Maine: Orono, ME. Retrieved November 2019 from <https://umaine.edu/climate-ag/wp-content/uploads/sites/110/2017/01/Maine-Climate-Change-Farm-Response-Factsheet-2017.pdf>
- 193 **NOTE:** GIS data from City of Portland GIS; City of South Portland Open Space Plan (2019); Maine Office of GIS; USGS National Land Cover Data
- 194 Environmental Protection Agency. (2016). Climate Change Indicators in the United States: Lyme Disease. Retrieved from www.epa.gov/climate-indicators

6. Social Vulnerability and Adaptability

6.1 Factors of Social Vulnerability

Many climate hazards, such as more intense storms or higher temperatures, will affect all areas of Portland and South Portland. The impact of those hazards, however, will be felt very differently across communities and households. Existing stresses—which can include health conditions, social discrimination, poverty, or other factors—can impact our ability to adapt and ultimately amplify the harm caused by climate change. The following sections explore a number of demographic or social contextual factors for individuals and households in Portland and South Portland that may create greater social vulnerability to acute and chronic stresses caused by climate change.

IMPORTANT TO NOTE

These “factors of vulnerability” are overlapping and highly varied: a large proportion of Portland’s and South Portland’s populations experience at least one of these vulnerabilities. In many cases, “vulnerability” points to physical conditions or barriers, but it is important to recognize the degree to which social marginalization and inequities play a significant role in making those characteristics a vulnerability.

It is also important to note that the following list of social vulnerabilities includes only a snapshot of factors, and include characteristics that are most easily mapped. Vulnerabilities ultimately come in many different forms; residents seeking asylum, experiencing homelessness, or suffering from addiction are some of many other factors that may increase risk and challenges when responding to climate hazards.

6.2 Age and Health

OLDER ADULTS

In Portland and South Portland collectively, 14 percent of residents (approximately 13,042 individuals) are over age 65.¹⁹⁵ Climate change brings greater risk for older adults who are more likely to have compromised health and a higher susceptibility to climate or environmental hazards.

The likelihood of pre-existing medical conditions—ranging from chronic disease, to reduced cognitive capacity, to restricted mobility—increases with age. These existing stresses compromise the capacity of older adults to adapt to incremental climate changes or respond quickly in emergency situations.¹⁹⁶ These limitations may come in the form of limited physical ability to drive or relocate in an emergency; limited financial resources for added expenses due to living on a fixed income; or health limitations such as needing regular medications, medical care, or medical resources that may be less accessible in an emergency. These risks become amplified for residents over age 65 who are living alone and may be more socially isolated.

Likewise, research indicates that a number of climate hazards will have more significant health repercussions for older adults. Adults over age 65 have a greater sensitivity to air pollution, such as particulate matter, dust, and ground-level ozone—all of which are expected to increase with climate change due to more wildfires, wind storms, and increased temperatures.¹⁹⁷ Age is also the greatest determinant for whether a person will be adversely impacted by extreme heat.¹⁹⁸ Heat stroke occurs at rates 12 to 23 times higher for individuals 65 years old and older, compared to other age groups.¹⁹⁹ Older adults have higher rates of cardiopulmonary diseases and diabetes, which increase the risk for heat-related illness, and certain medications commonly used by older adults also can compromise thermoregulatory

capacity. Seniors thus experience disproportionate rates of heat-related morbidity and mortality.

Figures 6.1 and 6.2 show the percentage of residents within each Census Block who are over age 65 and over age 65 and living alone, respectively. Certain neighborhoods in South Portland (Knightville, south of Meetinghouse Hill, and south of Crocket's Corner), in particular, have slightly higher proportions of older residents and older residents living alone.

RESIDENTS LIVING WITH A DISABILITY

In Portland and South Portland collectively, 9 percent of residents (approximately 8,272 individuals) under age 65 live with a disability.²⁰⁰ In this context, a disability is defined

Residents over Age 65

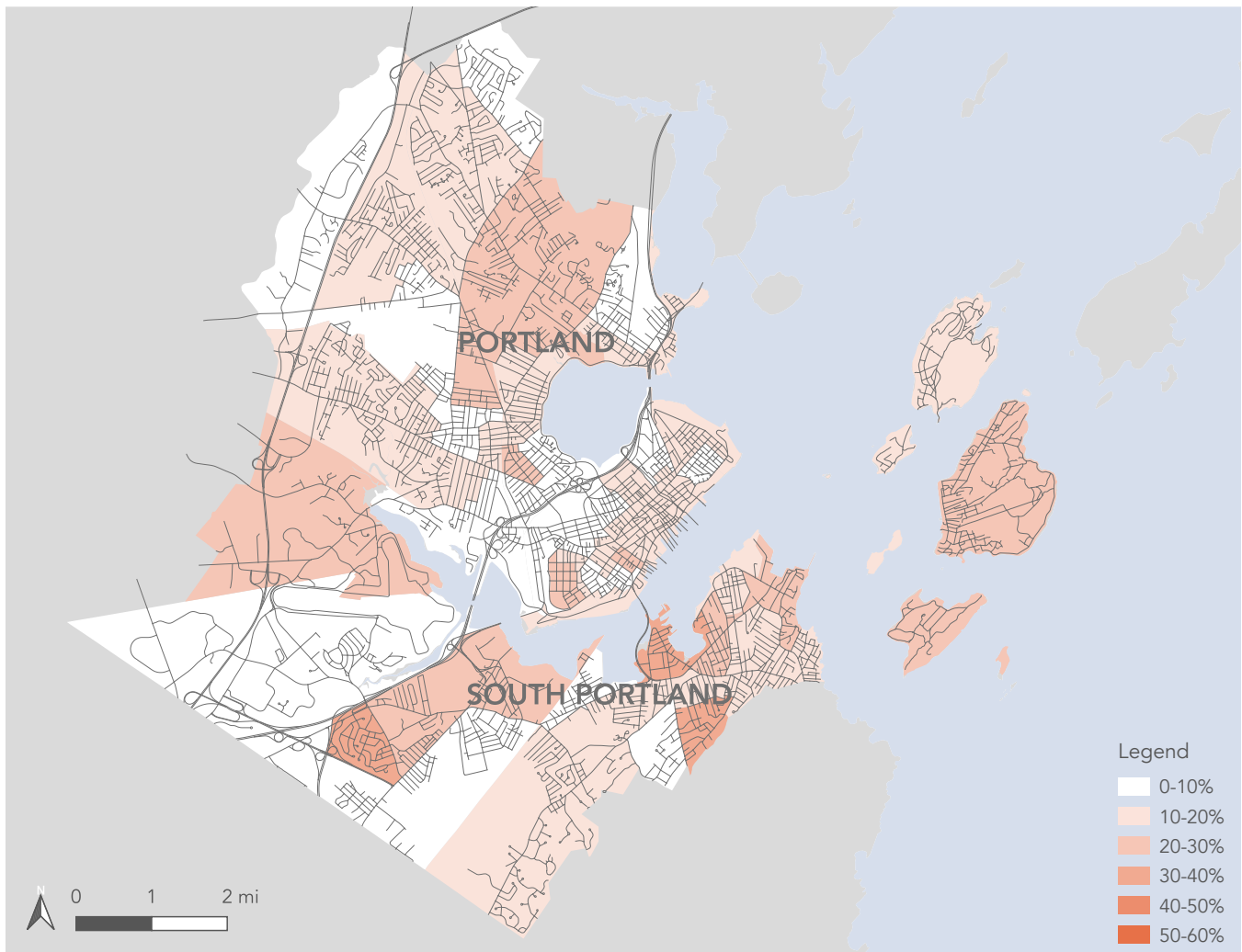


Figure 6.1. Percentage of residents in Portland and South Portland over age 65 by Census Block. Data source: U.S. Census Bureau, American Community Survey (2012-2016).

Residents over Age 65 and Living Alone

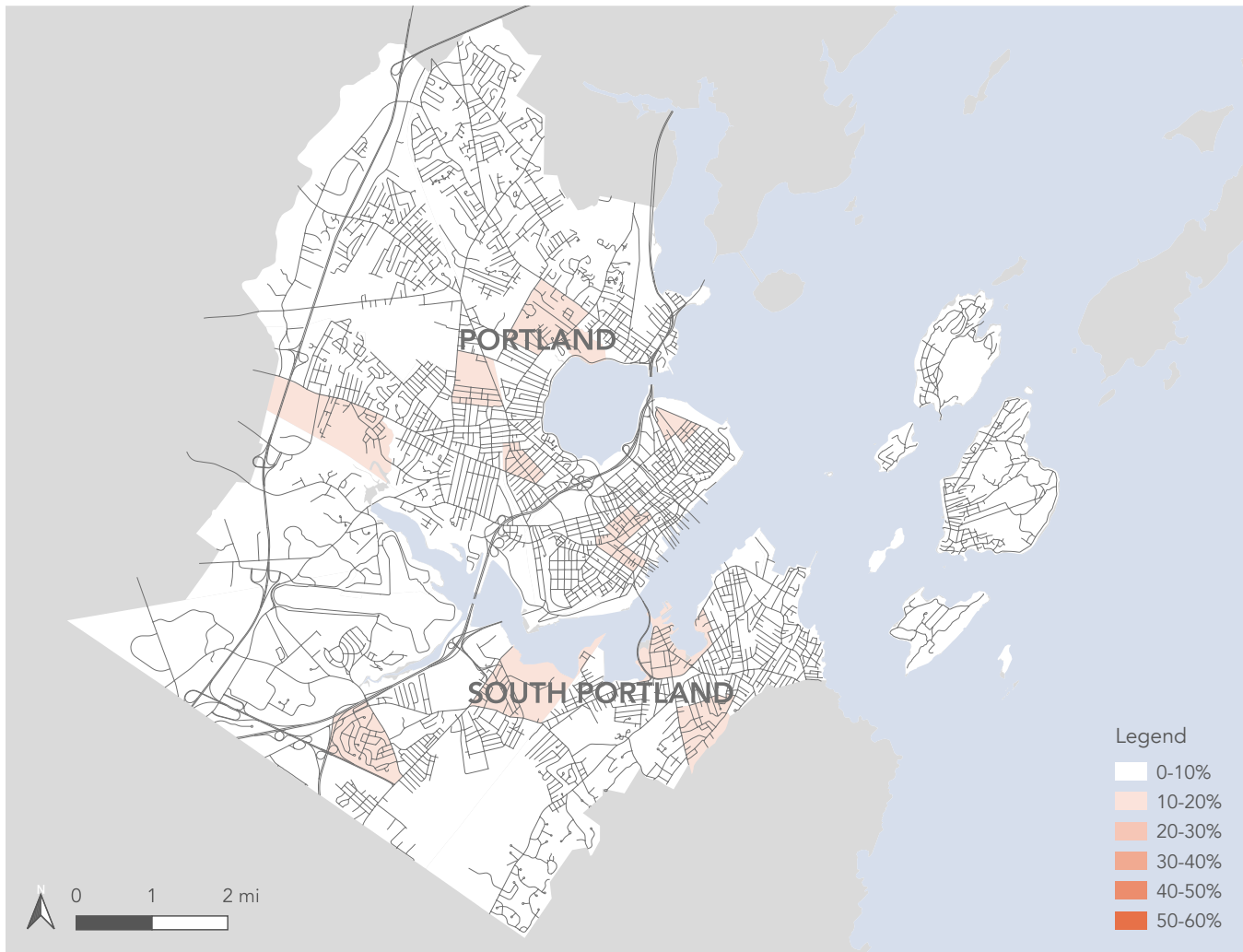


Figure 6.2. Percentage of residents in Portland and South Portland over age 65 and living alone by Census Block. Data source: U.S. Census Bureau, American Community Survey (2012-2016).

as a physical or mental impairment that creates difficulty with hearing, vision, cognitive tasks, ambulatory tasks, self-care, and/or independent living.

Because disabilities take a wide range of forms, the disability-related challenges created by climate change hazards are equally as varied. Broadly speaking, however, many of the challenges faced by individuals with a disability are similar to those for older adults, including reduced mobility due to physical limitations or an inability to drive, limited financial resources for added expenses due to fixed or limited incomes, and greater need for care and medical resources in an emergency situation. Residents with certain disorders or cognitive disabilities, such as autism or Alzheimer's, experience

additional stress and disorientation during emergencies when forced out of a familiar routine or location.²⁰¹

Likewise, residents with hearing impairments and/or non-verbal residents will face increased communication barriers in providing and receiving information in emergency situations.

Certain disabilities also amplify the sensitivity of individuals to extreme heat. A number of disabilities including, for example, multiple sclerosis, schizophrenia, and spinal cord injuries can impact a person's thermoregulation, increasing the risk of heat-related illness.²⁰² Certain antipsychotic medications also contribute to dysfunction in a body's ability to thermoregulate.

Physical and mental disabilities disproportionately affect individuals with other types of vulnerabilities, including people with lower incomes, older adults, and unemployed individuals, which therefore compounds the challenges people with disabilities experience from climate change.²⁰³ Underlying these connections is the degree to which inequity and social marginalization play a role in creating or heightening climate vulnerability. Studies have pointed to the degree to which people with disabilities have been disadvantaged by the design and delivery of emergency relief, whether due to inaccessible shelters, information inaccessibility, or the exclusion of disabled persons from adaptation efforts.²⁰⁴ Physical and social barriers that limit residents' abilities to access resources on a day-to-day basis ultimately play a significant role in creating or increasing climate vulnerability.

Figure 6.3 shows the percentage of households within each Census Block in Portland and South Portland that have one or more individuals who currently live with a disability. The western side of Portland and South Portland have a greater proportion of households with residents with disabilities, particularly the neighborhoods directly south of Crocket's Corner in South Portland.

RESIDENTS UNDER AGE 18

In Portland and South Portland collectively, 17 percent of residents (approximately 15,645 individuals) are under age 18.²⁰⁵ Adolescents, children, and infants are more susceptible to negative health impacts from climate and environmental hazards, both for physiological and behavioral reasons. Children are less able to adapt to

Households with One or More Persons with a Disability

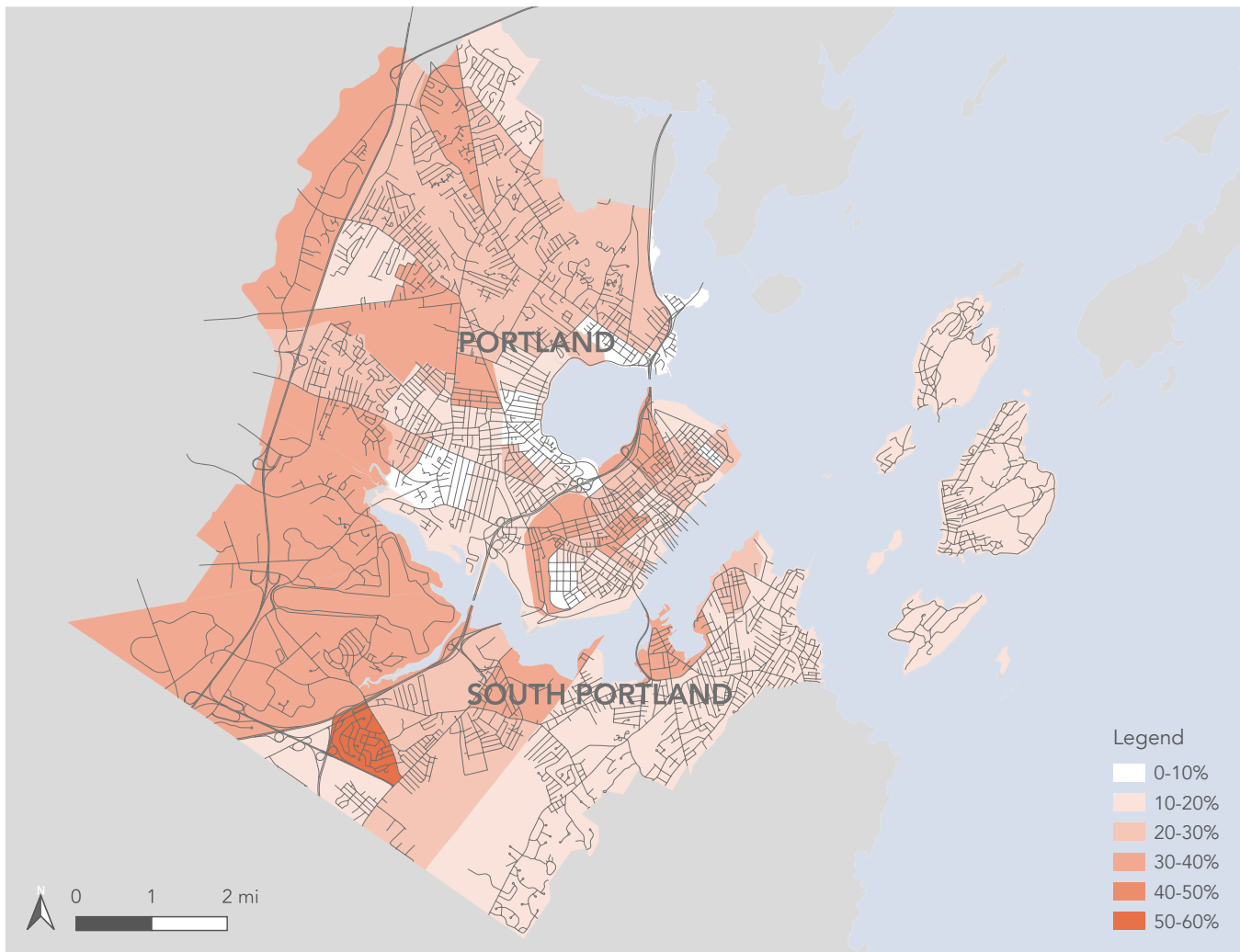


Figure 6.3. Percentage of households in Portland and South Portland with one or more individual living with a disability. Data source: U.S. Census Bureau, American Community Survey (2012-2016).

high heat because they produce more metabolic heat per mass, have higher heat gain, and less capacity to sweat.²⁰⁶ Children also are less likely to manage their heat risk by staying hydrated, and have less control of their exposure to heat due to more limited independence.²⁰⁷

Like older adults, children and adolescents also have a higher risk of respiratory problems from particulate matter, dust, and ground-level ozone, because they spend more time outside and have faster breathing rates.²⁰⁸ Due to time spent outside, children may also be more exposed to vector-borne disease.

Broadly speaking, the vulnerability of infants, children, and adolescents is also impacted by their dependence

on caregivers to ensure their safety and wellbeing. Households with children ultimately have a greater set of financial, social, and emotional needs that add to the challenges of adapting to climate change and responding to emergencies. While children generally show an “innate resilience” to negative events, children are more likely to be impaired by a climate hazard, and tend to show higher rates of lingering post-traumatic stress disorder (PTSD) symptoms than adults.²⁰⁹

Figure 6.4 show the percentage of residents within each Census Block who are under age 18. The Riverton neighborhood in Portland, particularly west of I-95 and south of Warren Ave have the highest proportions of residents under age 18.

Residents Under Age 18

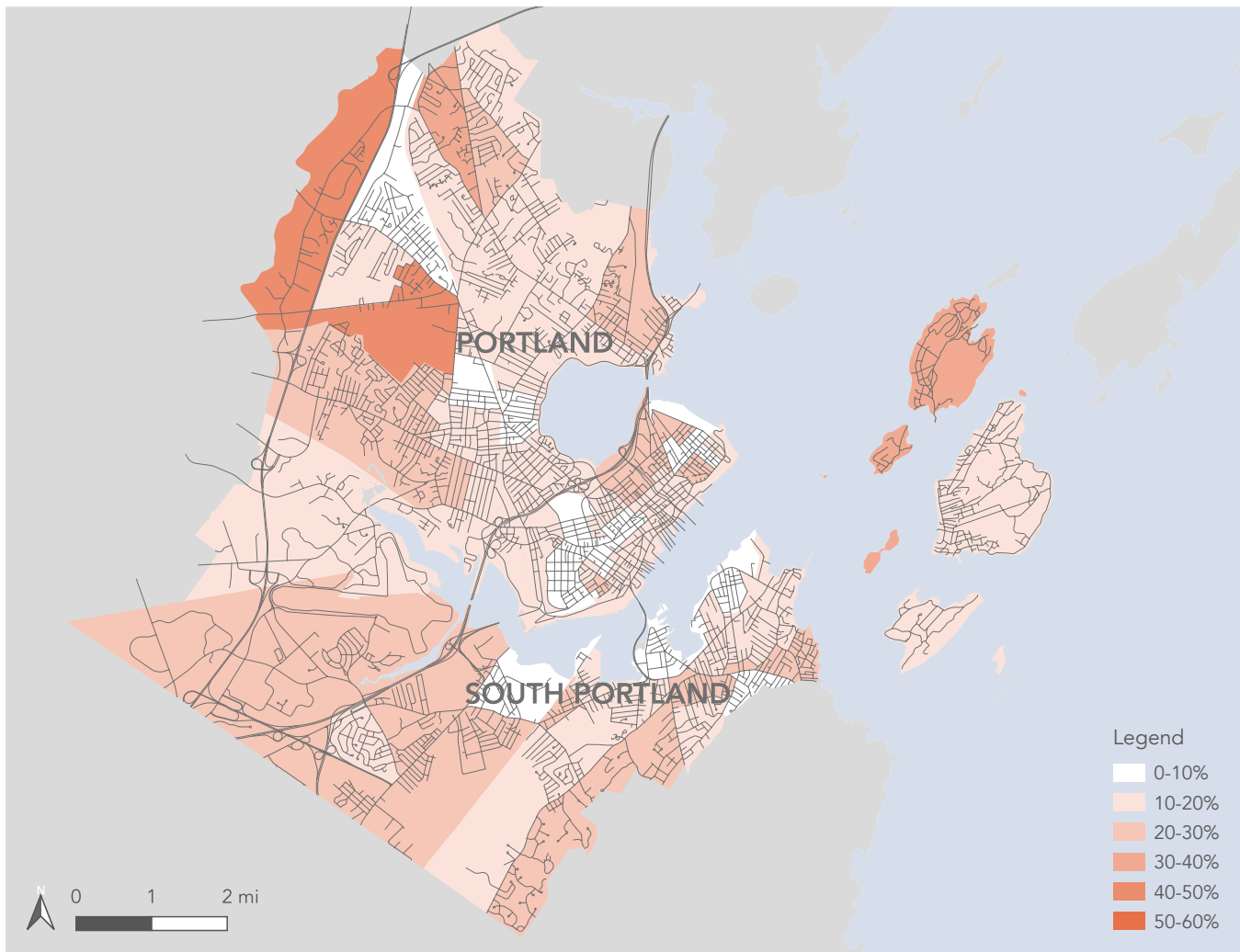


Figure 6.4. Percentage of residents in Portland and South Portland under age 18 by Census Block. Data source: U.S. Census Bureau, American Community Survey (2012-2016).

6.3 Language, Race, and Ethnicity

PEOPLE WHO SPEAK ENGLISH LESS THAN WELL

In Portland and South Portland collectively, roughly 3 percent of the population over age 5 (approximately 2,593 people) speak English less than well.²¹⁰ However, it is possible that this population is larger due to undercounting in the Census. French, Spanish, Arabic, and Portuguese are the most commonly spoken languages other than English across the two cities.

The majority of systems in the United States, including those in Portland and South Portland,

assume participants have a basic fluency in English. These systems can include healthcare, social services, professional and educational systems, transportation, financial services, among others. Residents with limited English language skills are thus more likely to have inadequate access to services or resources both on a day-to-day basis or in an emergency—both due to language barriers and in many cases due to navigating an unfamiliar context and culture after having immigrated.

The City of Portland offers a system for routine notifications and emergency alerts in over 60 languages. Signing up for the system, however, requires knowledge

Residents Who Speak English “Less than Well”

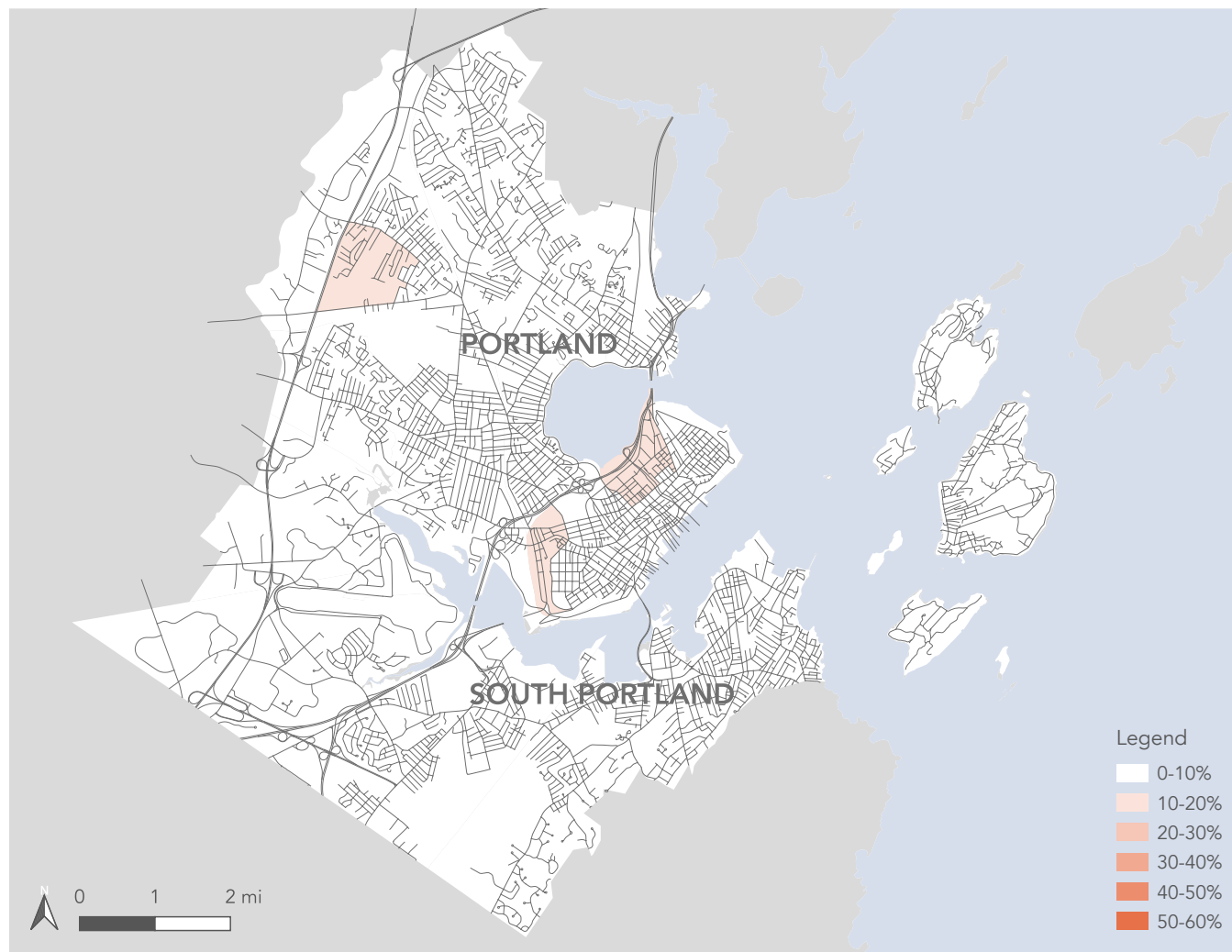


Figure 6.5. Percentage of residents in Portland and South Portland who speak English “less than well” by Census Block. Data source: U.S. Census Bureau, American Community Survey (2012-2016).

of the service or navigation of the website in English. Furthermore, residents with limited English proficiency will have more difficulty with all other formal and informal communication during emergency situations. Conversations around long-term adaptation to climate change and the resources and strategies available are also currently less accessible.

Figure 6.5 shows the percentage of residents within each Census Block who speak English less than well. Portland neighborhoods East and West Bayside, Valley Street, and Riverton south of Route 302 have the largest proportions of residents who do not speak English well.

PEOPLE OF COLOR

People of color include all residents in Portland and South Portland, except for those who identify as both white and non-Hispanic/Latinx. People of color make up 13.4 percent of residents in the two cities (approximately 12,300 individuals).²¹¹ However, it is possible that the population of people of color is larger due to undercounting in the Census, specifically of New Mainers.

National and local studies show that as a result of historical and persistent patterns of structural racism, people of color are more likely to have fewer financial resources than white populations, have lower access to health care, and are more likely to be exposed to environmental hazards. The State of Working Maine

Residents of Color

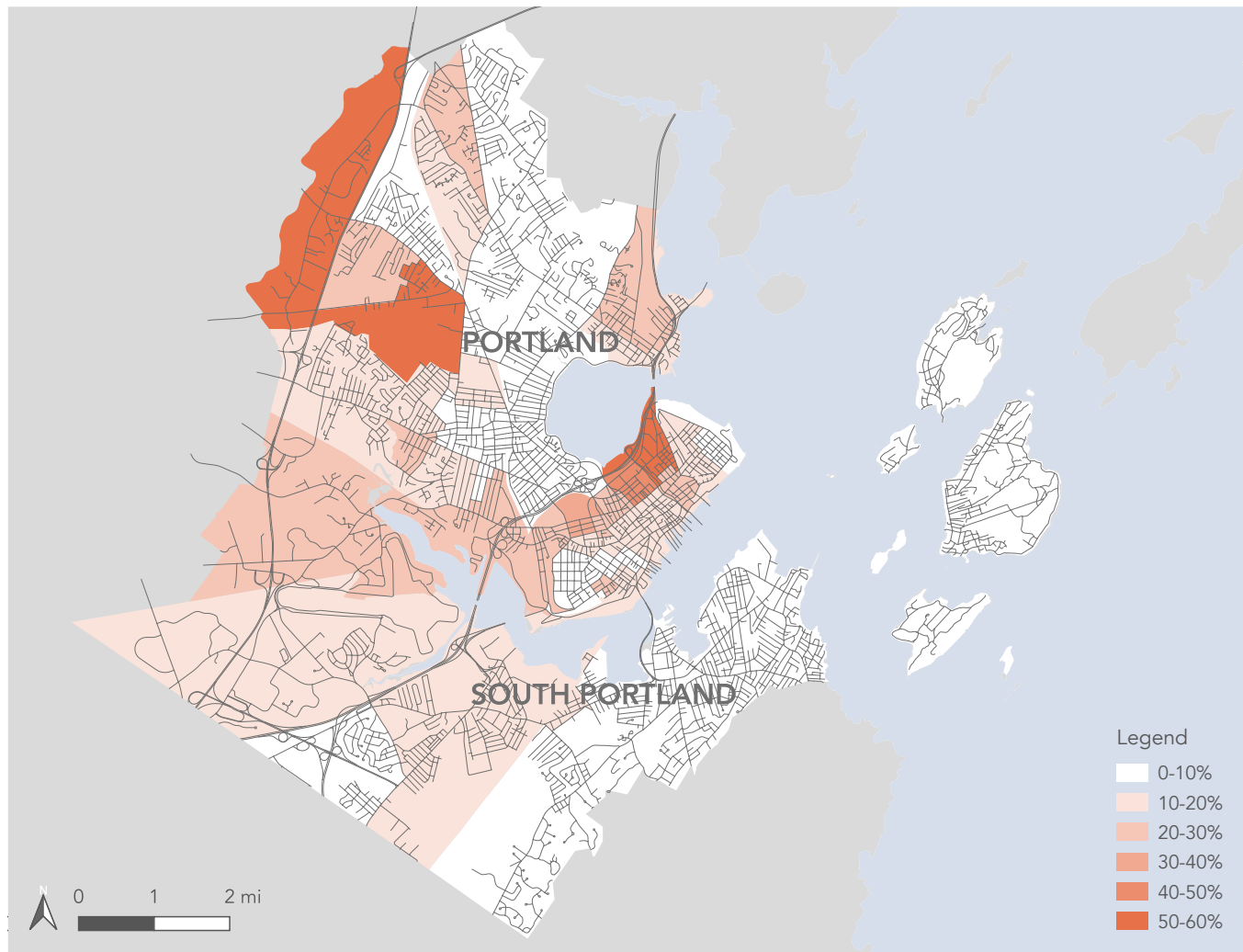


Figure 6.6. Percentage of residents in Portland and South Portland who are people of color by Census Block. People of color include everyone except white, non-Hispanic/Latinx individuals. Data source: U.S. Census Bureau, American Community Survey (2012-2016).

Report (2017) states that “full-time, year-round workers of color earn 85 cents for every dollar earned by white non-Hispanic Mainers.” (Women of color make only 67 cents on every dollar earned by white men.)²¹² Additional structural inequities, such as hiring discrimination, further limit the earning power of people of color. Black Mainers with a bachelor’s degree tend to have the same level of unemployment as white Mainers with only a high school education. Consequently, Maine has some of the highest poverty rates for people of color: roughly 45 percent of black Mainers live in poverty.²¹³

A lack of economic equality makes it so that Mainers of color are twice as likely as their white neighbors to be unable to afford healthcare, despite having higher exposure to many environmental health risks.²¹⁴ Rates of asthma are significantly higher for people of color in Maine (19 percent of adults of color, versus 15 percent of white adults).²¹⁵ Lower income residents, including New Mainers in particular, also face greater exposure to building toxins, such as lead, from older and lower quality rental housing. Both of these health risks are expected to increase with climate change, as air quality decreases and more flooding and precipitation erode housing quality and lead to mold growth and chemical leaching.

Racial bias is also evident in Maine’s education and criminal justice systems. Black students are 2.4 times as likely to be suspended from school, and black Mainers are 6 times as likely to be incarcerated than their white counterparts.²¹⁶ While seemingly separate from climate adaptation concerns, all of these factors create added social vulnerability for people of color by restricting economic and educational opportunity, access to health resources, and the ability to respond to additional economic and health impacts from climate change.

Figure 6.6 shows the percentage of residents who are people of color within each Census Block. Portland neighborhoods East Bayside, West Bayside, and Riverton, particularly west of Interstate 95 and south of Warren Ave, have the highest proportion of people of color.

6.4 Income and Access to Resources

RESIDENTS FACING POVERTY AND/OR UNEMPLOYMENT

In Portland and South Portland collectively, 16.6 percent of the population (approximately 15,329 individuals) live in households whose incomes fall below the poverty threshold.²¹⁷ Poverty thresholds are set at a national scale and vary based on household size. For example, the threshold for 2018 was \$12,793 for a single-person household, and \$25,707 for a four-person household.²¹⁸

Climate hazards disproportionately impact people with lower incomes due to many factors including higher exposure to health risks that are further exacerbated by climate change, limited financial safety nets to absorb additional expenses, and subsequently, more acute emotional stress from the harm posed by climate hazards.

Low-quality living environments, high levels of stress, and poor physical and mental health are all highly correlated for people with lower incomes. Residents facing poverty tend to live in poorer quality housing and in areas with greater exposure to particulate matter, mold, ground-level ozone, and other toxins, with those exposures expected to increase with climate change. At the same time, residents facing poverty tend to have worse mental and physical health, including higher rates of asthma, diabetes, pulmonary disease, and depression.²¹⁹ Over 30 percent of adults in Maine making less than \$15,000 a year reported poor mental health and poor physical health, separately—which is more than double the rates for poor mental and physical health for individuals who make \$25,000–\$34,000 per year.²²⁰ Simultaneously, low-income individuals are much less likely to have health insurance; residents without health insurance make up 8 percent of people in Portland and South Portland.²²¹

Households with incomes at or below the poverty line are also less likely to have property insurance or savings for added or unexpected expenses, such as higher energy or food costs, costs to repair building or property damage, and/or lodging or transportation costs in the

need to evacuate. These added expenses are particularly detrimental for individuals who are unemployed and currently living on fixed or no personal income. Likewise, many residents with lower incomes work hourly jobs without paid time off; consequently, disruptions in transportation or business continuity that restrict being able to work lead to significant loss of income.

Residents with limited disposable income are able to spend fewer dollars on mitigating the impacts of climate hazards. For example, in needing to reduce extra expenses, people tend to avoid purchasing or running air conditioners, fans, or heat, making periods of extreme heat or cold more dangerous for financially-burdened households. Furthermore, studies have shown that

residents who live in higher floors of multistory buildings or who live in smaller housing units tend to face greater stress from extreme heat.²²²

Figures 6.7 and 6.8 show the percentage of residents within each Census Block who have incomes below the poverty line and who are unemployed, respectively. Many areas on the Portland peninsula (i.e., the West Bayside, India Street, and Valley Street neighborhoods), as well as North Deering, specifically between Washington Ave and Route 100, have some of the highest proportions of residents facing poverty. Generally speaking, similar areas see higher unemployment for Portland; Knightville and Pleasantdale/Cash Corner see higher proportions of people who are unemployed in South Portland.

Residents with Household Incomes below the Poverty Threshold

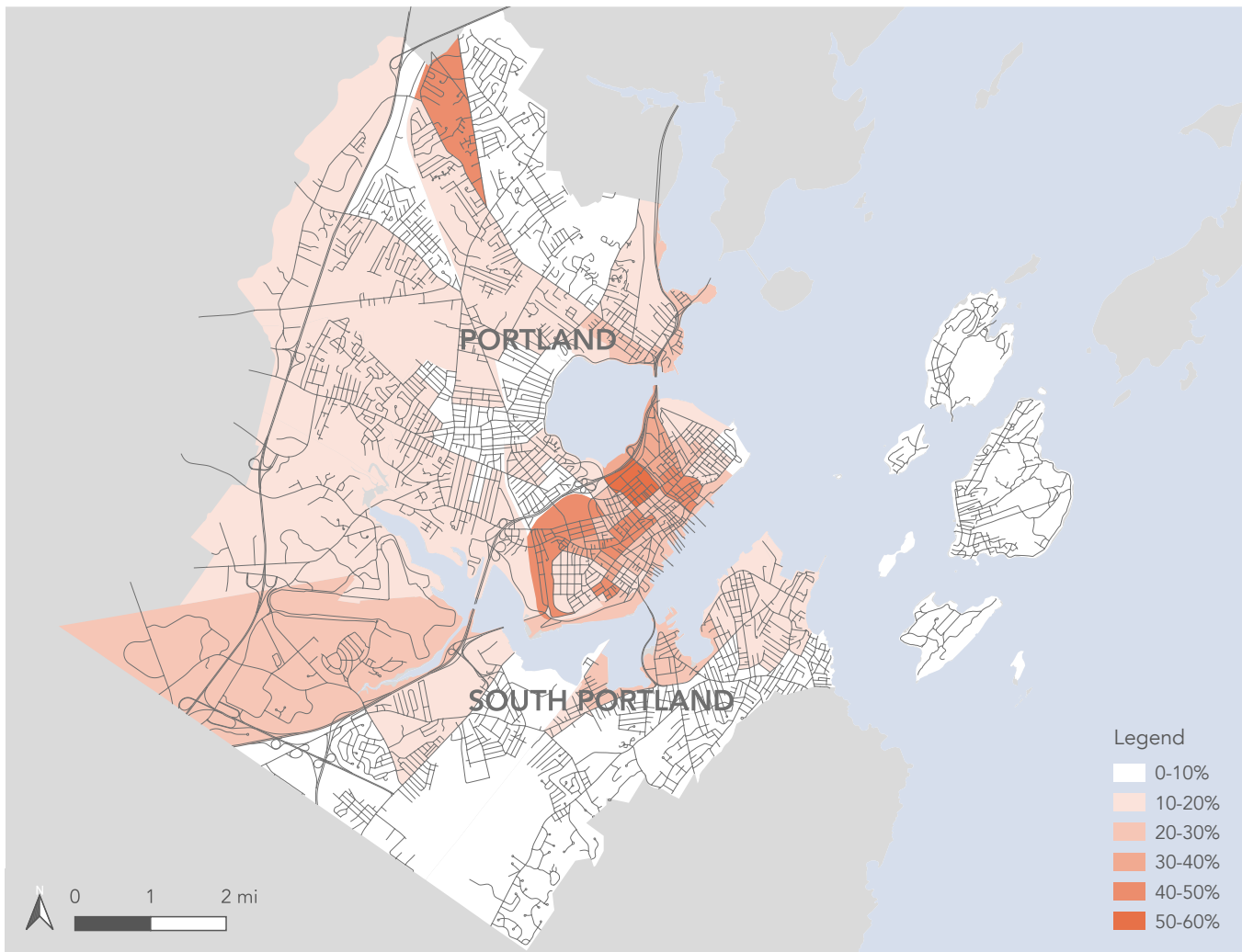


Figure 6.7. Percentage of residents in Portland and South Portland whose household incomes are below the poverty threshold by Census Block. Data source: U.S. Census Bureau, American Community Survey (2012-2016).

Residents who are Unemployed

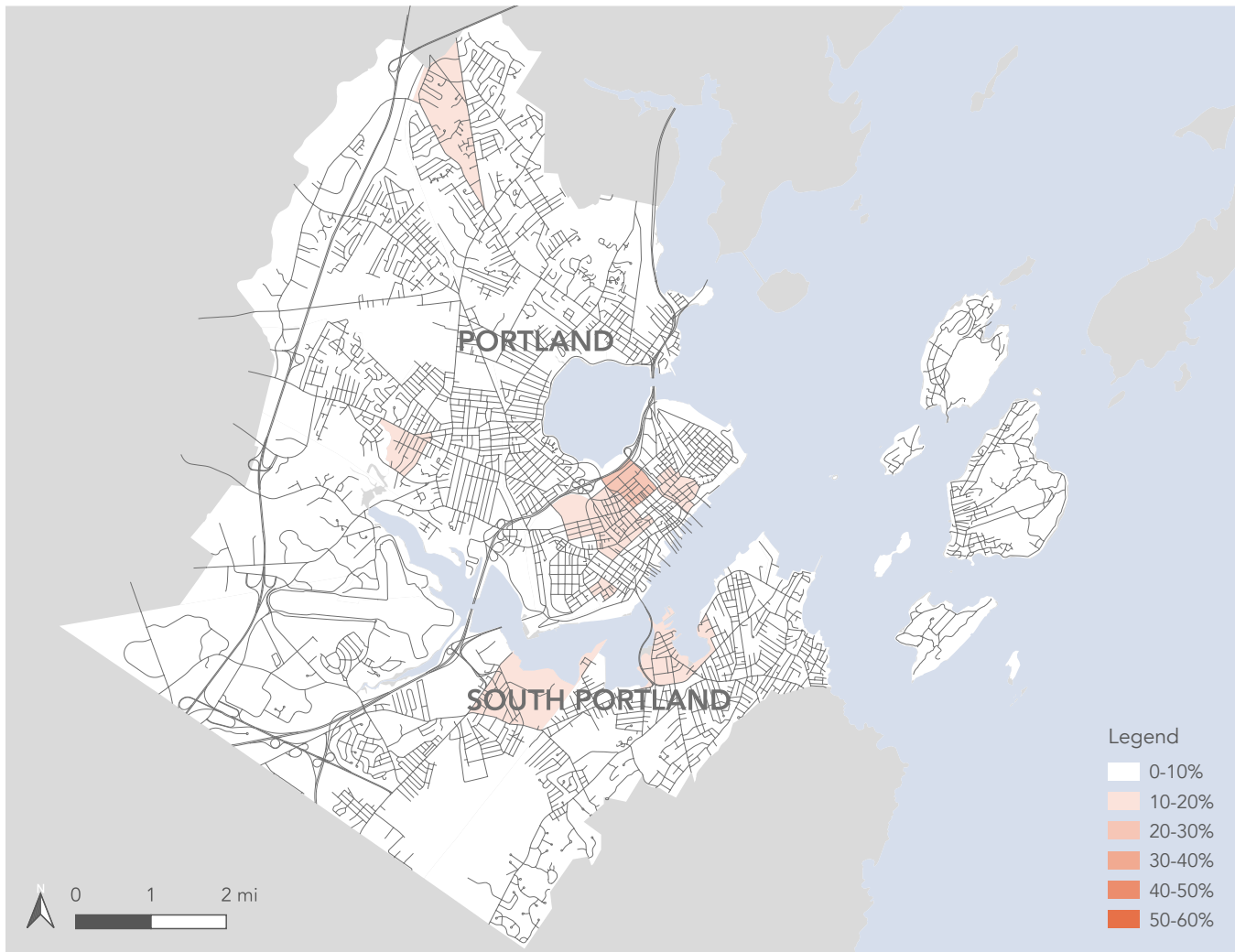


Figure 6.8. Percentage of residents in Portland and South Portland who are over age 16 and unemployed by Census Block. Data source: U.S. Census Bureau, American Community Survey (2012-2016).

RESIDENTS WITHOUT A HIGH SCHOOL DIPLOMA

In Portland and South Portland collectively, 7 percent of residents over the age of 25 (approximately 4,395 individuals) do not have a high school diploma.²²³

Generally speaking, adults without a high school diploma have a lower earning potential. Therefore, much of the enhanced vulnerabilities to climate change overlap with those who are facing poverty or unemployment, as well as the socioeconomic, health, and environmental factors (based on one's neighborhood or housing) that correlate with having lower financial security. Studies at a global scale suggest that educational attainment is one of the most significant indicators of adaptive capacity to climate

disasters, particularly since it is a primary determinant of other socioeconomic outcomes.²²⁴

Additionally, education has shown to play a role in increasing a person's connections to other people and information. People with more formal education tend to have greater access to communication sources and risk information, and a greater capacity to plan for longer timeframes.²²⁵ Likewise, studies also suggest that individuals with more education have stronger social capital, which includes a person's social networks and support.²²⁶ Individuals who did not complete high school may have fewer connections to support networks and information by comparison.

Residents without a High School Diploma

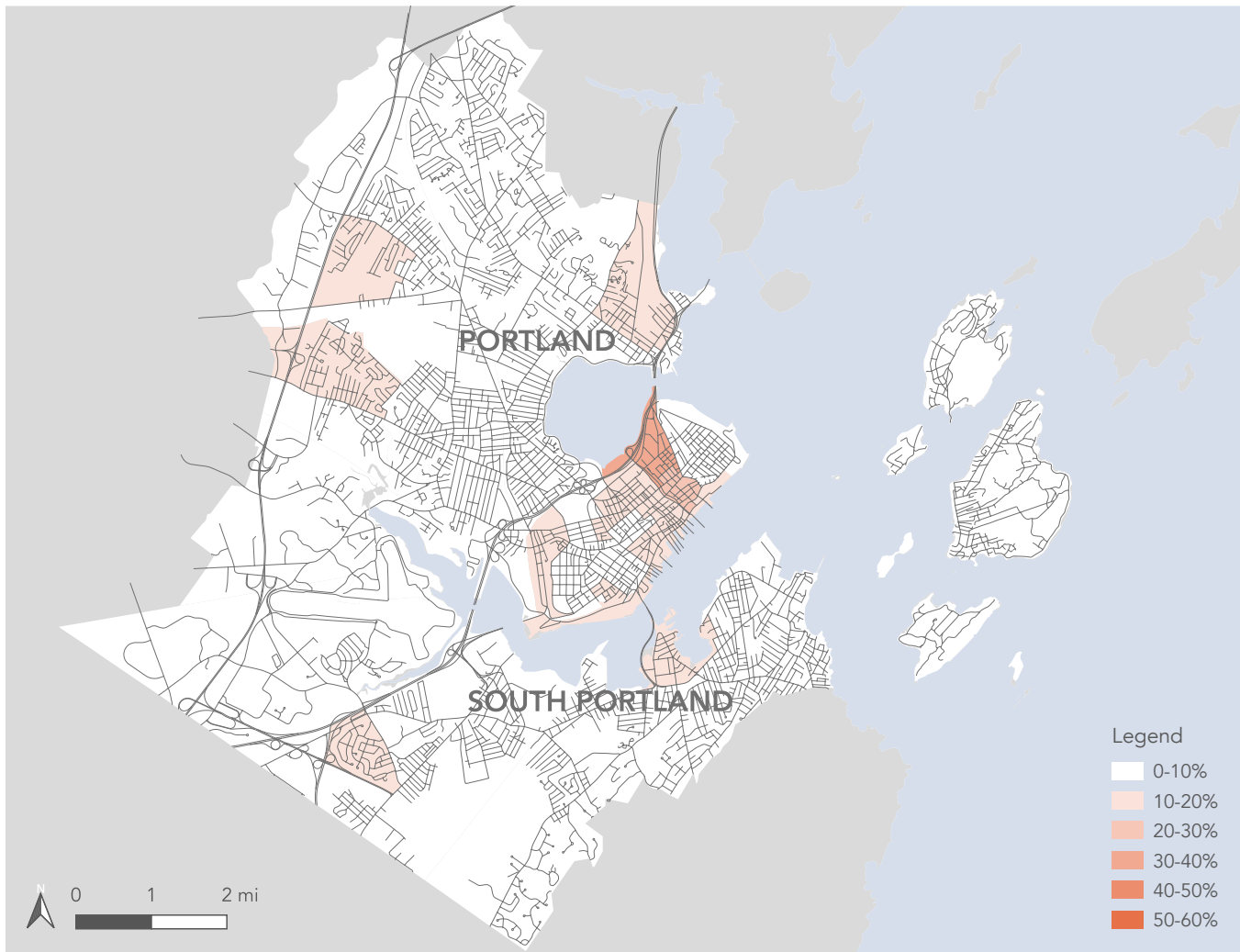


Figure 6.9. Percentage of residents in Portland and South Portland who are over age 25 and do not have a high school diploma by Census Block.

Figure 6.9 shows the percentage of residents over age 25 within each Census Block who do not have a high school diploma. The East Bayside neighborhood in Portland has the highest percentage, followed by a number of areas on the Portland peninsula, East Deering, a portion of Riverton, Nason's Corner, Knightville, and the neighborhoods south of Crocket's Corner.

6.5 Compounding Social Vulnerability and Climate Hazards

While each individual factor discussed in the previous section will increase an individual's or household's vulnerability to climate change, many of these vulnerabilities "overlap" in ways that create new and compounding vulnerability. Additional challenges emerge when many of these individual vulnerabilities are experienced simultaneously. For example, an elderly individual living alone may face challenges during a power

outage; these challenges may be more significant if their closest family member has young children, little financial means, and is reliant on public transportation, which may not be running at that point in time.

The Social Vulnerability Index is a way of looking at a large number of factors collectively to see which neighborhoods have greater social vulnerability across a number of factors. **Figure 6.10** shows a Social Vulnerability Index that was developed specifically for Maine communities by the Maine Coastal Risk Explorer Project.²²⁷ The index integrates 17 factors by percentile,

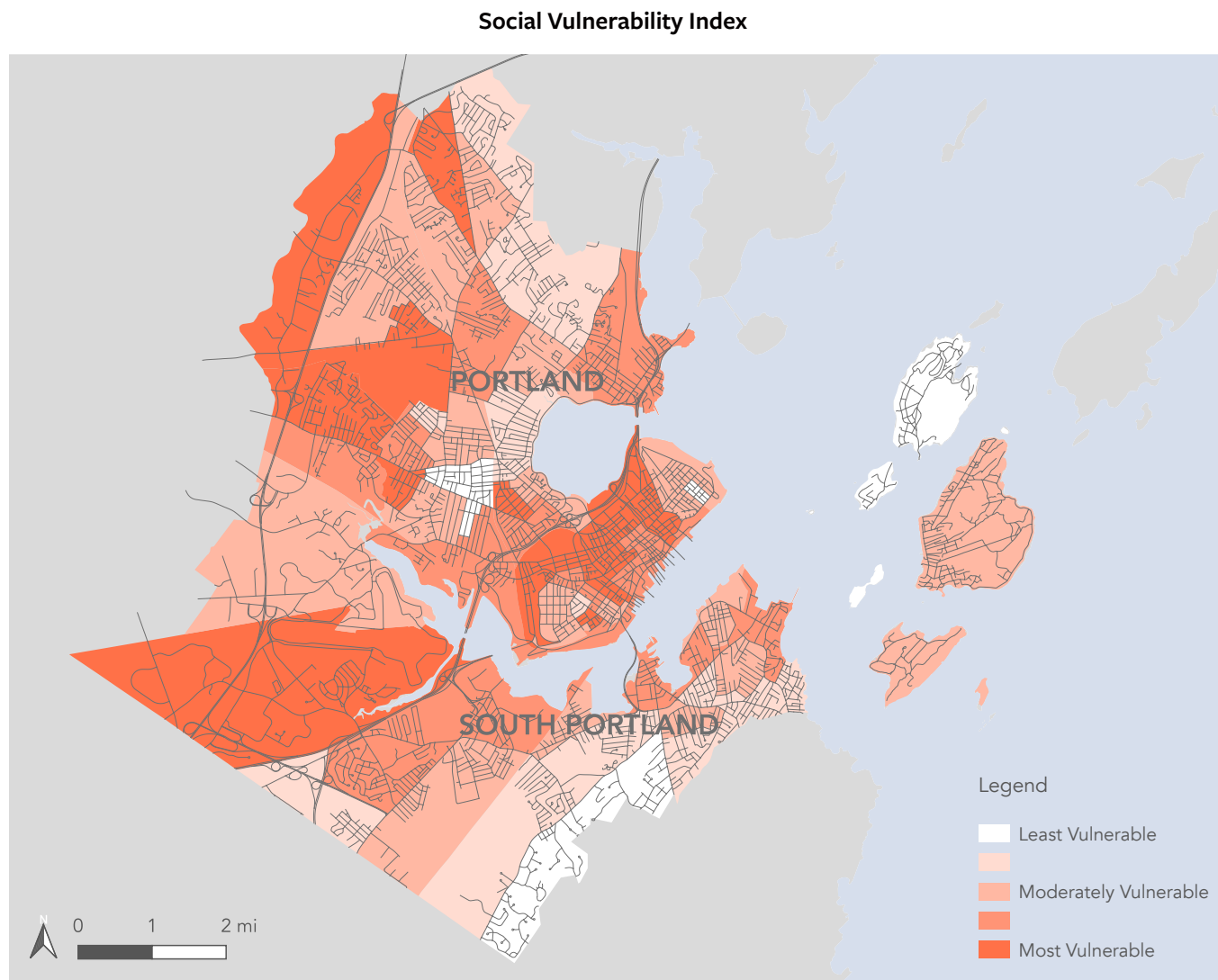


Figure 6.10. Social Vulnerability Index (SVI), aggregating 17 measures of social vulnerability, by Census Block. The SVI was developed specifically for Maine communities by the Maine Coastal Risk Explorer Project. For further information on the development of the SVI see Johnson et al. (2018).²²⁸

Factors Included in the Social Vulnerability Index

SVI Factor:	Description:	Percent Calculation Based On:
Below the poverty level	Ratio of income to poverty level up to 0.99	Total population for whom population is established
Unemployed	Unemployed population in labor force	Population 16 years or over in the labor force
Natural resource occupation	Population employed in a natural resource occupation (agriculture, forestry, fishing and hunting, and mining)	Population 16 years or over in the labor force
Self employed	Population that is self-employed in own incorporated business	Population 16 years or over in the labor force
Income	Per capita income for total population	Per capita income for total population
No high school diploma	Population who has not completed a high school education	Total population 25-years-old and older
Age 65 or over	Population 65-years-old and older	Total population
Age 65 or over and living alone	Population 65-years-old and older and living alone	Total population
Age 18 or younger	Population 18-years-old and younger	Total population
Disability	Households with one or more members with a disability	Total households
Single parent household	Household with single parent and children under age 18	Total households
People of Color	All persons except white, non-Hispanic	Total population
Speaks English less than well	Population with ability to speak English “not well” or “not at all”	Total population 5-years-old and older
Multi-unit structure	Housing in structures with 10 or more units	Total housing units
Mobile homes	Mobile homes	Total housing units
Crowding	Instances where there are more people than rooms in a household (including owner-occupied and renters)	Total households
No vehicle	Households with no vehicle available	Total households

Table 6.1. Factors in the Social Vulnerability Index (SVI) developed as part of the Maine Coastal Risk Explorer Project. For further information on the development of the SVI see Johnson et al. (2018).²²⁹

listed in **Table 6.1**. Based on the aggregation of these factors, South Portland’s West End, as well the portions of Rivertown west of I-95 and south of Warren Ave, a portion of North Deering west of Auburn Street/SR 100, a portion of Oakdale near the USM campus, as well as much of the western side of the Portland peninsula show the highest levels of social vulnerability.

Some climate change hazards—particularly flooding from sea level rise and storm surge—will affect some areas of Portland and South Portland more than others. The following maps illustrate how impacts from climate hazards may be spatially concentrated, and how these impacts overlap with social vulnerability in the cities.

Figure 6.11 illustrates the Social Vulnerability Index, as well as roads that will be inundated or inaccessible to emergency responders and addresses that would be inaccessible to emergency responders with 3.3 feet of sea level rise on top of the highest annual tide. East and West Bayside in Portland show the most significant impact from this level of flooding, on top of high social vulnerability.

While higher temperatures will impact all of Portland and South Portland, areas with greater amounts of

impervious surface will likely feel the effects of higher heat more acutely. Impervious surfaces such as pavement and asphalt tend to absorb and retain more heat, creating higher surface temperatures. Consequently, the quantity of impervious surfaces in a given area can serve as a proxy for understanding which areas of the cities will likely feel warmer on any given day. **Figure 6.12** illustrates the Social Vulnerability Index overlaid with impervious surfaces within the cities. South Portland's West End in particular has a substantial amount of impervious surface on top of relatively high social vulnerability.

Social Vulnerability and Flood Risk

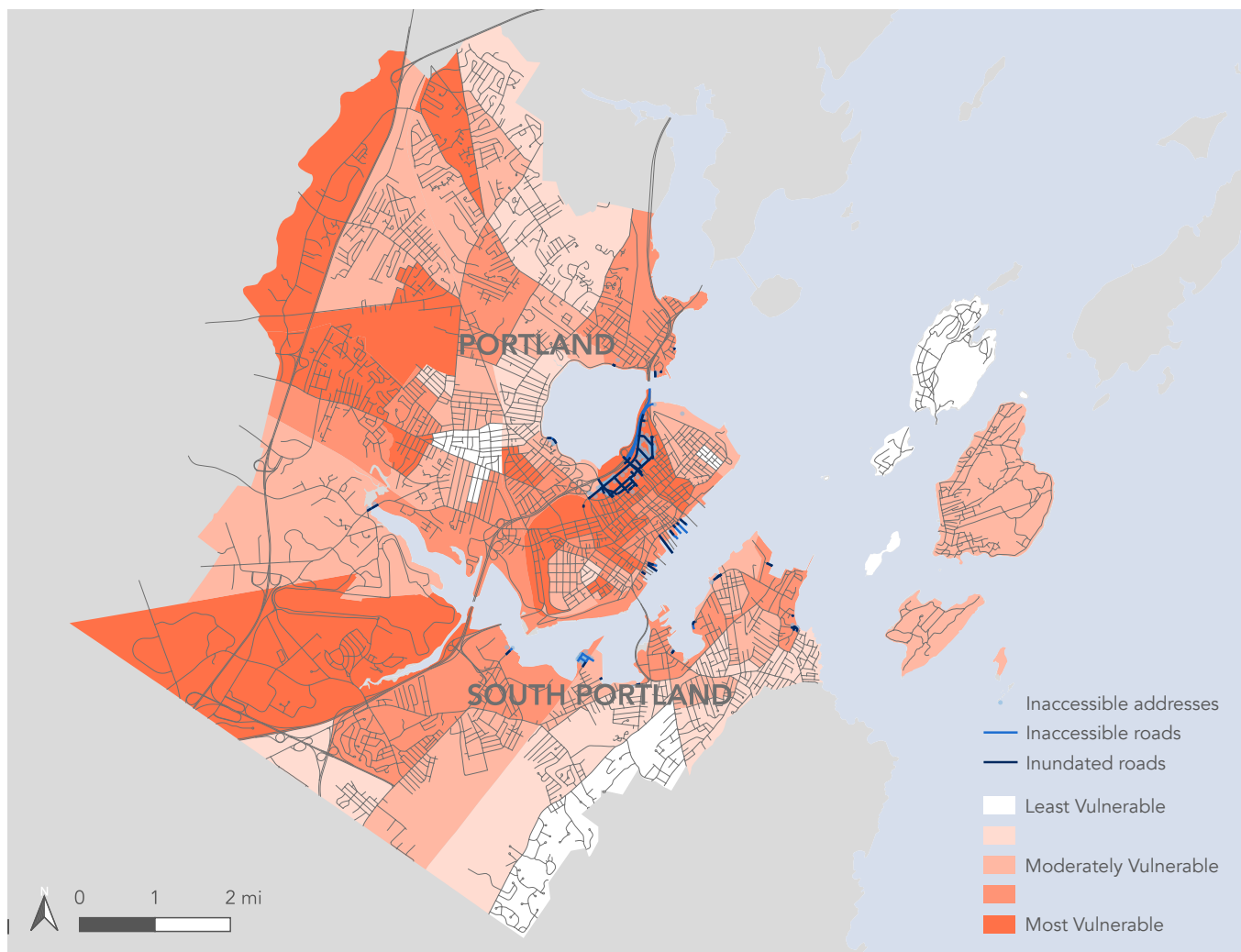


Figure 6.11. The Social Vulnerability Index by Census Block, as well as inundated roads, inaccessible roads, and inaccessible addresses with 3.3 feet (1 meter) of sea level rise on top of the highest annual tide. Inundated roads are road sections of the Maine E911 road data set that could be covered by water and therefore not passable at highest annual tide. Inaccessible roads are road sections of the Maine E911 road dataset that are adjacent to inundated roads and could be inaccessible to emergency responders from the nearest Emergency Management Service (EMS) station. Inaccessible addresses are address points that are adjacent to Inaccessible Roads and could be inaccessible to EMS stations at the highest annual tide. Data source: Maine Coastal Risk Explorer Project. See Johnson et al. (2018) for further details.²³⁰

Social Vulnerability and Impervious Surfaces

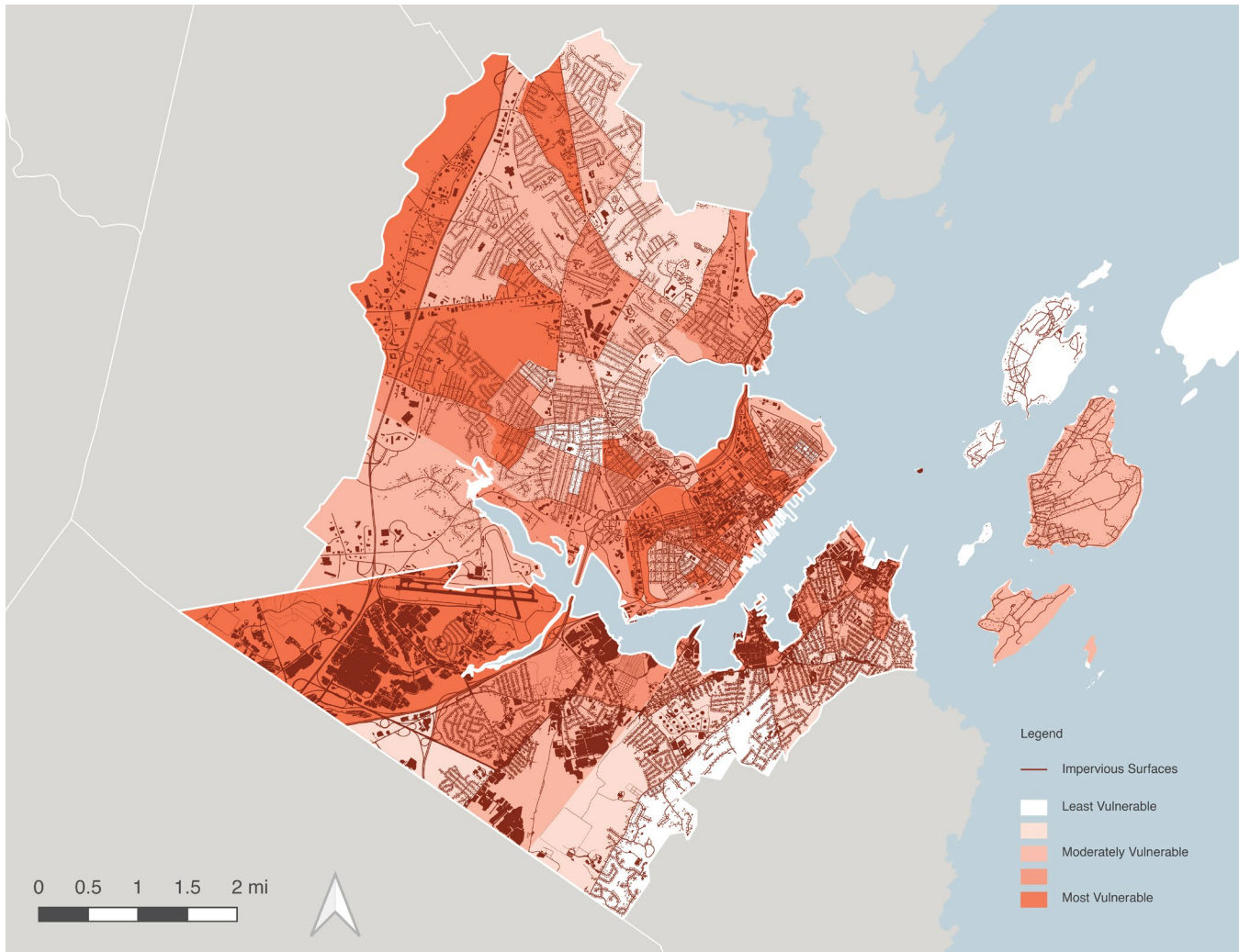


Figure 6.12. The Social Vulnerability Index (SVI) by Census Block overlaid with impervious surfaces across Portland and South Portland. Impervious surfaces can serve as a proxy for understanding which areas of the cities may feel warmer on high heat days. SVI data from the Maine Coastal Risk Explorer Project;²³¹ Impervious surface data from the Cities of Portland and South Portland.

SECTION SIX ENDNOTES

- 195 U.S. Census Bureau, Population Estimates Program (PEP), July 1, 2018 (V2018).
- 196 Balbus, J.M., & Malina, C. (2009). "Identifying vulnerable subpopulations for climate change health effects in the United States," *Journal of Occupational and Environmental Medicine* 51, no. 1: 33-37.
- 197 Bell, M.L., Zanobetti, A. & Dominici, F. (2014). "Who is more affected by ozone pollution? A systematic review and meta-analysis," *American Journal of Epidemiology*: kww115.
- 198 Reid, C. E., M. S. O'Neill, C. J. Gronlund, S. J. Brines, D. G. Brown, A. V. Diez-Roux, and J. Schwartz. 2009. "Mapping Community Determinants of Heat Vulnerability." *Environmental Health Perspectives* 117 (11): 1730-1736.
- 199 Gamble, J.L., Hurley, B.J., Schultz, P.A., Jaglom, W.S., Krishnan, N., & Harris M. (2013). "Climate Change and Older Americans: State of the Science." *Environmental Health Perspectives* 121, no. 1: 15-22.
- 200 U.S. Census Bureau, Population Estimates Program (PEP), July 1, 2018 (V2018).
- 201 Gaskin, C.J., Taylor, D., Kinnear, S., Mann, J., Hillman, W., & Moran, M. (2017). "Factors Associated with the Climate Change Vulnerability and the Adaptive Capacity of People with Disability: A Systematic Review." *Weather, Climate, and Society* 9, no. 4: 801-14.

- 202 Gaskin, C.J., Taylor, D., Kinnear, S., Mann, J., Hillman, W., & Moran, M. (2017). "Factors Associated with the Climate Change Vulnerability and the Adaptive Capacity of People with Disability: A Systematic Review." *Weather, Climate, and Society* 9, no. 4: 801–14.
- 203 Gaskin, C.J., Taylor, D., Kinnear, S., Mann, J., Hillman, W., & Moran, M. (2017). "Factors Associated with the Climate Change Vulnerability and the Adaptive Capacity of People with Disability: A Systematic Review." *Weather, Climate, and Society* 9, no. 4: 801–14.
- 204 Hemingway, L., & Priestley, M. (2014). "Natural Hazards, Human Vulnerability and Disabling Societies: A Disaster for Disabled People?" *Review of Disability Studies: An International Journal* 2, no. 3.
- 205 U.S. Census Bureau, Population Estimates Program (PEP), July 1, 2018 (V2018).
- 206 American Academy of Pediatrics. (2000). "Climatic Heat Stress and the Exercising Child and Adolescent." Committee on Sports Medicine and Fitness. *Pediatrics* 106 (1 Pt 1):158–159.
- 207 Zivin, J.G., & Shrader, J. (2016). "Temperature Extremes, Health, and Human Capital." *The Future of Children*. Vol. 26, No. 1.
- 208 Balbus, J.M. & Malina, C. (2009). "Identifying vulnerable subpopulations for climate change health effects in the United States," *Journal of Occupational and Environmental Medicine* 51, no. 1: 33–37.
- 209 USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp.
- 210 US Census Bureau American Community Survey (ACS), one-year estimates (2017).
- 211 U.S. Census Bureau, Population Estimates Program (PEP), July 1, 2018 (V2018).
- 212 Maine Center for Economic Policy. (2017). *State of Working Maine: 2017*. Augusta, ME.
- 213 Maine Center for Economic Policy. (2017). *State of Working Maine: 2017*. Augusta, ME.
- 214 Myall, J. (2019). Data on racial inequality shows need for solutions to advance racial justice. Maine Center for Economic Policy. Retrieved from <https://www.mecp.org/fact-sheet-data-on-racial-inequality-shows-need-for-solutions-to-advance-racial-justice/>
- 215 Yob, D., Huston S.L., Teach, F., Braddick, J., Severson, D. (2018). *The Burden of Asthma in Maine: 2006-2010*. Augusta, ME: Maine Center for Disease Control and Prevention.
- 216 Myall, J. (2019). Data on racial inequality shows need for solutions to advance racial justice. Maine Center for Economic Policy. Retrieved from <https://www.mecp.org/fact-sheet-data-on-racial-inequality-shows-need-for-solutions-to-advance-racial-justice>
- 217 US Census Bureau American Community Survey (ACS), five-year estimates (2013-2017).
- 218 US Census Bureau preliminary poverty threshold estimates for 2018. Final thresholds will be released in September 2019.
- 219 Centers for Disease Control and Prevention. (2011). "CDC Health Disparities and Inequalities Report — United States, 2011," *Morbidity and Mortality Weekly Report*, 60 Suppl.
- 220 MaineHealth. (2017) "Health Index 2017 Report: Measuring Our Success in Improving the Health of Maine." Portland, ME.
- 221 US Census Bureau American Community Survey (ACS), one-year estimates (2017).
- 222 Poumadere, M., C. Mays, S. Le Mer, and R. Blong. (2005). "The 2003 heat wave in France: Dangerous climate change here and now." *Risk Analysis* 25 (6): 1483–1494.
- 223 US Census Bureau American Community Survey (ACS), five-year estimates (2013-2017).
- 224 Striessnig, E., Lutz, W., & Patt, A. (2013). Effects of Educational Attainment on Climate Risk Vulnerability. *Ecology and Society*,18(1).
- 225 Striessnig, E., Lutz, W., & Patt, A. (2013). Effects of Educational Attainment on Climate Risk Vulnerability. *Ecology and Society*,18(1).
- 226 Department for Business Innovation & Skills (BIS). 2013. The benefits of higher education participation for individuals and society: key findings and reports "The Quadrants." BIS Research Paper No. 146. London, UK.
- 227 Johnson, E.S., Bell, J.M., Coker, D., Hertz, E., LaBarge, N., & Blake, G. (2018). A lifeline and social vulnerability analysis of sea level rise impacts on rural coastal communities. *Shore & Beach*. 86(4).
- 228 Johnson, E.S., Bell, J.M., Coker, D., Hertz, E., LaBarge, N., & Blake, G. (2018). A lifeline and social vulnerability analysis of sea level rise impacts on rural coastal communities. *Shore & Beach*. 86(4).
- 229 Johnson, E.S., Bell, J.M., Coker, D., Hertz, E., LaBarge, N., & Blake, G. (2018). A lifeline and social vulnerability analysis of sea level rise impacts on rural coastal communities. *Shore & Beach*. 86(4).
- 230 Data from the Maine Coastal Risk Explorer Project. For further information see: Johnson, E.S., Bell, J.M., Coker, D., Hertz, E., LaBarge, N., & Blake, G. (2018). A lifeline and social vulnerability analysis of sea level rise impacts on rural coastal communities. *Shore & Beach*. 86(4)
- 231 Social Vulnerability Index data from the Maine Coastal Risk Explorer Project. For further information see: Johnson, E.S., Bell, J.M., Coker, D., Hertz, E., LaBarge, N., & Blake, G. (2018). A lifeline and social vulnerability analysis of sea level rise impacts on rural coastal communities. *Shore & Beach*. 86(4). Impervious surface data from the Cities of Portland and South Portland.

7. Conclusion

With greater knowledge of our vulnerability, we'll have greater capacity to act.

We know that climate change will bring significant challenges to Portland and South Portland. Sea level rise, storm surge, ocean acidification, more extreme weather, and higher air and water temperatures create new risk and exacerbate existing vulnerabilities across our infrastructure, environment, economy, and communities. This vulnerability assessment investigates the many vulnerabilities our cities will need to consider, highlighting the need and opportunity to work together for solutions.

Driven by the research, conversations, workshops, and analyses that informed this assessment, ten key areas of vulnerability rise to the surface. These are described in full in the Executive Summary, and briefly re-summarized below (not in any particular order).

1. RELEASE OF HAZARDOUS WASTE

There is high risk that shoreline retreat due to sea level rise, changes in groundwater tables, as well as wind and wave action from severe storms will submerge or erode hazardous waste sites, causing structural damage to above ground or subsurface hazardous waste containments, as well as releasing soil-bound contaminants.

2. GRID SYSTEM RELIABILITY AND BUSINESS CONTINUITY

The New England electrical power system is undergoing significant change, and climate hazards are expected to reduce system function and reliability. Power outages are a high concern for businesses and tend to be the most frequent root cause of cascading system failures across other infrastructural systems.

3. IMPACT TO PROPERTY VALUES, COMMERCIAL AREAS, AND TAX BASE

Rising sea levels and storm surge are expected to damage buildings and property, as well as create more lasting effects on property values, real estate markets, commercial centers, and the cities' tax bases. The cities' access to additional capital for resilience investments is also dependent on municipal credit ratings, which can be lowered based on flood risk.

4. DISRUPTION TO CRITICAL TRANSPORTATION ROUTES

Sea level rise and storm surge are expected to increasingly inundate roads, and most critically portions of I-295. A category 2 hurricane could cut off connections between the two cities by affecting all bridges that cross the Fore River within the two cities.

5. VULNERABILITY OF SEWER AND STORMWATER CRITICAL ASSETS

The sewer and stormwater systems in both cities show vulnerability to storms and sea level rise in areas along the waterfronts. The South Portland wastewater treatment facility is vulnerable to storm surge under a category 2 hurricane or higher, as well as to 6.1 feet of sea level rise above the highest astronomical tide.

6. DEGRADATION OF ECOSYSTEM HEALTH

Sea level rise may lead to habitat loss for sensitive tidal wetlands, and higher volumes of stormwater runoff may exacerbate coastal ecosystem degradation. Changes in temperature and precipitation patterns are also allowing new invasive species and pests to thrive.

7. PUBLIC HEALTH CHALLENGES, PARTICULARLY HIGH HEAT

Unseasonably hot days, extreme heat, as well as extended heat waves could lead to more heat-related hospitalizations and deaths. Climate change is also likely to exacerbate asthma from worsened air quality, bring higher rates of vector-borne disease, and affect mental health.

8. GREATER NEED FOR SOCIAL SERVICES

Without proactive plans to support, fund, modify, coordinate, and/or expand social service networks and systems in the cities, current programs risk becoming overstrained and under-resourced to adapt to changing social service needs.

9. VULNERABILITY OF FOOD SYSTEMS

Sea level rise and storm surge will likely restrict food delivery, and impact a large proportion of the cities' major supermarkets. Residents that rely on public transportation and/or food assistance will likely face greater food insecurity driven by closures in public transportation, social services, or rising food prices.

10. RISK OF INCREASING SOCIAL INEQUITY

There is a significant risk that climate change may contribute to greater social inequity, by exacerbating factors (such as poverty) that enhance vulnerability. Evidence from other cities have shown ways in which adaptation measures have also inadvertently enhanced inequity by continuing to invest in areas that have more resources.

These vulnerabilities are complex and intertwined. Yet as we continue to understand these climate risks, we become more and more equipped in how we take action.

WHAT COMES NEXT

Through June 2020, Portland and South Portland are charting a course for reducing climate vulnerability as part of the joint climate action and adaptation planning process: *One Climate Future*.

Driven by input from residents, businesses, organizations, and City staff, the plan will take the information from this vulnerability assessment and develop a set of pathways for becoming more resilient—first and foremost addressing the ten key areas outlined above.

The strategies will address infrastructure upgrades, design standards, and zoning revisions, and will serve as a reference and roadmap for concurrent and future planning processes, including ReCode Portland and the South Portland Waterfront Masterplan.

In addition to enhancing the resilience of the built environment, the strategies will also focus on programs and initiatives that will strengthen our communities, protect our health, and allow us all to better adapt to new acute and chronic stresses.

Through focusing on these vulnerabilities and expanding our strengths, we have the capacity to become increasingly inclusive, vibrant communities where residents and businesses can thrive in a changing climate.

Bibliography

- American Academy of Pediatrics. (2000). "Climatic Heat Stress and the Exercising Child and Adolescent." Committee on Sports Medicine and Fitness. *Pediatrics* 106 (1 Pt 1):158–159.
- Balbus, J.M., & Malina, C. (2009). "Identifying vulnerable subpopulations for climate change health effects in the United States," *Journal of Occupational and Environmental Medicine* 51, no. 1: 33-37.
- Beck, D.R., Carleton, N., Steinhoff, H., Wallace, D., & Lapping, M. (2011). *Maine's Food System: An Overview and an Assessment*. Maine Policy Review, 20:1.
- Bell, M.L., Zanobetti, A. & Dominici, F. (2014). "Who is more affected by ozone pollution? A systematic review and meta-analysis," *American Journal of Epidemiology*: kwu115.
- Bohlen, C., Blair, M., Boundy, V., Freshley, C., Sands, K. (2019). *Nutrient Pollution in Casco Bay, Maine*. Casco Bay Estuary Partnership, Muskie School of Public Service, University of Southern Maine. Portland, ME.
- Bohlen, C., Stelk, M., Craig, M., Redmond, L., & Gerber, C. (2012). *Geomorphology and the Effects of Sea Level Rise on Tidal Marshes in Casco Bay*. University of Southern Maine, Muskie School of Public Services, Casco Bay Estuary Partnership.
- Bohlen, C., Stelk, M., Craig, M., & Gerber, C. (2013). *Sea Level Rise and Casco Bay's Wetlands: A Look at Potential Impacts*, Portland Edition. Casco Bay Estuary Partnership.
- Bohlen, C., Stelk, M., Craig, M., & Gerber, C. (2013). *Sea Level Rise and Casco Bay's Wetlands: A Look at Potential Impacts*, South Portland Edition. Casco Bay Estuary Partnership.
- Breton, R. (2019). Longer 'red tide' outbreak impacting Maine shellfish industry. News Center Maine. Retrieved from <https://www.newscentermaine.com/article/news/longer-red-tide-outbreak-impacting-maine-shellfish-industry/97-f3421fa7-e4c7-4ced-a0c3-e63b20cd1130>
- Burillo, D. (2018). *Effects of Climate Change in Electric Power Infrastructures*. Retrieved from 10.5772/intechopen.82146
- Casco Bay Estuary Partnership. (2015). *State of the Bay 2015 Report*. Portland, Maine.
- Casco Bay Estuary Partnership, Natural Choices, Waterview Consulting. (2017). *Casco Bay Climate Change Vulnerability Report*. University of Southern Maine, Muskie School of Public Service, Casco Bay Estuary Partnership: Portland, ME.
- Catalysis Adaptation Partners. (2013). *Executive Summary: Flooding Vulnerability Assessment Using the COAST Tool and Approach for the Portland Society for Architecture and the City of Portland, ME for the Commercial Street Waterfront Area*.
- Centers for Disease Control and Prevention. (2011). "CDC Health Disparities and Inequalities Report — United States, 2011," *Morbidity and Mortality Weekly Report*, 60 Suppl.
- Centers for Disease Control and Prevention. (2019). *Most Recent Asthma State or Territory Data*. Retrieved from: https://www.cdc.gov/asthma/most_recent_data_states.htm#source
- Center for Health and the Global Environment. (2009). *Climate Change and Health in Maine*. Cambridge, MA: Harvard Medical School.
- Chinowsky, P., Helman, J., Sahil, G., Neumann, J., & Martinich, J. (2019). Impacts of climate change on operation of the US rail network. *Transport Policy*. 75: 183-191.
- City of Portland. (2016). *Portland Open Space Vision and Implementation Plan*. Portland, ME.
- City of Portland. (2017). *Portland's Plan 2030*. Portland, ME.
- City of Portland, New England Environmental Finance Center, Woodard & Curran, RPS ASA, & Jordan Environmental Engineering. (2017). *Bayside Adapts Phase 1: Sewer and Stormwater System Data Gap Analysis*. Portland, ME.
- City of South Portland. (2018). *Maine Flood Resilience Checklist: Summary and Recommendations Report*.
- City of South Portland. (2019). *Wastewater Plant O&M*. Retrieved from <https://www.southportland.org/departments/water-resource-protection/treatment-systems/pump-station-o-m/>
- City of South Portland. (n.d.) *Parks Department*. Retrieved from <https://www.southportland.org/departments/parks-recreation-aquaticspool/parks-department/>
- Climate Central. (2016). *Sea Level Rise and Coastal Flood Risk: Summary for Portland, ME*.
- Climate Central. (2016). *Sea Level Rise and Coastal Flood Risk: Summary for South Portland, ME*.
- Climate Central. (n.d.) "Maine Drought." *States at Risk*, Climate Central. Retrieved July 2019 from <https://statesatrisk.org/maine/drought>

- Coastal Risk Explorer. (2018). Retrieved from <https://maps.coastalresilience.org/maine/>
- Comes, T., & Van de Walle, B. (2014). Measuring Disaster Resilience: The Impact of Hurricane Sandy on Critical Infrastructure Systems. Proceedings of the 11th International ISCRAM Conference. Hiltz, S.R., Pfaff, M.S., Plotnick, L. & Shih, P.C. eds. Pennsylvania, USA.
- Cumberland County Emergency Management Agency (CCEMA). (2017). Cumberland County Hazard Mitigation Plan.
- Department for Business Innovation & Skills (BIS). 2013. The benefits of higher education participation for individuals and society: key findings and reports “The Quadrants.” BIS Research Paper No. 146. London, UK.
- Environment Maine (n.d.) “Local, Sustainable Maine Food.” Portland, ME. Retrieved from <https://environmentmaine.org/programs/mee/local-sustainable-maine-food/>; H.P. 848 (2019). Resolve, To End Hunger in Maine by 2030. 129th Maine Legislature. Legislative Document No. 1159.
- Feeding America. (2017). Food Insecurity in Cumberland County. Retrieved from <https://map.feedingamerica.org/county/2017/overall/maine/county/cumberland>
- FEMA (n.d.) “Definitions of FEMA Flood Zone Designations.” FEMA Map Service Center. Retrieved from <https://snmapmod.snco.us/fmm/document/fema-flood-zone-definitions.pdf>
- Fernandez, I. J., Schmitt, C. V., Birkel, S. D., Stancioff, E., Pershing, A. J., Kelley, J. T., ... Mayewski, P. A. (2015). Maine’s Climate Future: 2015 Update. Orono, ME: University of Maine.
- Flynn, T.J., Walesh, S.G., Titus, J.G., & Barth, M.C. (n.d.) Implications of Sea Level Rise for Hazardous Waste Sites in Coastal Floodplains. Retrieved from <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.391.7715&rep=rep1&type=pdf>
- Friends of Casco Bay. (2019). Casco Bay Matters: Advancing the conversation—and action—on climate change. Casco Baykeeper. Retrieved from <https://www.cascobay.org/tag/casco-baykeeper/>
- Gamble, J.L., Hurley, B.J., Schultz, P.A., Jaglom, W.S., Krishnan, N., & Harris M. (2013). “Climate Change and Older Americans: State of the Science.” Environmental Health Perspectives 121, no. 1: 15–22.
- Gaskin, C.J., Taylor, D., Kinnear, S., Mann, J., Hillman, W., & Moran, M. (2017). “Factors Associated with the Climate Change Vulnerability and the Adaptive Capacity of People with Disability: A Systematic Review.” Weather, Climate, and Society 9, no. 4: 801–14.
- Greater Portland Council of Governments, & Maine Geological Survey. (2012). Adapting to Sea Level Rise in South Portland. South Portland, ME.
- Greater Portland Council of Governments; Sustain Southern Maine. (2013). Sea Level Rise Vulnerability Assessment.
- Hare, J. A., Morrison, W.E., Nelson, M.W., Stachura, M.M., Teeters, E.J., Griffis, R.B., et al. (2016). A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast US Continental Shelf. PLoS ONE, 11(2).
- Hawes, E. (1994). The Dirty History of Portland Harbor. Casco Bay Estuary Partnership, Muskie School of Public Service, University of Southern Maine. Portland, ME. Retrieved from <https://www.cascobayestuary.org/wp-content/uploads/2018/02/2006-Dirty-History-Fact-Sheet-1994-reprint.pdf>, 1994.
- Hemingway, L., & Priestley, M. (2014). “Natural Hazards, Human Vulnerability and Disabling Societies: A Disaster for Disabled People?” Review of Disability Studies: An International Journal 2, no. 3.
- Insurance Information Institute. (2019). “Spotlight on: Flood Insurance.” Retrieved from <https://www.iii.org/article/spotlight-on-flood-insurance>
- International Panel on Climate Change (IPCC). 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.). Geneva, Switzerland: IPCC.
- ISO New England. (2019). Energy Security Improvements. ISO Discussion Paper, April 2019 – Version 1. Holyoke, MA.
- Jacobson, G. L., Fernandez, I. J., Mayewski, P. A., & Schmitt, C. V (editors). (2009). Maine’s Climate Future: An Initial Assessment. Orono, ME: University of Maine.
- Johnson, E.S., Bell, J.M., Coker, D., Hertz, E., LaBarge, N., & Blake, G. (2018). A lifeline and social vulnerability analysis of sea level rise impacts on rural coastal communities. Shore & Beach. 86(4).
- Karl F. Seidman Consulting Services & Karp Strategies. (2015). South Portland Economic Development Plan: Positioning South Portland for Balanced and Healthy Growth. South Portland, ME; City of Portland. (2017). Portland’s Plan 2030. Portland, ME.
- Kartez, J. (2017). Bayside Adapts Working Group Final Report. New England Environmental Finance Center, University of Southern Maine.
- Kebede, A.S. (2009). Assessing Potential Risks of Impacts of Climate Change on Coastal Landfill Sites: A Case Study of Pennington Landfill Site - Hampshire, United Kingdom. (Unpublished master’s thesis). University of Southampton, Southampton, England.

- Kimball, J. W. (2013). *Protecting the Edge, Exposing the Tides: Creating Resiliency on Portland, Maine's Working Waterfront*. University of Toronto.
- Kleisner, K.M., et al. (2017). Marine species distribution shifts on the U.S. Northeast Continental Shelf under continued ocean warming. *Progress in Oceanography*. 153: 24-36.
- Kotamarthi, V. R., Wang, J., & Drewniak, B. (2016). *Climate Models Datasets for Climate Assessments: A Summary for the State of Maine*.
- Kristin Kelleher. (2019). *Businesses Acting on Rising Seas*. Climate Action Business Association. Boston, MA.
- Laaka, Julia. (2018). South Portland fire station mold could cost city \$1.3M. *Portland Press Herald*.
- Maco, B. et al. (2018). Resilient remediation: Addressing extreme weather and climate change, creating community value. *Remediation*. Retrieved from <https://onlinelibrary.wiley.com/doi/abs/10.1002/rem.21585>
- Maine Center for Business and Economic Research, University of Southern Maine, & rboubier consulting. (2017). *The Economic Contribution of Casco Bay*. University of Southern Maine, Muskie School of Public Services, Casco Bay Estuary Partnership.
- Maine Center for Economic Policy. (2017). *State of Working Maine: 2017*. Augusta, ME.
- Maine Coastal Program, & Maine Department of Agriculture Conservation and Forestry. (2017). *The Maine Flood Resilience Checklist*.
- Maine Department of Agriculture, Conservation, and Forestry (2017). *Terrestrial Invasive Plant List*. Retrieved from <https://www.maine.gov/dacf/php/horticulture/invasiveplants.shtml>
- Maine Department of Environmental Protection. (2010). *People and Nature Adapting to Climate Change: Charting Maine's Course*.
- Maine Department of Environmental Protection. (2018). *Handbook for Hazardous Waste Generators*. Retrieved from <https://www.maine.gov/dep/waste/hazardouswaste/documents/hazardous-waste-handbook-2018.pdf>
- Maine Department of Environmental Protection. (2019). *EGAD (Environmental and Geographic Analysis Database)*. Retrieved from <http://www.maine.gov/dep/maps-data/egad/>
- Maine Department of Marine Resources. (n.d.) *Historical Eelgrass Coverage Viewer*. Retrieved from <https://maine.maps.arcgis.com/apps/MapSeries/index.html?appid=ac2f7b3d29b34268a230a060d6b78b25>
- Maine Department of Transportation & Gates, J. (2009). "Climate Change and Transportation in Maine." *Transportation Documents*. 58.
- Maine Geological Survey (2019). *Maine Beach Mapping Program Shoreline Changes*. Retrieved from https://www.maine.gov/dacf/mgs/hazards/beach_mapping/index.shtml
- Maine Geological Survey. (2019). *Potential Hurricane Inundation Mapping - Frequently Asked Questions*. Retrieved from <https://www.maine.gov/dacf/mgs/hazards/slosh/faq.htm>
- Maine State Legislature; Maine Office of Policy and Legal Analysis; Bentley, Curtis; and Schneider, D. (2015). *Report of the Commission to Study the Effects of Coastal and Ocean Acidification and its Existing and Potential Effects on Species that are Commercially Harvested and Grown Along the Maine Coast*.
- MaineHealth. (2017) "Health Index 2017 Report: Measuring Our Success in Improving the Health of Maine." Portland, ME.
- McAlpine, S.A. & Porter, J.R. (2018). Estimating Recent Local Impacts of Sea-Level Rise on Current Real-Estate Losses: A Housing Market Case Study in Miami-Dade, Florida. *Population Research and Policy Review*. 37(6): 871-895.
- McCabe, M.S. & Burke, J. (2012). "The New England Food System in 2060: Envisioning Tomorrow's Policy Through Assessments." University of New Hampshire School of Law Scholar's Repository. 65 ME. L. REV 549.
- McGuire, P. (2017). Late-season toxic algae bloom closes most shellfishing areas in Casco Bay. *Portland Press Herald*. Retrieved from <https://www.pressherald.com/2017/12/06/toxic-bloom-closes-casco-bay-shellfish-industry/>
- Merrill, S., Kirshen, P. Yakovlev, D. Lloyd, S. Keeley, C. & Hill, B. (2012). *COAST in Action: 2012 Projects from New Hampshire and Maine*. University of Maine, New England Environmental Finance Center. Series Report #12-05. Portland, ME.
- Mills, K.E., Pershing, A.J., Brown, C.J., Chen, Y., Chiang, F.S., Holland, D.S., Lehuta, S., Nye, J.A., Sun, J.C., Thomas, A.C., & Wahle, R.A. (2013). Fisheries management in a changing climate: lessons from the 2012 ocean heat wave in the Northwest Atlantic. *Oceanography* 26(2):191-195.
- Moftakhari, H.R., AghaKouchak, A., Sanders, B.F., Allaire, M., & Matthew, R.A. (2018). "What Is Nuisance Flooding? Defining and Monitoring an Emerging Challenge." *Water Resources Research*. 54, no. 7: 4218-27.
- Morley, J.W., Selden, R.L., Latour, R.J., Frolicher, T.L., Seagraves, R.J., Pinsky, M.L. (2018). Projecting shifts in thermal habitat for 686 species on the North American continental shelf. *PLoS ONE*. 13(5).
- Murphy, Z. et al. (2019). "Gone in a Generation." *Huffington Post*. Retrieved from https://www.washingtonpost.com/graphics/2019/national/gone-in-a-generation/?utm_term=.452f1f2ce06d#lobster

- National Ocean and Atmospheric Administration (NOAA). (2018). "Relative Sea Level Trend: 8418150 Portland, Maine." Tides and Currents. Retrieved from https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8418150.
- National Wildlife Federation & Asthma and Allergy Foundation of America. (2010). Extreme Allergies and Global Warming. Retrieved from <https://www.aafa.org/media/1634/extreme-allergies-global-warming-report-2010.pdf>
- Natural Resources Council of Maine. (n.d). Climate Change Threatens Maine's Farms. Retrieved November 2019 from <https://www.nrcm.org/programs/federal/federal-climate-and-energy-issues/climate-change-threatens-maines-farms/>
- Nijhuis, M. (2013). How Climate Change is Helping Invasive Species Take Over. Smithsonian Magazine. Retrieved from <https://www.smithsonianmag.com/science-nature/how-climate-change-is-helping-invasive-species-take-over-180947630/>
- Pershing, A. J., Alexander, M.A., Hernandez, C.M., Kerr, L.A., Le Bris, A., Mills, K.E., Nye, J.A., Record, N.R., Scannell, H.A., Scott, J.D., Sherwood, G.D., Thomas, A.C. (2015). Slow adaptation in the face of rapid warming leads to the collapse of the Gulf of Maine cod fishery. *Science*. 350, no 6262: 809-12.
- Pershing, A. & Stephenson, R. (2019). The Gulf of Maine in 2050. Gulf of Maine 2050 International Symposium, Portland, ME.
- Portland Water District (2017). Sebago Lake Watershed Map. As cited in Sebago Clean Waters. Retrieved from <https://www.sebagocleanwaters.org/watershed-map>
- Portland Water District. (2019.) Annual Water Quality Report. Retrieved from https://www.pwd.org/sites/default/files/annual_water_report_2019.pdf.
- Poumadere, M., C. Mays, S. Le Mer, and R. Blong. (2005). "The 2003 heat wave in France: Dangerous climate change here and now." *Risk Analysis* 25 (6): 1483-1494.
- Reid, C. E., M. S. O'Neill, C. J. Gronlund, S. J. Brines, D. G. Brown, A. V. Diez-Roux, and J. Schwartz. 2009. "Mapping Community Determinants of Heat Vulnerability." *Environmental Health Perspectives* 117 (11): 1730-1736.
- Ridlington, E. & Leavitt, C. (2018). Trouble in the Air: Millions of Americans Breathe Polluted Air. Environment Maine Research and Policy Center, Frontier Group, and US PIRG Education Fund, 55 pp.
- Robinson, S., & Mosseau, N. (2019). Report to Maine Legislature: Lyme and other Tick-borne Illnesses. Maine Center for Disease Control and Prevention.
- Schauffler, M. (2015). Climate Trends in the Casco Bay Region. University of Southern Maine, Muskie School of Public Services, Casco Bay Estuary Partnership.
- Schauffler, M., & Natural Choices. (2015). Climate Adaptation Resource Guide for Casco Bay Communities. Portland, Maine. University of Southern Maine, Muskie School of Public Services, Casco Bay Estuary Partnership.
- Slovinsky, P. (2019). State of Maine's Beaches in 2019. Maine Geological Survey. Augusta, ME.
- Slovinsky, P.A. & Dickson, S.M. (2011). Coastal Sand Dune Geology: Willard Beach, South Portland, Maine. Maine Geological Survey. Augusta, ME.
- South Portland Land Trust (n.d.) Mission. Retrieved from <https://www.southportlandlandtrust.org/what-we-do>
- Stantec Consulting Services. (2017). Background Analysis: An analysis of existing conditions and background information of the PACTS/GPCOG region and transit operators. Prepared for Greater Portland Council of Governments.
- Striessnig, E., Lutz, W., & Patt, A. (2013). Effects of Educational Attainment on Climate Risk Vulnerability. *Ecology and Society*, 18(1).
- Sweet, W.V., Kopp, R.E., Weaver, C. P., Obeysekera, J., Horton, R. M., Thieler, E.R., & Zervas, C. (2017). Global and Regional Sea Level Rise Scenarios for the United States. NOAA Technical Report NOS CO-OPS 83.
- Union of Concerned Scientists. (2014). "The Climate Risks of Natural Gas." Retrieved from https://www.ucsusa.org/sites/default/files/legacy/assets/documents/clean_energy/Climate-Risks-of-Natural-Gas-Full-Infographic.pdf
- Union of Concerned Scientists. (2018). Underwater: Rising Seas, Chronic Floods, and the Implications for US Coastal Real Estate. Cambridge, MA.
- Union of Concerned Scientists (2019). "Hurricanes and Climate Change." Retrieved from <https://www.ucsusa.org/resources/hurricanes-and-climate-change>
- University of Maine. (n.d.) Maine Invasive Species Network. Retrieved from <https://extension.umaine.edu/invasivespecies/>
- Urban Land Institute. (2014). Waterfronts of Portland and South Portland Maine: A ULI Advisory Services Panel Report.
- USAID. (2013). Addressing Climate Change Impacts on Infrastructure: Preparing for Climate Change. Washington DC.
- U.S. Department of Homeland Security (DHS). (2016). Casco Bay Region Climate Change Resiliency Assessment. Regional Resiliency Assessment Program.
- U.S. Environmental Protection Agency (EPA). (2016). Climate Change Indicators in the United States: Heat-Related Deaths. Retrieved from www.epa.gov/climate-indicators

- U.S. Environmental Protection Agency (EPA). (2016). What Climate Change Means for Maine. Retrieved from <https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-me.pdf>
- U.S. Environmental Protection Agency (EPA). (2019). Categories of Hazardous Waste Generators. Retrieved from www.epa.gov/hwgenerators/categories-hazardous-waste-generators.
- U.S. Global Change Research Program (USGCRP). (2016). The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska (Eds.) U.S. Global Change Research Program, Washington DC, 312 pp.
- U.S. Global Change Research Program (USGCRP). (2018). Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (Eds.). U.S. Global Change Research Program, Washington DC.
- U.S. Energy Information Administration. (2016). State Energy Data System, Table C1. Energy Consumption Overview: Estimates by Energy Source and End-Use Sector.
- Wake, C., Burakowski, E., Hayhoe, K., Watson, C., Douglas, E., VanDorn, J., ... Keating, C. (2009). Climate Change in the Casco Bay Watershed: Past, Present, and Future. University of Southern Maine, Muskie School of Public Services, Casco Bay Estuary Partnership.
- Walberg, E., VanDoren, W., & Sartoris, J. (2013). Sebago Lake Watershed, Maine Climate Change Adaptation Plan.
- Wallace, R.D., Bouvier, R. Yeitz, L.M., Colgan, C.S. (2017). The Economic Contribution of Casco Bay. Prepared for the Casco Bay Estuary Partnership by the Maine Center for Business and Economic Research at University of Southern Maine and rbouvier consulting.
- Walmsley, D. (2010). "Climate Change and Its Effects on Humans." State of the Gulf of Maine Report. Gulf of Maine Council on the Marine Environment.
- Woodard & Curran. (2013). CMOM Assessment and Corrective Action Plan Report. Retrieved from <https://www.portlandmaine.gov/DocumentCenter/View/13789/20131118-CMOM-Report>
- Yan, Y. E., Pierce, J., Mahat, V., Jared, A., Collis, S., Verner, D., & Wall, T. (2016). Urban Flooding Analysis Using Radar Rainfall Data and 2-D Hydrodynamic Model: A Pilot Study of Back Cove Area, Portland, Maine.
- Zeuli, K & Nijhuis, A. (2017). The Resilience of America's Urban Food Systems: Evidence from Five Cities. Initiative for a Competitive Urban City (ICIC). Roxbury, MA.
- Zivin, J.G., & Shrader, J. (2016). "Temperature Extremes, Health, and Human Capital." The Future of Children. Vol. 26, No. 1.

Appendix

APPENDIX A - SEA LEVEL RISE MAPS

- Figure A.1 Sea Level Rise Scenarios in Greater Portland up to Intermediate Scenario
- Figure A.2 Sea Level Rise Scenarios in Greater Portland up to Intermediate-High Scenario
- Figure A.3 Sea Level Rise Scenarios in Greater Portland up to High Scenario
- Figure A.4 Sea Level Rise Scenarios in Greater Portland up to Extreme Scenario
- Figure A.5 Sea Level Rise Scenarios in Back Cove up to Intermediate Scenario
- Figure A.6 Sea Level Rise Scenarios in Back Cove up to Intermediate-High Scenario
- Figure A.7 Sea Level Rise Scenarios in Back Cove up to High Scenario
- Figure A.8 Sea Level Rise Scenarios in Back Cove up to Extreme Scenario
- Figure A.9 Sea Level Rise Scenarios in South Portland and Portland Waterfronts up to Intermediate Scenario
- Figure A.10 Sea Level Rise Scenarios in South Portland and Portland Waterfronts up to Intermediate-High Scenario
- Figure A.11 Sea Level Rise Scenarios in South Portland and Portland Waterfronts up to High Scenario
- Figure A.12 Sea Level Rise Scenarios in South Portland and Portland Waterfronts up to Extreme Scenario

APPENDIX B - HURRICANE SURGE INUNDATION MAPS

- Figure B.1 Storm Surge Inundation from Hurricane Category 1 in Greater Portland
- Figure B.2 Storm Surge Inundation from Hurricane Category 2 in Greater Portland
- Figure B.3 Storm Surge Inundation from Hurricane Category 3 in Greater Portland
- Figure B.4 Storm Surge Inundation from Hurricane Category 4 in Greater Portland
- Figure B.5 Storm Surge Inundation from Hurricane Category 1 in Back Cove
- Figure B.6 Storm Surge Inundation from Hurricane Category 2 in Back Cove
- Figure B.7 Storm Surge Inundation from Hurricane Category 3 in Back Cove
- Figure B.8 Storm Surge Inundation from Hurricane Category 4 in Back Cove
- Figure B.9 Storm Surge Inundation from Hurricane Category 1 in South Portland and Portland Waterfronts
- Figure B.10 Storm Surge Inundation from Hurricane Category 2 in South Portland and Portland Waterfronts
- Figure B.11 Storm Surge Inundation from Hurricane Category 3 in South Portland and Portland Waterfronts
- Figure B.12 Storm Surge Inundation from Hurricane Category 4 in South Portland and Portland Waterfronts

APPENDIX C - TEMPERATURE AND PRECIPITATION GRAPHS

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- Figure C.3 Heating Degree Days
- Figure C.4 Average Maximum Summer Temperature
- Figure C.5 Average Minimum Summer Temperature
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Figure C.8 Average Maximum Winter Temperature
 Figure C.9 Average Minimum Winter Temperature
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 Figure C.12 Number of Days Below 0°F Per Year
 Figure C.13 Temperature on the Coldest Night of the Year
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 Figure C.15 Temperature on the Hottest Night of the Year
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 Figure C.21 Precipitation on the Wettest Day of the Year

APPENDIX D - IMPACTS TO UPCOMING CAPITAL IMPROVEMENT PROJECTS

Figure D.1 FY19 and FY20 Construction Projects in Portland Vulnerable to Sea Level Rise
 Table D.1. FY19 – FY20 Vulnerable Projects Underway
 Figure D.2 FY19 and FY20 Construction Projects in Portland Vulnerable to the 1% Annual Chance Flood
 Figure D.3 South Portland Areas Vulnerable to the 1% Annual Chance Flood
 Figure D.4 South Portland Areas Vulnerable to Sea Level Rise
 Figure D.4 South Portland Wastewater Treatment Facility Flood Vulnerability

ON THE FOLLOWING PAGES...

Appendix A: Sea Level Rise Maps

Appendix B: Hurricane Surge Inundation Maps

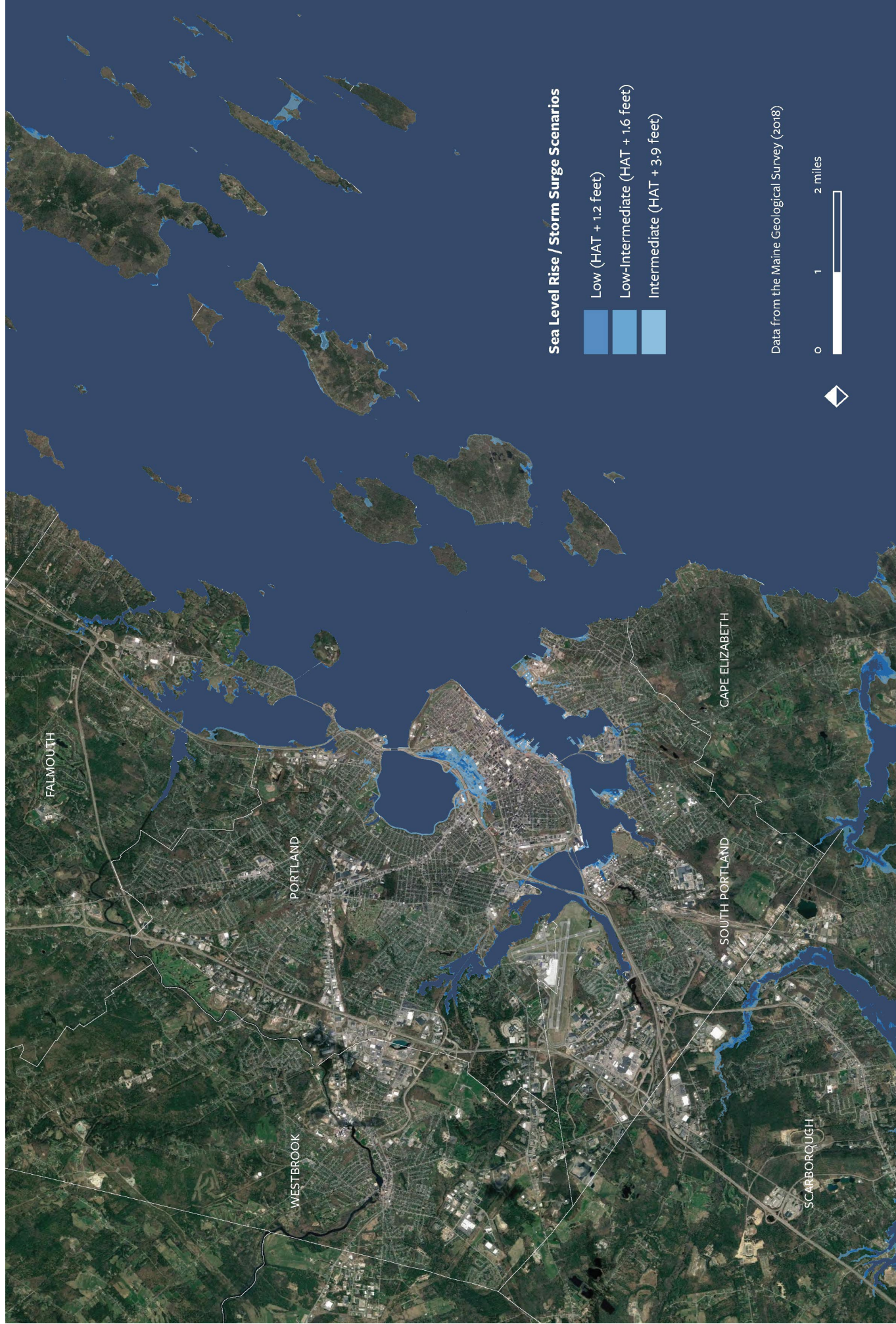


Figure A.1. Sea level rise scenarios for the year 2100 in the Greater Portland area up to 3.9 feet above the highest astronomical tide (HAT) (Intermediate scenario). Data source: Maine Geological Survey Sea Level Rise/Storm Surge Data (2018).

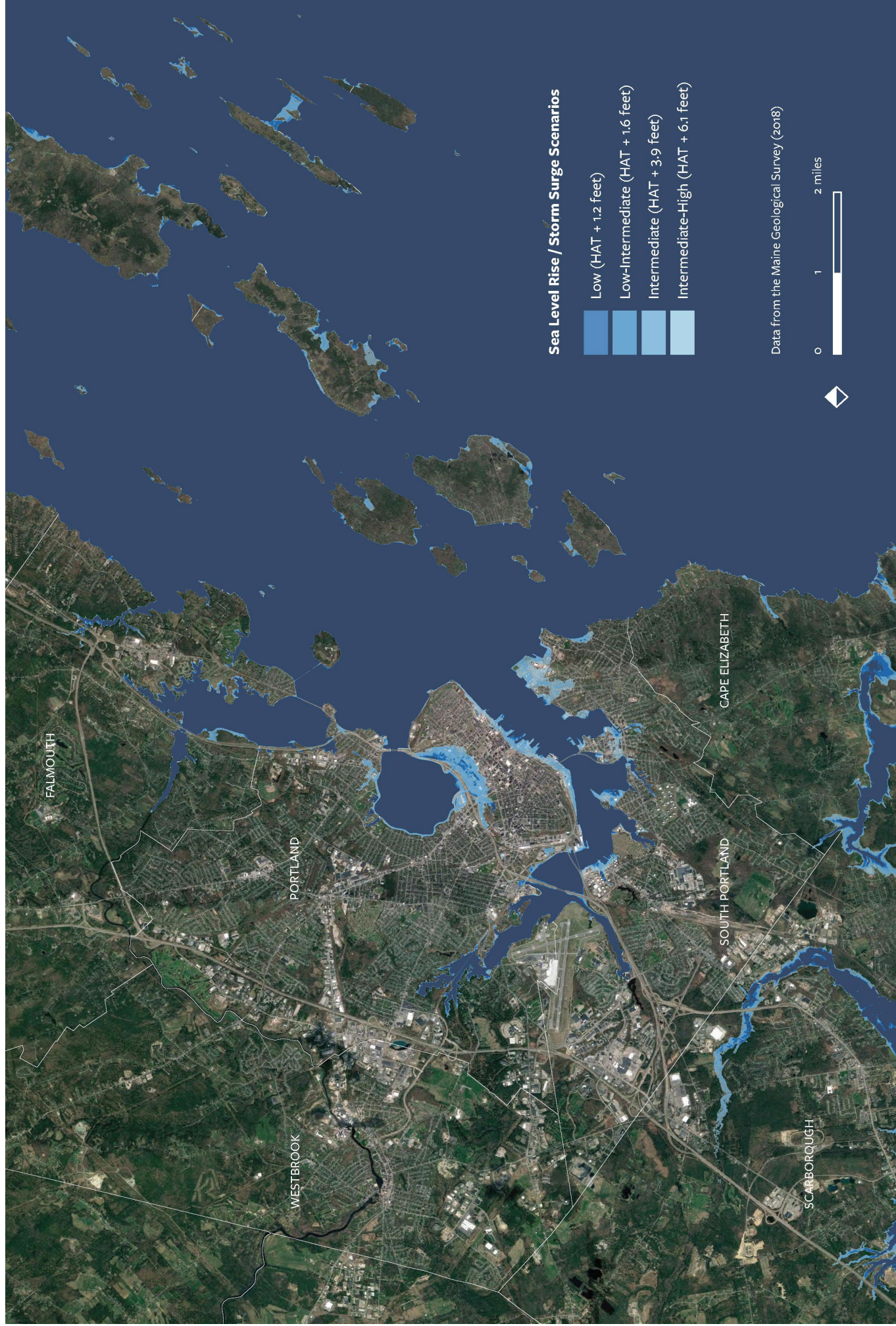


Figure A.2. Sea level rise scenarios for the year 2100 in the Greater Portland area up to 6.1 feet above the highest astronomical tide (HAT) (Intermediate-High scenario). Data source: Maine Geological Survey Sea Level Rise/Storm Surge Data (2018).

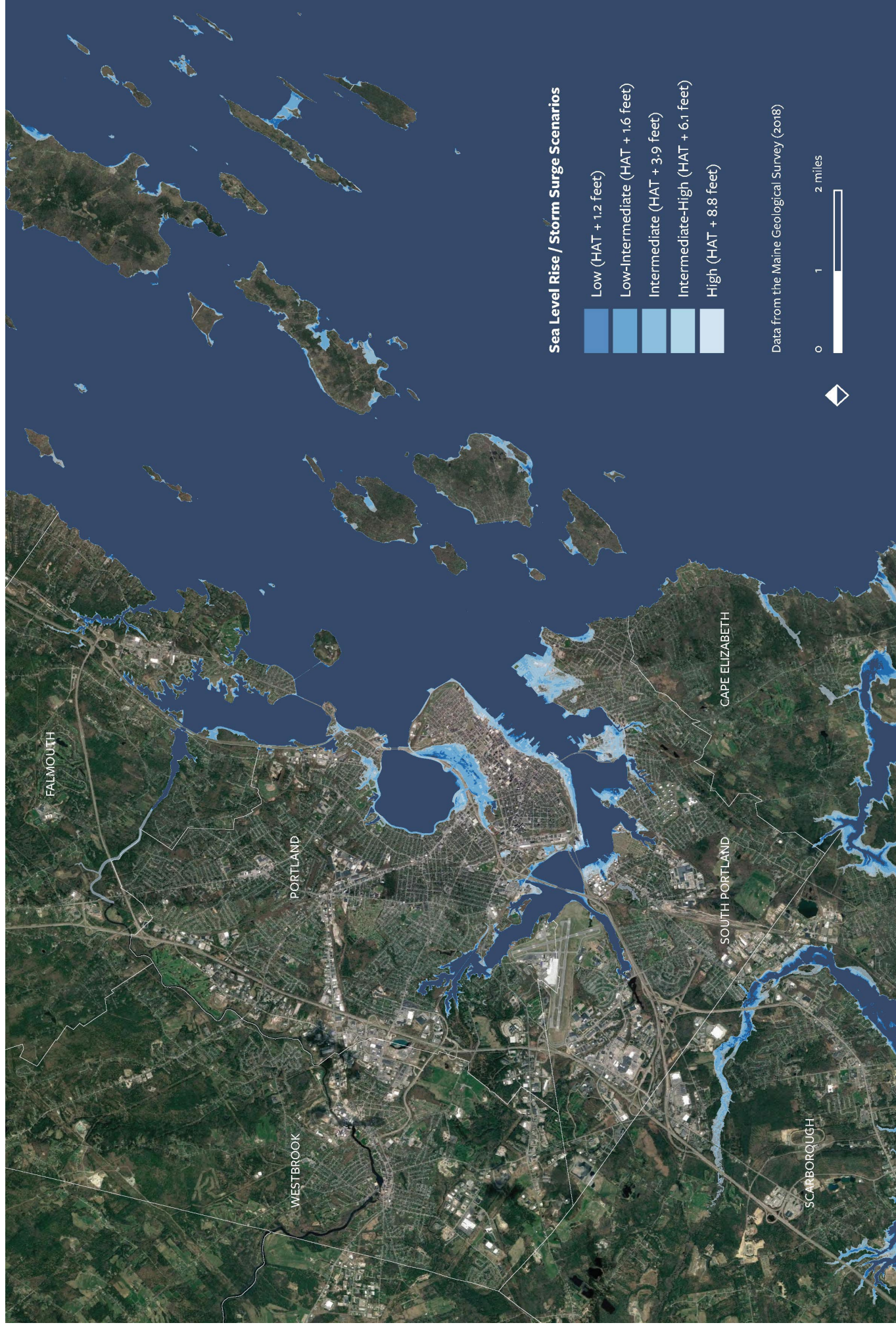


Figure A.3. Sea level rise scenarios for the year 2100 in the Greater Portland area up to 8.8 feet above the highest astronomical tide (HAT) (High scenario). Data source: Maine Geological Survey Sea Level Rise/Storm Surge Data (2018).

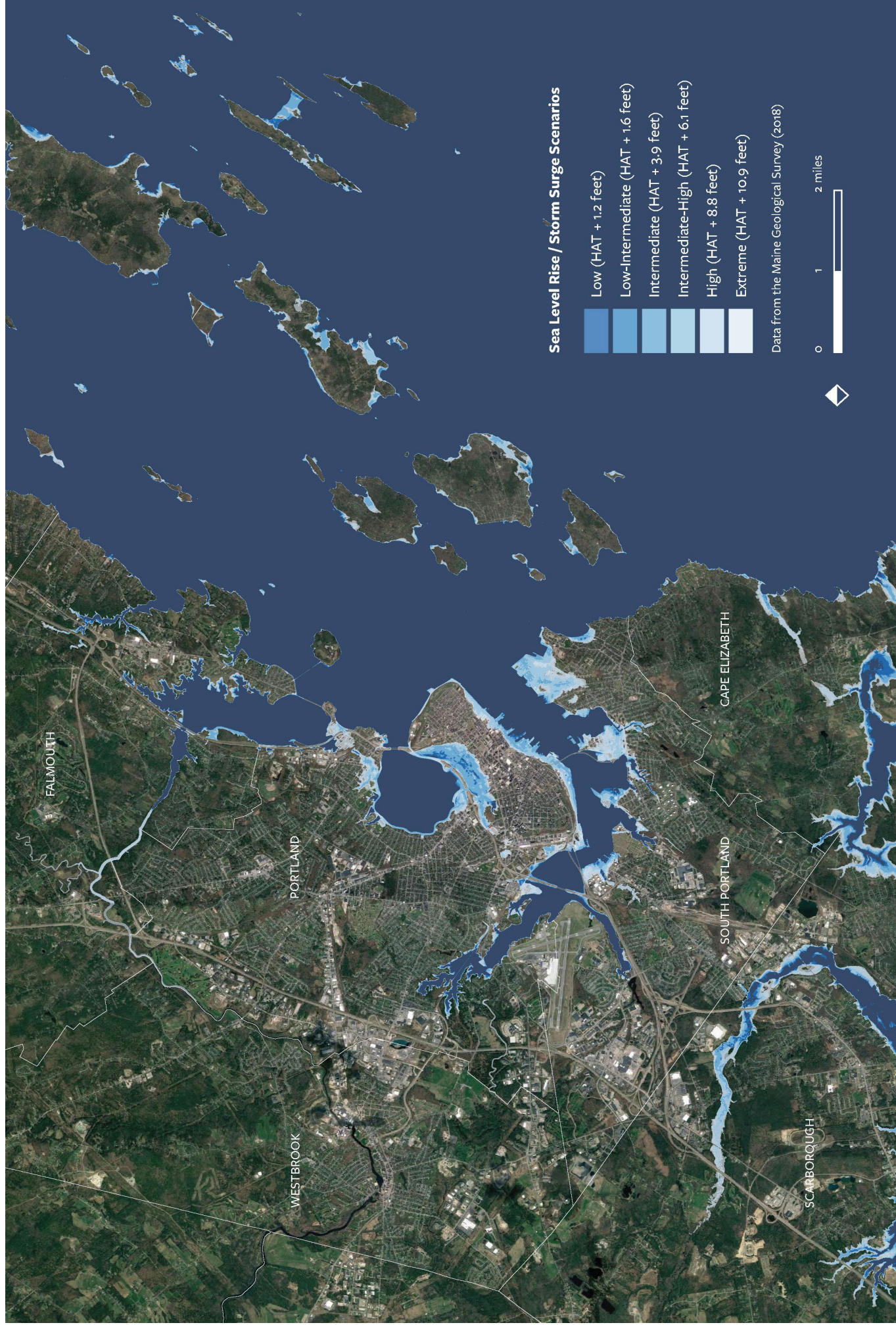


Figure A.4. Sea level rise scenarios for the year 2100 in the Greater Portland area up to 10.9 feet above the highest astronomical tide (HAT) (Extreme scenario). Data source: Maine Geological Survey Sea Level Rise/Storm Surge Data (2018).



Figure A-5. Sea level rise scenarios for the year 2100 in the Back Cove area of Portland up to 3.9 feet above the highest astronomical tide (HAT) (Intermediate scenario). Data source: Maine Geological Survey Sea Level Rise/Storm Surge Data (2018).



Figure A.6. Sea level rise scenarios for the year 2100 in the Back Cove area of Portland up to 6.1 feet above the highest astronomical tide (HAT) (Intermediate-High scenario). Data source: Maine Geological Survey Sea Level Rise/Storm Surge Data (2018).



Figure A.7. Sea level rise scenarios for the year 2100 in the Back Cove area of Portland up to 8.8 feet above the highest astronomical tide (HAT) (High scenario). Data source: Maine Geological Survey Sea Level Rise/Storm Surge Data (2018).

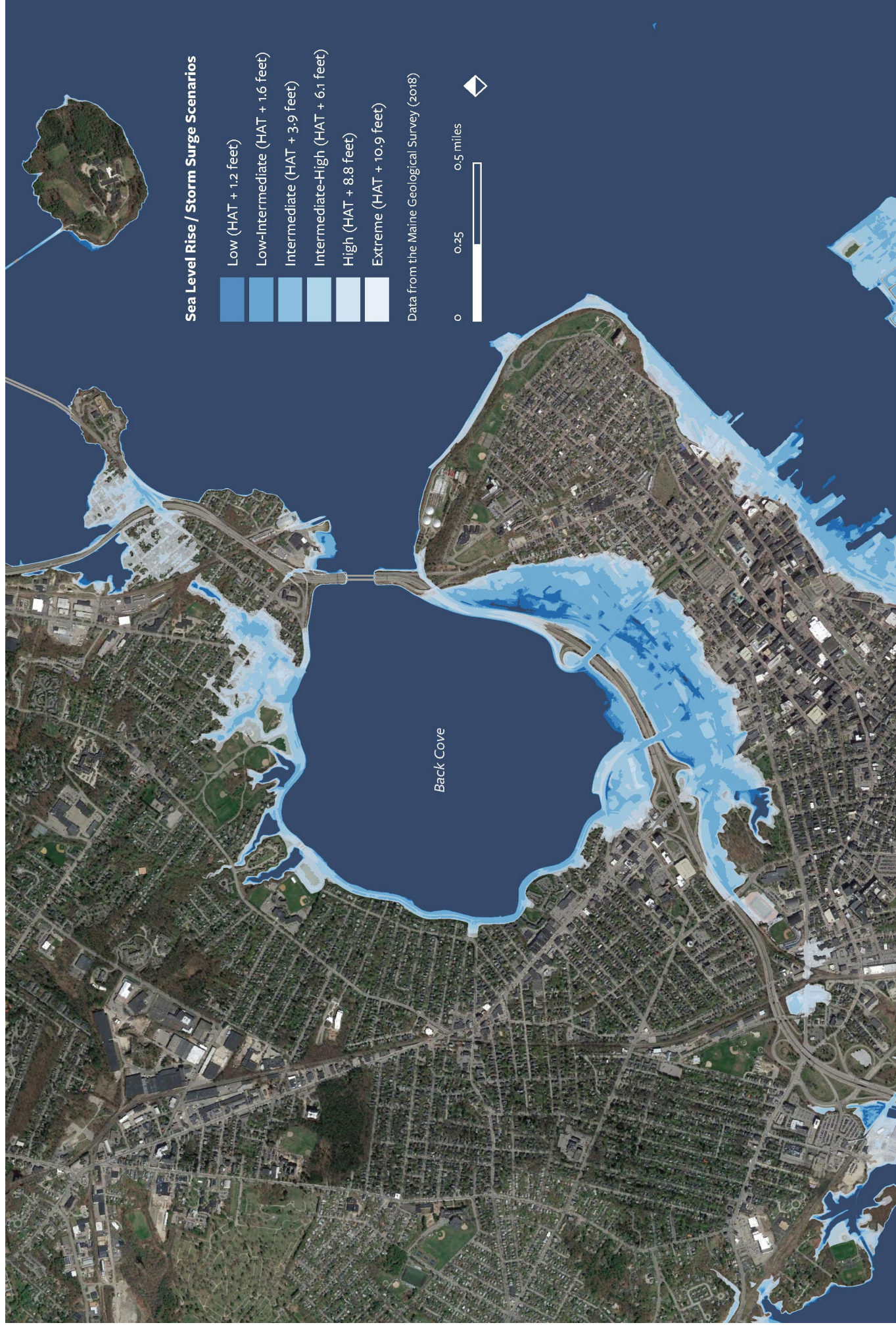


Figure A.8. Sea level rise scenarios for the year 2100 in the Back Cove area of Portland up to 10.9 feet above the highest astronomical tide (HAT) (Extreme scenario). Data source: Maine Geological Survey Sea Level Rise/Storm Surge Data (2018).



Figure A.9. Sea level rise scenarios for the year 2100 for the South Portland and Portland waterfronts up to 3.9 feet above the highest astronomical tide (HAT) (Intermediate scenario). Data source: Maine Geological Survey Sea Level Rise/Storm Surge Data (2018).



Figure A.10. Sea level rise scenarios for the year 2100 for the South Portland and Portland waterfronts up to 6.1 feet above the highest astronomical tide (HAT) (Intermediate-High scenario). Data source: Maine Geological Survey Sea Level Rise/Storm Surge Data (2018).

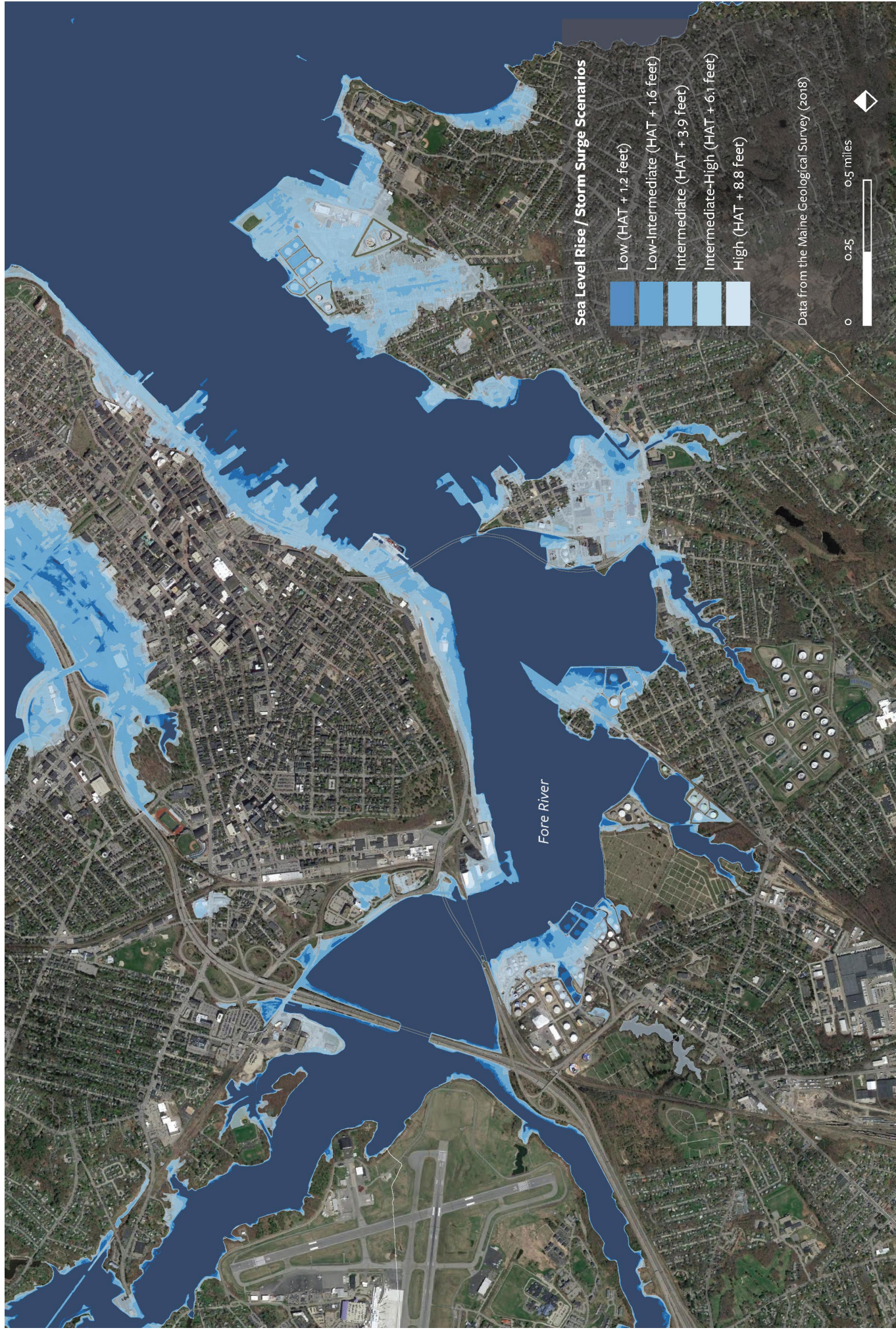


Figure A.11. Sea level rise scenarios for the year 2100 for the South Portland and Portland waterfronts up to 8.8 feet above the highest astronomical tide (HAT) (High scenario). Data source: Maine Geological Survey Sea Level Rise/Storm Surge Data (2018).



Figure A.12. Sea level rise scenarios for the year 2100 for the South Portland and Portland waterfronts up to 10.9 feet above the highest astronomical tide (HAT) (Extreme scenario). Data source: Maine Geological Survey Sea Level Rise/Storm Surge Data (2018).

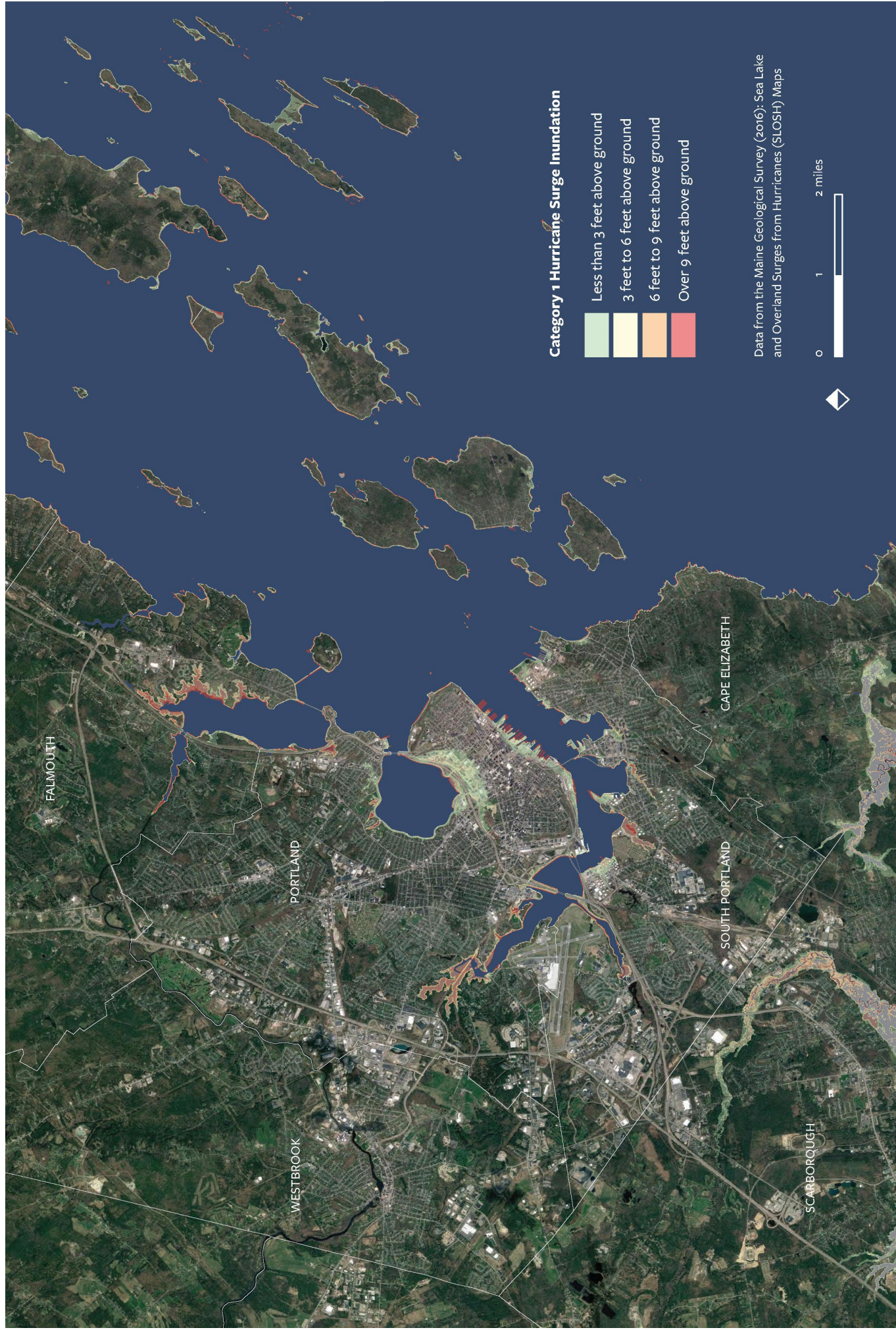


Figure B.1. Areas in the Greater Portland area that would be potentially inundated by storm surge from a category 1 hurricane at mean high tide. Data source: Maine Geological Survey Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Data (2016).

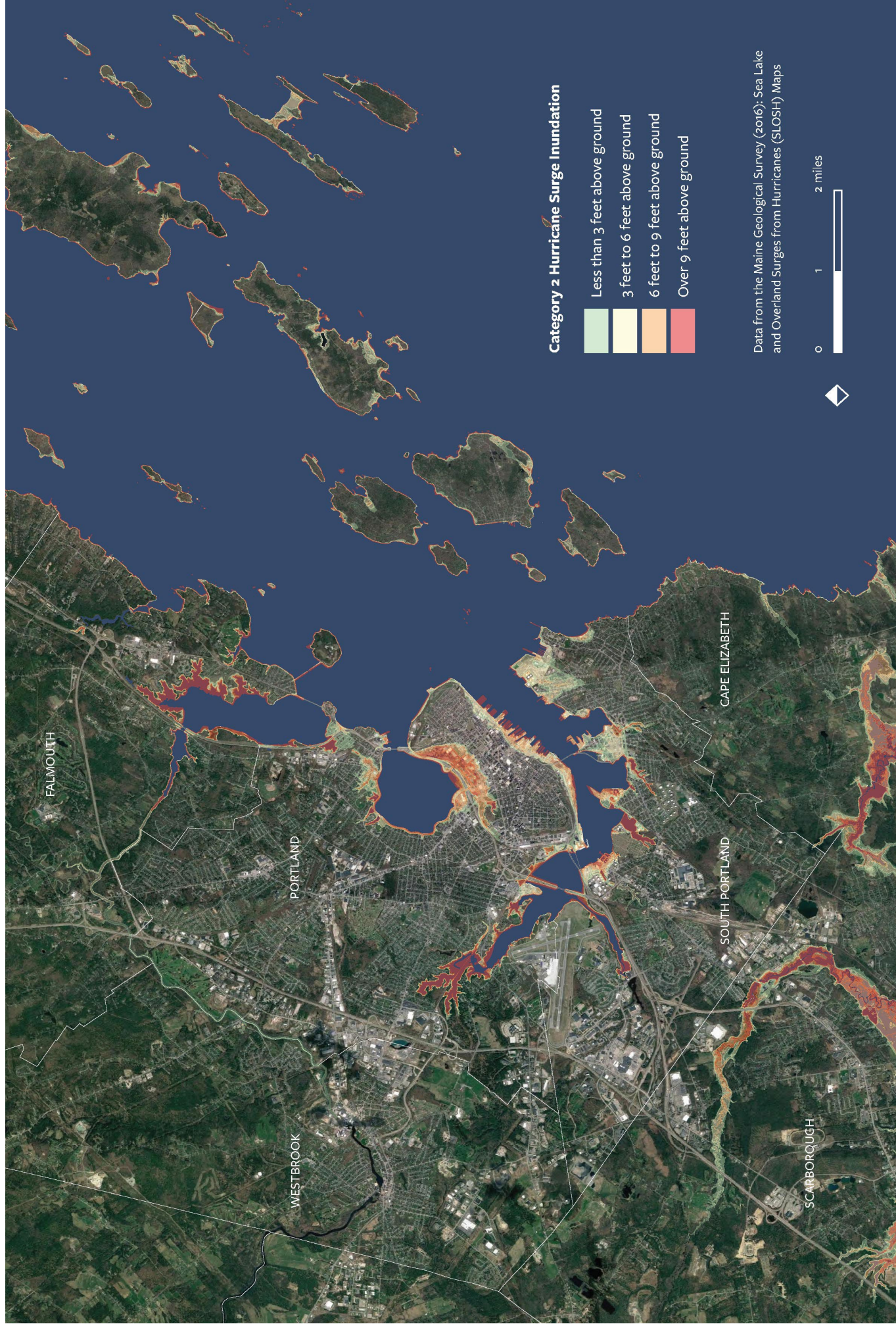


Figure B.2. Areas in the Greater Portland area that would be potentially inundated by storm surge from a category 2 hurricane at mean high tide. Data source: Maine Geological Survey Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Data (2016).

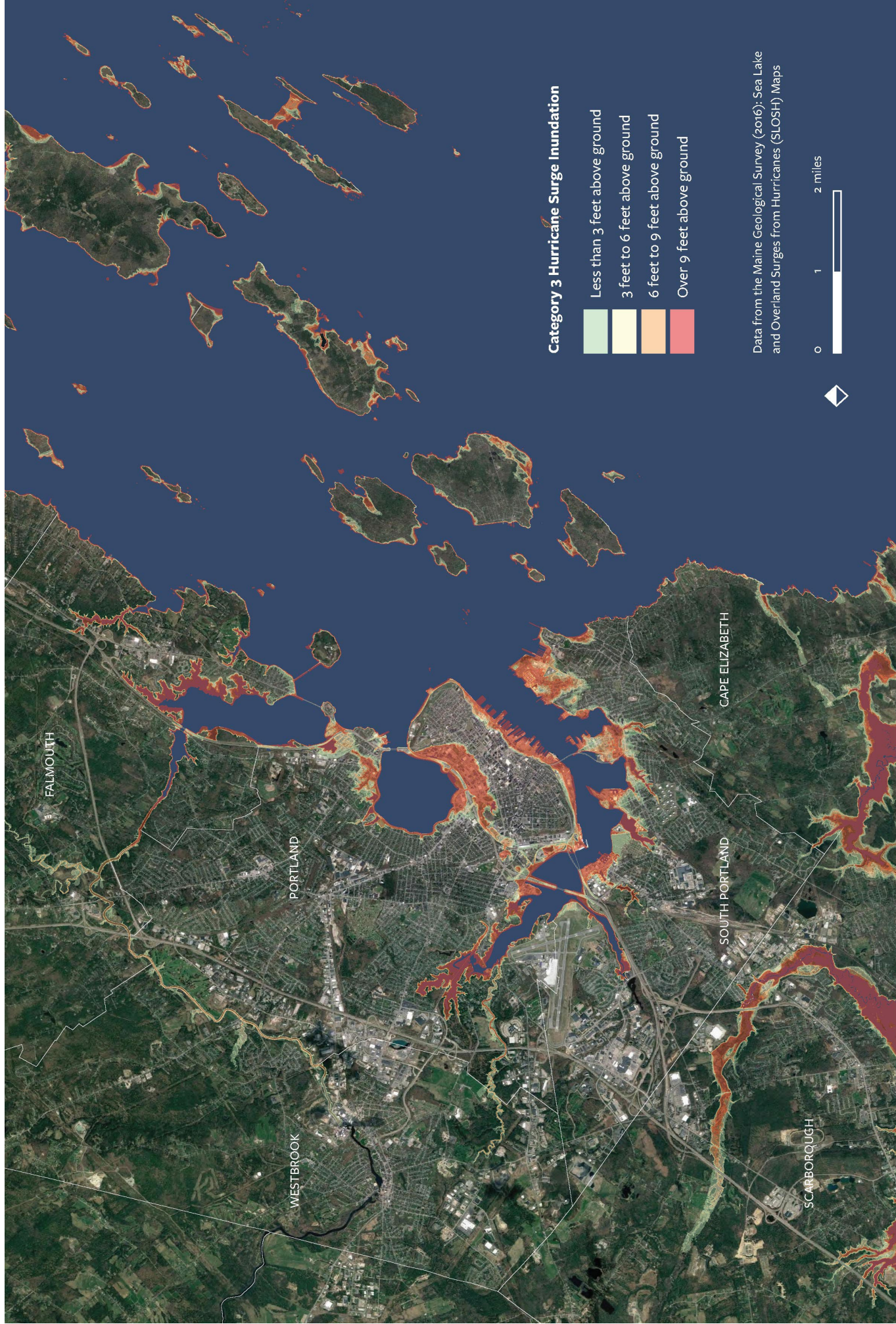


Figure B.3: Areas in the Greater Portland area that would be potentially inundated by storm surge from a category 3 hurricane at mean high tide. Data source: Maine Geological Survey Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Data (2016).

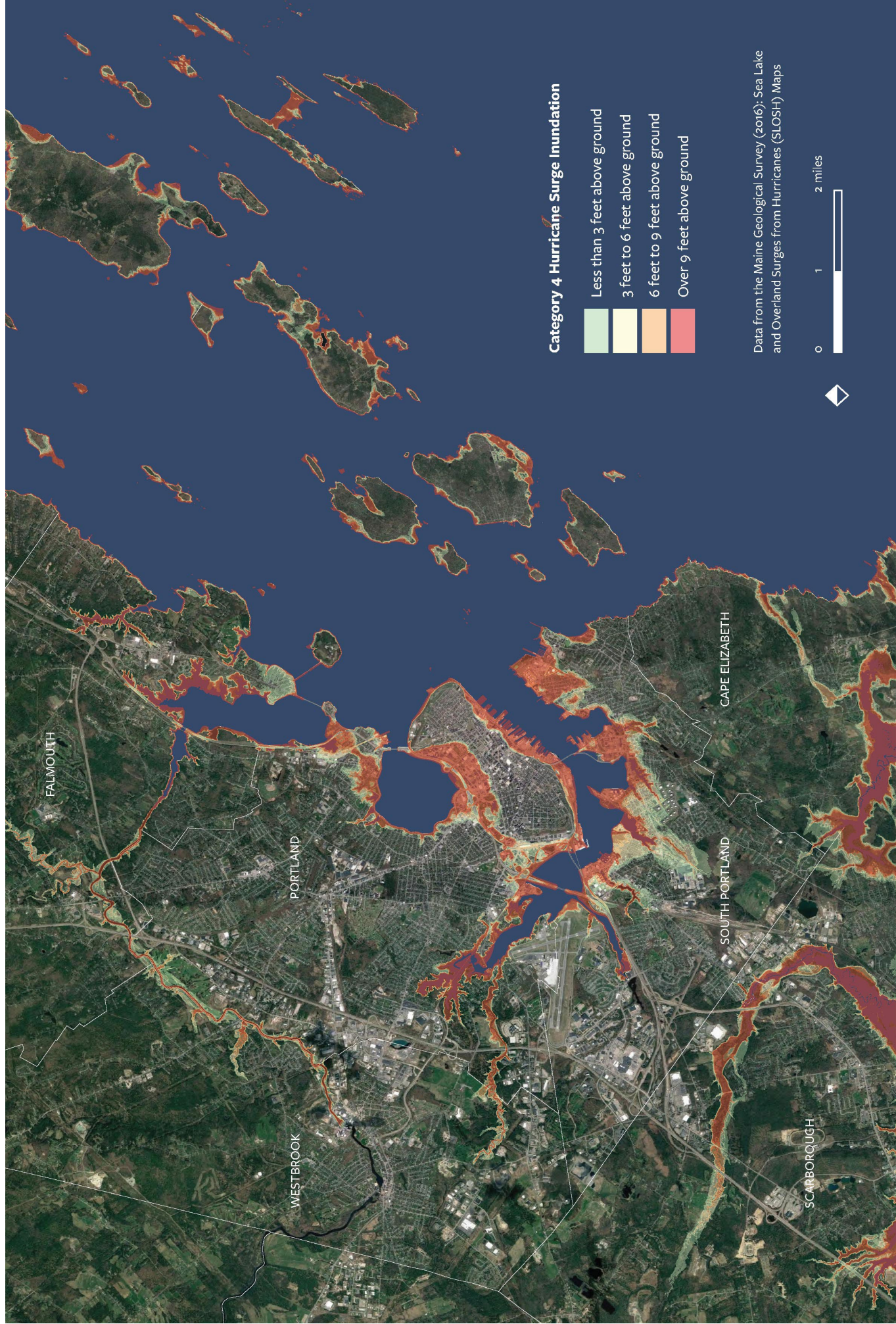


Figure B.4. Areas in the Greater Portland area that would be potentially inundated by storm surge from a category 4 hurricane at mean high tide. Data source: Maine Geological Survey Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Data (2016).

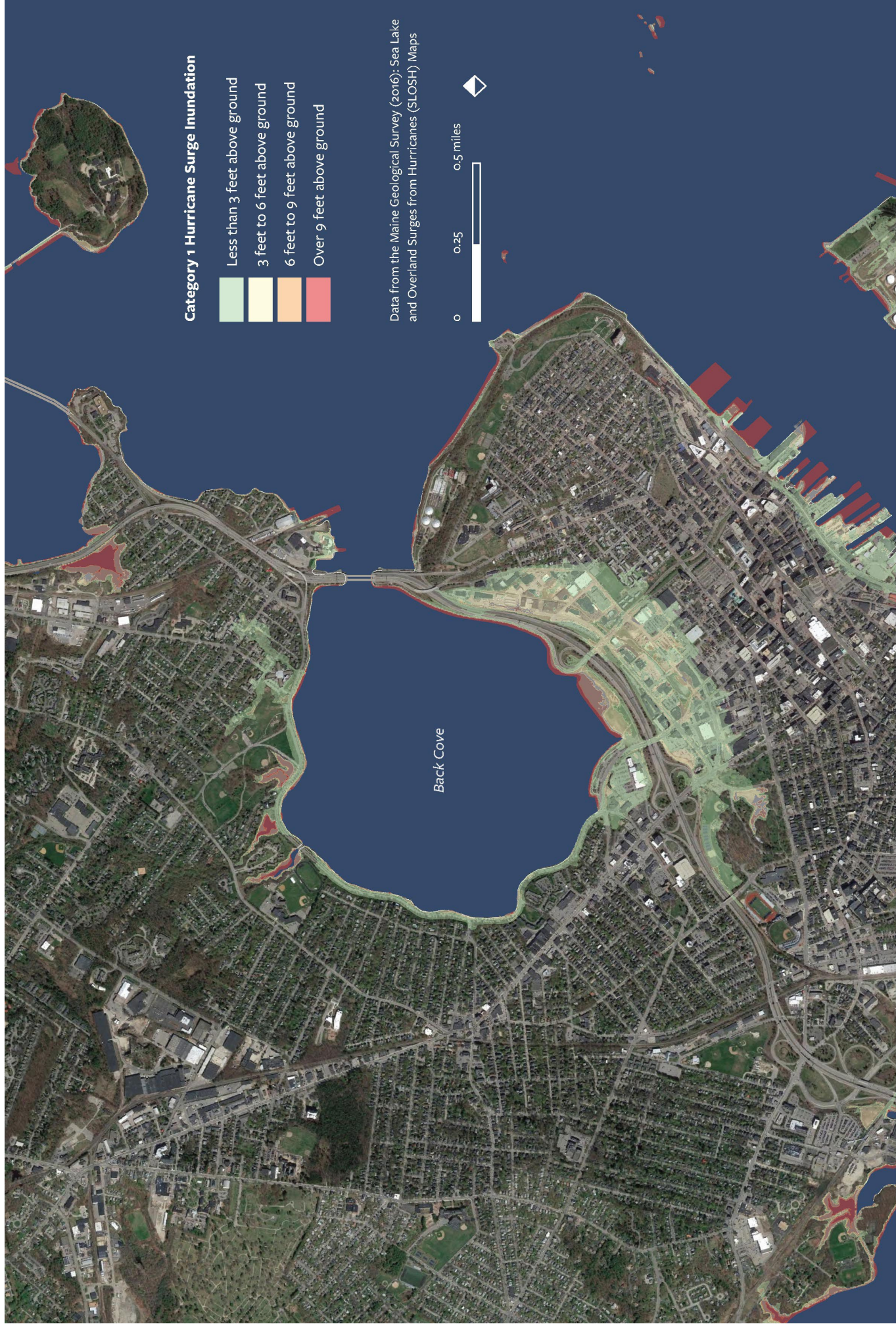


Figure B.5: Areas in the Back Cove area of Portland that would be potentially inundated by storm surge from a category 1 hurricane at mean high tide. Data source: Maine Geological Survey Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Data (2016).

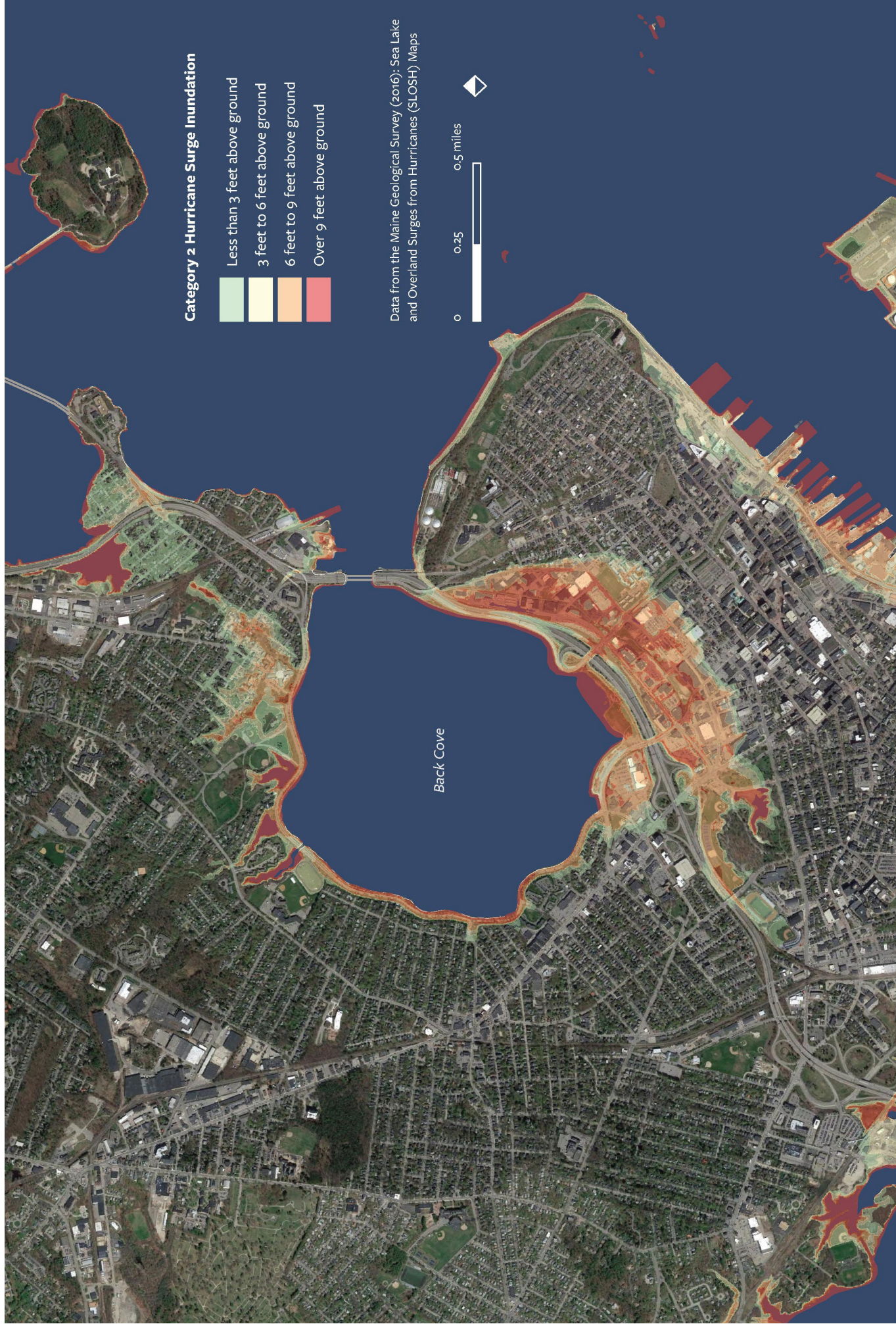


Figure B.6. Areas in the Back Cove area of Portland that would be potentially inundated by storm surge from a category 2 hurricane at mean high tide. Data source: Maine Geological Survey Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Data (2016).

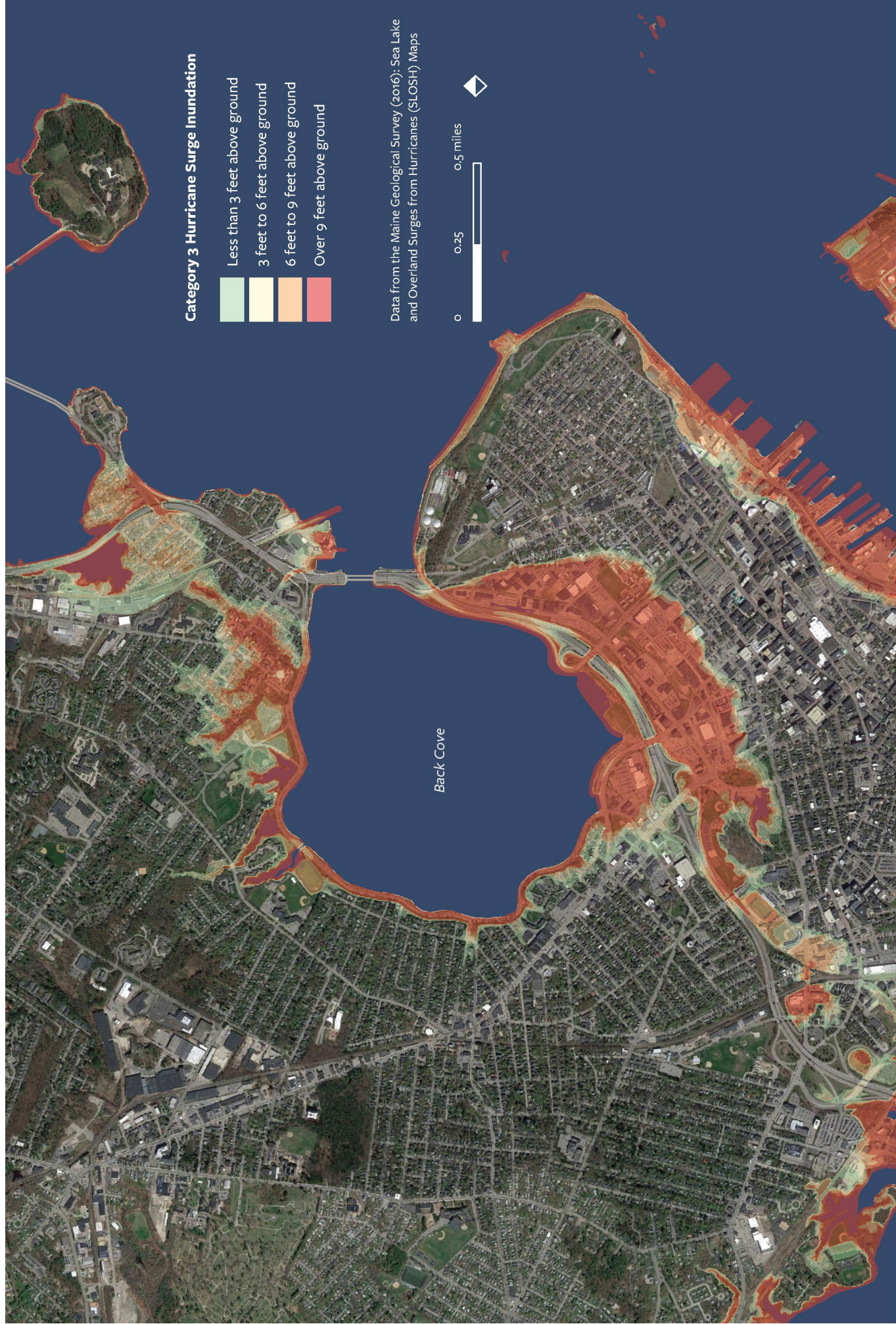


Figure B.7. Areas in the Back Cove area of Portland that would be potentially inundated by storm surge from a category 3 hurricane at mean high tide. Data source: Maine Geological Survey Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Data (2016).

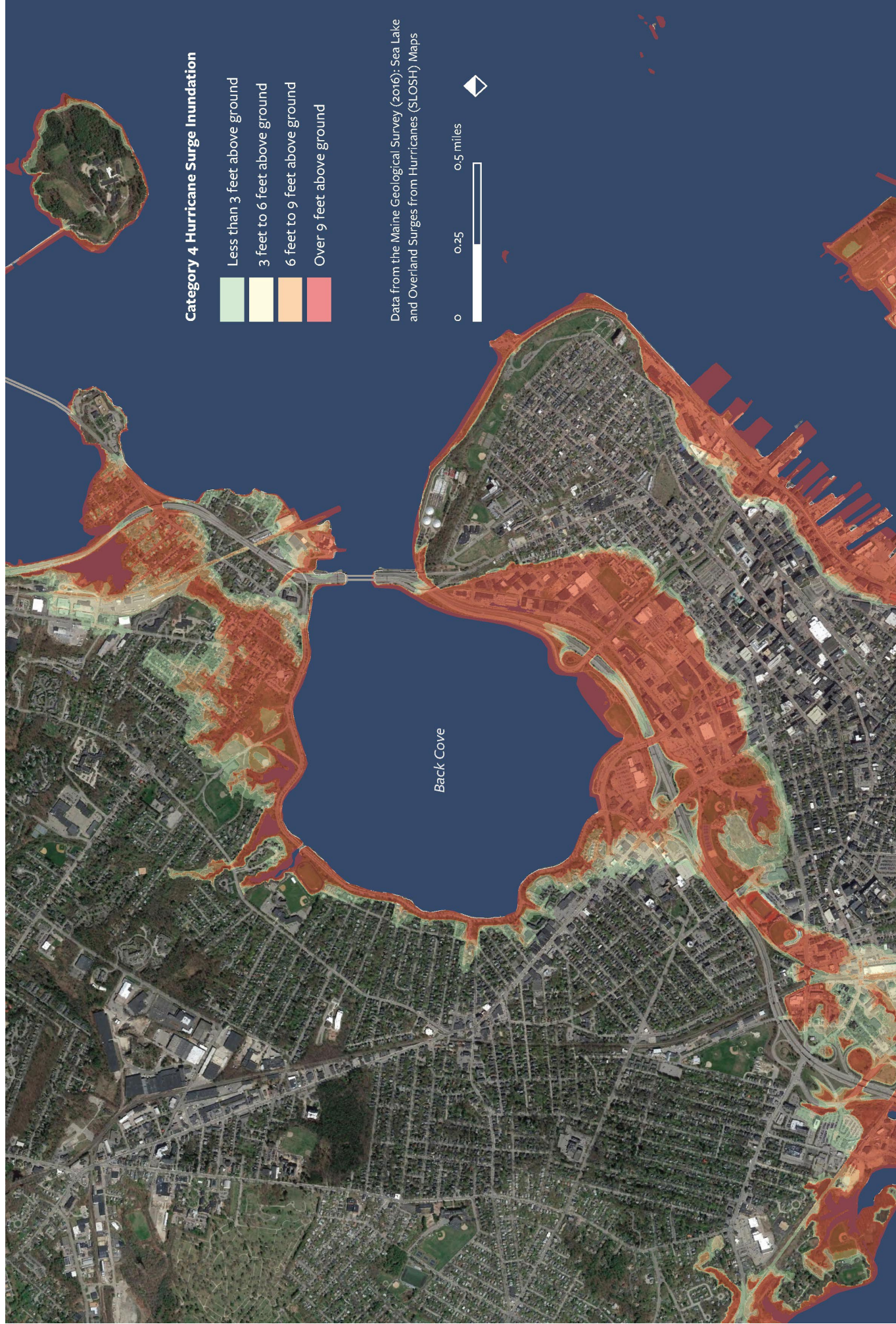


Figure B.8. Areas in the Back Cove area of Portland that would be potentially inundated by storm surge from a category 4 hurricane at mean high tide. Data source: Maine Geological Survey Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Data (2016).

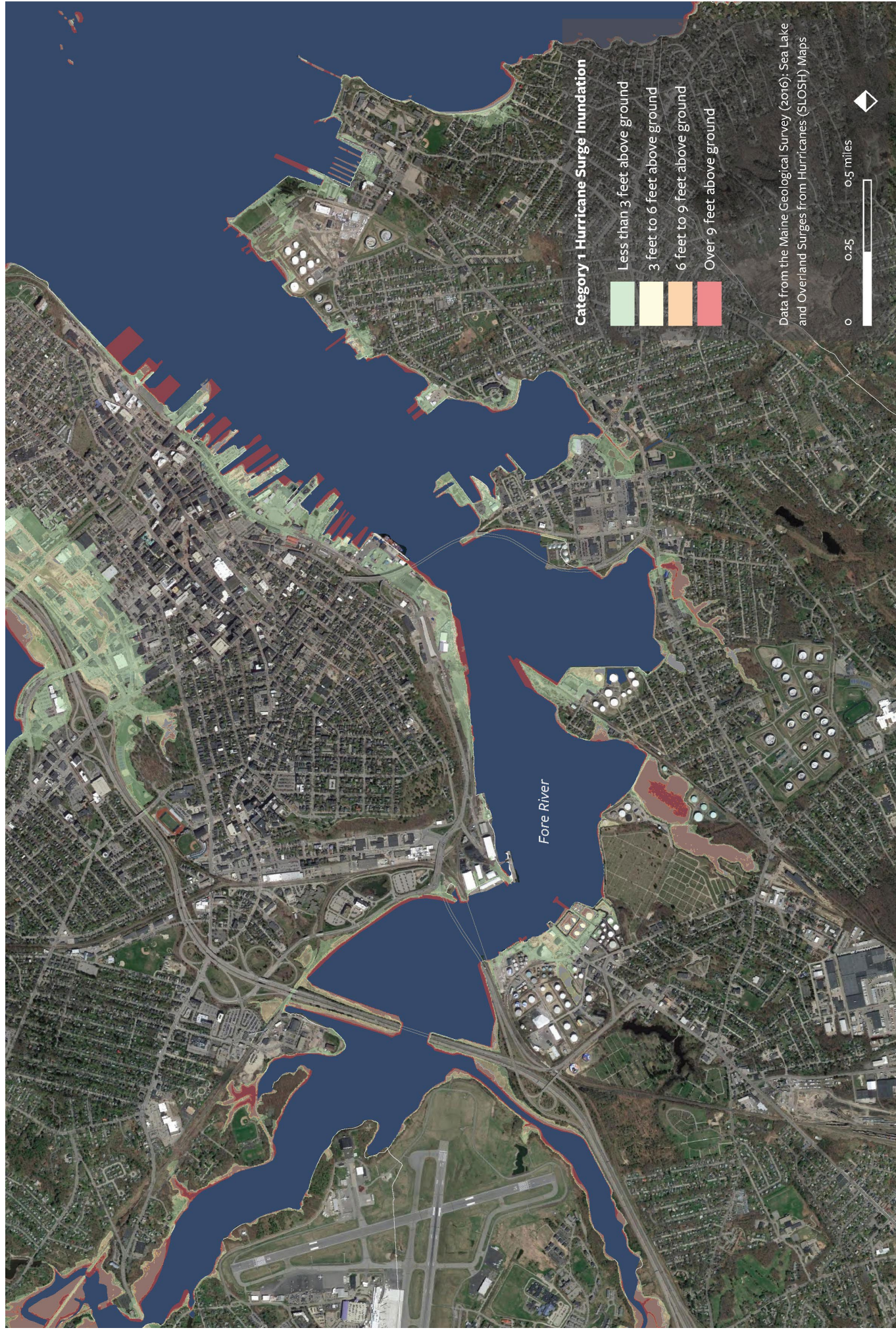


Figure B.9. Areas in the South Portland and Portland waterfronts that would be potentially inundated by storm surge from a category 1 hurricane at mean high tide. Data source: Maine Geological Survey Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Data (2016).

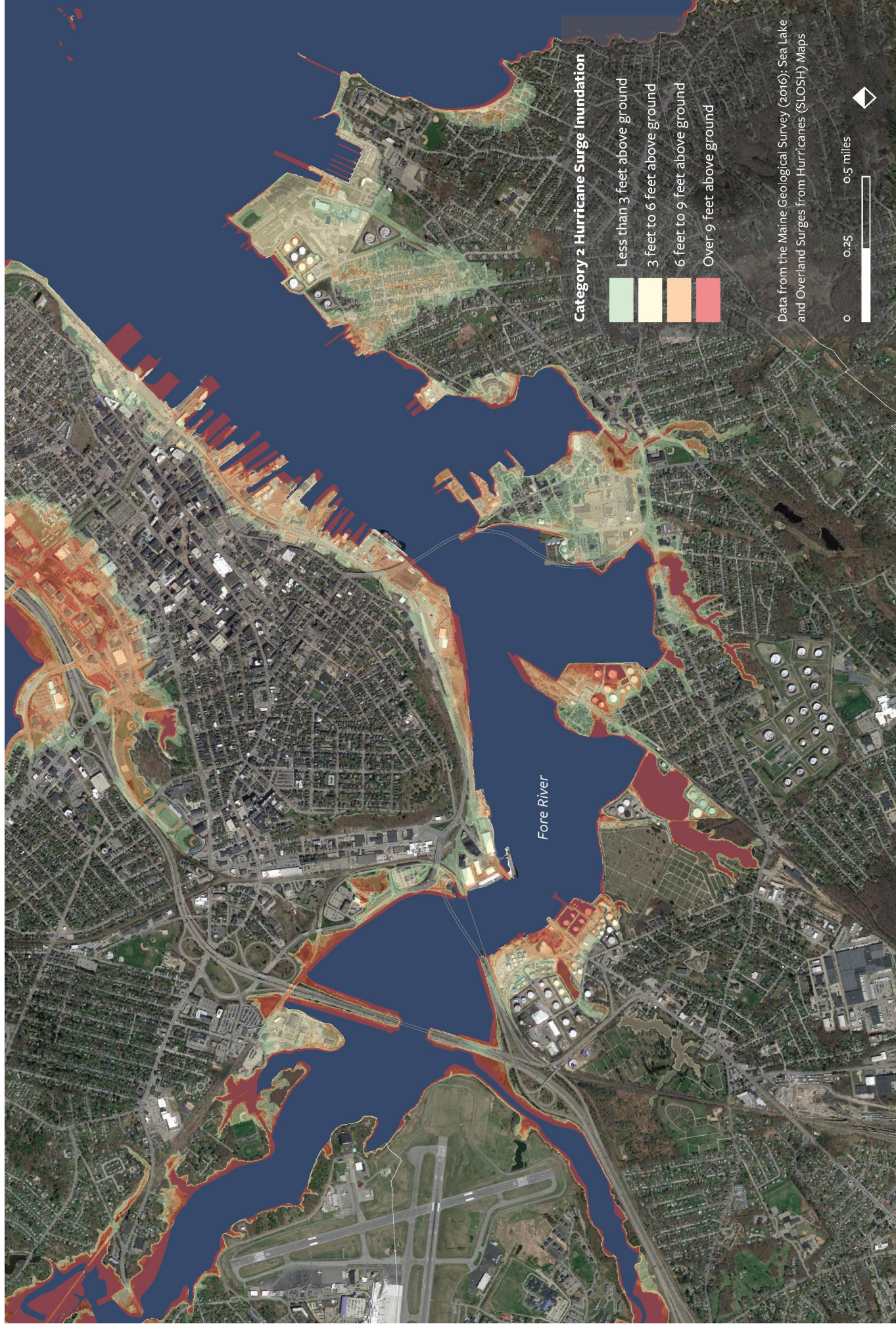


Figure B.10. Areas in the South Portland and Portland waterfronts that would be potentially inundated by storm surge from a category 2 hurricane at mean high tide. Data source: Maine Geological Survey Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Data (2016).

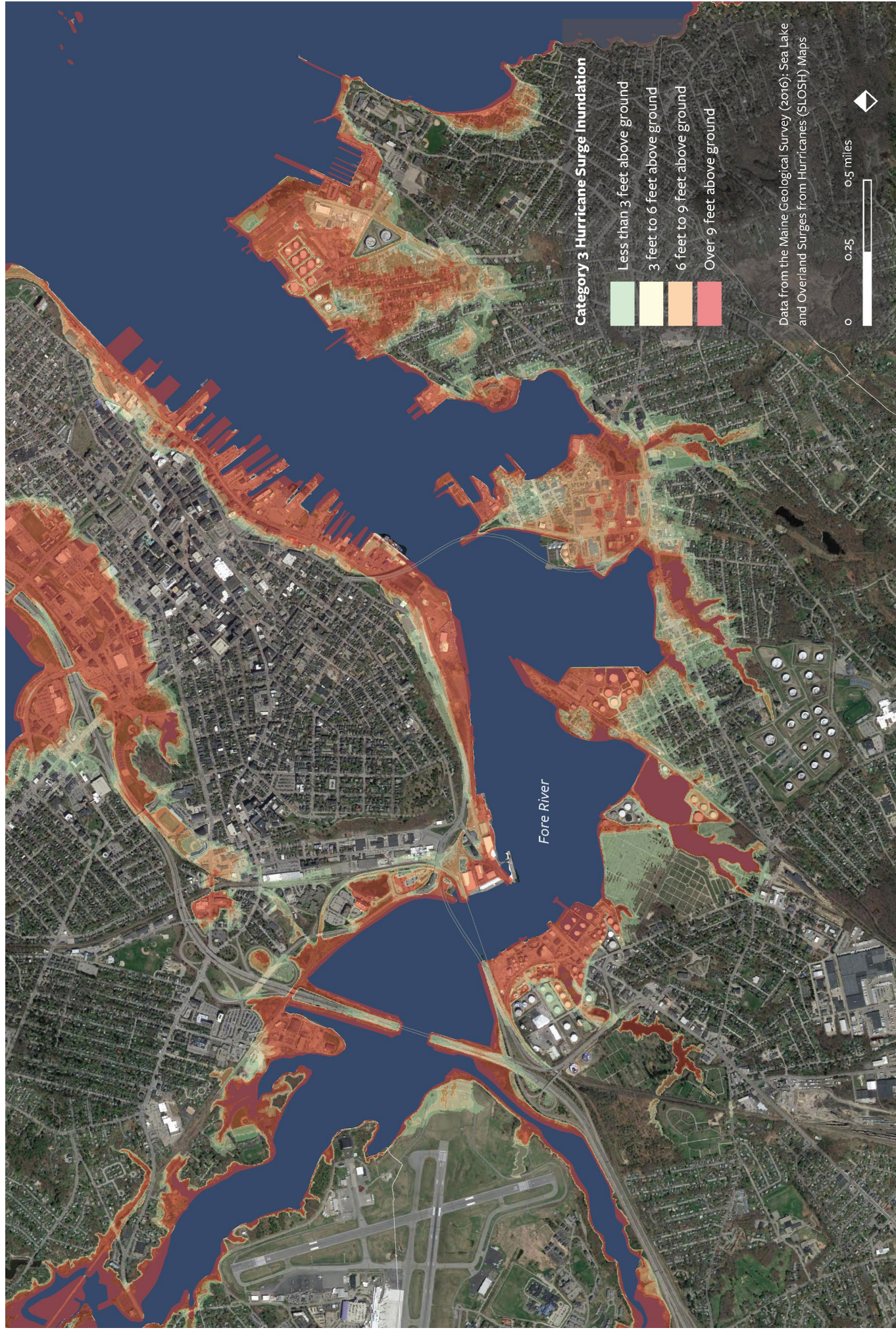


Figure B.11. Areas in the South Portland and Portland waterfronts that would be potentially inundated by storm surge from a category 3 hurricane at mean high tide. Data source: Maine Geological Survey Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Data (2016).

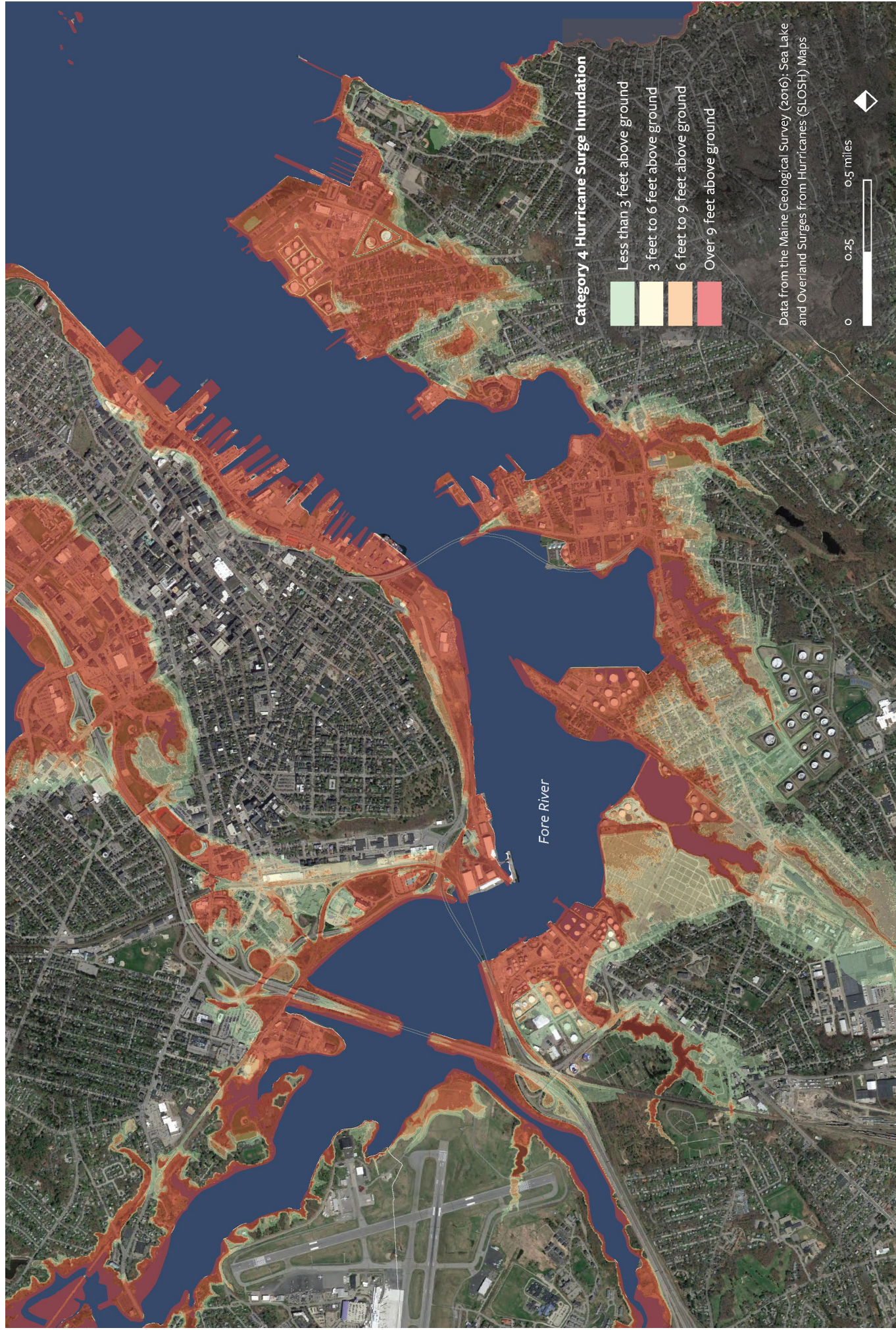


Figure B.12. Areas in the South Portland and Portland waterfronts that would be potentially inundated by storm surge from a category 4 hurricane at mean high tide. Data source: Maine Geological Survey Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Data (2016).

Appendix C: Temperature and Precipitation Graphs

Caption for all temperature and precipitation graphs on subsequent pages. Historical simulations (1980–2005) and future projections (2006–2099) in [insert Y-axis variable] from a 29-member, high resolution (4 km) statistically downscaled Coupled Model Intercomparison Project (CMIP5) ensemble mean lower (RCP 4.5 - blue line) and higher (RCP 8.5 - orange line) representative concentration pathway (RCP) emission scenarios. Orange and blue lines for the period 1980–2005 are identical. The light blue (light orange) shading represent the highest and lowest values from the 29 different model RCP 4.5 (RCP 8.5) simulations for each year. Graphs from Elizabeth Burakowski and Cameron Wake, Earth System Research Center/EOS, University of New Hampshire.

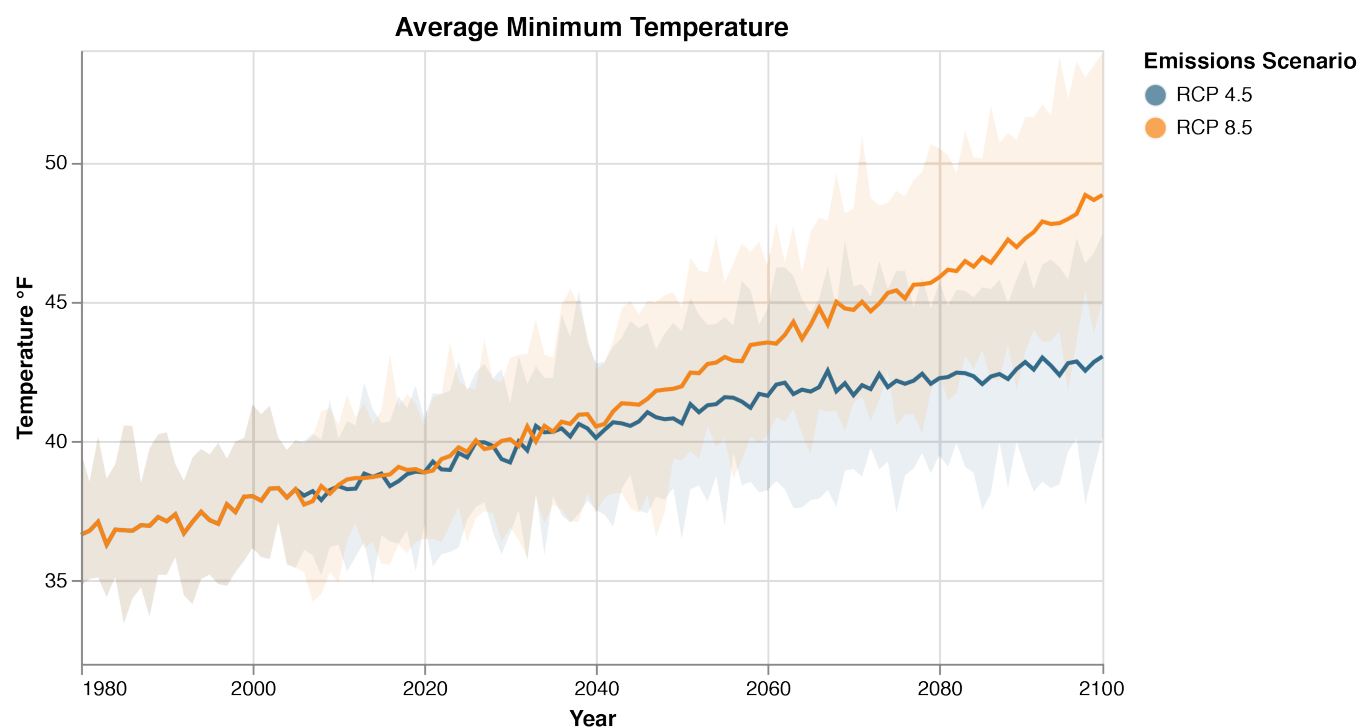


Figure C.1. Historical simulations (1980–2005) and future projections (2006–2099) for average minimum temperature in Greater Portland. See first page of Appendix C for full caption.

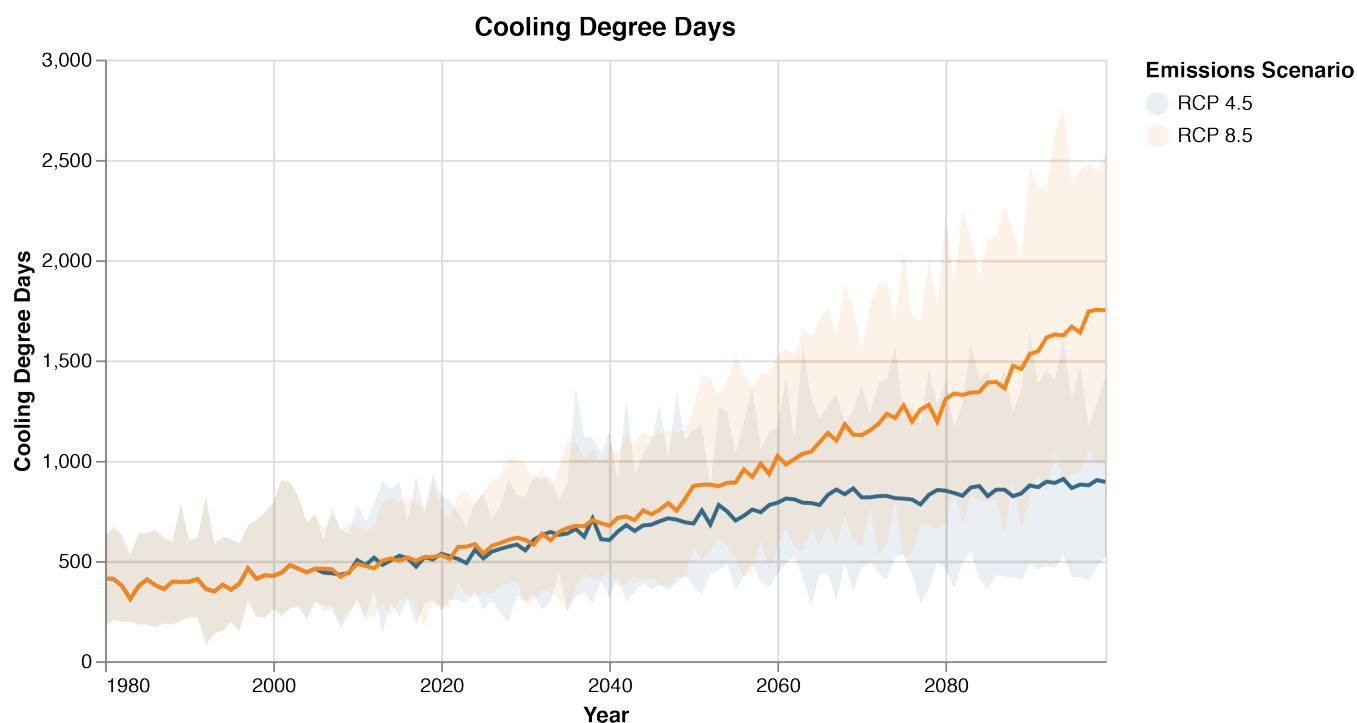


Figure C.2. Historical simulations (1980–2005) and future projections (2006–2099) for cooling degree days in Greater Portland. See first page of Appendix C for full caption.

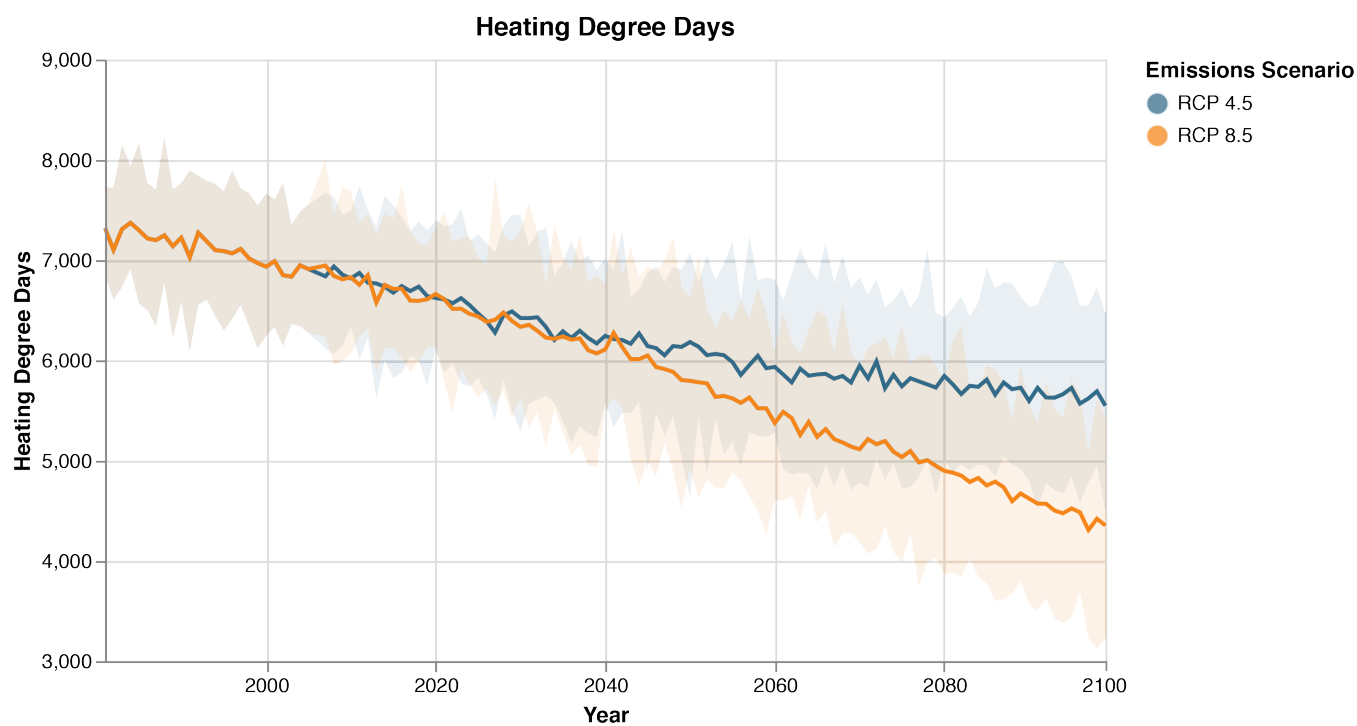


Figure C.3. Historical simulations (1980–2005) and future projections (2006–2099) for heating degree days in Greater Portland. See first page of Appendix C for full caption.

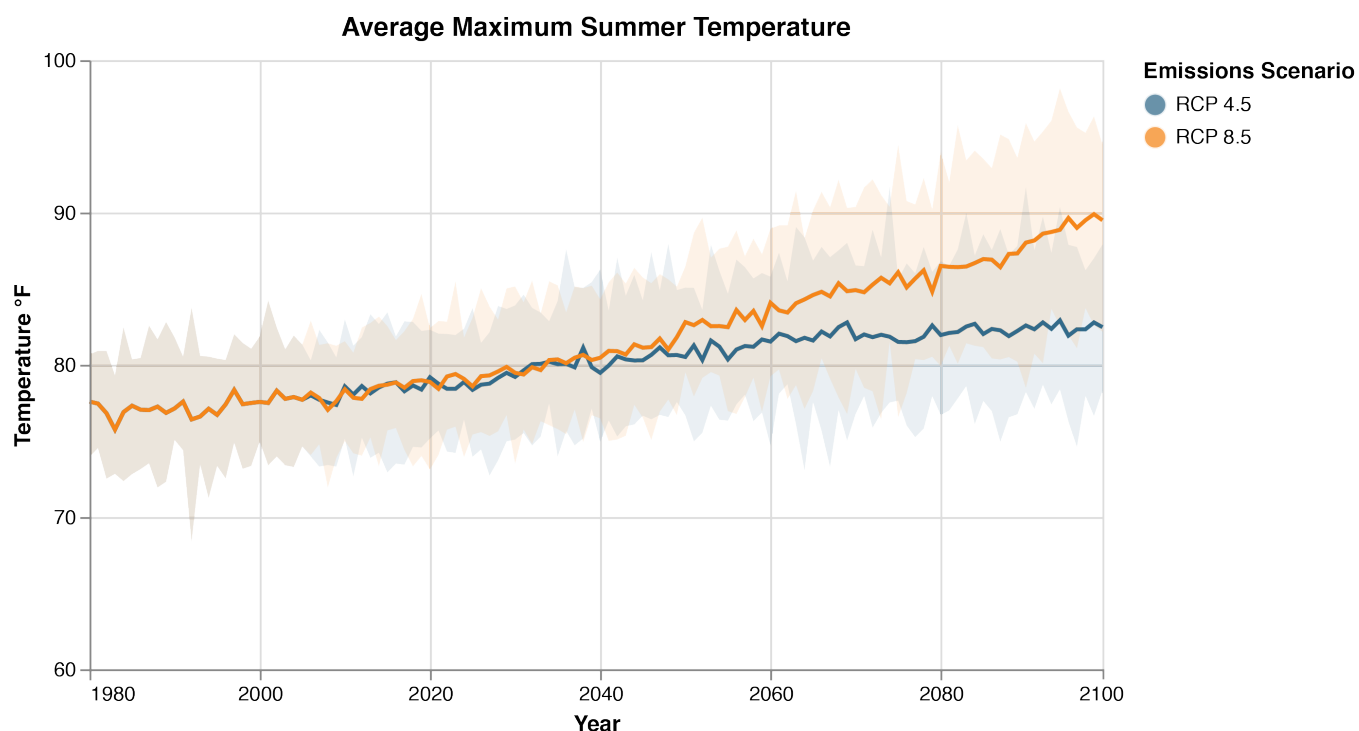


Figure C.4. Historical simulations (1980–2005) and future projections (2006–2099) for maximum summer temperature in Greater Portland. See first page of Appendix C for full caption.

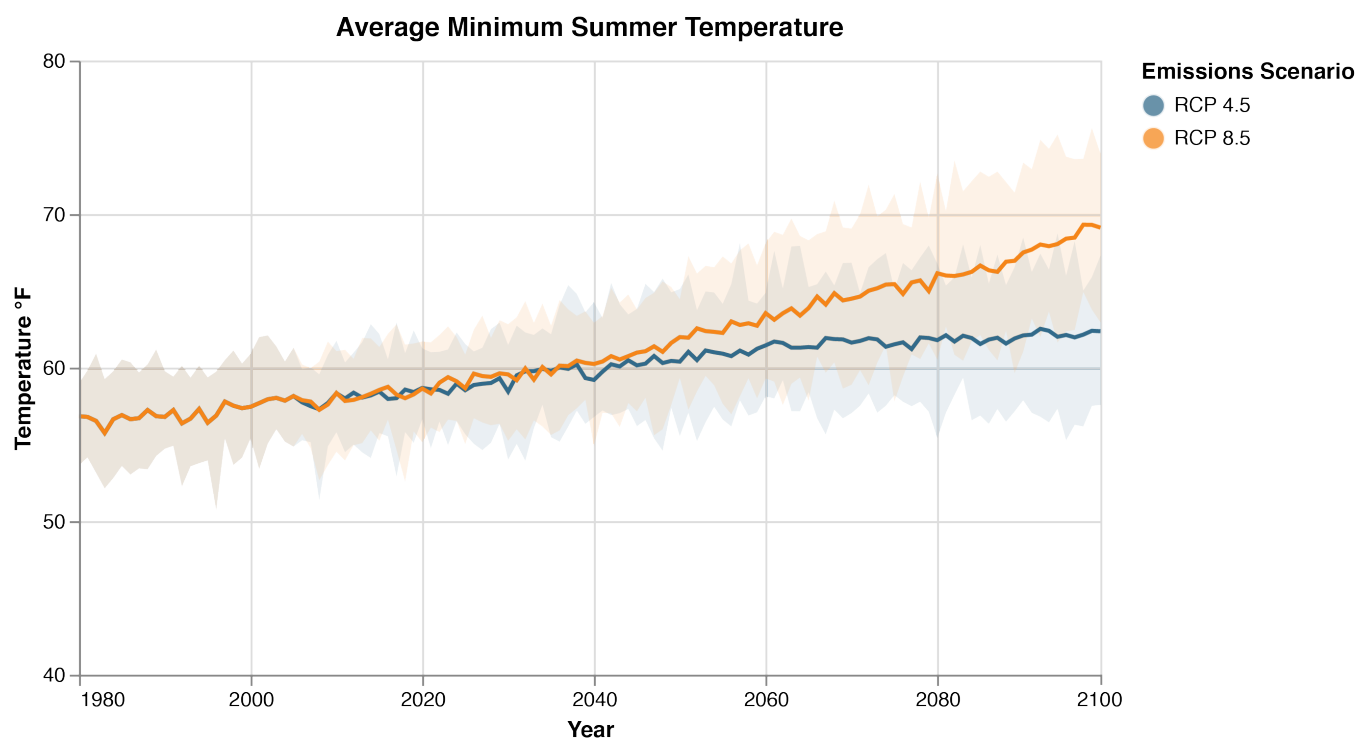


Figure C.5. Historical simulations (1980–2005) and future projections (2006–2099) for minimum summer temperature in Greater Portland. See top of Appendix C for full caption.

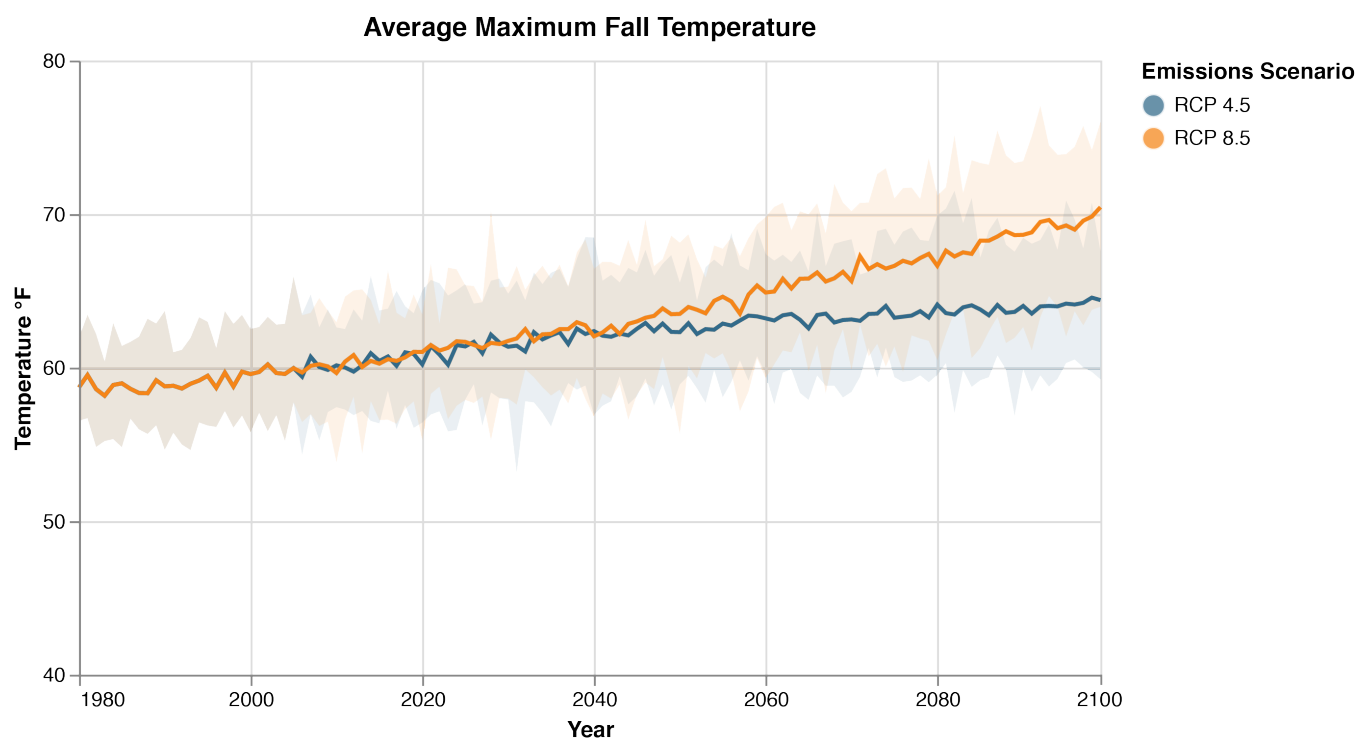


Figure C.6. Historical simulations (1980–2005) and future projections (2006–2099) for maximum fall temperature in Greater Portland. See top of Appendix C for full caption.

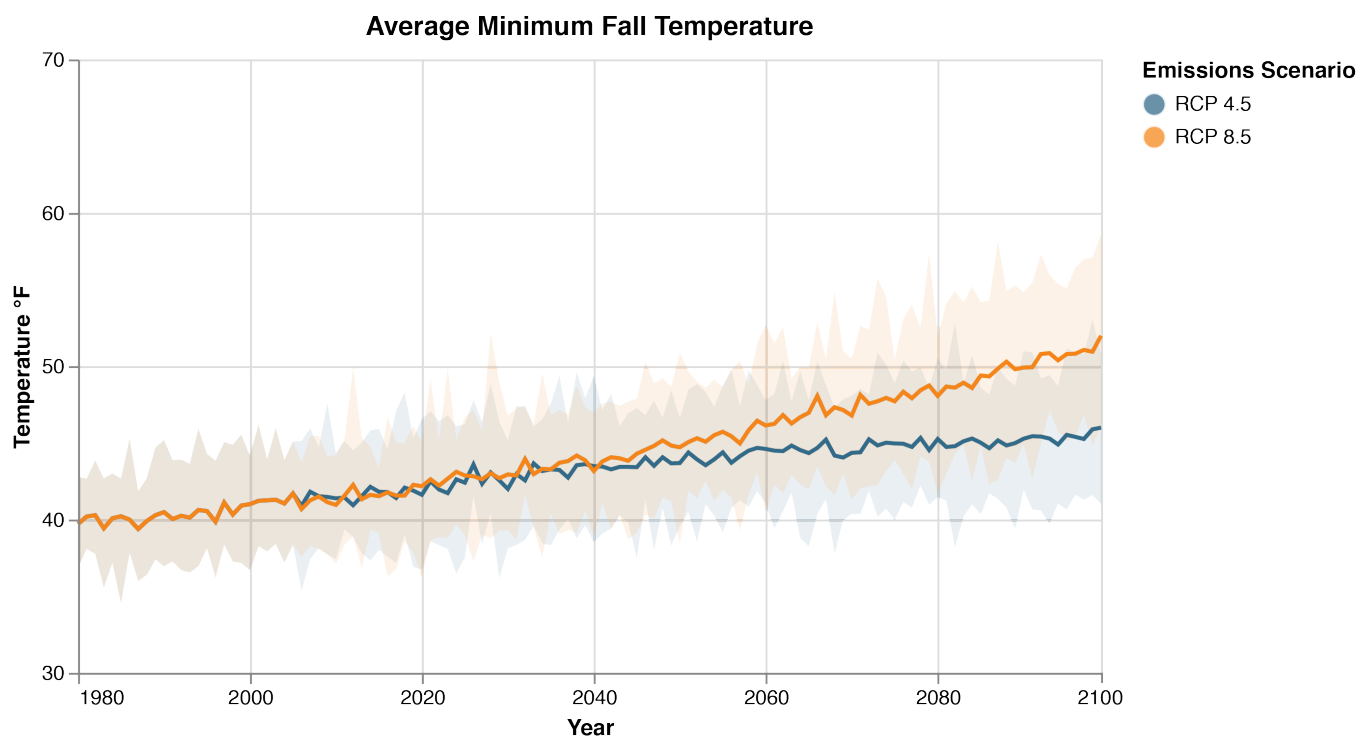


Figure C.7. Historical simulations (1980–2005) and future projections (2006–2099) for minimum fall temperature in Greater Portland. See top of Appendix C for full caption.

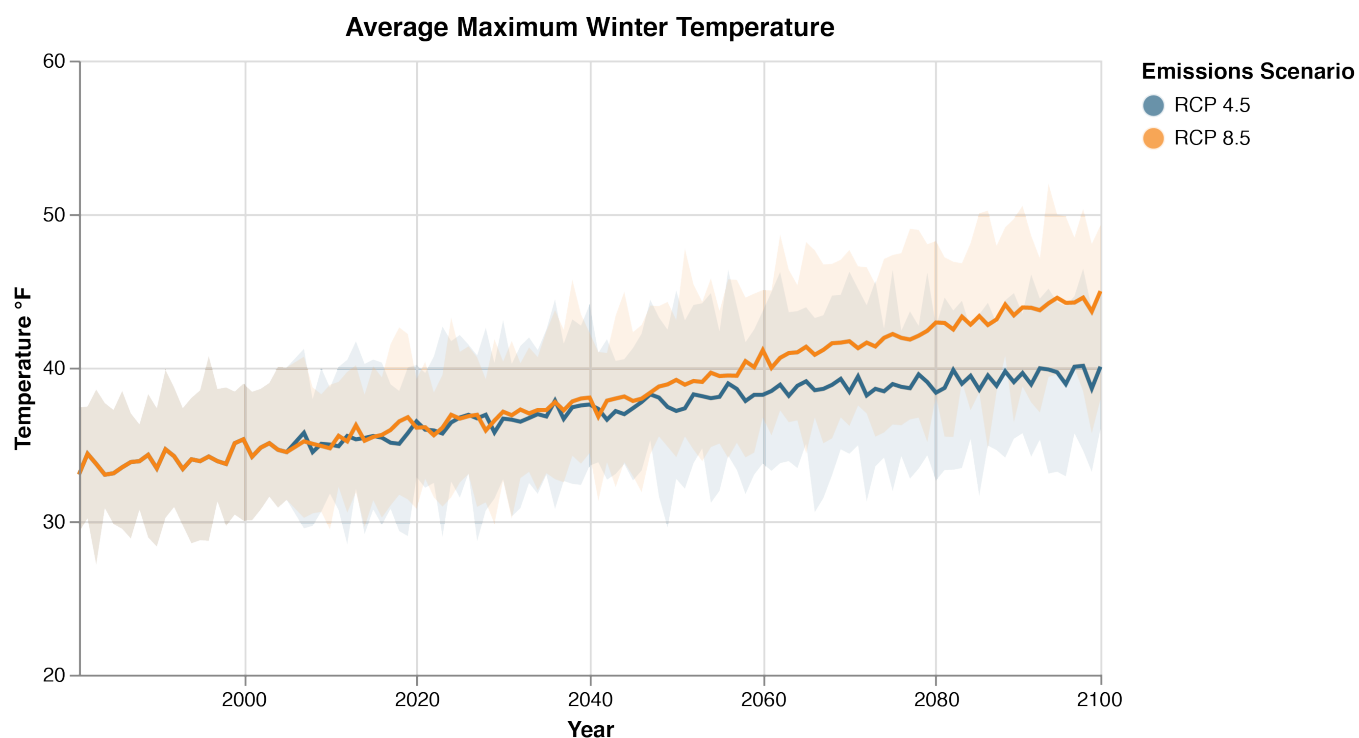


Figure C.8. Historical simulations (1980–2005) and future projections (2006–2099) for maximum winter temperature in Greater Portland. See top of Appendix C for full caption.

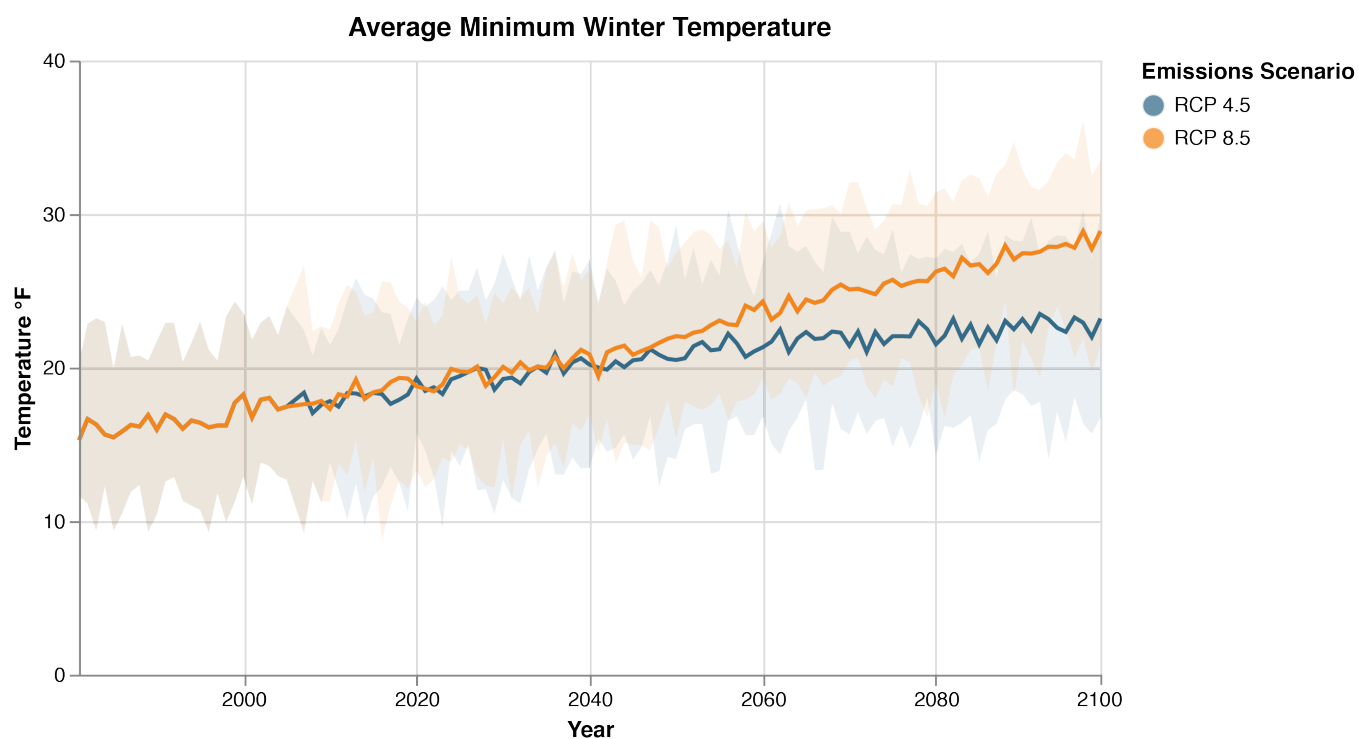


Figure C.9. Historical simulations (1980–2005) and future projections (2006–2099) for minimum winter temperature in Greater Portland. See top of Appendix C for full caption.

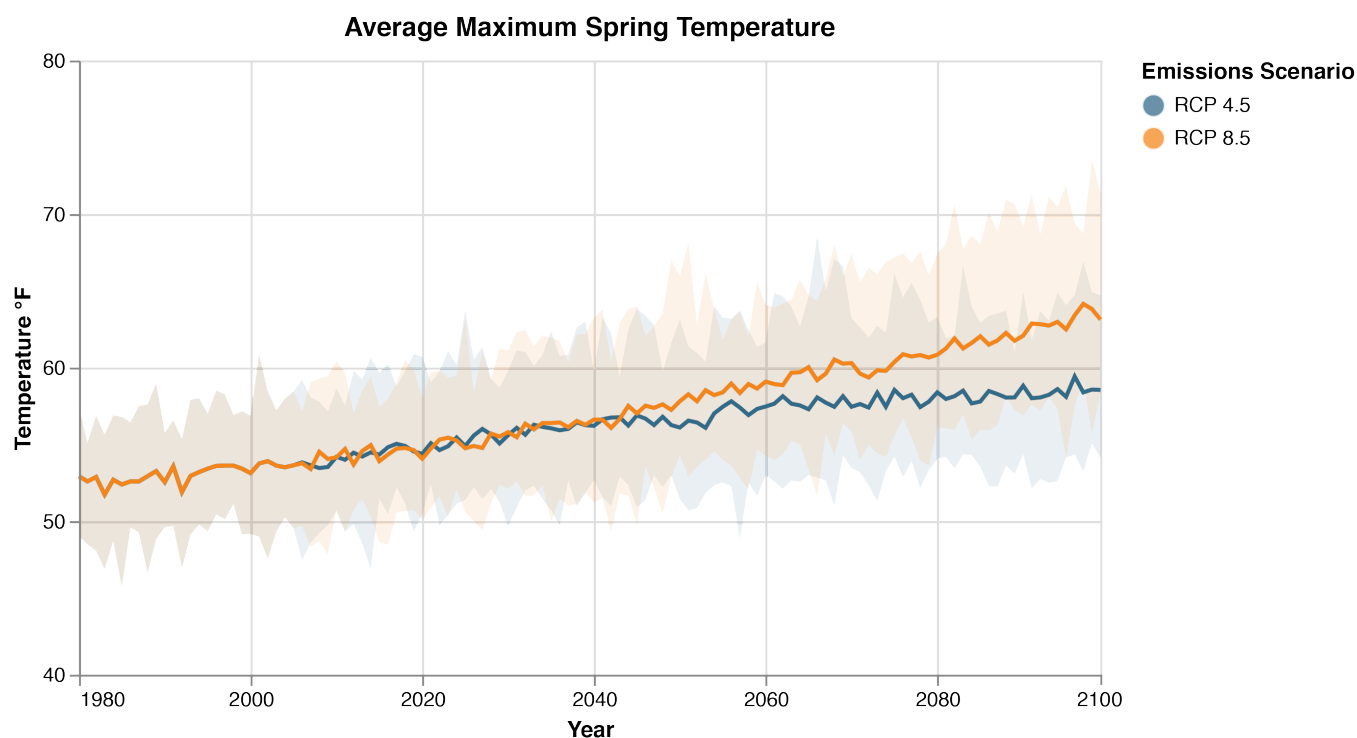


Figure C.10. Historical simulations (1980–2005) and future projections (2006–2099) for maximum spring temperature in Greater Portland. See top of Appendix C for full caption.

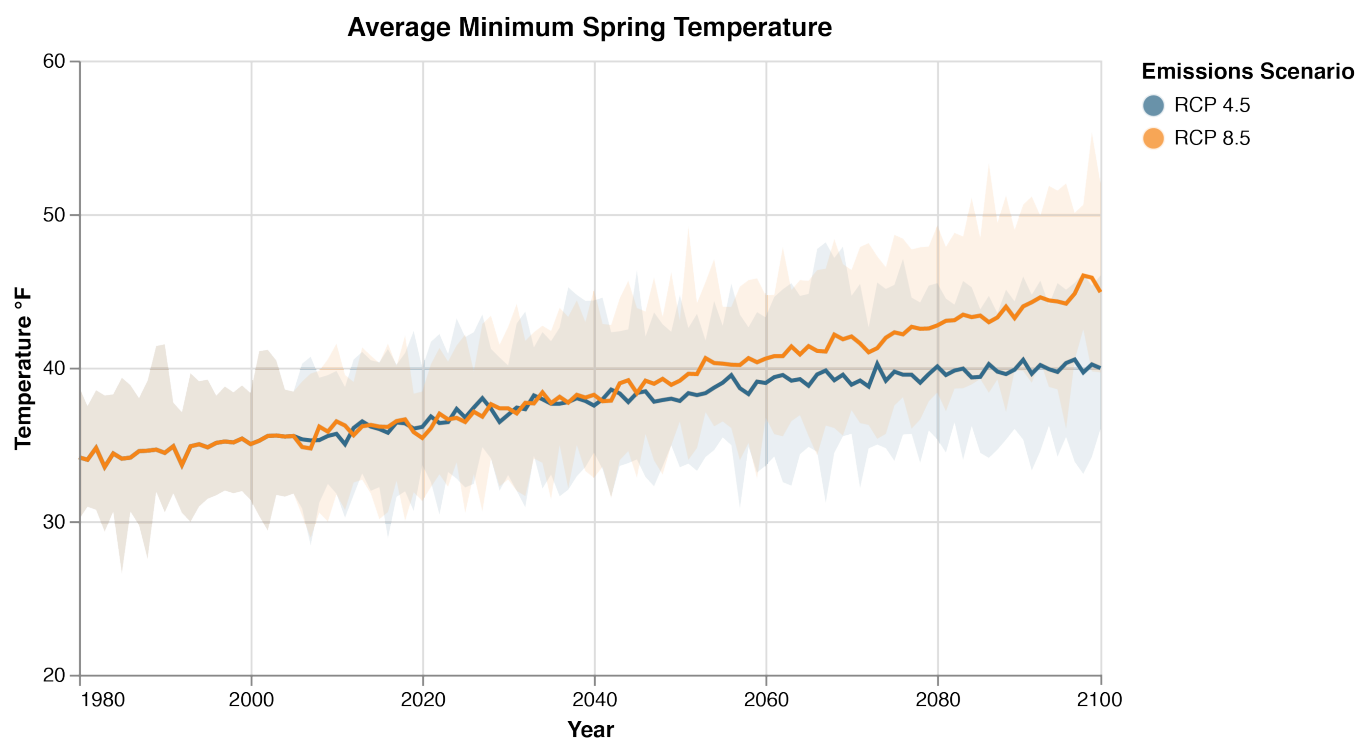


Figure C.11. Historical simulations (1980–2005) and future projections (2006–2099) for minimum spring temperature in Greater Portland. See top of Appendix C for full caption.

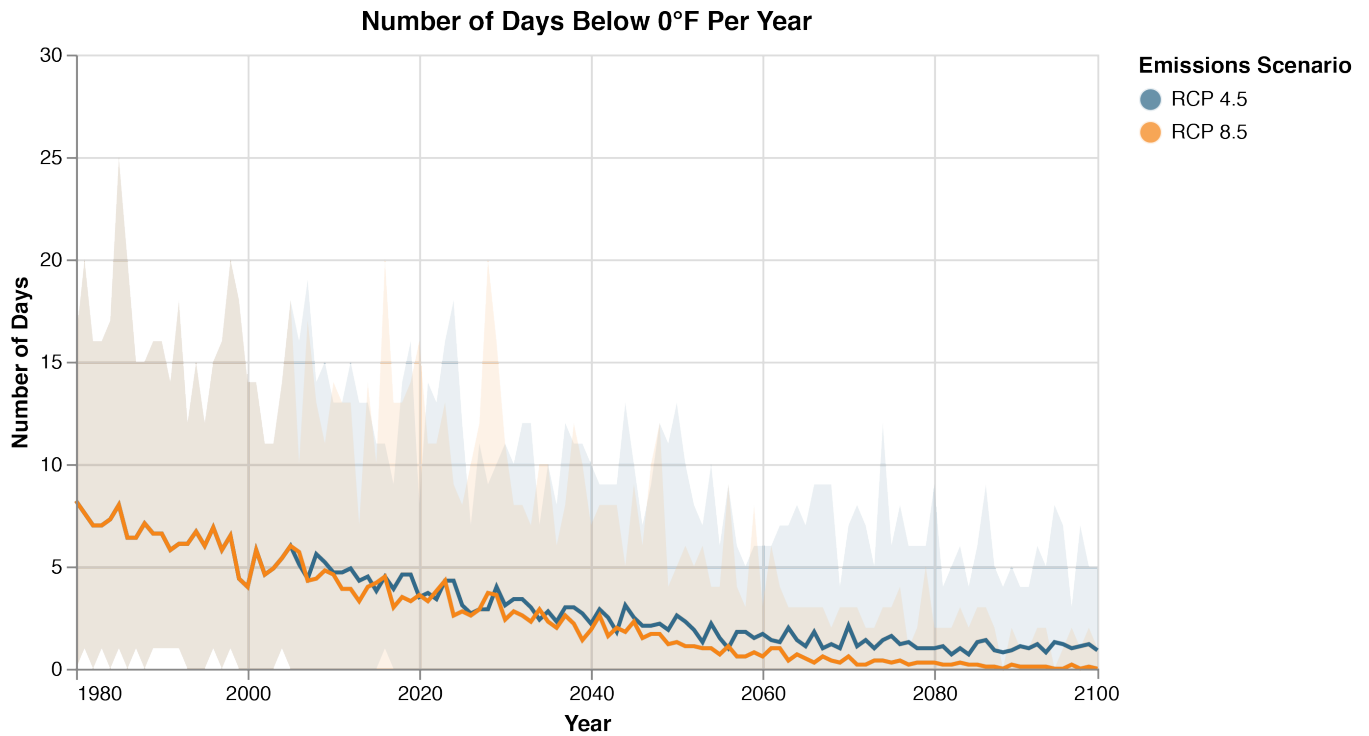


Figure C.12. Historical simulations (1980–2005) and future projections (2006–2099) for number of days below 0°F per year in Greater Portland. See top of Appendix C for full caption.

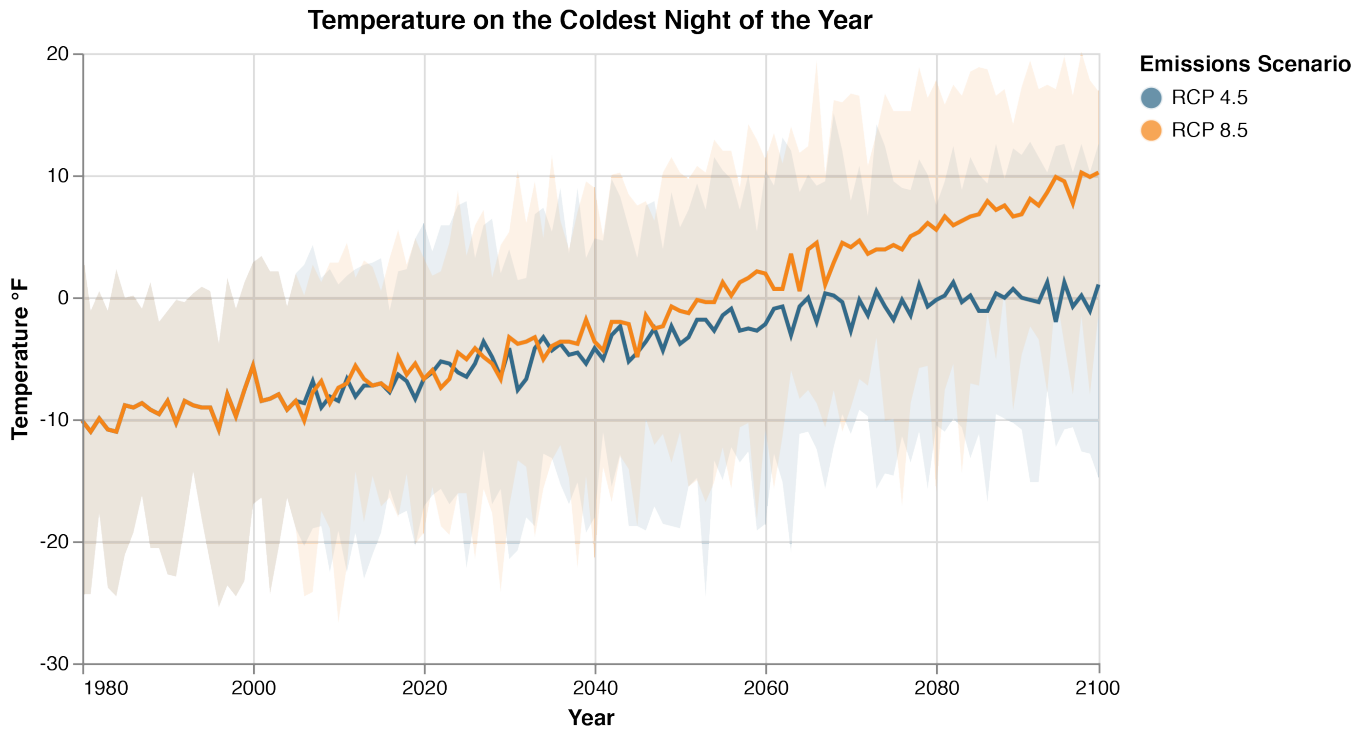


Figure C.13. Historical simulations (1980–2005) and future projections (2006–2099) for temperature on the coldest night of the year in Greater Portland. See top of Appendix C for full caption.

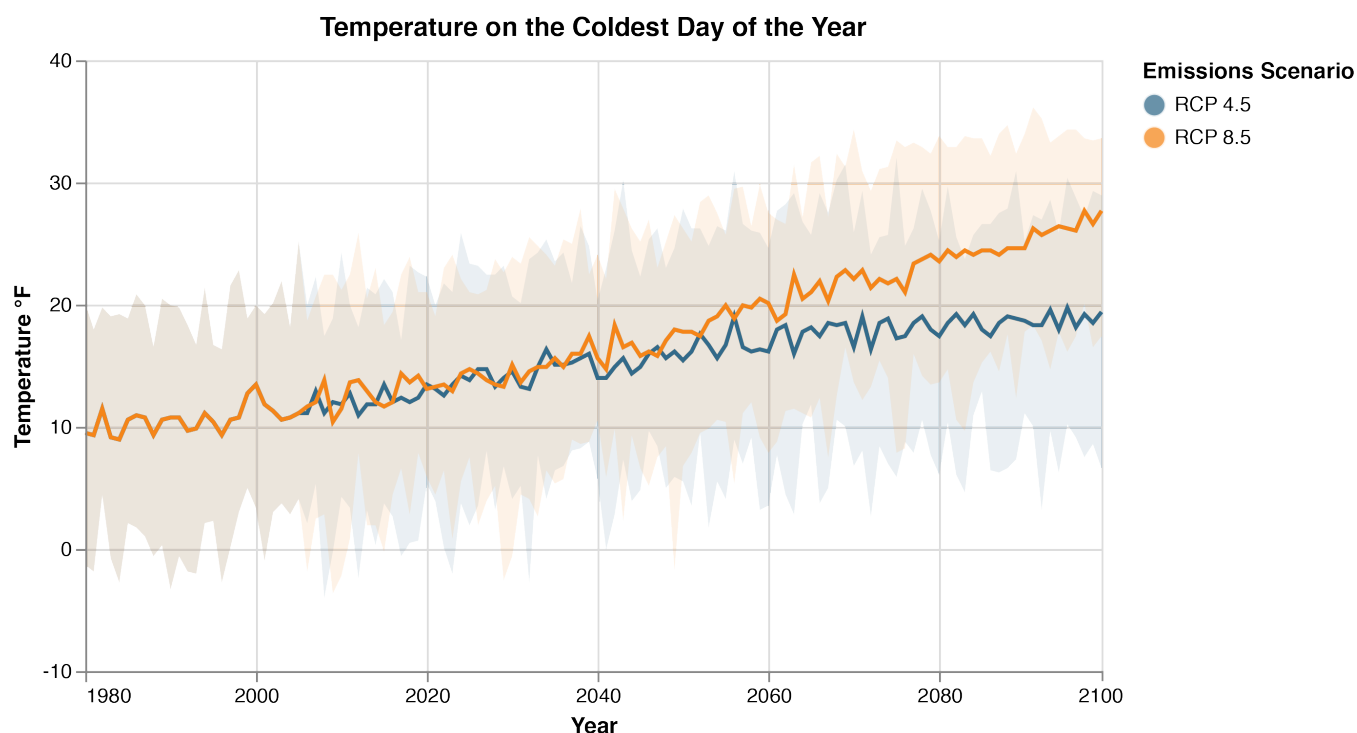


Figure C.14. Historical simulations (1980–2005) and future projections (2006–2099) for temperature on the coldest day of the year in Greater Portland. See top of Appendix C for full caption.

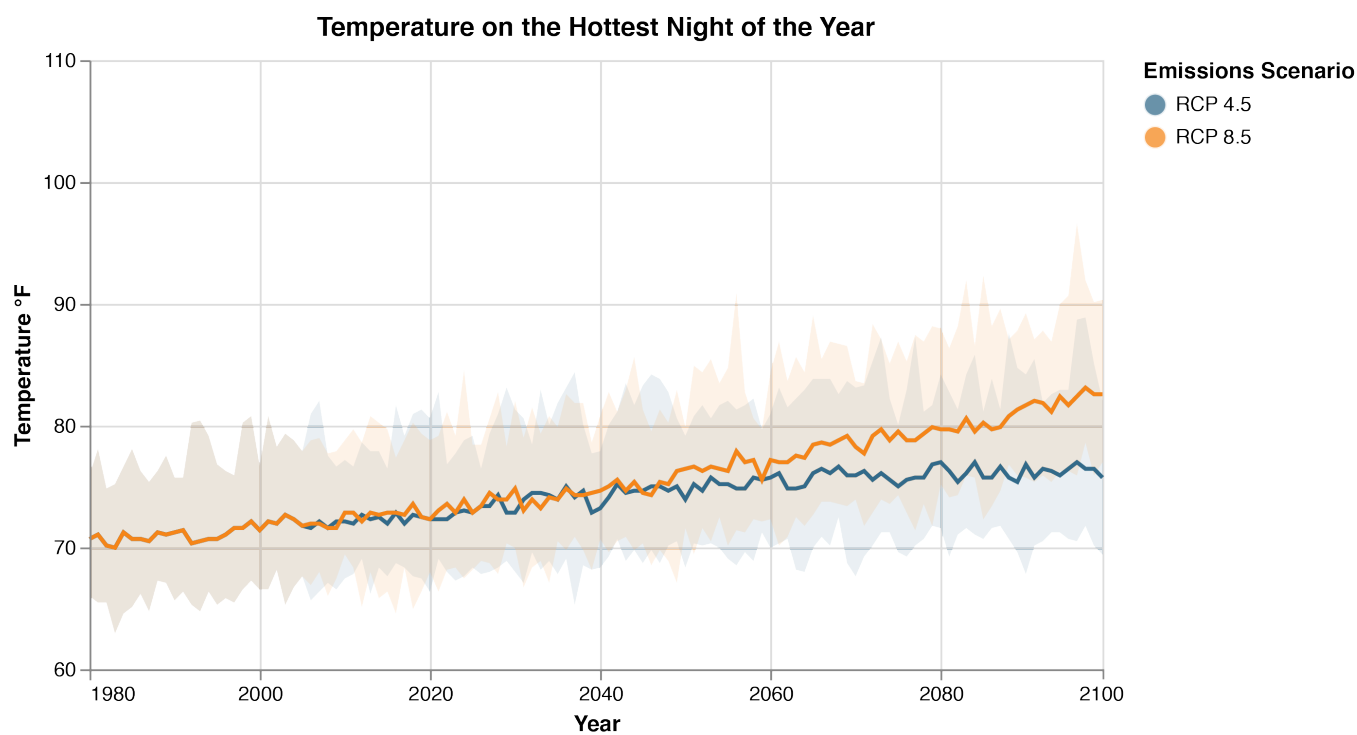


Figure C.15. Historical simulations (1980–2005) and future projections (2006–2099) for temperature on the hottest night of the year in Greater Portland. See top of Appendix C for full caption.

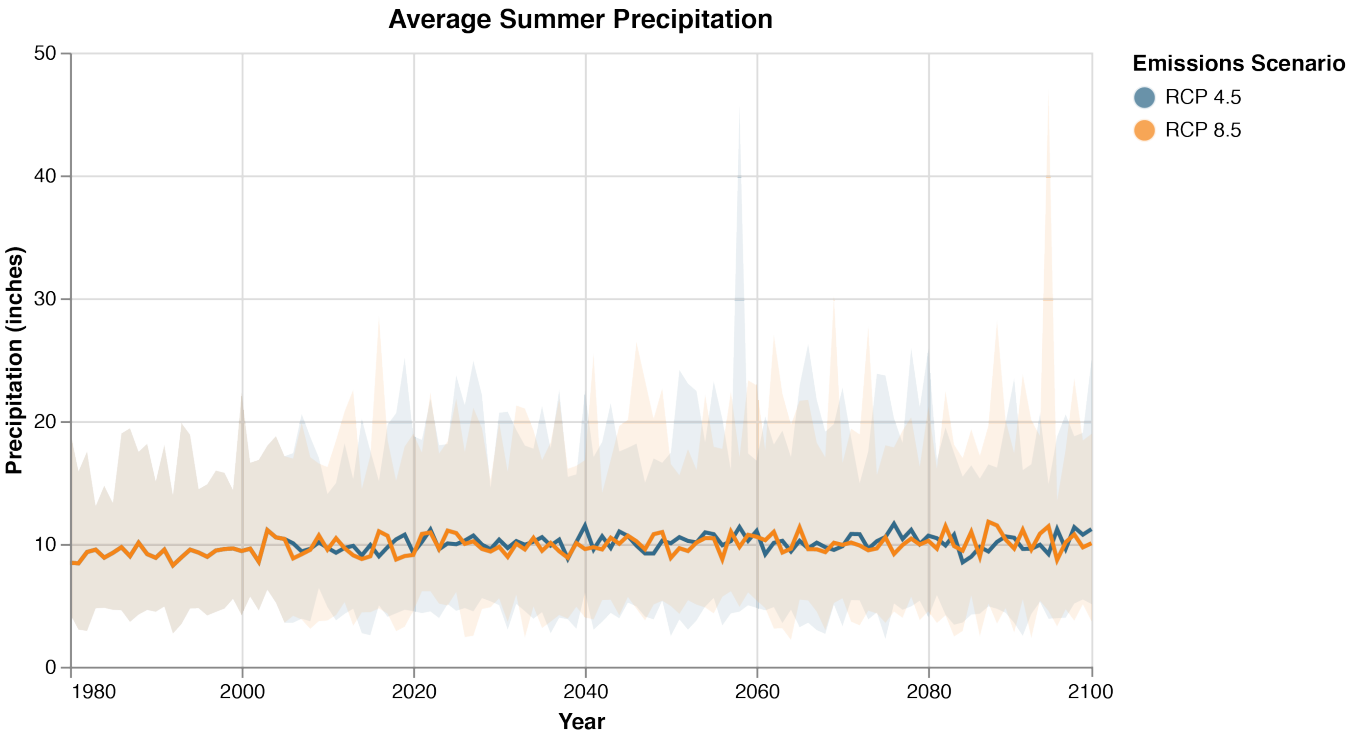


Figure C.16. Historical simulations (1980–2005) and future projections (2006–2099) for average summer precipitation in Greater Portland. See top of Appendix C for full caption.

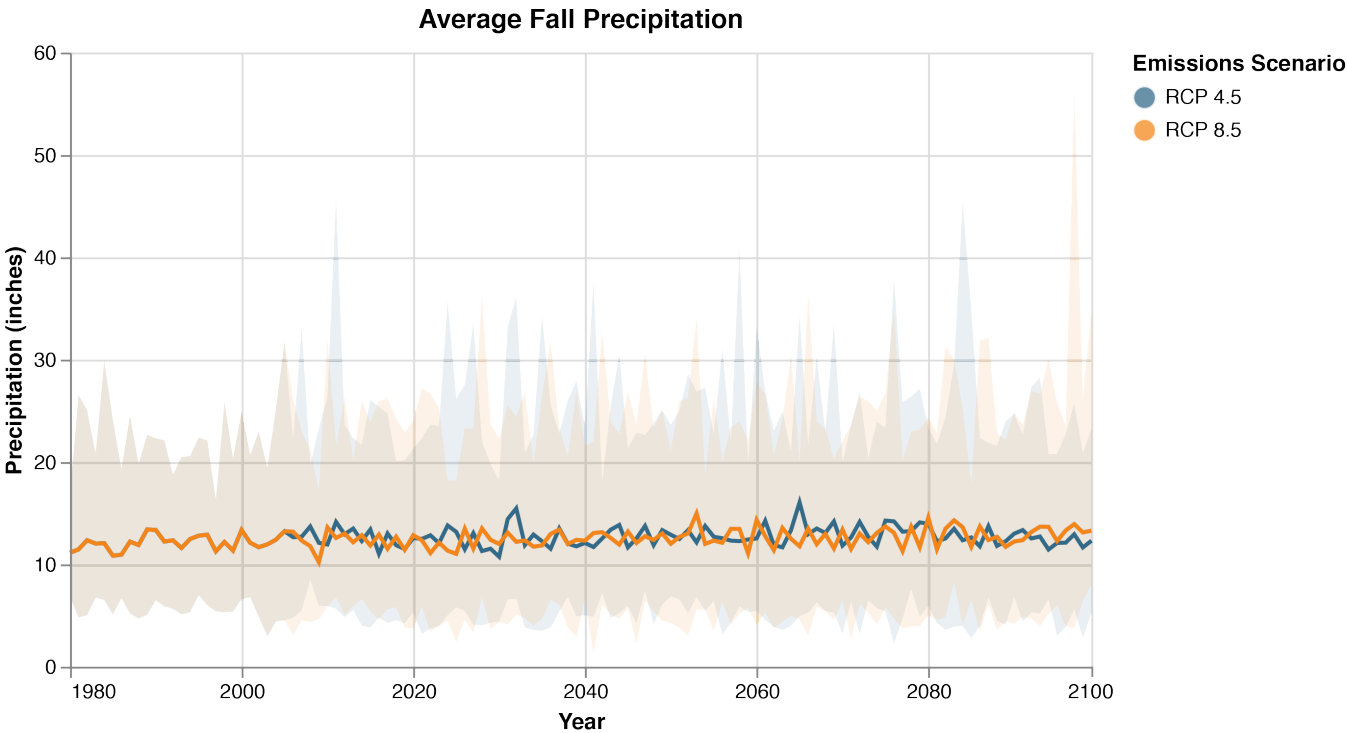


Figure C.17. Historical simulations (1980–2005) and future projections (2006–2099) for average fall precipitation in Greater Portland. See top of Appendix C for full caption.

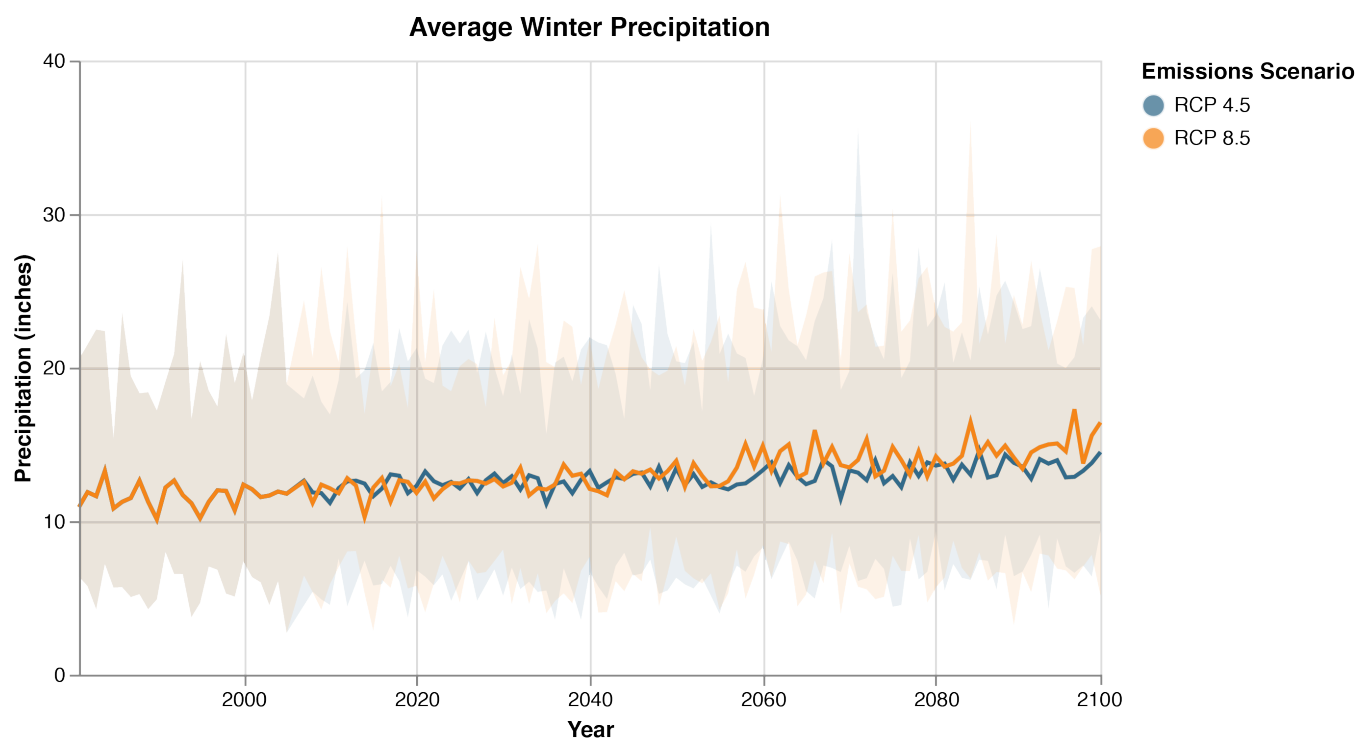


Figure C.18. Historical simulations (1980–2005) and future projections (2006–2099) for average winter precipitation in Greater Portland. See top of Appendix C for full caption.

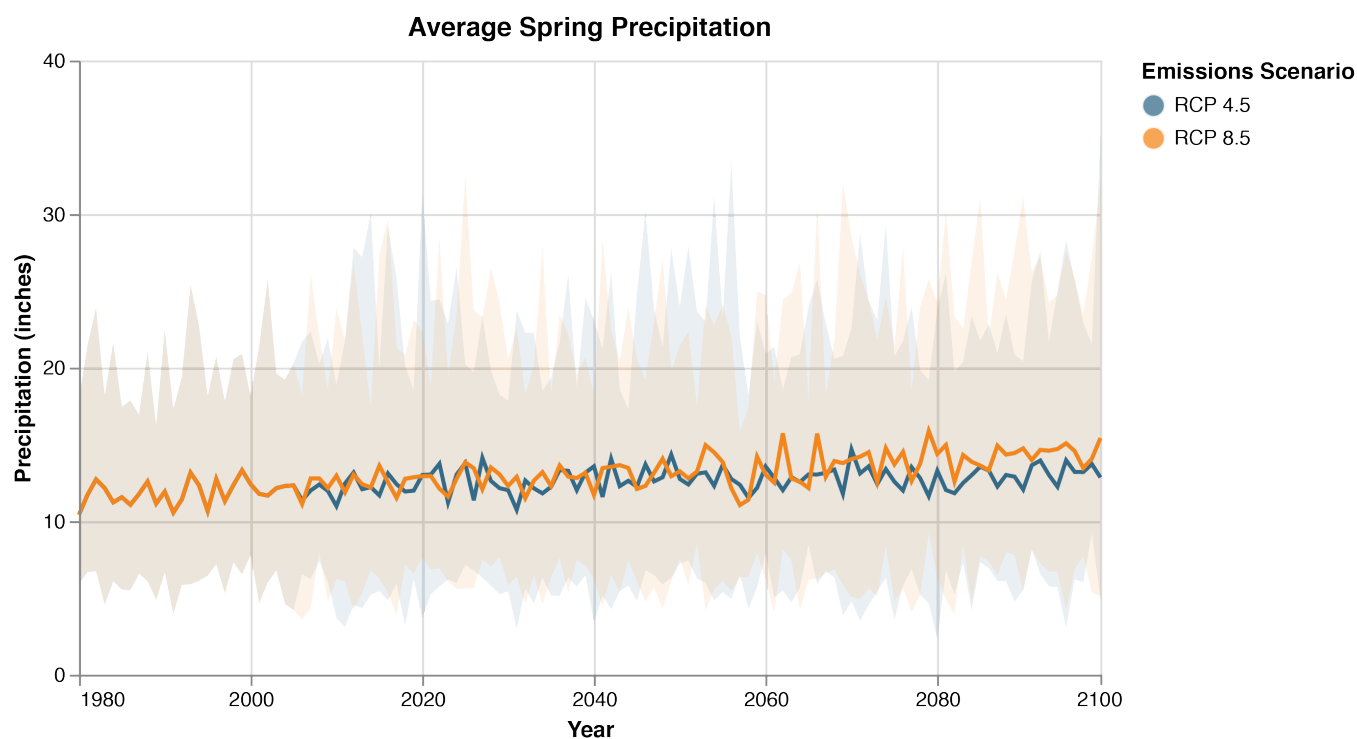


Figure C.19. Historical simulations (1980–2005) and future projections (2006–2099) for average spring precipitation in Greater Portland. See top of Appendix C for full caption.

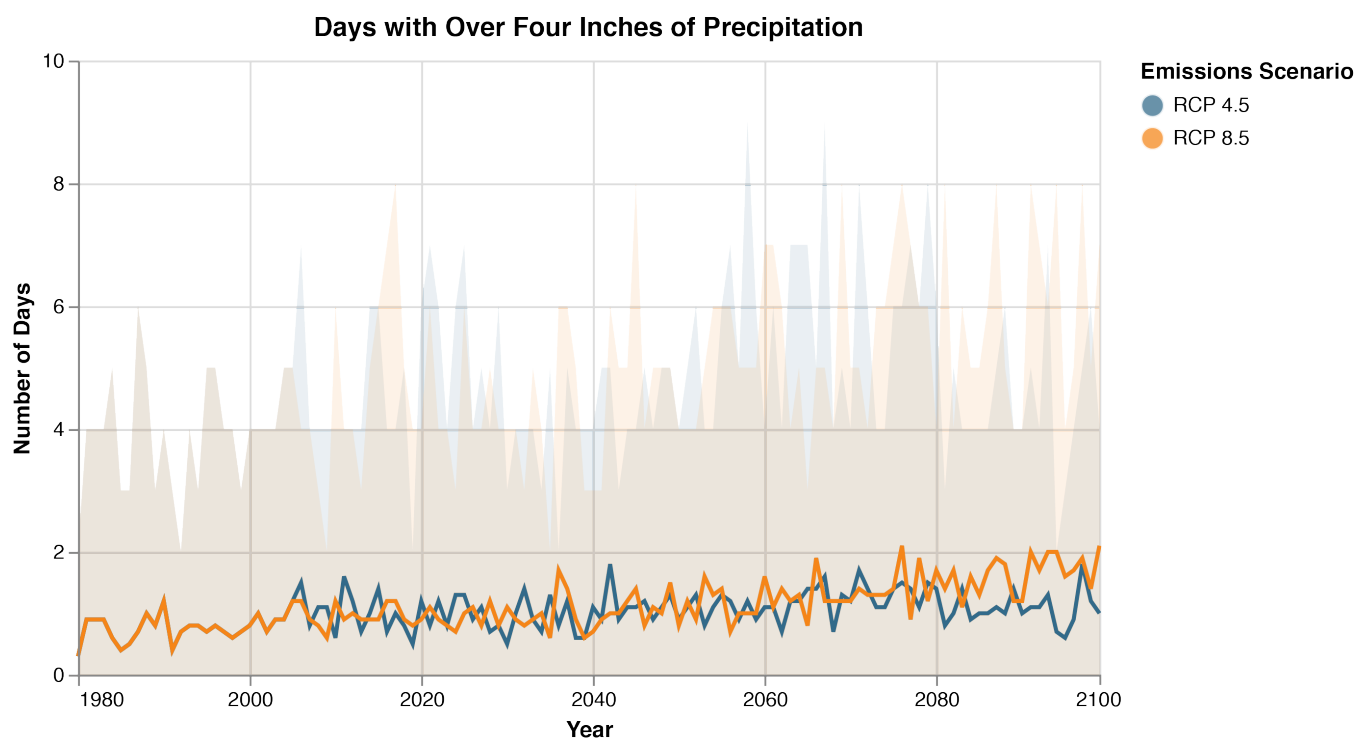


Figure C.20. Historical simulations (1980–2005) and future projections (2006–2099) for number of days per year with over four inches of rain in Greater Portland. See top of Appendix C for full caption.

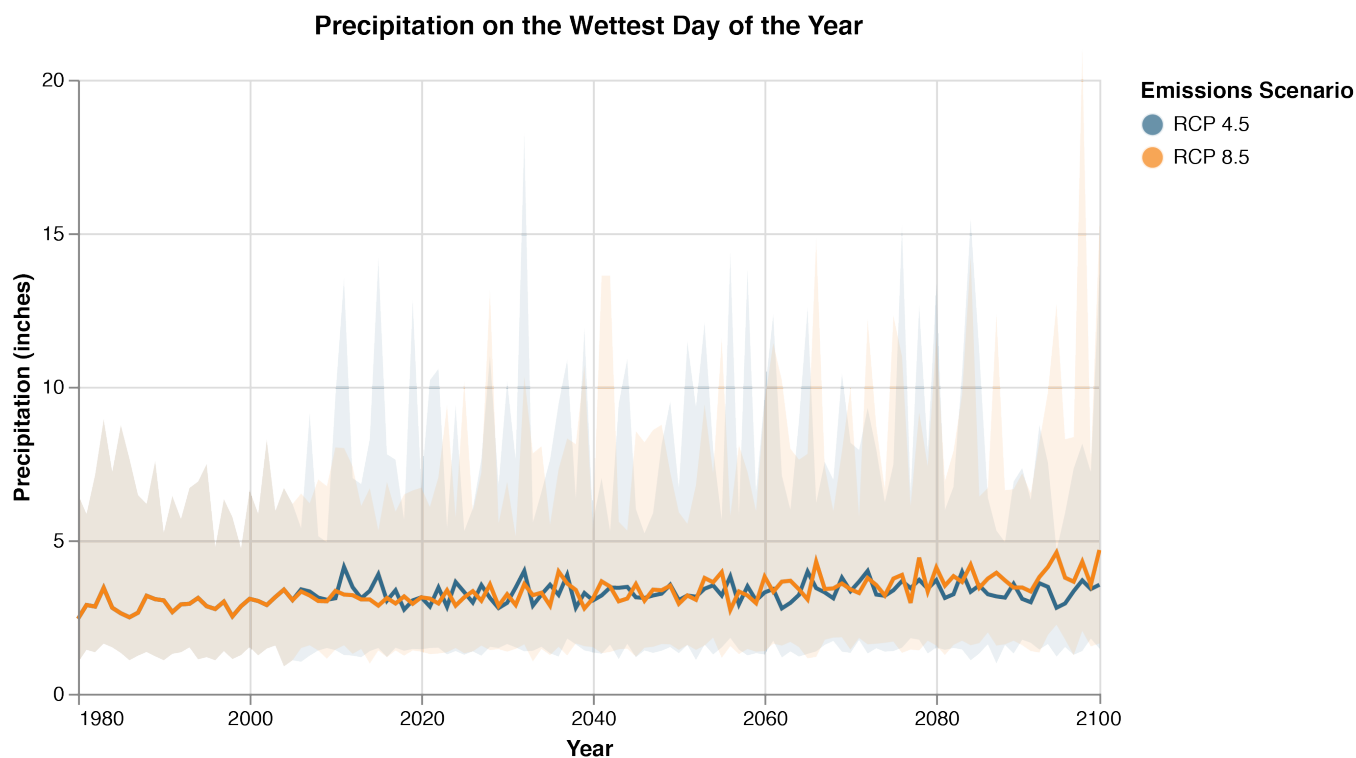


Figure C.21. Historical simulations (1980–2005) and future projections (2006–2099) for amount of precipitation on the wettest day of the year in Greater Portland. See top of Appendix C for full caption.

Appendix D: Impacts to Upcoming Capital Improvement Projects

Incorporating climate change projections and hazard mitigation goals into a municipality's Capital Improvement Planning (CIP) process is becoming a best practice for supporting climate resilience. Joining the two efforts provides an opportunity to fund efforts to reduce vulnerability through projects that are already being planned. The Capital Improvement Plans currently in place for Portland and South Portland both have projects that will likely play a role in reducing climate vulnerability, and may be vulnerable to future impacts from climate change.

Projects in locations that will fall within future inundation areas from the highest astronomical tide face a greater risk of damage from direct exposure to seawater, including inundation, erosion and scour due to tidal action, and corrosion by saltwater. Even projects outside this zone are vulnerable to the effects of changing precipitation and more intense weather patterns, including structural damage by wind and hydrodynamic loads, as well as debris.

Portland — The City of Portland Capital Improvement Plan represents the City's capital needs for 2019 through 2023. Projects included in the plan require a significant capital investment, therefore necessitating communication and planning. A large number of projects focus on environmental or climate mitigation goals—such as bike and pedestrian infrastructure improvements or energy efficiency—which can play a role in decreasing the city's infrastructure vulnerability in a number of ways.

Projects in the FY 2020 – FY 2023 CIP are also vulnerable to climate change based on either location, project type, or both. Location vulnerabilities include improvements near the coast, such as the West Commercial Street Pathway Greenway along Back Cove. Project type vulnerabilities include the 21 sewer and stormwater project requests for FY 2020 – FY 2023, including several CSO abatements. These CSO abatements will ultimately play a role in decreasing environmental vulnerability—abating some of the pollution impacts of increased

**Portland FY2019 – FY2020
Potentially Vulnerable CIP Projects Underway**

Project Category	Project Name
Sewer	State Street Sewer - Forest to Cumberland
Sewer	Back Cove West Storage Conduit
Sewer	Mackworth Ocean Walton Sewer Sep. & Water Repl.
Sewer	Preble Street Sewer Separation
Sewer/Stormwater	Bedford Street CSO
Sewer/Stormwater	Back Cove South Storage Facility
Sewer/Stormwater	Diamond Tide Gate
Sewer/Stormwater	Franklin St Pump Station
Transportation	Bayside Trail – Eastern Promenade Trail Junction Plaza
Transportation	Forest Avenue at State and High Intersection Work
Transportation	Forest Avenue at State and High Intersection Work
Transportation	State Street Sidewalk Rehab
Transportation	West Commercial St Pathway Phase II
Transportation	Route 22 Paving
Transportation	Valley Street
Transportation	Somerset Street Reconnection
Transportation	Somerset Street Reconnection
Transportation	Somerset Street Reconnection
Transportation	High Street Paving Project Part 1
Transportation	High Street Paving Project Part 2
Transportation	Bayside Trail-Planet Dog Pathway Enhancement
Transportation	Fox Street Paving
Transportation	Dana Street Reconstruction
Transportation	Thames St Extension
Transportation	Preble St Sidewalk Reconstruction Project (CDBG)
Transportation	Waldo Street Paving
Transportation	Fore River Parkway Paving Project
Transportation	Forest Ave at Marginal Way Sidewalk
Transportation	Forest Ave at State and High Intersection Sidewalk

Table D.1. City of Portland capital improvement projects underway that are vulnerable to sea level rise based on four sea level rise scenarios for the year 2100.

precipitation and subsequent overflows—but require careful consideration in the design of new drainage systems to ensure they will be able to handle increased precipitation.

In addition to these future projects, Portland has specific construction projects underway that include addressing CSOs, paving, intersection improvements, pump station rehabilitation, sidewalk reconstruction and improvements, storm drain extensions, trail improvement, water quality improvements, and sewer system rehabilitation.

Figure D.1 displays FY 2019 and FY 2020 Capital Improvement Projects alongside Maine Geological Survey Sea Level Rise/Storm Surge data to illustrate which projects are vulnerable to sea level rise under a number of scenarios. In the case of roadway projects, the specific length of the project that falls within the sea level rise area of inundation is bolded, but the whole length of the project is visible in yellow. The vulnerable projects are summarized in **Table D.1** with the majority of them being located along Back Cove and in the low-lying Bayside area. All the projects seen in bold along Back Cove are sanitary or sanitary/sewer projects.

FY19 and FY20 Construction Projects in Portland Vulnerable to Sea Level Rise



Figure D.1. City of Portland construction projects that are planned or underway for fiscal years 2019 and 2020, overlaid with the extent of inundation from four sea level rise scenarios (1.6 feet, 3.9 feet, 6.1 feet, and 8.8 feet on top of the highest astronomical tide). Data source: City of Portland ArcGIS Online Major Construction Projects Map (2019); Maine Geological Survey, Sea Level Rise/Storm Surge Map (2018).

Further evaluation of these capital project locations in conjunction with FEMA Flood Zones provides further information on flood vulnerability. **Figure D.2** shows the portions of projects that may be impacted by the 1% annual chance flood event. No vertical projects are within FEMA flood zones, but many roadway projects are. The majority of these projects are near Capisic Brook and Back Cove.

Brook should integrate design considerations for higher exposure to flooding and storm surge, as well as heavy precipitation, if they have not already. Projects may be brought into flood or tidal zones in the future and become subject to the damaging forces of waves and saltwater, including erosion, scour, corrosion and inundation.

From a vulnerability perspective, new capital improvement projects located around Back Cove, along the waterfront/Fore River, and along Capisic

FY19 and FY20 Construction Projects in Portland Vulnerable to the 1% Annual Chance Flood

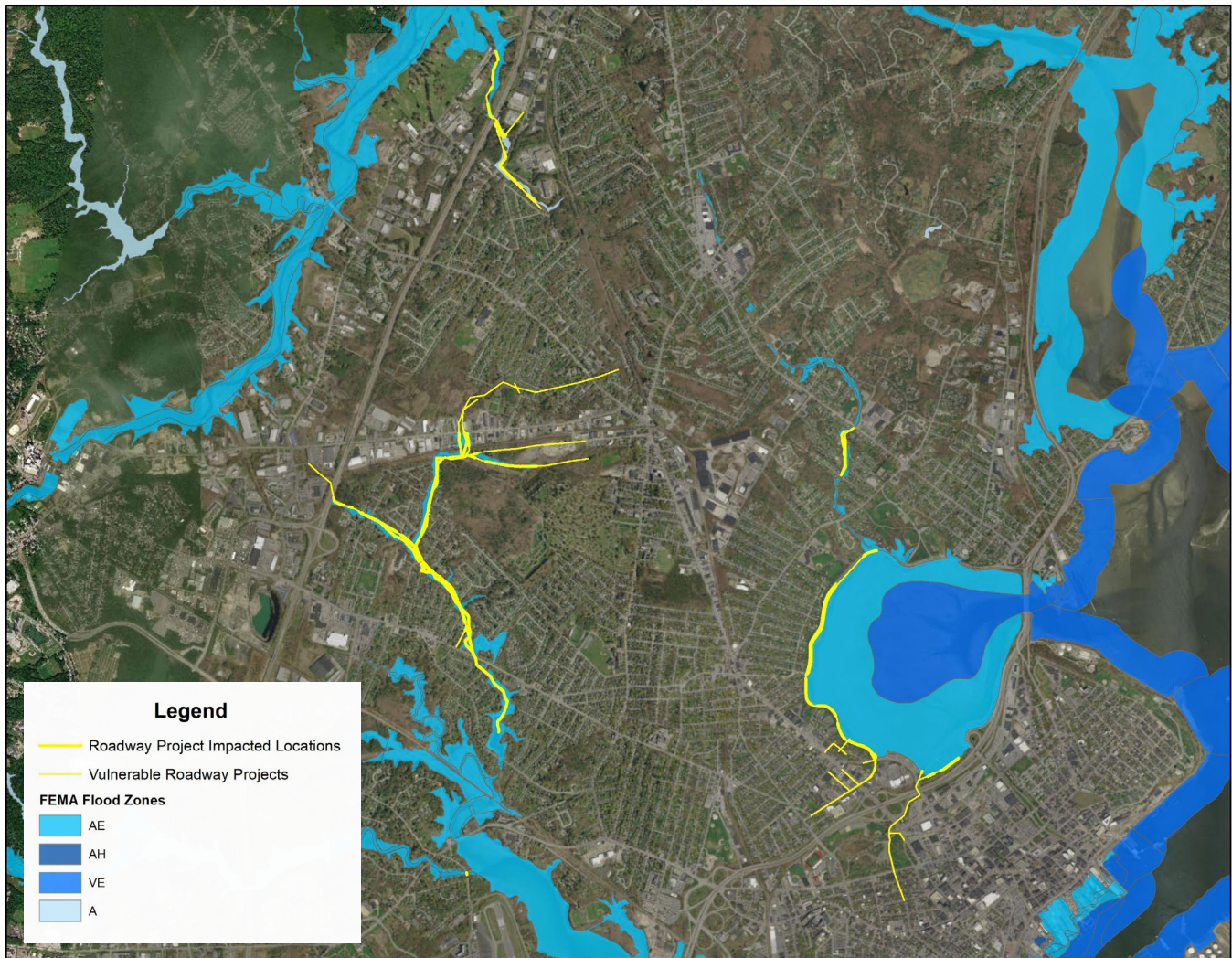


Figure D.2. City of Portland construction projects that are planned or underway for fiscal years 2019 and 2020, overlaid with the extent of inundation from the 1% annual flood. Data sources: City of Portland ArcGIS Online Major Construction Projects Map, 2019 (construction projects); FEMA preliminary flood zones (2018).

South Portland — Though unable to access geospatial data for South Portland’s ongoing or upcoming CIP projects for this report, in looking at the FEMA Flood Map and the Maine Geological Survey Sea Level Rise/ Storm Surge data, it is apparent that the specific areas of concern for South Portland with regard to flooding and sea level rise are along the Fore River and Long Creek.

The FY 2019 South Portland Capital Improvement Plan includes projects that may help reduce environmental vulnerability that will be exacerbated by climate hazards. Some of the projects are also located in areas that are vulnerable to sea level rise or storm surge, as identified in **Figure D.3** and **Figure D.4**.

- **CSOs | Pleasantdale Separation Project** – Separating CSOs decreases the vulnerability of the stormwater system by reducing the environmental impact of increased precipitation and flooding events. The FY19 CIP included the Pleasantdale Separation Project to address the Elm Street CSO. The project is designed for co-benefits including replacing aging utilities by Portland Water District and Unutil and when the street is reconstructed, incorporating Complete Street Principles.
- **Marsh Road Sewer Replacement** – This CIP request was for the replacement of 565 feet of sewer pipe located next to Trout Brook along Marsh Road (existing pipe dates back to the 1940s and is cracked). Trout Brook is an urban impaired stream and the City of South Portland has been working to address its degradation for almost ten years through its Watershed Management Plan. Replacing the line will eliminate sewage entering Trout Brook, thereby reducing the vulnerability of the stream ecosystem. Marsh Road is in a FEMA 1% annual chance flood zone. Infrastructure in this area of the city may be vulnerable to flooding impacts.
- **Electrical System Upgrades to the Wastewater Treatment Plant** – Over \$1 million dollars in electrical system upgrades are included in the CIP, which has the potential to decrease the vulnerability of the WWTP to climate hazards if upgrades incorporate redundancy and flood- and weather-proofing of the system. While the WWTP assets are not technically in a FEMA floodplain (**Figure D.5**) the site will be impacted by sea level rise starting at 3.9 feet above the highest astronomical tide. The plant’s components will be impacted at 6.1 feet of sea level rise and the full site is projected to be inundated at 8.8 feet (**Figure D.5**).

South Portland Areas Vulnerable to the 1% Annual Chance Flood

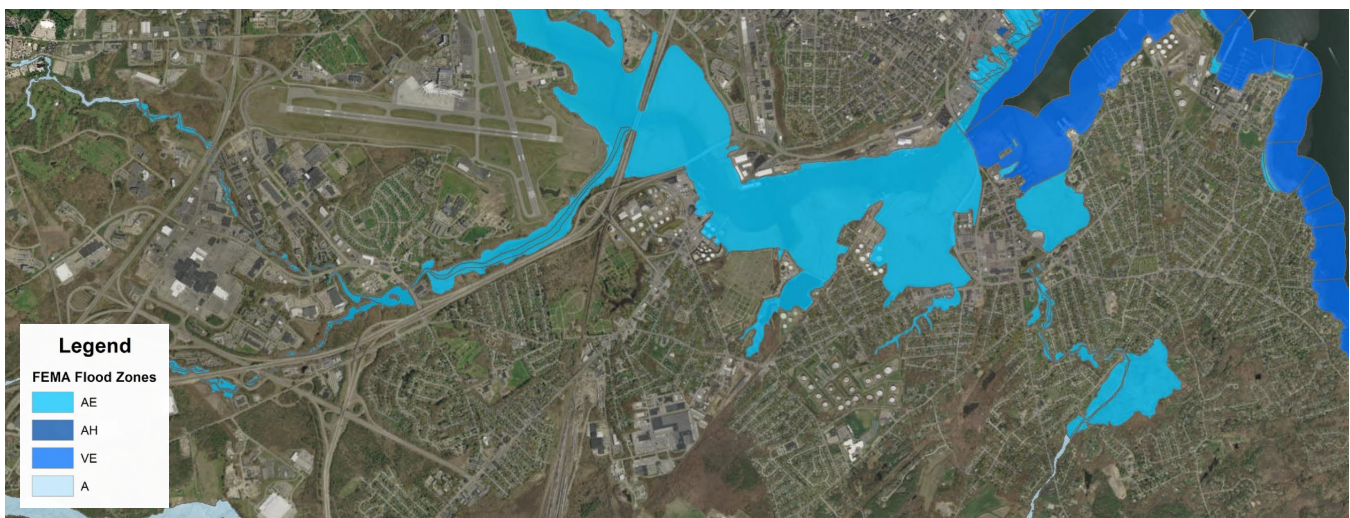


Figure D.3. Areas vulnerable to inundation from the 1% annual flood in South Portland. Data source: FEMA preliminary flood zones (2018).

South Portland Areas Vulnerable to Sea Level Rise



Figure D.4. Areas vulnerable to inundation from four sea level rise scenarios (1.6 feet, 3.9 feet, 6.1 feet, and 8.8 feet on top of the highest astronomical tide). Data source: Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).

South Portland Wastewater Treatment Facility Flood Vulnerability

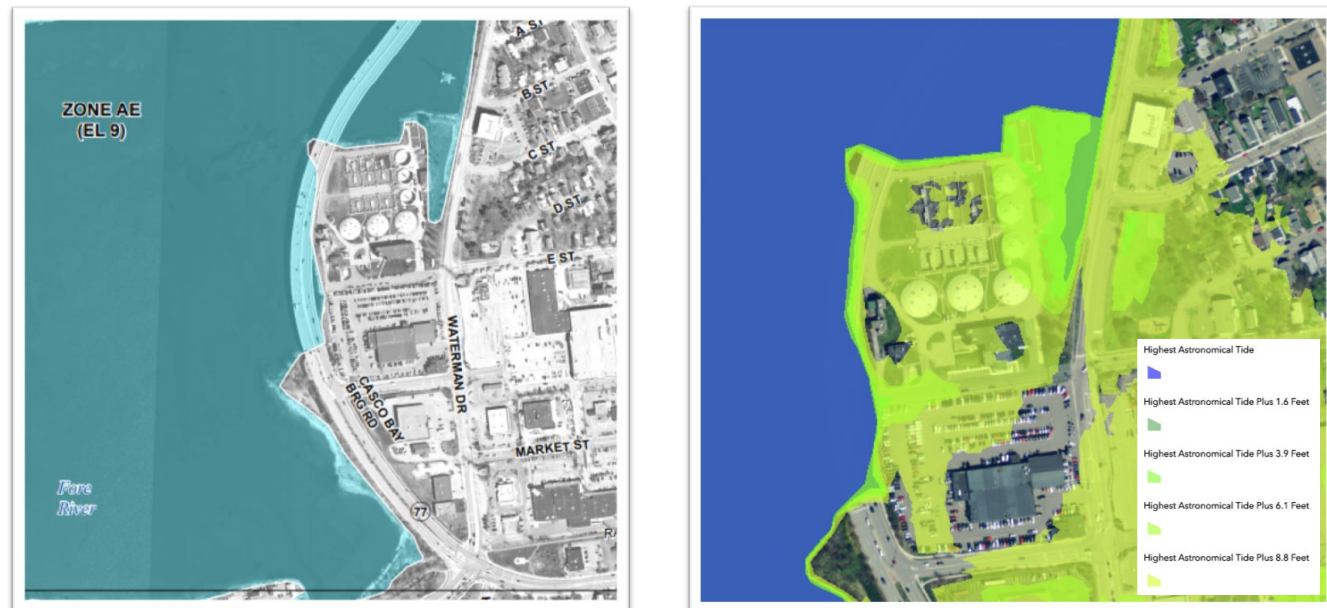


Figure D.5. The South Portland wastewater treatment facility overlaid with FEMA flood zones for the 1% annual flood (left) and overlaid with sea level rise projections based on four sea level rise scenarios for 2100 (right). Data source: FEMA preliminary flood zones (2018); Maine Geological Survey Sea Level Rise/Storm Surge Scenarios (2018).



**ONE
CLIMATE
FUTURE**
Charting a Course for
Portland and South Portland

Climate Change Impacts on Portland and South Portland

Sea level rise, storm surges, more extreme weather, higher air and water temperatures, and ocean acidification are all hazards that will make our infrastructure, environment, economy, and communities more vulnerable. As part of *One Climate Future*, we have used a range of information — including local climate models, environmental and economic research, and residents' experiences — to better understand the risks our cities will face.

Key Climate Vulnerabilities



Building and Property Damage

Sea level rise and more extreme storms will damage buildings and decrease property values if we don't increase the resilience of existing buildings and new development.



Exposure to Hazardous Waste

Without proactive preparedness, sea level rise and more extreme storms could increase our exposure to toxins from hazardous waste sites along the coast, posing a risk to human and environmental health.



More Power Outages

Extreme storms increase the likelihood of power outages, which can disrupt transportation, communication, and water systems, and create short- and long-term economic losses for businesses.



Public Health Challenges

Heat-related illnesses, diseases carried by ticks, poor air quality, and emotional stress are some of the public health challenges our region will increasingly face as our climate changes.



Transportation Closures

Sea level rise and storm surge are expected to increasingly flood roads, including portions of I-295. A category 2 hurricane could cut off access to bridges between the two cities.



Strain on Social Services

Climate hazards will increase the need for social services. At the same time, climate hazards can make essential services inaccessible to vulnerable populations during weather-related emergencies.



Stormwater and Sewer System Risks

Portions of the cities' sewer and stormwater systems along the coast are vulnerable to storms and sea level rise that may lead to pipe damage, saltwater infiltration, and failure of electrical pumping equipment.



Food System Vulnerability

International droughts, floods, and new pests will impact global food systems and potentially increase food prices here in Maine. Climate hazards locally will likely compromise food distribution and food access.



Ecosystem Impacts

Climate change will affect freshwater, marine, and land ecosystems by allowing new invasive species and pests to thrive. Sea level rise and more stormwater runoff can further degrade sensitive tidal ecosystems.



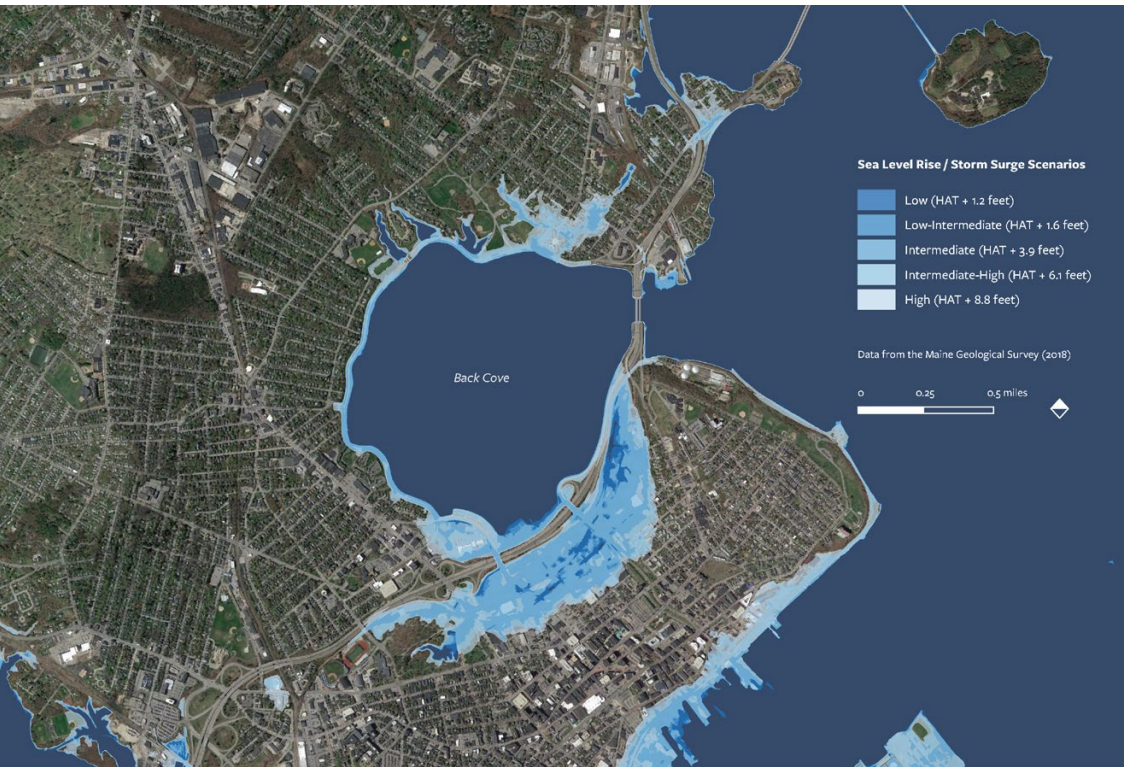
Greater Social Inequity

Residents facing poverty, a disability, or other forms of marginalization will experience disproportionate harm from climate change. Climate adaptation planning and implementation must address these inequities to ensure that benefits are shared equitably among our communities.



Portland and South Portland are taking action together to reduce our vulnerabilities to climate change.

The maps show five sea level rise scenarios for the year 2100. If we continue to increase the rate at which we are burning fossil fuels (oil, natural gas, and gasoline/diesel) in our homes, businesses, and cars and fail to minimize our waste, it is likely we could see the “Intermediate” scenario shown in the maps below as early as 2050.



Even under the low scenarios shown, Portland and South Portland are facing at least one foot of sea level rise by the end of the century. Through *One Climate Future*, the cities are working together to ensure we are prepared.



Sea level rise scenarios are noted in feet above the highest astronomical tide (HAT). Data source: Maine Geological Survey Sea Level Rise/Storm Surge Data (2018).



Learn more at www.oneclimatefuture.org