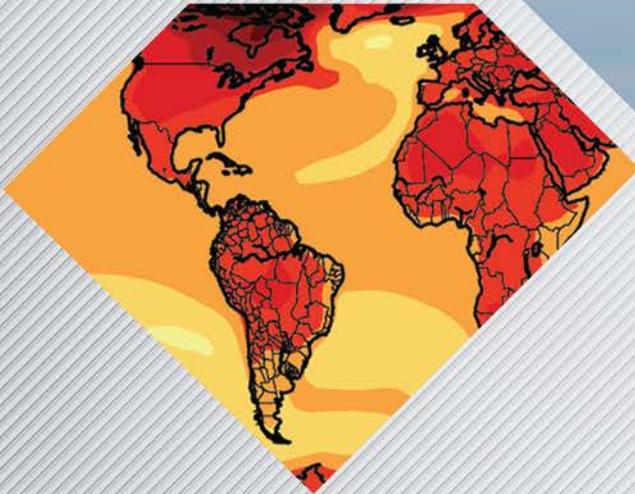




Homeland  
Security

March 2016

# RESILIENCY ASSESSMENT



CASCO BAY REGION CLIMATE CHANGE

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# U.S. Department of Homeland Security

## Regional Resiliency Assessment Program

The Regional Resiliency Assessment Program (RRAP) is a cooperative, non-regulatory, Office of Infrastructure Protection (IP) led assessment of specific critical infrastructure and regional analysis of the surrounding infrastructure. The RRAP focuses on infrastructure systems within a designated geographic area and addresses a range of hazards that could have regionally and nationally significant consequences. Each year, IP selects RRAP locations around the Nation with input and guidance from Federal and State partners. Each RRAP is typically a year-long data gathering and analytical effort followed by continued technical assistance to support resilience-building, and can incorporate various components, including voluntary facility vulnerability assessments, targeted studies and modeling, first responder capability assessments, subject matter expert workshops, and other valuable information and data exchanges.

The goal of the RRAP is to mitigate the Nation's risk of loss of life and physical and economic damage from natural and manmade hazards. This goal is achieved by:

- Assessing critical infrastructure on a regional level, focusing on threats, vulnerabilities, and consequences from an all-hazards perspective;
- Identifying critical infrastructure dependencies, interdependencies, cascading effects, and resilience characteristics and gaps;
- Assessing the integrated preparedness and protection capabilities of critical infrastructure owners and operators and emergency planning and response organizations; and
- Coordinating protection and response planning efforts to enhance resilience and address security gaps within the geographic region.

Strong partnerships with State, local, tribal, and territorial government officials are vital to the RRAP process, owing to their central coordinating role in regional infrastructure resilience. The RRAP also relies on engagement and information-sharing with Federal agencies, private sector facility owners and operators, law enforcement, emergency response organizations, academic institutions, and other stakeholders.

The RRAP evolved from earlier DHS initiatives focused on the protection of high-consequence clusters of critical infrastructure. Beginning in 2009, IP began addressing broader, more regionally based issues through the RRAP. Since the RRAP's inception, projects have been conducted in regions throughout the United States, and have focused on sectors such as Energy, Transportation, Commercial Facilities, and Food and Agriculture. The cumulative knowledge and experience built through successive RRAPs has increasingly revealed operational dependencies, common resilience gaps, and other crucial links across regions and sectors. This knowledge and experience is applied in subsequent RRAPs to continuously expand the value the RRAP brings to participants.

The culmination of RRAP activities, research, and analysis is presented in a Resiliency Assessment documenting project results and findings, including key regional resilience gaps and options for addressing these shortfalls. The Resiliency Assessment, along with supporting documents and information, is provided to select RRAP participants in the form of a multimedia presentation. Facility owners and operators, regional organizations, and government agencies can use the results to help guide strategic investments in equipment, planning, training, and resources to enhance the resilience and protection of facilities, surrounding communities, and entire regions.

For more information about the Regional Resiliency Assessment Program, please contact [Resilience@dhs.gov](mailto:Resilience@dhs.gov).

### What is the Office of Infrastructure Protection?

The Office of Infrastructure Protection, a component within the National Protection and Programs Directorate, leads the national effort to mitigate risk to, strengthen the protection of, and enhance the all-hazard resilience of the Nation's critical infrastructure.

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# Executive Summary

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## RRAP Focus

The State of Maine is experiencing shifts in atmospheric and oceanographic conditions that put it at the precipice of abrupt climate change. This RRAP focuses on the local and regional consequences of climate disruptions and their impacts on critical infrastructure in the Casco Bay Region, the most developed and populous region in Maine. Climate disruptions that are already occurring include record flooding; the fastest rise (tied with Vermont) in annual average ambient temperature for all states in the past 30 years; and water temperatures in the Gulf of Maine that are warming faster than 99 percent of the world's oceans (Portland Press Herald 2014). Projections indicate that these trends will continue, resulting in higher sea levels, more frequent flooding, higher-intensity storms, and record heat waves, which can lead to failure and/or degradation of the region's energy, transportation, water/wastewater, and telecommunication infrastructure.

## Summary of Findings

This RRAP identifies vulnerabilities that may potentially affect the region's ability to maintain its critical infrastructure systems and recover from the impacts of climate change. Resilience Enhancement Options include the following:

- Formation of an integrated planning body to address the impacts of climate change at the regional level;
- Working with Federal partners to model future climate change impacts on infrastructure and develop adaptation strategies; and
- Conduct an assessment of critical infrastructure dependencies to develop a better understanding of potential cascading impacts due to climate change.

## Introduction

The Office of Infrastructure Protection (IP) within the U.S. Department of Homeland Security (DHS) identified the critical lifeline infrastructure systems (energy, transportation, water/wastewater, and telecommunications) in the Casco Bay Region of Maine as the focus for one of 10 Regional Resiliency Assessment Program (RRAP) projects conducted nationwide in Fiscal Year 2014. The Casco Bay Region Climate Change Adaptation Planning (Casco Bay) RRAP is the first RRAP in the history of the program to focus on climate change and provide information and methodologies to stakeholders to enable effective regional climate change adaptation planning.

The effort involved a close working relationship between DHS and key partners in State and local government and academia, including Maine Emergency Management Agency; Maine Department of Environmental Protection; Maine Geological Survey at the Department of Agriculture, Conservation and Forestry; University of Maine Climate Change Institute; and the cities of Portland and South Portland. This Assessment Report provides the Key Findings of that effort, along with corresponding Resilience Enhancement Options that these and other partners may consider in their efforts to pursue greater resilience to climate change.

## Assessment Process

A range of stakeholders—response organizations; critical infrastructure owners and operators; and government officials from Federal, State, and local agencies—play distinct roles during the RRAP process by participating in interviews and facilitated discussions. As part of the Casco Bay RRAP, the RRAP team gathered data during workshops with a variety of public and private sector organizations to determine the climate change hazards, vulnerabilities, and interdependencies faced by energy, transportation, water/wastewater, and telecommunications infrastructure in the region.

DHS compiled and analyzed the data and information from the workshops to develop the Key Findings for this RRAP. This Assessment Report communicates these Key Findings and provides Resilience Enhancement Options that could support Federal, State, local, and private sector organizations' efforts to improve the resilience to climate change for infrastructure and lifeline systems.

## Key Findings

The Casco Bay RRAP examined the critical lifeline infrastructure systems (energy, transportation, water/wastewater, and telecommunications) for impacts from projected regional climate change. These include the following impacts:

- Water resource systems may be affected by changes in precipitation patterns, air and sea temperature, and sea level. In addition, storm activity will affect the quantity and quality of water supplies and the infrastructure that connects these supplies to communities.
- Energy systems (electrical power, petroleum, natural gas) are vulnerable to both direct impacts—such as extreme weather, storm surge and sea-level inundation of electrical generation and transmission facilities and petroleum storage—and indirect impacts such as climate-induced changes in energy demand.
- Transportation systems could be affected by extreme weather, storm surge, and sea-level rise, particularly along coastal systems such as rail lines, seaport terminals, ferry terminals, and low-lying roads and causeways.
- Telecommunications are physically vulnerable to increased tropical cyclone activity, which could increase wind loading on cellular and microwave towers; coastal and inland flooding at support facilities; and increasing high-temperature days, which affect electronic equipment. System dependencies on intersecting infrastructure systems—such as electrical power and transportation access—are also significant.

The Casco Bay RRAP identifies three key vulnerabilities that may affect the region’s ability to maintain its energy, transportation, water/wastewater, and telecommunications systems and recover from the impacts of climate change. Casco Bay RRAP stakeholders and partners may consider

### RRAP Participants

Federal Government	DHS Office of Infrastructure Protection, DHS National Cybersecurity and Communications Integration Center/ National Coordinating Center for Communications Federal Emergency Management Agency U.S. Environmental Protection Agency National Oceanic and Atmospheric Administration
State Government	Maine Governor’s Energy Office Maine Department of Environmental Protection Maine Emergency Management Agency Maine Office of Information Technology Maine Office of Geographic Information Systems Maine Department of Transportation Maine Department of Agriculture, Conservation and Forestry Maine Turnpike Authority Maine Port Authority University of Maine, Climate Change Institute University of Southern Maine University of Maine Extension
Regional, County, and City Government	Greater Portland Council of Government Cumberland County Emergency Management Agency City of South Portland City of Portland Portland Water District Town of Saco Water District Town of Brunswick Sewer District Town of Freeport Southern Maine Planning and Development Commission Casco Bay Estuary Partnership Portland Jetport
Private Sector and Not-for-Profit Organizations	Trans-Canada/Portland Natural Gas Transmission System Central Maine Power AT&T Wireless Verizon Wireless St. Lawrence & Atlantic Railroad Global Petroleum Conservation Law Foundation Casco Bay Lines

implementing the associated Resilience Enhancement Options to mitigate the vulnerabilities described in the Key Findings.

- **Institutional barriers and challenges to meeting regulatory requirements are hindering effective adaptation planning.** Critical infrastructure owners and operators either lack, or have not fully developed, climate change adaptation planning strategies. This state of affairs is due, in part, to institutional barriers, such as the lack of a coordinated planning effort to address regional climate change and challenges to meeting regulatory requirements presented by some adaptation actions.
- **Critical infrastructure is vulnerable to climate change impacts.** Coastal critical infrastructure systems are vulnerable to sea level rise and storm surge. For example, coastal electric infrastructure vulnerabilities can lead to local power outages that affect dependent infrastructure systems. Similarly, storm surge can affect low-lying roads, causeways, rail lines, and marine infrastructure, thereby disrupting mobility within the region and the accessibility of important facilities. Other infrastructure vulnerabilities can result from broader systemic impacts such as sea level rise and increased ambient air temperatures. Sea level rise, and resulting increases in coastal aquifer salinity, can significantly degrade drinking water supplies in the region. Temperature increases can increase seasonal electricity demand, while simultaneously reducing power plant and transmission line capacity. This set of circumstances can result in rolling brownouts across the region if the infrastructure systems cannot adapt to the changing climate.
- **Critical dependencies and interdependencies exist that can compound climate change impacts across multiple infrastructure systems.** Workshops conducted as part of this RRAP revealed that the region does not have a comprehensive understanding of infrastructure dependencies and interdependencies, or of the associated cascading effects that could be triggered as a result of disruptions that climate change hazards could cause. This understanding is necessary in order to develop effective adaptation strategies that improve the region's resilience to climate change impacts.

## Conclusion

DHS IP, the State of Maine, and all the stakeholders involved in the Casco Bay RRAP intend for this Assessment Report, along with all associated documents and data, to provide valuable information on addressing the vulnerabilities associated with climate change impacts to the region's energy, transportation, water/wastewater, and telecommunications infrastructure systems. Public- and private-sector stakeholders can cooperatively implement the Resilience Enhancement Options identified in the report to mitigate these vulnerabilities. The Resilience Enhancement Options also provide the opportunity to build partnerships between the energy, transportation, water/wastewater, and telecommunications industries and the Federal, State, and local emergency management organizations responsible for providing support to those systems during times of crisis.

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# Introduction

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The U.S. Department of Homeland Security (DHS), National Protection and Programs Directorate's Office of Infrastructure Protection (IP), and the State of Maine identified the Casco Bay Region as an appropriate subject for one of the 10 Regional Resiliency Assessment Program (RRAP) projects conducted nationwide in Fiscal Year (FY) 2014.

The Casco Bay RRAP is the first RRAP to focus specifically on adaptation planning and strategies to mitigate the threats from climate change and the impacts of climate change on critical infrastructure systems. Across the globe, changes in the earth's climate have been observed for decades, including rising sea levels, decreases in polar ice, and increasing average sea and air temperatures. Impacts from climate change are already occurring in Maine, as evidenced by sea level rise, and by increasingly frequent and intense storm events; shorter, warmer winters; and longer, hotter summers. Regional climate model downscaling<sup>1</sup> efforts indicate that these changes are expected to continue into the future.<sup>2,3</sup> Such changes will have implications for lifeline infrastructure systems, in both the near and long term; this will ultimately affect the safety, economic prosperity, and quality of life of Maine residents.

The Casco Bay RRAP is aligned with numerous recently enacted, national-level climate change actions, which are described below.

The **President's Climate Action Plan** (June 2013)<sup>4</sup> lays out the steps that the Administration will take to address climate change. One of the key pillars of the President's plan is to reduce carbon pollution and promote clean sources of energy to protect public health (especially for children), create jobs, and lower home energy bills. Another pillar aims to prepare the United States for the impacts of climate change that are already being felt across the country. This effort includes providing support so that State and local government entities can strengthen U.S. roads, bridges, and shorelines to better protect people's homes, businesses, and ways of life from severe weather. The plan consists of a wide variety of executive actions, the first of which (Executive Order 13653—Preparing the United States for

## Resilience

The critical infrastructure mission has evolved in recent years from focusing primarily on protective security, to including a greater emphasis on resilience, to consideration of disruptive events. Resilience, as defined by Presidential Policy Directive-8 (PPD-8), National Preparedness, is "the ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies." PPD-21, Critical Infrastructure Security and Resilience, directed the Federal Government to work with critical infrastructure owners and operators and State, local, tribal, and territorial partners to strengthen the security and resilience of its critical infrastructure against both physical and cyber threats.

National priorities, mission partner requirements, scholarship, and experience have highlighted the need to build a more resilient Nation through strengthening disaster preparedness, mitigation, response, and recovery capabilities. The RRAP was developed to help address this critical need.

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<sup>1</sup> Downscaling is an analytical "method that derives local to regional scale (10 to 100 km) [climate] information from larger scale [climate] models or data analyses." Intergovernmental Panel on Climate Change (IPCC), 2013a, "Annex III: Glossary," S. Planton, ed., *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley, eds., Cambridge University Press, Cambridge, United Kingdom and New York, N.Y.

<sup>2</sup> Wang, J. and Kotamarthi, V. R., 2015, "High-resolution Dynamically Downscaled Projections of Precipitation in the Mid and Late 21st Century over North America. Earth's Future," Accepted Author Manuscript. doi:10.1002/2015EF000304.

<sup>3</sup> Walsh, J., and Wuebbles, D., 2014, *Climate Change Impacts in the United States: The Third National Climate Assessment*, U.S. Global Change Research Program, <http://nca2014.globalchange.gov/downloads>, accessed July 30, 2015..

<sup>4</sup> The White House, 2013a, *The President's Climate Action Plan*, June, <https://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf>, accessed July 31, 2015.

the Impacts of Climate Change<sup>5</sup>) established a Task Force on Climate Preparedness and Resilience to advise the Administration on how the Federal Government can respond to the needs of communities that are dealing with the impacts of climate change. In November 2014, Task Force members presented their recommendations to the Administration.<sup>6</sup> The recommendations offer guidance on how the Federal Government should modernize programs and policies to incorporate climate change; incentivize and remove barriers to community resilience; and provide useful, actionable information and tools.<sup>7</sup>

Delivering on a commitment in the President's Climate Action Plan, the Administration launched the **Climate Data Initiative** (March 2014)<sup>8</sup> as a broad effort to leverage the Federal Government's extensive, freely available, and climate-relevant data resources to stimulate innovation and private-sector entrepreneurship in support of national climate-change preparedness. Data include previously hard-to-access information in areas such as health, energy, education, public safety, and global development.<sup>9</sup> This initiative brings together extensive open-government data with design competitions and leverages commitments from the private and philanthropic sectors to develop data-driven planning and resilience tools for local communities. This effort will help give communities across the United States the information and tools they need to better understand and manage the risks associated with climate change and plan for current and future climate impacts.

The **U.S. National Climate Assessment** (NCA) (May 2014) is considered the most authoritative and comprehensive source of scientific information ever generated about climate-change impacts in the United States.<sup>10</sup> The third NCA report<sup>11</sup> assesses and summarizes the science of climate change and its impacts on the Nation, both now and in the future. It documents climate-change-related impacts and responses for various sectors and geographic regions, with the goal of better informing public and private decisionmaking on climate preparedness and response. Report findings indicate that climate change is already having important impacts across all U.S. regions and key sectors of the national economy.

In response to the President's Climate Action Plan and Executive Order (E.O.) 13653, the White House launched the **Climate Resilience Toolkit** (November 2014)<sup>12</sup> to provide centralized, authoritative, and easy-to-use scientific tools, information, expertise, and best practices to help the Nation prepare for climate-related changes and impacts, manage climate-related risks and opportunities, and improve resilience to the impacts of climate change (e.g., extreme events). The online portal offers a wide range of

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<sup>5</sup> The White House, 2013b, Executive Order 13653, *Preparing the United States for the Impacts of Climate Change*, <http://www.gpo.gov/fdsys/pkg/FR-2013-11-06/pdf/2013-26785.pdf>, accessed July 31, 2015.

<sup>6</sup> The White House, 2014a, *Fact Sheet: Recommendations of the President's State, Local and Tribal Leaders Task Force on Climate Preparedness and Resilience and New Executive Actions*, November 17, [http://www.whitehouse.gov/administration/eop/ceq/Press\\_Releases/November\\_17\\_2014](http://www.whitehouse.gov/administration/eop/ceq/Press_Releases/November_17_2014), accessed February 16, 2015.

<sup>7</sup> The White House, 2013c, *State, Local, and Tribal Leaders Task Force on Climate Preparedness and Resilience*, November 1, <http://www.whitehouse.gov/administration/eop/ceq/initiatives/resilience/taskforce>, accessed February 16, 2015.

<sup>8</sup> The White House, 2014b, *Fact Sheet: The President's Climate Data Initiative: Empowering America's Communities to Prepare for the Effects of Climate Change*, March 19, <http://www.whitehouse.gov/the-press-office/2014/03/19/fact-sheet-president-s-climate-data-initiative-empowering-america-s-comm>, accessed February 16, 2015.

<sup>9</sup> Podesta, J., 2014, *Climate Data Initiative Launches with Strong Public and Private Sector Commitments*, The White House Blog, March 19, <http://www.whitehouse.gov/blog/2014/03/19/climate-data-initiative-launches-strong-public-and-private-sector-commitments>, accessed February 16, 2015.

<sup>10</sup> The White House, 2015a, *Preparing for the Impacts of Climate Change: Assess the Impacts of Climate Change*, <http://www.whitehouse.gov/energy/climate-change>, accessed February 16, 2015.

<sup>11</sup> Melillo, J.M., T.C. Richmond, and G.W. Yohe, eds., 2014, *Climate Change Impacts in the United States: The Third National Climate Assessment*, U.S. Global Change Research Program, <http://nca2014.globalchange.gov/downloads>, accessed February 16, 2015.

<sup>12</sup> NOAA (National Oceanic and Atmospheric Administration), 2014, *U.S. Climate Resilience Toolkit*, November 17, <http://toolkit.climate.gov>, accessed February 16, 2015.

resources and interactive tools that are designed to serve interested citizens, communities, businesses, resource managers, planners, and policy leaders at all levels of government.

In December of 2014, the Council on Environmental Quality (CEQ) issued a revised draft **Guidance for Greenhouse Gas Emissions and Climate Change Impacts**<sup>13</sup> for public comment that describes when and how all Federal departments and agencies should consider the effects of greenhouse gas (GHG) emissions and climate change in their National Environmental Policy Act (NEPA) reviews. The 2014 revised draft guidance supersedes the earlier 2010 draft<sup>14</sup> and reflects CEQ's consideration of comments received on the 2010 draft, in addition to input received from other Federal agencies and affected stakeholders.<sup>15</sup> This guidance explains that agencies should consider both the potential effects of a proposed action on climate change, as indicated by its estimated GHG emissions, and the implications of climate change for the environmental effects of a proposed action. The guidance also emphasizes that agency analyses should be commensurate with projected GHG emissions and climate impacts, and should employ appropriate quantitative or qualitative analytical methods to help ensure that useful information is available to inform the public and decisionmaking processes in distinguishing between alternatives and mitigations.

To further the President's Climate Action Plan, **E.O. 13690– Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input**<sup>16</sup> (which amends the existing E.O. 11988 on Floodplain Management, 1977), issued in January 2015, establishes the flood level to which all new and rebuilt federally funded structures or facilities must be resilient, in order to protect communities and Federal investments. In implementing the standard, agencies will have the flexibility to select one of three approaches for establishing the flood elevation and hazard area they use in siting, design, and construction: (1) applying a climate-informed scientific approach that utilizes best available, actionable data and methods that integrate current and future changes in flooding; (2) adding 2–3 feet of elevation to the 100-year (or 1 percent-annual-chance) flood elevation; or (3) using the 500-year (or 0.2 percent-annual-chance) flood elevation. To carry out this process, the Federal Emergency Management Agency (FEMA) simultaneously published the draft **Revised Guidelines for Implementing Executive Order 11988, Floodplain Management**,<sup>17</sup> which, in part, emphasizes integration with NEPA, for public review.<sup>18</sup>

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<sup>13</sup> CEQ (Council on Environmental Quality), 2014, *Revised Draft Guidance for Greenhouse Gas Emissions and Climate Change Impacts*, Executive Office of the President, December 18, [http://www.whitehouse.gov/sites/default/files/docs/nepa\\_revised\\_draft\\_ghg\\_guidance.pdf](http://www.whitehouse.gov/sites/default/files/docs/nepa_revised_draft_ghg_guidance.pdf), accessed January 20, 2015.

<sup>14</sup> CEQ, 2010, *Draft NEPA Guidance on Consideration of the Effects of Climate Change and Greenhouse Gas Emissions*, Executive Office of the President, February 18, <http://www.whitehouse.gov/sites/default/files/microsites/ceq/20100218-nepa-consideration-effects-ghg-draft-guidance.pdf>, accessed January 20, 2015.

<sup>15</sup> The White House, undated, *Council on Environmental Quality*, <http://www.whitehouse.gov/administration/eop/ceq/initiatives/nepa/ghg-guidance>, accessed January 20, 2015.

<sup>16</sup> The White House, 2015b, *Executive Order 13690 – Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input*, January 30, <http://www.whitehouse.gov/the-press-office/2015/01/30/executive-order-establishing-federal-flood-risk-management-standard-and->, accessed February 16, 2015.

<sup>17</sup> FEMA, 2015, *Revised Guidelines for Implementing Executive Order 11988, Floodplain Management*, Draft for Public Comment, January 28, <http://www.energy.gov/sites/prod/files/2015/02/f19/DraftRevisedImplementingGuidelines.pdf>, accessed February 16, 2015.

<sup>18</sup> DOE (U.S. Department of Energy), 2015, *New Executive Order Establishes a Federal Flood Risk Management Standard*, February 5, <http://www.energy.gov/nepa/articles/new-executive-order-establishes-federal-flood-risk-management-standard>, accessed February 16, 2015.

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# Project Overview

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## Goals and Objectives

The primary goal of the Casco Bay RRAP is to provide State and local government officials with an analysis that they can act upon to strengthen climate change adaptation<sup>19</sup> efforts, specifically as they relate to the dependencies and interdependencies of the energy, transportation, water/wastewater, and telecommunications infrastructure serving the region. To accomplish this goal, four focused objectives were established:

- Identify gaps in the understanding of regional or sector-specific issues related to climate change impacts on critical infrastructure.
- Provide resources, including climate change impact projections, and develop methodologies to help regional stakeholders better understand and manage the risks associated with extreme weather and other impacts of climate change.
- Conduct local data collection activities, such as open-source research, subject matter expert interviews, and facilitated discussion workshops to fill identified data requirements.
- Provide technical assistance to decision makers and communities within the region to assist in the development of climate change adaptation plans and strategies, which can be used to prepare for, respond to, and recover from impacts.

DHS set out to accomplish these objectives through facilitated discussions, modeling, analysis, and scientific research designed to evaluate the regional vulnerabilities, estimate the potential impacts from climate change hazards (with specific focus on the dependencies and interdependencies of infrastructure systems), and identify adaptation measures. This approach builds upon the structure and process of the risk-based framework outlined by the United Nations Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (AR5), and it aligns with the Principles for Effective Adaptation that have been identified by the IPCC to foster broader resilience to climate change. These principles stress that adaptation is most effective when it is place- and context-specific, and when the process fully recognizes the diversity of approaches taken by various intersecting organizations, sectors, and communities. Employing such a place- and context-specific approach (1) requires that those involved in the planning recognize the diverse perceptions of risk, approaches to decisionmaking, and compounding influences on adaptation; and (2) underscores the importance of coordination among interagency adaptation plans. The 10 Principles for Effective Adaptation are as follows:

1. Adaptation is place- and context-specific, with no single approach for reducing risks appropriate across all settings.

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<sup>19</sup> Adaptation is “the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.” IPCC, 2013b, “Annex II: Glossary,” J. Agard and E.L.F. Schipper, eds., *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, C.B. Field., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White, eds., Cambridge University Press, Cambridge, United Kingdom and New York, N.Y.

2. Adaptation planning and implementation can be enhanced through complementary actions across levels, from individuals to governments.
3. A first step toward adapting to future climate change is reducing vulnerability and exposure to present climate variability.
4. Adaptation planning and implementation at all levels of governance are contingent on societal values, objectives, and risk perceptions. Recognition of diverse interests, circumstances, social-cultural contexts, and expectations can benefit decisionmaking processes.
5. Decision support is most effective when it is sensitive to context and the diversity of decision types, decision processes, and constituencies.
6. Existing and emerging economic instruments can foster adaptation by providing incentives for anticipating and reducing impacts.
7. Constraints (e.g., limited financial and human resources, governance coordination, impact uncertainty, differing perceptions of risks, competing values, absence of adaptation advocates and leaders, limited tools to monitor and measure adaptation effectiveness) can interact to impede adaptation planning and implementation.
8. Poor planning, overemphasizing short-term outcomes, or failing to anticipate consequences sufficiently can result in maladaptation.
9. Limited evidence indicates a gap between global adaptation needs and the funds available for adaptation.
10. Significant co-benefits, synergies, and tradeoffs exist between mitigation and adaptation and among different adaptation responses; interactions occur both within and across regions.<sup>20</sup>

## Hazard Considerations

Hazards related to climate change in the Casco Bay Region are expected to include changes in air and water temperature, precipitation, sea level, and tropical and winter storms. The impacts associated with these hazards do not occur in isolation but frequently interact with and compound one another. For example, higher sea levels can contribute to more pronounced impacts from storm surge. This section presents a summary of the observed historical changes to key climate-related hazards in the northeastern United States that may affect critical infrastructure systems. Both global and regional climate change projection efforts suggest that these historical changes will continue in the future;<sup>21</sup> projections relevant specifically to the Casco Bay Region are presented later in this report.

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<sup>20</sup> IPCC WGII (Intergovernmental Panel on Climate Change Working Group II), 2014, *AR5 Summary for Policymakers*, March 31, [https://ipcc-wg2.gov/AR5/images/uploads/IPCC\\_WG2AR5\\_SPM\\_Approved.pdf](https://ipcc-wg2.gov/AR5/images/uploads/IPCC_WG2AR5_SPM_Approved.pdf), accessed February 15, 2015.

<sup>21</sup> Horton, R., G. Yohe, W. Easterling, R. Kates, M. Ruth, E. Sussman, A. Whelchel, D. Wolfe, and F. Lipschultz, 2014, "Ch. 16: Northeast," *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, eds., U.S. Global Change Research Program, <http://nca2014.globalchange.gov/report/regions/northeast>, accessed February 20, 2015.

## Temperature

In comparison to other locations in the United States, the State of Maine is uniquely located between powerful streams of cold and warm air arriving from the Arctic and the Gulf of Maine (respectively), both of which are warming rapidly and thus leading to stronger climate fluctuations within the region.<sup>22</sup> This regional warming in Maine is symptomatic of the widespread increases in average annual air temperature that have been observed across the United States. The U.S. Global Change Research Program (USGCRP) notes that “the period from 2001 to 2012 was warmer than any previous decade in every region.”<sup>23</sup> These observed increases are particularly pronounced in the northeastern United States, where average annual temperatures have increased up to 2° Fahrenheit (F) during the 20th century.<sup>24</sup> The map in Figure 1 illustrates the temperature difference between the 1991–2012 average and that from 1901–1960. Although this trend shows some variability across the region, Maine is uniformly associated with the highest-magnitude temperature change observed in the region. The inset bar graph in Figure 1 displays the decadal trend of these changes, with a distinct warming trend observed toward the end of the 20th century. These warming trends can have adverse impacts on physical infrastructure systems, as well as operational and maintenance activities. For example, higher temperatures lead to an increased demand for cooling at power plants, while simultaneously reducing the transmission capacity of power lines. This set of demand conditions is particularly problematic as residential and commercial demand for air-conditioning (and therefore, electrical power) also typically increases coincident with higher temperature.

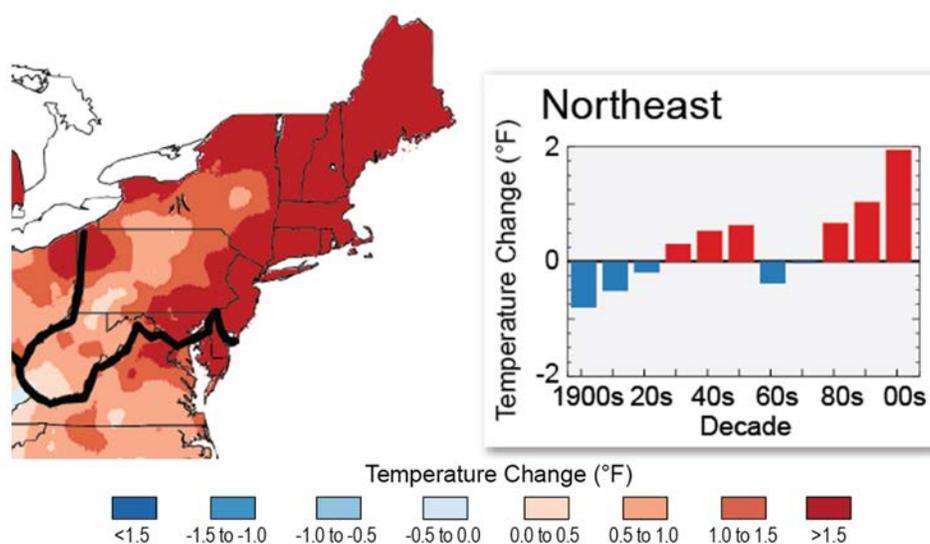


Figure 1 Changes in Average Temperature in the Northeast<sup>25</sup>

<sup>22</sup> Abel, D., 2014, “In Maine, Scientists See Signs of Climate Change,” *The Boston Globe*, September 14, <http://www.bostonglobe.com/metro/2014/09/20/maine-climate-change-taking-toll/P41vVDd9v3knTUeDH2U6SP/story.html>, accessed February 16, 2015.

<sup>23</sup> Observed U.S. Temperature Change, <http://www.globalchange.gov/browse/multimedia/observed-us-temperature-change>, accessed February 20, 2015.

<sup>24</sup> Ibid.

<sup>25</sup> Adapted from: Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville, 2014, “Ch. 2: Our Changing Climate,” *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, eds., U.S. Global Change, [http://s3.amazonaws.com/nca2014/low/NCA3\\_Full\\_Report\\_02\\_Our\\_Changing\\_Climate\\_LowRes.pdf?download=1](http://s3.amazonaws.com/nca2014/low/NCA3_Full_Report_02_Our_Changing_Climate_LowRes.pdf?download=1), accessed May 27, 2015.

## Precipitation

Over the course of the 20th century, increases in the average annual precipitation (inches per year) in the United States have been observed, with the Northeast experiencing an average increase of 8 percent. However, the observed changes in precipitation are highly variable across the region. Figure 2, which illustrates the average precipitation change from 1901–1960 to 1991–2012, reveals that some areas of the northeastern United States have experienced an increase in average precipitation in excess of 15 percent. Perhaps more notable are several additional trends that have been observed in overall precipitation patterns of the United States (including the Northeast). The first is that precipitation is becoming increasingly seasonal, with progressively wetter winters and gradually drier summers. This change in seasonality, coupled with the trend of increasing average annual precipitation amounts, translates to distinct increases in heavy precipitation volumes observed across the continental United States, with the most pronounced increases in the Northeast. As shown in Figure 3, between 1958 and 2012 the Northeast has experienced a 71 percent increase “in the amount of precipitation falling in [...] the heaviest 1 percent of all daily events,” meaning that the intensity of annual storm activity (i.e., non-hurricane, heavy-precipitation events) has increased significantly in fewer than six decades.<sup>26</sup>

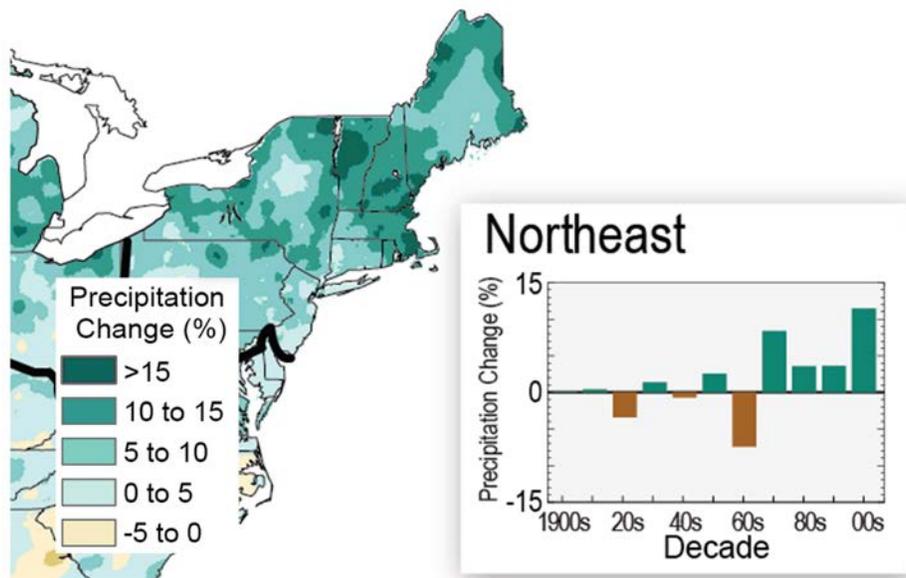


Figure 2 Changes in Average Precipitation in the Northeast<sup>27</sup>

<sup>26</sup> Observed Change in Very Heavy Precipitation, <http://nca2014.globalchange.gov/report/our-changing-climate/heavy-downpours-increasing#graphic-16693>, accessed May 23, 2015.

<sup>27</sup> Adapted from: Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville, 2014, “Ch. 2: Our Changing Climate,” *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, eds., U.S. Global Change, [http://s3.amazonaws.com/nca2014/low/NCA3\\_Full\\_Report\\_02\\_Our\\_Changing\\_Climate\\_LowRes.pdf?download=1](http://s3.amazonaws.com/nca2014/low/NCA3_Full_Report_02_Our_Changing_Climate_LowRes.pdf?download=1), accessed May 27, 2015.

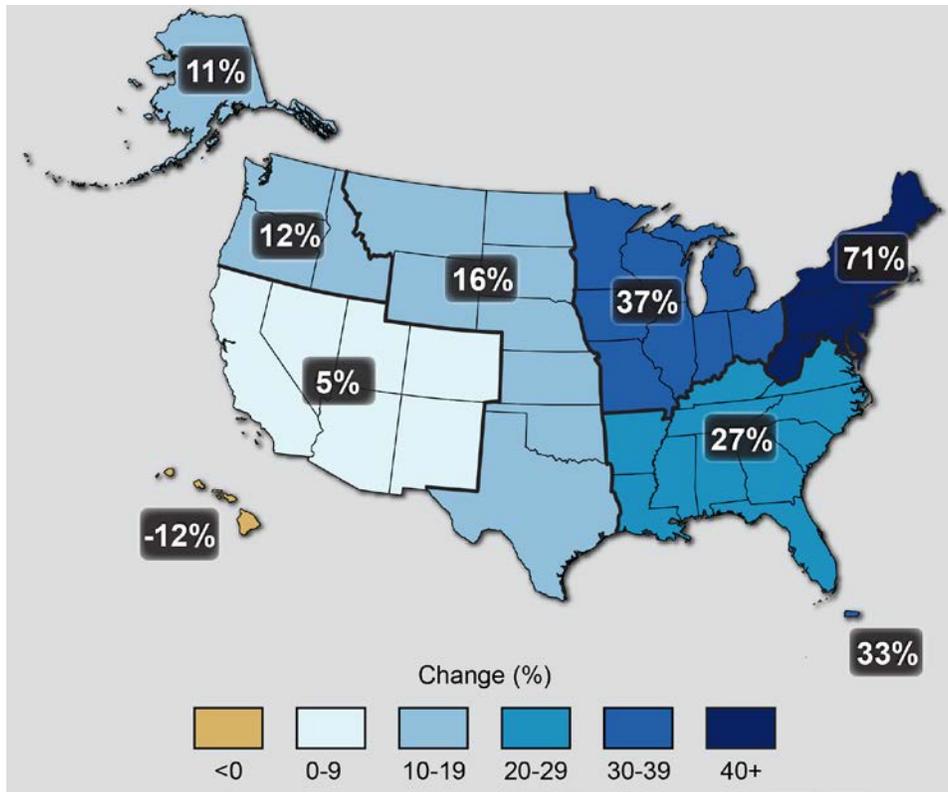


Figure 3 Observed Changes in Very Heavy Precipitation<sup>28</sup>

Changes in both average and heavy precipitation can have significant impacts on critical infrastructure systems. Increases in both average and heavy precipitation lead to more surface runoff, which places greater stress on stormwater drainage systems and roadway culverts, as well as greater scouring and degradation of bridge support piers. When the capacity of drainage systems is exceeded, widespread flooding can damage infrastructure and lead to broader disruptions in operations. For example, disruptions in the transportation sector can significantly limit mobility and potentially cut off access to important life-safety facilities, such as hospitals and emergency services.

### Sea Level Rise and Storms

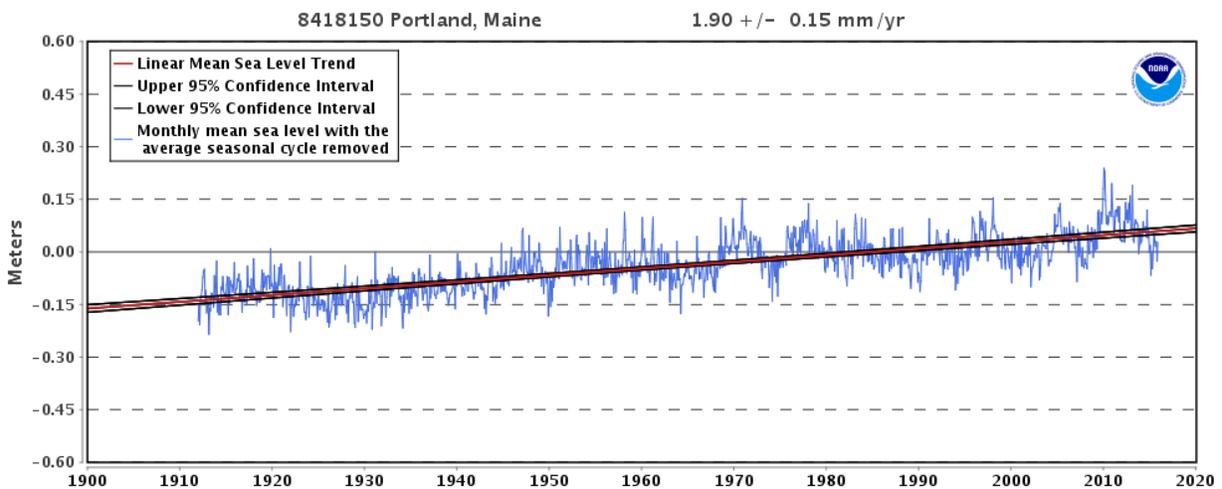
Sea level rise along the northeastern coast of the United States “exceeds the global average of approximately 8 inches,” as a result of additional land subsidence in the region.<sup>29</sup> Figure 4 shows sea level rise trends in Portland, Maine, which has seen an equivalent increase in sea level rise of 0.62 feet between 1912 and 2014. In addition to long-term rise in sea levels, abrupt sea level changes could have significant impacts in Maine. For example, between 2009 and 2010, sea levels along the northeast coastline were on average approximately 4 inches higher than historical rates of sea level rise would have projected; for

<sup>28</sup> Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville, 2014, “Ch. 2: Our Changing Climate,” *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, eds., U.S. Global Change, [http://s3.amazonaws.com/nca2014/low/NCA3\\_Full\\_Report\\_02\\_Our\\_Changing\\_Climate\\_LowRes.pdf?download=1](http://s3.amazonaws.com/nca2014/low/NCA3_Full_Report_02_Our_Changing_Climate_LowRes.pdf?download=1), accessed May 27, 2015.

<sup>29</sup> National Climate Assessment: Northeast, <http://nca2014.globalchange.gov/report/regions/northeast#narrative-page-16957>, accessed May 23, 2015.

2009, the rate of sea level rise in Portland, Maine increased to approximately 2.5 inches/year, as compared to a historic regional trend of approximately 0.57 inches/year.<sup>30</sup>

While sea level rise can affect coastal infrastructure systems through an increased risk of tidal flooding, it can also exacerbate storm-related flooding. This factor is particularly important as both the power and force of hurricanes have intensified in the Northern Atlantic over the last 30 years. This is depicted in Figure 5, which displays the trends in the power dissipation index (PDI) for North Atlantic hurricanes. The PDI is “an aggregate of storm intensity, frequency, and duration and provides a measure of total hurricane power over a hurricane season.”<sup>31</sup> The effects of sea level rise and the compounding effects on storm surge can have profound impacts on coastal infrastructure. As a prime example, Hurricane Sandy flooded the 14th Street electrical substation in downtown Manhattan, which disrupted power to 250,000 people; Public Service Electric and Gas Company had to cut off service to 500,000 customers because of flooding in a handful of substations, affecting residents in Newark and Jersey City, New Jersey.<sup>32</sup>



<sup>30</sup> Goddard, P.B., J. Yin, S.M., Griffies, and S. Zhang, 2015, “An extreme event of sea-level rise along the Northeast coast of North America in 2009-2010,” *Nature Communications*, <http://www.nature.com/ncomms/2015/150224/ncomms7346/full/ncomms7346.html>, accessed February 23, 2016.

<sup>31</sup> Ibid.

<sup>32</sup> Hurricane Sandy utility outages may be worsened by underinvestment, lack of planning. See *Huff Post Green*, 2012, “Hurricane Sandy Utility Outages May be Worsened by Underinvestment, Lack of Planning,” updated November 2, [http://www.huffingtonpost.com/2012/11/01/hurricane-sandy-utility-outages\\_n\\_2053120.html](http://www.huffingtonpost.com/2012/11/01/hurricane-sandy-utility-outages_n_2053120.html), accessed February 20, 2015.

<sup>33</sup> U.S. Department of Commerce, 2013, Mean Sea Level Trend, 8418150 Portland, ME, NOAA, October 15, [http://tidesandcurrents.noaa.gov/sltrends/sltrends\\_station.shtml?stnid=8418150](http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8418150), accessed February 9, 2016.

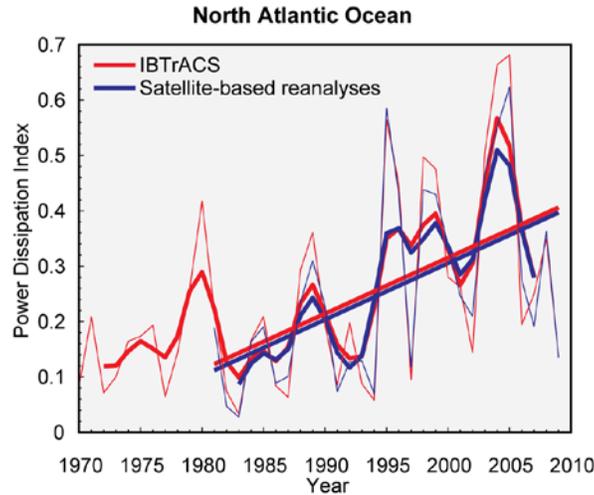


Figure 5 Changes in Hurricane Power Dissipation Index in the North Atlantic<sup>34</sup>

It is also a broadly understood principle that the intensity of tropical cyclones and hurricanes is closely correlated with the sea's surface temperature. Global studies have attempted to quantify this effect in the context of climate change, suggesting that storms' core precipitation rates will increase globally between 6 and 18 percent for every 1° Celsius increase in tropical sea surface temperature.<sup>35</sup> It is therefore notable that the Gulf of Maine is warming at a rate that is faster than 99 percent of the world's oceans.<sup>36</sup>

A 2014 study from National Oceanic and Atmospheric Administration (NOAA) found that “nuisance” flooding has increased between 300 and 925 percent on U.S. coasts since the 1960s.<sup>37</sup> The report, *Sea Level Rise and Nuisance Flood Frequency Changes around the United States*, identified the highest increases in flooding frequency along the East Coast. Nuisance flooding now occurs with high tides in many locations because of climate-related sea level rise, land subsidence, and the loss of natural barriers,

<sup>34</sup> Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville, 2014, “Ch. 2: Our Changing Climate,” *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, eds., U.S. Global Change, [http://s3.amazonaws.com/nca2014/low/NCA3\\_Full\\_Report\\_02\\_Our\\_Changing\\_Climate\\_LowRes.pdf?download=1](http://s3.amazonaws.com/nca2014/low/NCA3_Full_Report_02_Our_Changing_Climate_LowRes.pdf?download=1), accessed May 27, 2015.

<sup>35</sup> Gutowski, W. J., et al., 2008, “Causes of Observed Changes in Extremes and Projections of Future Changes,” *Weather and Climate Extremes in a Changing Climate Regional Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands*, T.R. Karl, G.A. Meehl, C.D. Miller, S.J. Hassol, A.M. Waple, and W.L. Murray, eds., U.S. Climate Change Science Program, Washington, D.C.

<sup>36</sup> Whittle, P., 2014, “Gulf of Maine Warming Faster than Most Bodies of Saltwater, Research Finds,” *Portland Press Herald*, September 3, <http://www.pressherald.com/2014/09/03/gulf-of-maine-is-warming-faster-than-99-of-worlds-oceans-say-scientists>, accessed February 20, 2015.

<sup>37</sup> Phillips, A., 2014, “Tidal ‘Nuisance Flooding’ On the Rise in Coastal Cities as Sea Level Inches Upward,” *Climate Progress*, July 28, <http://thinkprogress.org/climate/2014/07/28/3464877/tidal-nuisance-flooding-on-the-rise-noaa-east-coast>, accessed May 14, 2015. Also: Sweet, W., J. Park, J. Marra, C. Zervas, and S. Gill, 2014, *Sea Level Rise and Nuisance Flood Frequency Changes around the United States*, NOAA, U.S. Department of Commerce, National Ocean Service Center for Operational Oceanographic Products and Services NOAA Technical Report NOS CO-OPS 073, June, [http://tidesandcurrents.noaa.gov/publications/NOAA\\_Technical\\_Report\\_NOS\\_COOPS\\_073.pdf](http://tidesandcurrents.noaa.gov/publications/NOAA_Technical_Report_NOS_COOPS_073.pdf), accessed June 1, 2015.

causing inconveniences such as road closures and overwhelming stormwater drainage systems.<sup>38</sup> Future sea level rise will further intensify nuisance flooding impacts and increase flooding frequency.<sup>39</sup>

## Regional Resiliency Assessment Program Activities

The Casco Bay RRAP examines the energy, transportation, water/wastewater, and telecommunications infrastructure systems and operations that support the Casco Bay Region and evaluates planning and preparation to assess the region's overall resilience to climate change hazards. It also evaluates the regional infrastructure systems and operations that depend on and are interdependent with these systems.

### Stakeholders and Outreach

Successful completion of the Casco Bay RRAP analysis phase required the coordinated involvement of numerous partners from Federal, State, and local government, as well as private-sector organizations. Participants in Casco Bay RRAP data collection activities are identified in Appendix A.

### Climate Change Adaptation Workshops

To engage infrastructure stakeholders in the public and private sector, DHS conducted a series of four facilitated climate change adaptation workshops. Each workshop focused on one of the four infrastructure sectors that support lifeline systems: energy, transportation, water/wastewater, and telecommunications. These workshops posed a series of five focus questions for discussion to stakeholders from each sector (see Appendix A for a complete list of stakeholders). The five questions asked of the stakeholders in the workshop discussions are as follows:

1. Are there critical nodes in the lifeline functions of your organization that could be affected by climate change?
2. Are there critical dependencies or interdependencies that could be affected by the projected impacts of climate change?
3. Does your organization have existing climate change adaptation plans or strategies?
4. What are the barriers that prevent active and effective adaptation planning in your organization?
5. What does your organization need to move forward with its adaptation planning efforts?

A final capstone workshop was held to present a summary of the four lifeline infrastructure system workshops, preliminary modeling, and analyses. The workshops resulted in several Key Findings that offer significant insight into the current state of planning for climate change adaptation across the critical infrastructure organizations in the Casco Bay Region.

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<sup>38</sup> NOAA, undated, "What is Nuisance Flooding?," <http://oceanservice.noaa.gov/facts/nuisance-flooding.html>, accessed May 14, 2015.

<sup>39</sup> Ibid.

## Resiliency Assessment and Implementation Phase Activities

DHS compiled and analyzed the data and information collected from the workshops, expert research, and modeling efforts to develop this Assessment Report. The assessment communicates the Key Findings and provides the partner agencies with Resilience Enhancement Options to address gaps in State- and local-level resources and operational procedures that can help to improve the overall climate resilience of critical infrastructure in the Casco Bay Region.

In the year following delivery of this Assessment Report, DHS will be available to provide technical assistance to Federal, State, and local officials; private industry; and other stakeholders to assist them in the implementation of select Resilience Enhancement Options.

The RRAP and its implementation phase activities serve to foster stronger relationships among RRAP participants. The implementation phase consists of the four tasks listed below, which will be undertaken in coordination with regional stakeholders and in response to needs identified throughout RRAP workshops and analysis activities. The products resulting from these tasks will be shared through key regional partners, including the University of Maine Climate Change Institute, Maine Geological Survey, and the Maine Department of Transportation (MaineDOT).

### 1. Regional Climate Data Modeling and Distribution

This task, conducted in partnership between climate scientists at Argonne National Laboratory (Argonne) and the University of Maine, makes the downscaled climate modeling data used in this RRAP available to project stakeholders and the public for use in broader adaptation planning and preparedness applications. Climate modeling activities conducted at Argonne will first be discussed with RRAP stakeholders to identify any necessary modifications to address regional needs. The updated regional climate dataset will then be transferred to the Climate Adaptation and Sustainability Climate Reanalyzer platform, hosted by the University of Maine's Climate Change Institute. The Climate Reanalyzer is an open, online data portal that will be used to make the region-specific climate projection data available to the public. The data hosted on this public portal will be accompanied by a user guide to provide decision makers with (1) a critical overview of relevant downscaling models, methodologies, and data; (2) the advantages and disadvantages of each method; (3) geographical dependence of bias for each method (e.g., systematic under- or over-prediction of climate impacts); and (4) uncertainties associated with the downscaling process and climate data in general.

### 2. Radar-Based Rainfall Data

A deeper understanding of historical rainfall trends across the Casco Bay Region is an important foundation for activities aimed at modeling region- and location-specific rainfall-related impacts under climate change. This task uses historical weather radar data to provide a higher-resolution geospatial record of rainfall trends than is available from the current point-based system of recording rainfall from individual gauge stations. High-resolution, spatial rainfall data can be used in a wide range of applications, from developing new hydrologic models that provide a better representation of runoff, to integration into regional climate modeling for better projections of location-specific changes in key climate conditions.

### 3. Climate-Based Regional Rainfall and Runoff Intensity-Duration-Frequency (IDF) Curves

Intensity-duration-frequency (IDF) curves are tools used in location-specific hydrological analyses that describe extreme rainfall events in comparison to historical record. They translate rainfall events into surface water runoff volumes for use by engineers, scientists, and planners in infrastructure design and management. However, because traditional IDF curves use historical rainfall data, they cannot account for future climate and may lead to inadequate design. This

implementation task develops “next generation” IDF curves for the Casco Bay Region using data from the regional climate modeling activities (Implementation Task 1) and radar-based rainfall data activities (Implementation Task 2) to account for future climatic conditions. This involves developing historical rainfall and runoff IDF curves for the Casco Bay watershed and calibrating those curves using projected climate.

#### **4. Storm Surge Infrastructure Risk Analysis**

This task utilizes storm surge inundation scenarios to develop a risk-based prioritization of critical infrastructure assets in the coastal areas of Portland and South Portland. The risk analysis will inform planning and design strategies to protect critical infrastructure against the threat of long-term sea level rise and storm surges. A report will document the risk assessment methodology and data protocols; in addition, a KMZ file will be provided to display results using Google Earth and GIS software.

# Operating Environment

## Regional Overview

Casco Bay is an inlet of the Gulf of Maine located along Maine’s southeastern coastline. The Casco Bay Region is the inland area along this coastline, roughly defined by the 986-square-mile watershed covering Cumberland County and neighboring areas (Figure 6). The area encompasses more than a dozen communities and 41 municipalities (including Portland, South Portland, Saco, and Brunswick). While it contains only about 3 percent of Maine’s total geographic land area, approximately one-quarter of the population of Maine lives within the Casco Bay Region watershed.

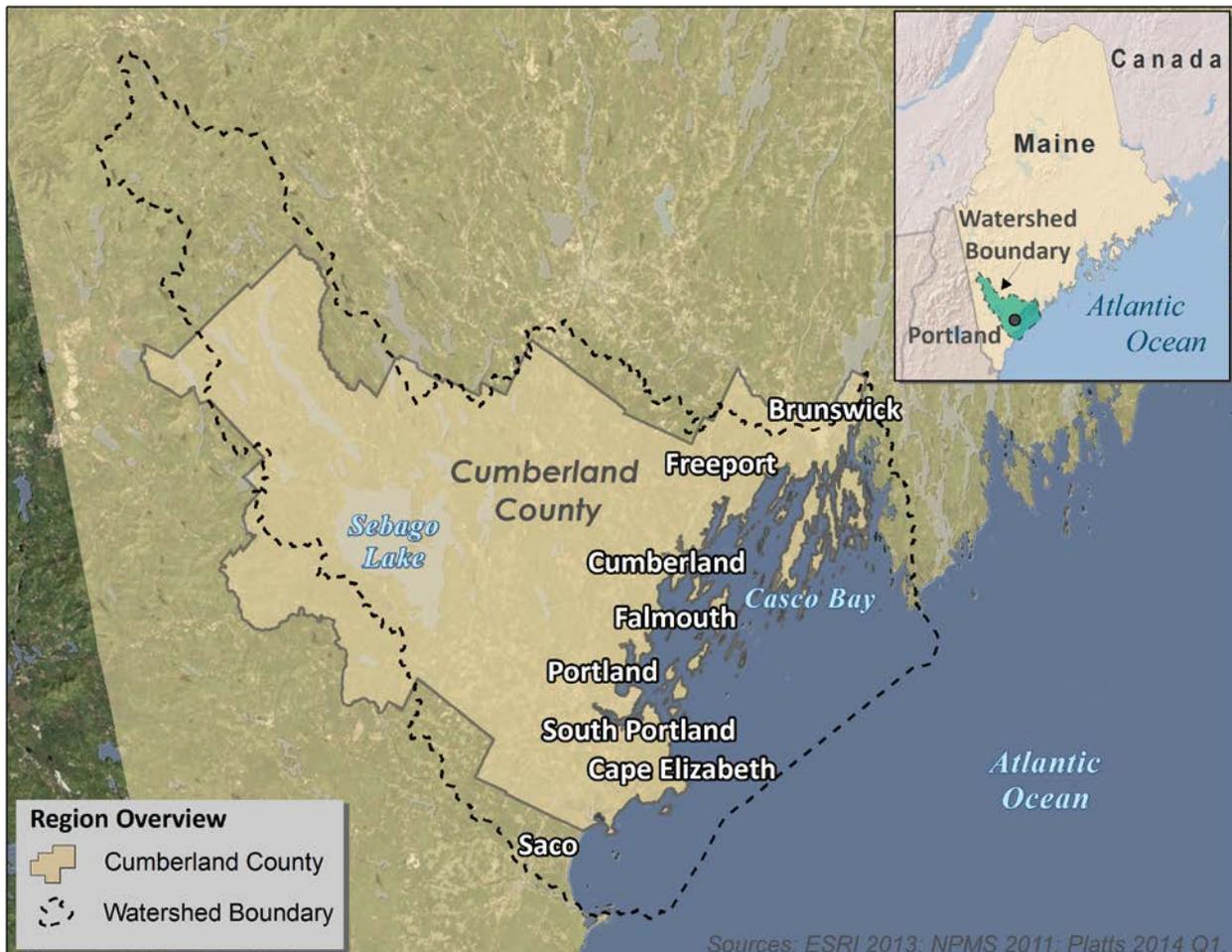


Figure 6 Area Map of the Casco Bay Watershed and Cumberland County

## Projected Regional Climate Change Hazards

Climate projections for the Casco Bay Region are based on global climate models, which are dynamically downscaled using a regional climate model to generate projections of climate with higher spatial

resolution.<sup>40</sup> Consistent with the climate hazards identified in the National Climate Assessment and presented above, the regional climate impact modeling presented in this section focuses primarily on temperature and precipitation projections for the near to mid-term (i.e., approximately 50 years), as well as sea level rise (and associated impacts).

### Temperature and Precipitation

Projected changes in average temperature and precipitation generally reflect a continuation of the historical trends described earlier. Using dynamically downscaled climate modeling techniques, Argonne generated a series of temperature and precipitation projections for the Casco Bay Region using the RCP8.5 (high) emission scenario. The results of this analysis suggest that portions of the Casco Bay Region could regularly experience average annual maximum temperatures ranging from 90 to 95 degrees Fahrenheit by the middle of the century, and over 100 degrees Fahrenheit by the end of the century (Figure 7). Regional climate projections also suggest that average daily precipitation in the Casco Bay Region will increase; the average daily precipitation amount is projected to increase by up to 16 percent by the middle of the century, and by as much as 34 percent by the end of the century (Figure 8). Northern regions of the State may experience even greater increases in daily precipitation by the end of the century.

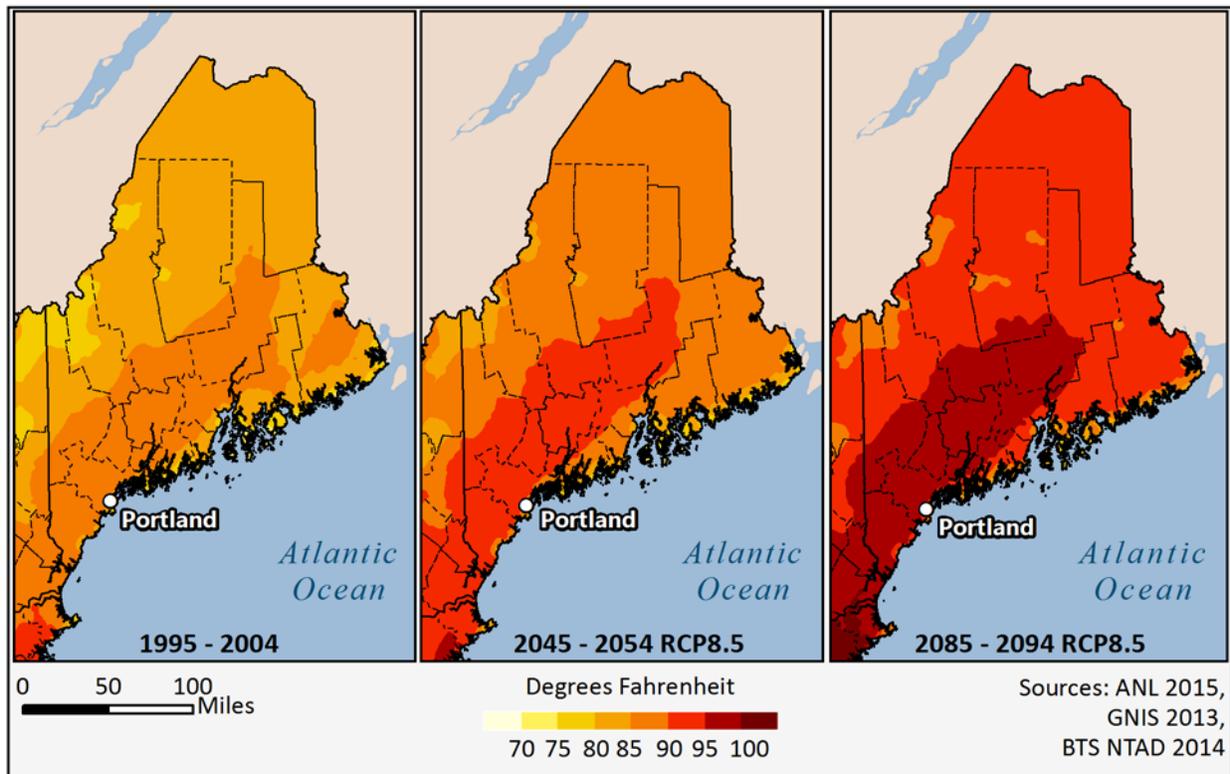
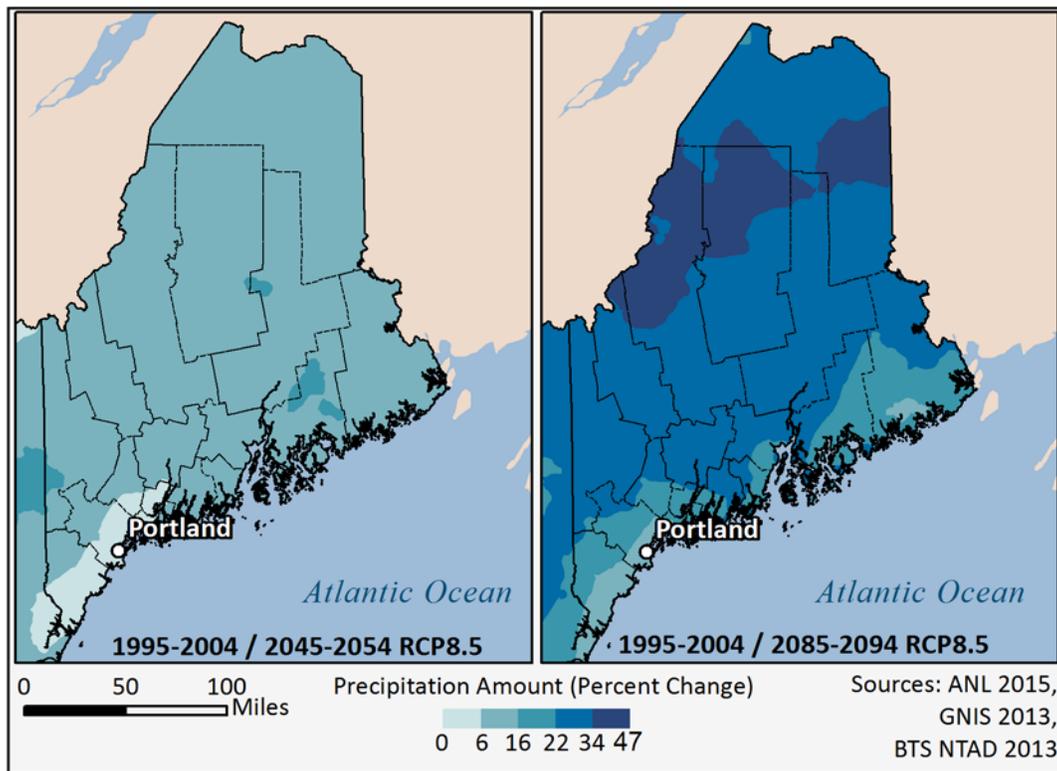


Figure 7 Projected Average Annual Maximum Temperature Trends (°F) in Maine

<sup>40</sup> Research conducted as part of the Strategic Environmental Research and Development Program, under contract number RC—2242. (This research used resources of the National Energy Research Scientific Computing Center, which is supported by DOE’s Office of Science under Contract No. DE-AC02-05CH11231 and employed the resources of the Argonne Leadership Computing Facility at Argonne National Laboratory, which is supported by DOE’s Office of Science under contract DE-AC02-06CH11357.)



**Figure 8 Projected Percentage Changes in Average Daily Precipitation Amount**

Regional climate projections also suggest that extreme temperature and precipitation events will increase in frequency and magnitude within the region. Figure 9 shows projected changes in the number of heat waves per decade across the State. Although increases in heat waves are not widespread by mid-century, a significant increase in the frequency of heat waves is projected by the end of the century across the Casco Bay Region. While heat waves are defined as two consecutive days with peak temperatures above 90°F, the trends shown in Figure 9 may suggest that in areas where the projected heat wave frequency is particularly high, prolonged periods could occur where temperatures remain above 90°F (consistent with the projected changes in average annual maximum temperature shown in Figure 7). Heavy precipitation is also projected to increase across the State. Figure 10 shows the heaviest (greater than 99th percentile) daily precipitation projections under the RCP8.5 (high) scenario. Note that while some heavy precipitation increases are projected across Maine by mid-century, these increases will become more widespread by the end of the century—particularly in western, central, and coastal regions of the State.

### Sea Level Rise and Storm Surge

Global sea level rise projections vary with the emission scenario selected for evaluation; however, all projections indicate a rising trend in mean sea level that will continue throughout the 21st century. In addition to affecting normal average tidal fluctuations, a higher sea level can also amplify the impacts of storm surge along coastlines. Preliminary analysis of storm surge in the Casco Bay Region examined potential impacts of storm surge as they may be influenced by sea level rise.<sup>41</sup> The analyses assumed that

<sup>41</sup> Altinakar, M., and Y. Ding, undated, *Maine Climate Change Adaptation Regional Resilience Assessment Program Support*, National Center for Computational Hydroscience and Engineering, University of Mississippi, Oxford, MS.

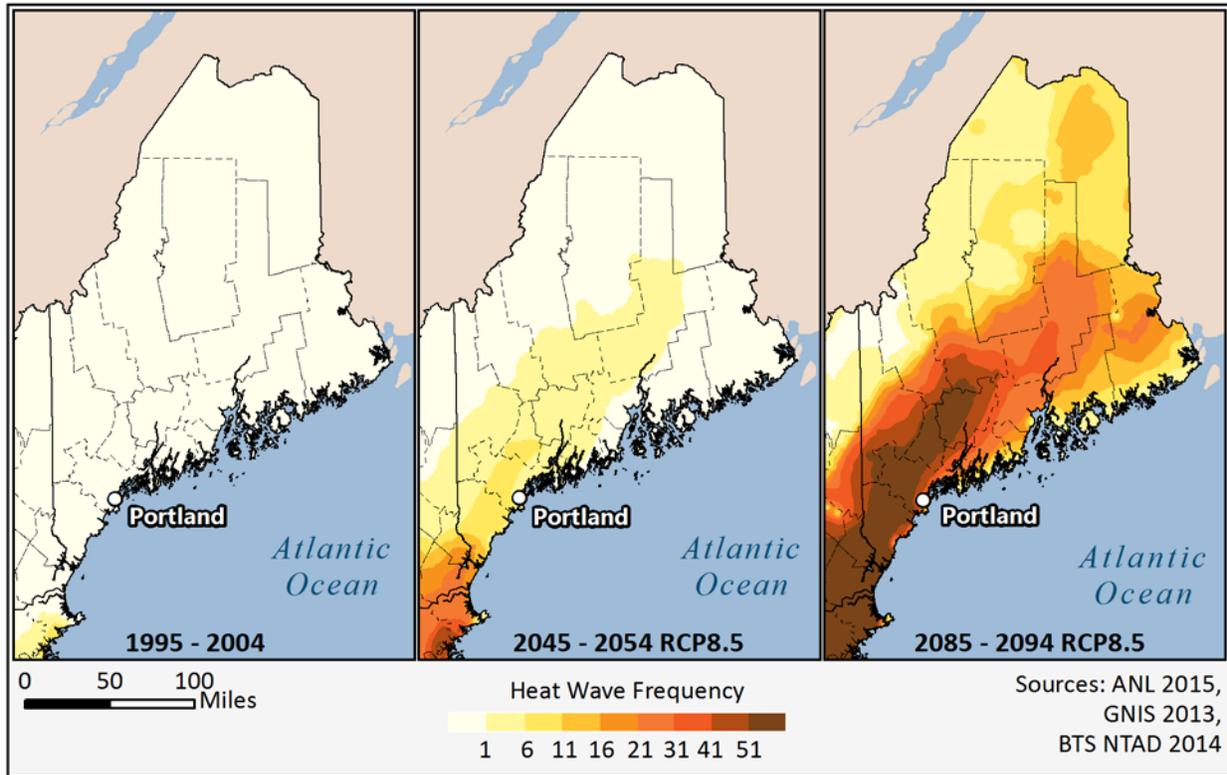


Figure 9 Projected Trends in the Number of Heatwaves per Decade in Maine

global average sea level rise will follow the trend projected for the highest emission scenario (i.e., greater increases in sea level), which is roughly similar to a continuation of the current path of global emissions increases.<sup>42,43</sup> On the basis of this assumption, three scenarios were examined: storm surge with present-day sea level, storm surge with a mid-century global sea level rise scenario (20.7 inches by 2050), and storm surge with an end-of-century global sea level rise scenario (38.6 inches by 2100).

The postulated storm used for the study was specified to be a storm similar in strength to Hurricane Sandy, impacting the Portland metropolitan area under the present-day and two projected sea level scenarios. Figure 11 presents a sample of this study's outcomes showing impacts to the Portland metropolitan area under each of the three scenarios. This figure shows that flooding may be expected along the Portland waterfront, particularly in the Back Cove and Portland Harbor areas along the Fore River. The figure also shows extensive potential flooding impacts in the downtown wharfs, ferry terminals, the Back Cove Park area, and the Fore River Sanctuary near the back of the Fore River Estuary.

<sup>42</sup> The Representative Concentration Pathways (RCPs) describe four different pathways of GHG emissions and atmospheric concentrations, air pollutant emissions, and land use. The RCPs have been developed as input to a wide range of climate model simulations to project their consequences for the climate system. These climate projections, in turn, are used for impacts and adaptation assessment. The scenarios are used to assess the costs associated with emission reductions consistent with particular concentration pathways. The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0), and one scenario with very high GHG emissions (RCP8.5). Source: IPCC, 2014, *Climate Change 2014: Synthesis Report*, [http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR\\_AR5\\_LONGERREPORT\\_Corr2.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_LONGERREPORT_Corr2.pdf), accessed February 20, 2015.

<sup>43</sup> Melillo, J.M., T.C. Richmond, and G.W. Yohe, eds., 2014, *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program, <http://nca2014.globalchange.gov/downloads>, accessed February 16, 2015.

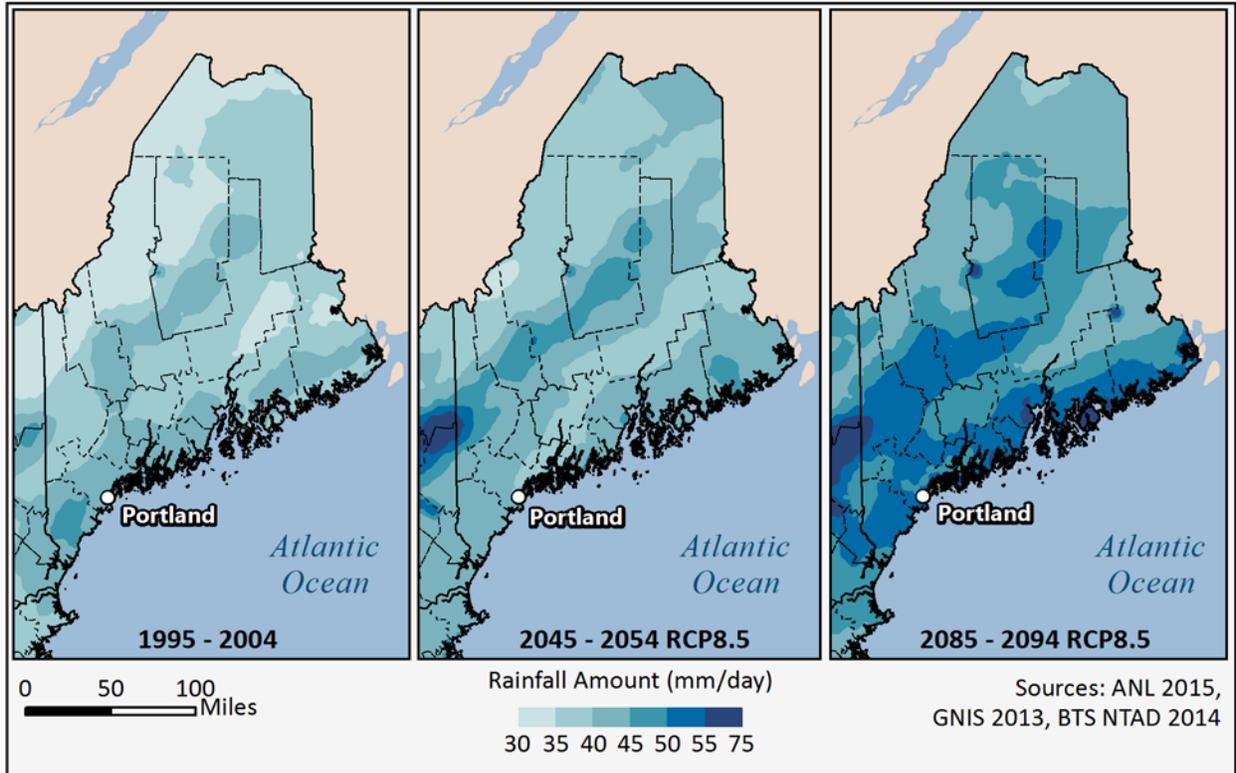


Figure 10 Projected Average Annual Maximum Precipitation (Greater than 99th Percentile) Trends in Maine

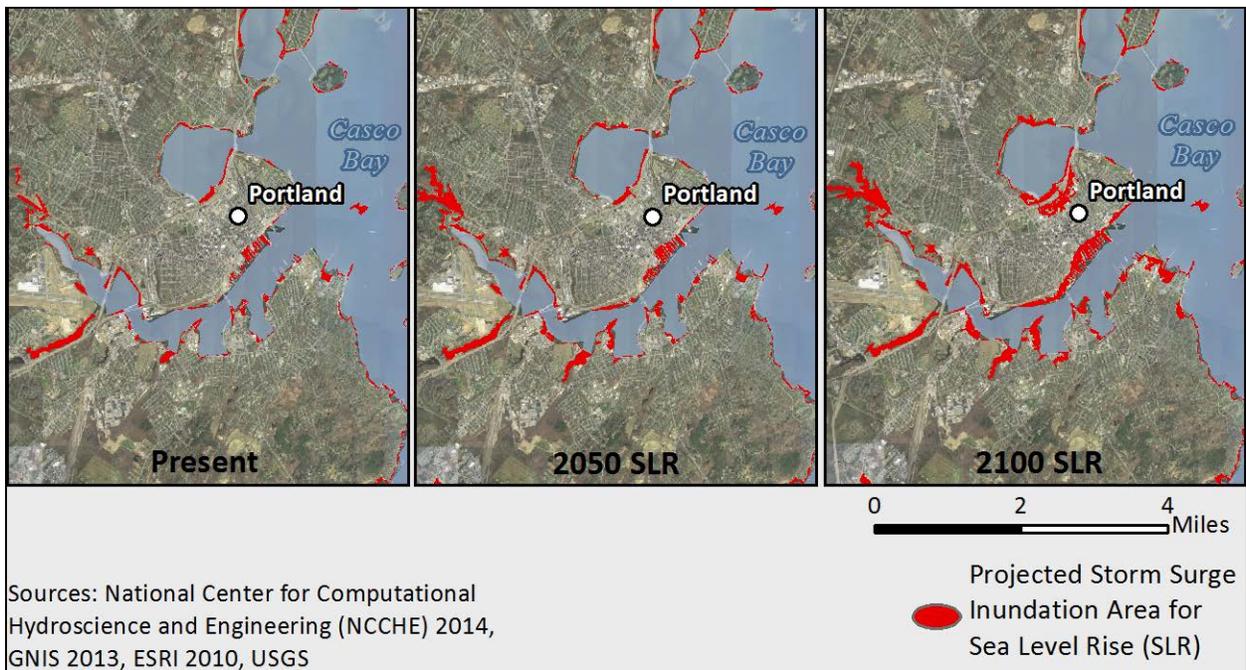


Figure 11 Sea Level Rise and Storm Surge Projected for Casco Bay

Saltwater intrusion is another impact closely related to sea level rise. Saltwater intrusion involves the hydraulic migration of saltwater into the coastal aquifers that supply drinking water to portions of the Casco Bay Region. Saltwater intrusion is a direct result of sea level rise, which alters the hydraulic gradient between the ocean and inland coastal aquifer, and of storm surge, which can cause ocean water to over wash inland areas and permeate down into the underlying aquifer. A preliminary analysis of saltwater intrusion risk was conducted, building upon the sea level rise and storm surge analyses described above, to identify key saltwater intrusion impacts in the Casco Bay Region. Results suggest that, with a 98.0-centimeter (38.6-inch) rise in sea level (i.e., the end-of-century projections), the hydraulic gradient for most well locations will become negative, which indicates an inward flow of sea water, resulting in widespread salinization of the coastal aquifers. Furthermore, the study suggests that in certain cases, a Sandy-like hurricane could cause the salinity of the water in the aquifers to exceed drinking-water standards for between 5 and 20 days after the event.

## Regional Climate and Critical Infrastructure Systems Impacts

Climate change impacts on the four critical infrastructure systems analyzed in the Casco Bay RRAP were identified through stakeholder workshop discussions and infrastructure analysis. These impacts are discussed in this section.

### Water Resource Systems

Changes in precipitation patterns, air and sea temperature, sea level, and storm activity will affect both the quantity and quality of water supplies and the infrastructure that connects these supplies to communities. Water quantity will be impacted by increased seasonality of precipitation (i.e., wetter winters and drier summers), which can pose a greater problem for water supply systems in areas where storage capacity is constrained. Water quality, particularly in coastal aquifers, can be impacted by saltwater intrusion, which raises salinity levels and requires greater desalinization system capacity to ensure potable water supplies. Temperature also affects water quality by “decreasing dissolved oxygen and leading to excess concentrations of nutrients (nitrogen and phosphorous), heavy metals (such as mercury), and other toxic agents in lake waters,”<sup>44</sup> which could increase the burden on water treatment facilities.

The Portland Water District (PWD) is the main water services provider in the Casco Bay Region. PWD operates the Sebago Lake Water Treatment Facility in Standish, Maine, which is the primary water treatment facility for the region<sup>45</sup> and provides drinking water to more than 190,000 individuals in the Casco Bay Region, including those in Portland, South Portland, Cape Elizabeth, Scarborough, Falmouth, Cumberland, and other locations (see Figure 6). Other towns within the region also operate and maintain their own water and wastewater infrastructure, including the towns of Saco, Brunswick, and Freeport.

PWD is also the primary wastewater treatment provider within the Casco Bay Region, operating four of the five regional wastewater treatment facilities (the Town of Falmouth Wastewater Department operates its own facility<sup>46</sup>). PWD’s East End wastewater treatment facility is the largest plant, with a peak flow capacity of 80 million gallons per day, and serves a population of 60,000.<sup>47</sup>

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<sup>44</sup> Georgakakos, A., et al., 2014, “Ch. 3: Water Resources,” *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, eds., U.S. Global Change Research Program, 69–112.

<sup>45</sup> PWD, 2015a, “Water Treatment,” <https://www.pwd.org/water-treatment>, accessed May 22, 2015.

<sup>46</sup> Falmouth Maine, undated, “Wastewater Department,” <http://www.falmouthme.org/wastewater-department>, accessed May 22, 2015.

<sup>47</sup> PWD, 2015b, “Facilities,” <https://www.pwd.org/facilities#portland>, accessed May 22, 2015.

## Energy Systems

Energy systems in the United States are vulnerable to both direct impacts, such as extreme weather events and physical impacts on generation and transmission facilities, and indirect impacts, such as climate-induced changes in energy demand. Extreme weather events, such as hurricanes, can affect “energy production and delivery facilities”—for example, electrical power plants, petroleum and natural gas storage and pumping facilities—“causing supply disruptions of varying lengths and magnitudes and affecting other infrastructure that depends on energy supply.”<sup>48</sup> Changing temperatures can also directly and indirectly affect energy infrastructure facilities. For example, “higher summer temperatures will increase electricity use, causing higher summer peak loads,”<sup>49</sup> which could increase natural gas demand for power generation. Regional energy systems addressed in the Casco Bay RRAP include electrical power, petroleum, and natural gas infrastructure systems.

### Electrical Power

Central Maine Power (CMP), a subsidiary of Iberdrola USA, is the primary electric power provider for southwestern Maine, providing nearly 9 million kilowatt-hours to more than 609,000 residential, commercial, industrial, and wholesale customers. The system, shown in Figure 12, consists of approximately 25,000 miles of transmission lines and 280 substations. Acute water-related impacts from changes in temperature are of primary concern in the Casco Bay Region. Increases in average temperature not only reduce the production and transmission capacity of electrical power infrastructure, but also increase the demand for power through increased usage of air conditioning and refrigeration.

Increases in precipitation can result in inland flooding as watersheds and drainage system capacities are overwhelmed. During the RRAP Energy Workshop, CMP noted that as a result of increasing flood conditions, it now regularly moves power lines out of areas that previously had no history of flooding. Similarly, sea level rise and coastal storm surge can result in more widespread and/or frequent coastal flooding. Each of these flooding-related hazards has the potential to cause acute disruption to electrical power substations and other transmission infrastructure.

Analysis of Maine’s electrical system (Figure 12) examined impacts arising from storm surge. A category 2 hurricane was projected for the years 2014 and 2050 (to account for sea level rise) along the coast of Maine. Results indicate that 13 power plants (with a combined generating capacity of 311 megawatts [MW]) and 15 coastal substations would be adversely affected by the projected inundation. The total reduction in active electrical generation internal to the State of Maine would be approximately 14 percent, which would result in localized power outages.

The electrical system analysis also considered changes in ambient air temperature, impacts on the operational characteristics of generation and transmission facilities, and demand. Results indicate that the projected mid-century (2045–2054) increases of between 3.6°F and 9°F in average maximum daily temperature across Maine could reduce overall plant generation output by 73 MW and diminish transmission line capacity by an average of 8 percent. Conversely, demand is projected to increase statewide by 10 percent, or approximately 176 MW.

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<sup>48</sup> Schwartz, H.G., and Meyer, 2014, “Ch. 5: Transportation,” *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, eds., U.S. Global Change Research Program, <http://nca2014.globalchange.gov/report/sectors/transportation>, accessed February 16, 2015.

<sup>49</sup> Ibid.

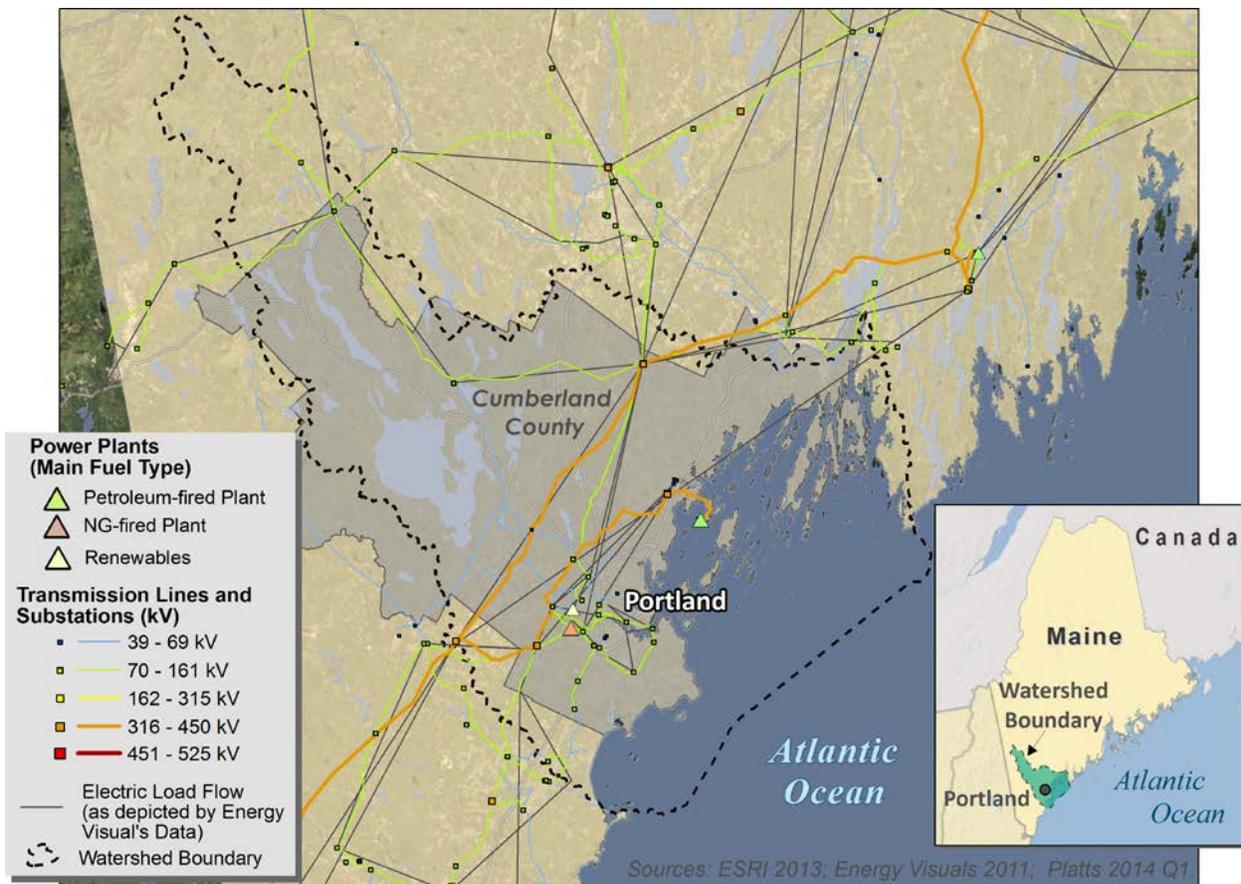


Figure 12 Casco Bay Region Electrical Power Infrastructure

### Petroleum Infrastructure

Petroleum infrastructure in Maine consists of storage, transportation, and distribution facilities (Figure 13). Maine receives more than half of its petroleum products at the Port of Portland; intrastate refined products are transported via the 124-mile Buckeye Pipeline, which originates in Portland and terminates in Bangor, with deliveries to ExxonMobil, Cold Brook Energy, Gulf Oil, and Webber Energy terminals. The Portland Pipeline Corporation–South Portland Crude Oil Terminal, the single crude oil terminal in the Casco Bay Region, has a total storage capacity of 3.9 million barrels; however, the region has no refining capacity. Instead, crude oil shipments received at the Port of Portland are transported to refineries in Quebec and Ontario via a pipeline operated by the Portland Pipe Line Corporation.

More than three-quarters of Maine’s households use fuel oil (distillate) for home heating. Despite this heavy reliance on fuel oil, fuel reserves in the region remain moderate: typical January–February inventory can meet 2–4 weeks of distillate demand, making the State vulnerable to distillate fuel oil shortages, price spikes, and other disruptions. The regional transportation sector’s dependence on petroleum products also makes it vulnerable to petroleum shortages. In 2010, Cumberland County consumed 106 million gallons of gasoline for automotive transportation,<sup>50</sup> and statewide gasoline accounts for about 50 percent of all transportation fuel consumed (29 percent diesel and 20 percent jet

<sup>50</sup> Lake, B., 2011, “Cumberland County, Maine: 2007 Energy Use and Emissions Inventory,” Greater Portland Council of Governments, December, <http://www.gpcog.org/energy/regional-energy-resources>, accessed May 27, 2015.

fuel).<sup>51</sup> Yet, typical January–February inventory can meet only 8–12 days’ worth of transportation-related demand if a disruption occurs to the regional fuel supply.<sup>52</sup> The State of Maine’s heavy dependence on truck transportation to move fuels from terminals to retail outlets and households adds an additional layer of dependence between petroleum and the transportation sector.

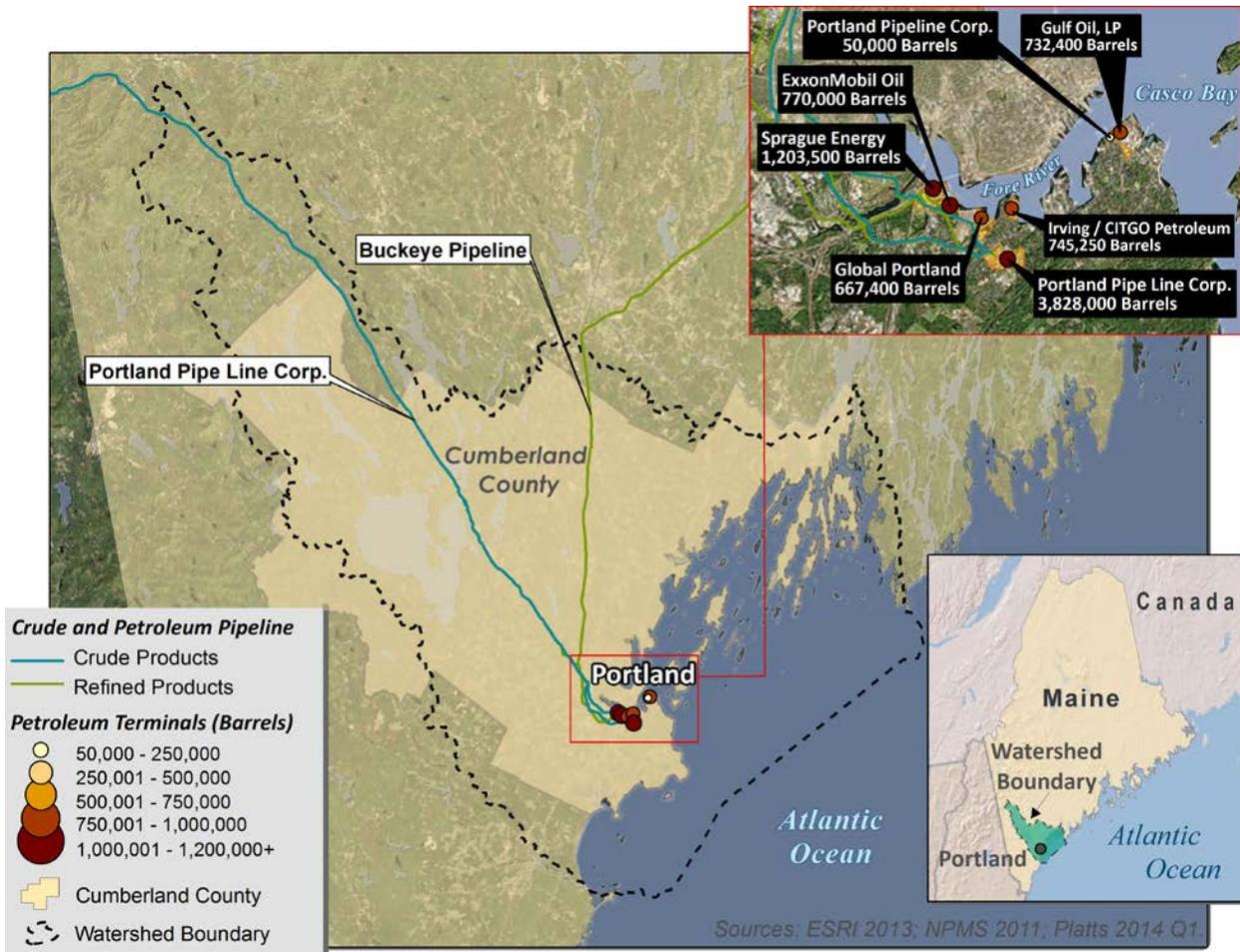


Figure 13 Casco Bay Region Petroleum Infrastructure

The coastal location of petroleum infrastructure in the Portland metropolitan area at the mouth of the Fore River (see Figure 13 inset) is particularly vulnerable to sea level rise and coastal storm surge. Hurricane modeling assessed the impacts of a storm with characteristics similar to those of Hurricane Sandy that makes landfall in the Portland area, projecting storm surge inundation scenarios with present-day sea level, as well as 20.7 inches of sea level rise (year 2050) and 38.6 inches of sea level rise (year 2100). The outcomes indicate inundation would spread across significant portions of the Portland and South Portland waterfront, flooding petroleum facilities. Figure 14 shows storm surge inundation under the 38.6-inch sea

<sup>51</sup> U.S. Energy Information Administration, 2014a, “Adjusted Sales of Distillate Fuel Oil by End Use,” *Petroleum & Other Liquids*, [http://www.eia.gov/dnav/pet/pet\\_cons\\_821dsta\\_dcu\\_SME\\_a.htm](http://www.eia.gov/dnav/pet/pet_cons_821dsta_dcu_SME_a.htm), accessed May 27, 2015.

<sup>52</sup> Determined using Prime Supplier Sales Volumes data for Maine, [http://www.eia.gov/dnav/pet/pet\\_cons\\_prim\\_dcu\\_SME\\_m.htm](http://www.eia.gov/dnav/pet/pet_cons_prim_dcu_SME_m.htm), accessed May 27, 2015, together with Refinery, Bulk Terminal, and Natural Gas Plant Stocks by State data for Maine, [http://www.eia.gov/dnav/pet/pet\\_stoc\\_st\\_dc\\_SME\\_mbb1\\_m.htm](http://www.eia.gov/dnav/pet/pet_stoc_st_dc_SME_mbb1_m.htm), accessed May 27, 2015.

level rise scenario, showing that significant portions of petroleum storage and distribution infrastructure along the Fore River will experience impacts, including the facilities belonging to ExxonMobil Oil, Irving/CITGO Petroleum, and Gulf Oil.

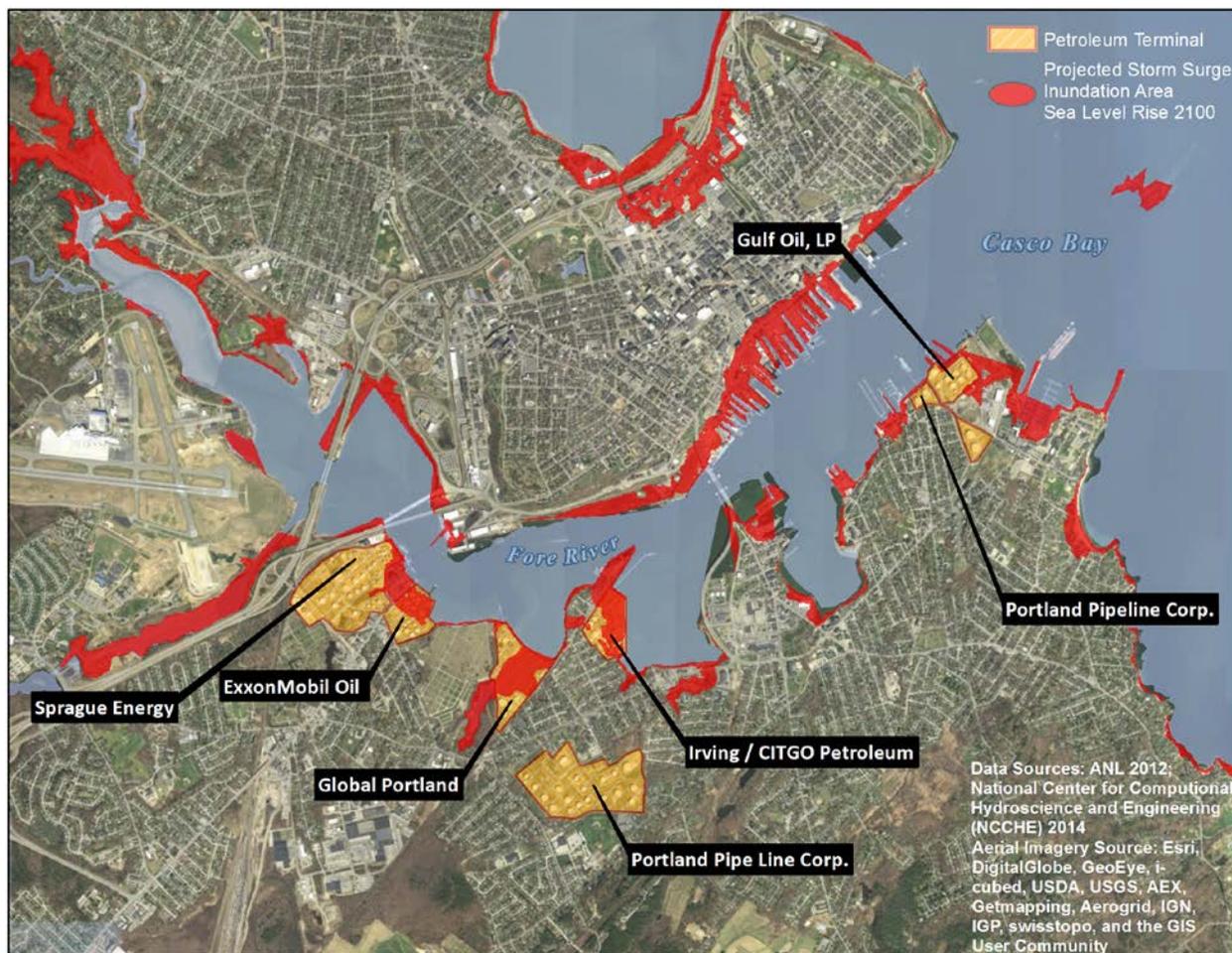


Figure 14 Petroleum Infrastructure Inundation Areas under End-of-Century Storm Surge Projections

### Natural Gas Infrastructure

Natural gas is consumed in Maine for industrial use (44 percent), electricity generation (42 percent), commercial use (11 percent), and residential use (2 percent).<sup>53</sup> Pipelines and compressor stations facilitate the distribution of natural gas within Maine and throughout the larger system in New England and Eastern Canada (Figure 15). The Maritime and Northeast Pipeline (M&NP) and Portland Natural Gas Transmission System (PNGTS) both import natural gas from Canada, and the M&NP system also provides natural gas to downstream markets in the United States. Four local distribution companies supply natural gas to the central and southern portions of Maine: Maine Natural Gas, LLC; Bangor Gas Company, LLC; Summit Natural Gas of Maine,; and Northern Utilities, the last of which is the primary supplier for the Casco Bay Region.

<sup>53</sup> U.S. Energy Information Administration, 2014b, “Natural Gas Summary,” *Natural Gas*, [http://www.eia.gov/dnav/ng/ng\\_sum\\_lsum\\_dcu\\_sme\\_a.htm](http://www.eia.gov/dnav/ng/ng_sum_lsum_dcu_sme_a.htm), accessed May 27, 2015.

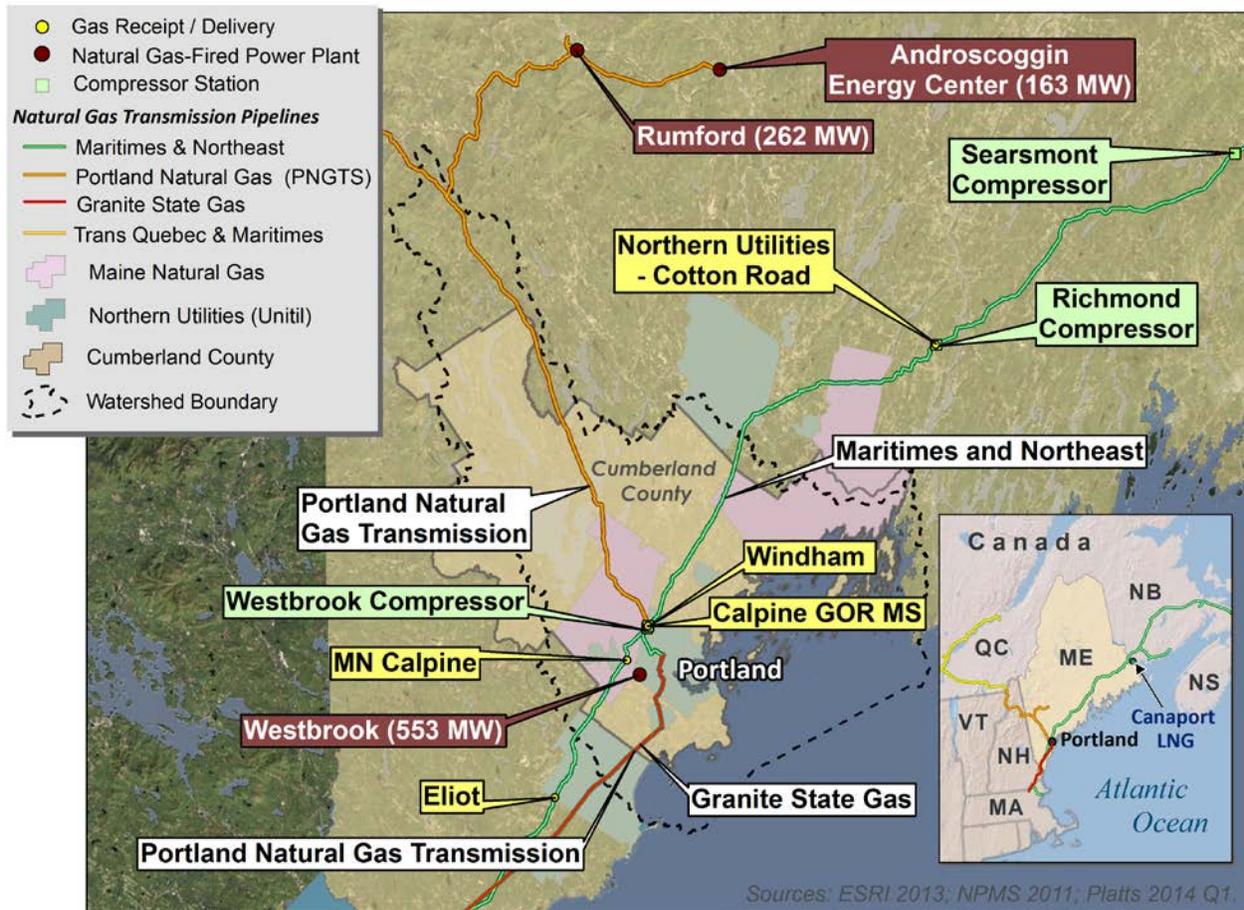


Figure 15 Casco Bay Region Natural Gas Infrastructure

Natural gas infrastructure is vulnerable to failures as a result of extreme weather impacts. Although natural gas infrastructure is generally located farther from the coastline, inland flooding resulting from heavy precipitation and hurricane activity is still of primary concern, particularly to compressor stations that maintain pipeline pressure and facilitate natural gas movement throughout the State and region. Furthermore, as both the M&NP and PNGTS systems operate single pipelines, a lack of systemic redundancy exacerbates their vulnerability to disruptions.

### Transportation

The National Climate Assessment notes that the transportation system is composed of four main components, each of which is uniquely vulnerable to the impacts of climate change:

1. Fixed-node infrastructure, such as ports, airports, and rail terminals;
2. Fixed-route infrastructure, such as roads, bridges, pedestrian/bicycle trails and lanes, locks, canals/channels, light rail, freight and commuter railways, and pipelines, with mixed public and private ownership and management;

3. Vehicles, such as cars, transit buses, and trucks; transit and railcars and locomotives; ships and barges; and aircraft—many privately owned; and
4. The people, institutions, laws, policies, and information systems that convert infrastructure and vehicles into working transportation networks.<sup>54</sup>

The first two items noted above underscore the concerns associated with coastal infrastructure systems, where changes in sea level and storm surge have the potential to cause temporary or permanent flooding of fixed infrastructure assets. Extreme events such as heavy precipitation can also significantly affect inland infrastructure. For example, a 50-year rainfall event centered over the Casco Bay Region in August 2014 dislodged manhole covers in Portland, blocked freeway exits, and flooded roadways in Falmouth, Yarmouth, Brunswick, and Scarborough.<sup>55</sup> In Vermont, the impacts of Tropical Storm Irene damaged more than 500 miles of State highway, 1,400 bridges and culverts, and 200 miles of rail.<sup>56</sup> Extreme temperatures can also adversely affect transportation systems, where “expansion joints on bridges and highways are stressed and some asphalt pavements deteriorate more rapidly”<sup>57</sup> and railroad tracks are more susceptible to buckling. The latter two points also best underscore stakeholders’ concerns with urban infrastructure, where disruptions to infrastructure can lead to severe socioeconomic impacts.<sup>58</sup>

Transportation infrastructure in the Casco Bay Region (Figure 16) consists of three interstate highways (I-95, I-295, and I-495), Portland International Jetport, freight and passenger railways, and both State and local roadway networks. Portland International Jetport, located adjacent to the mouth of the Fore River, is Maine’s largest airport, serving 1.67 million passengers and processing 22 million pounds of cargo in 2011.

Critical Transportation Sector nodes in the Casco Bay Region that could be impacted by climate change include rail lines (in addition to Pan Am rail bridges with collocated telecommunications infrastructure), marine infrastructure in South Portland (e.g., oil terminals), the International Marine Terminal, ferry terminals, low-lying roadways, and causeways that are susceptible to flooding from storm surge or high-intensity rainfall events. MaineDOT, which is currently conducting a Federal Highway Administration (FHWA)-sponsored climate change adaptation study, recently determined that even excluding potential storm surge, a segment of State Route 1 near the town of Scarborough would be affected by as little as a 1-foot rise in sea level under high tide.

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<sup>54</sup> Schwartz, H.G., and Meyer, 2014, “Ch. 5: Transportation,” *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, eds., U.S. Global Change Research Program, <http://nca2014.globalchange.gov/report/sectors/transportation>, accessed February 16, 2015.

<sup>55</sup> Harry, D., 2014, “Updated: Storm Swamps Greater Portland, Damages Roads, Buildings in City and Several nearby Communities,” *The Forecaster*, August 14, <http://www.theforecaster.net/news/print/2014/08/14/updated-storm-swamps-greater-portland-damages-road/206886>, accessed February 21, 2015.

<sup>56</sup> Pealer, S., 2012, “Lessons from Irene: Building Resiliency as We Rebuild,” Vermont Agency of Natural Resources, January 4, [http://www.anr.state.vt.us/anr/climatechange/Pubs/Irene\\_Facts.pdf](http://www.anr.state.vt.us/anr/climatechange/Pubs/Irene_Facts.pdf), accessed February 16, 2015.

<sup>57</sup> Schwartz, H.G., et al., 2014, “Ch. 5: Transportation,” *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, eds., U.S. Global Change Research Program, <http://nca2014.globalchange.gov/report/sectors/transportation>, accessed February 16, 2015.

<sup>58</sup> Wilbanks, T.J., and S. Fernandez, 2014, *Climate Change and Infrastructure, Urban Systems, and Vulnerabilities Technical Report for the U.S. Department of Energy in Support of the National Climate Assessment*, Oak Ridge National Laboratory, and DOE, February 29, <http://www.esd.ornl.gov/eess/Infrastructure.pdf>, accessed February 16, 2015.

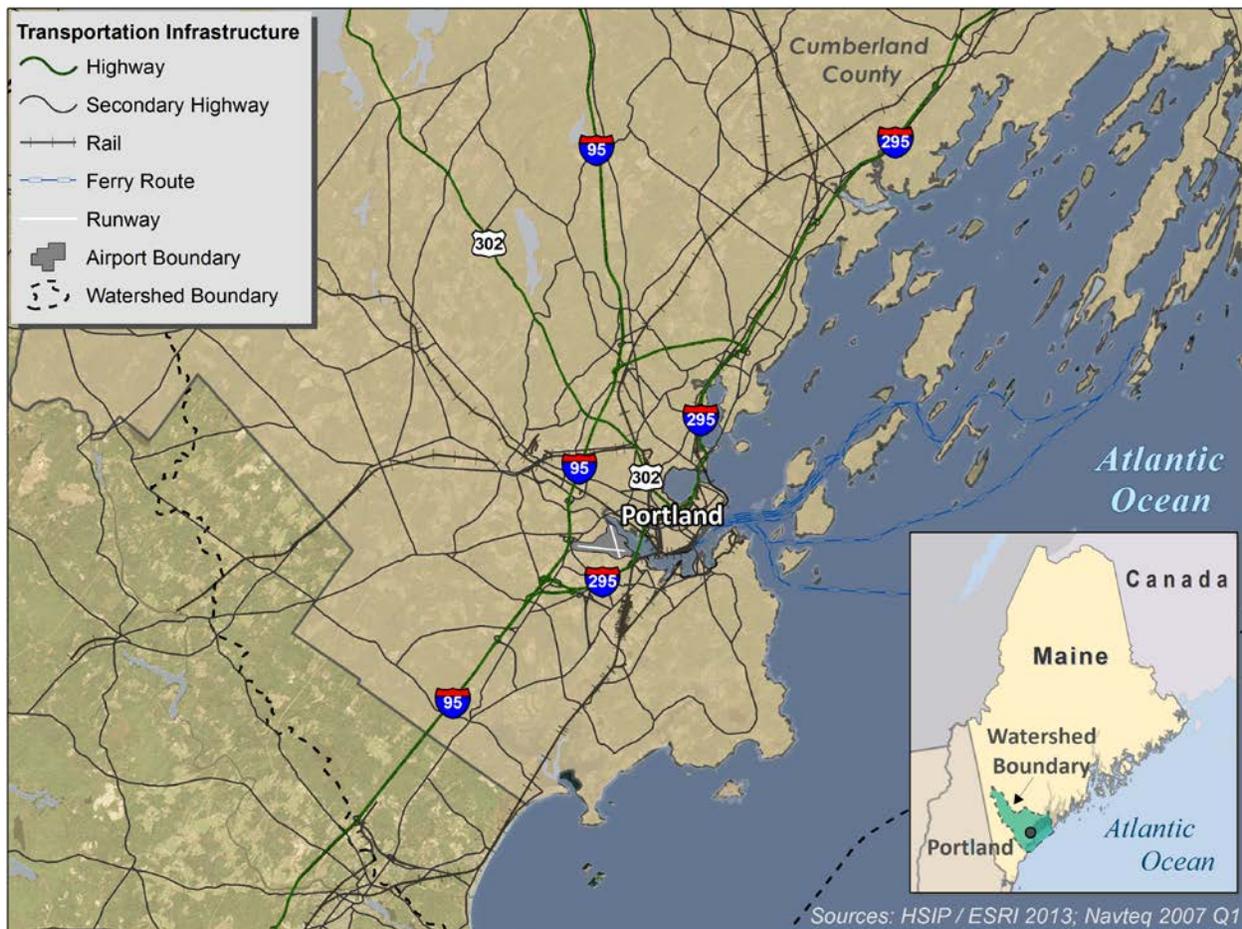


Figure 16 Casco Bay Region Transportation Infrastructure

Impacts on urban transportation infrastructure were also analyzed in the Portland area using the storm surge inundation projections discussed above (i.e., a Sandy-like hurricane with present-day sea levels, and both 20.7-inch and 38.6-inch sea level rise scenarios). The results suggest that significant portions of the Portland waterfront, particularly in Back Cove and along the Fore River waterfront areas, could experience storm surge inundation (see Figure 17). This outcome includes inundation and disruption of the rail line near the Fore River Sanctuary and along US-1 Alt/W Commercial Street. In addition, a number of downtown wharves and ferry terminals are within the inundation zone.



Figure 17 Storm Surge Inundation Impacts on Greater Portland Area Transportation Infrastructure

## Telecommunications

Telecommunications infrastructure provides a vital link, particularly to rural communities in Maine, for life safety, emergency response, and other socioeconomic functions. Telecommunications infrastructure assets include cellular towers and facilities, microwave service towers, fiber lines, landline telephone networks, and related facilities. Although there are several direct climate change vulnerabilities in the telecommunications infrastructure in the Casco Bay Region (e.g., hurricane wind loading to cellular and microwave towers, coastal and inland flooding of support facilities, high temperatures affecting electronic equipment), the system's dependencies on intersecting infrastructure systems are also significant. Telecommunications systems rely heavily on electric power from the Energy Sector to keep systems operating under normal conditions. When disruptions to electric energy occur, petroleum generators typically supply backup power. These generators themselves depend on the Transportation Sector for fuel replenishment (Figure 18), and given the remote locations of some cellular and microwave towers, access frequently relies on lesser-traveled and lesser-developed roadways. In addition, land-based fiber and telecommunications lines are frequently collocated with transportation facilities (e.g., bridges, roadway right-of-ways). Therefore, disruption to a significant asset, such as a bridge, may also affect the collocated telecommunications infrastructure.

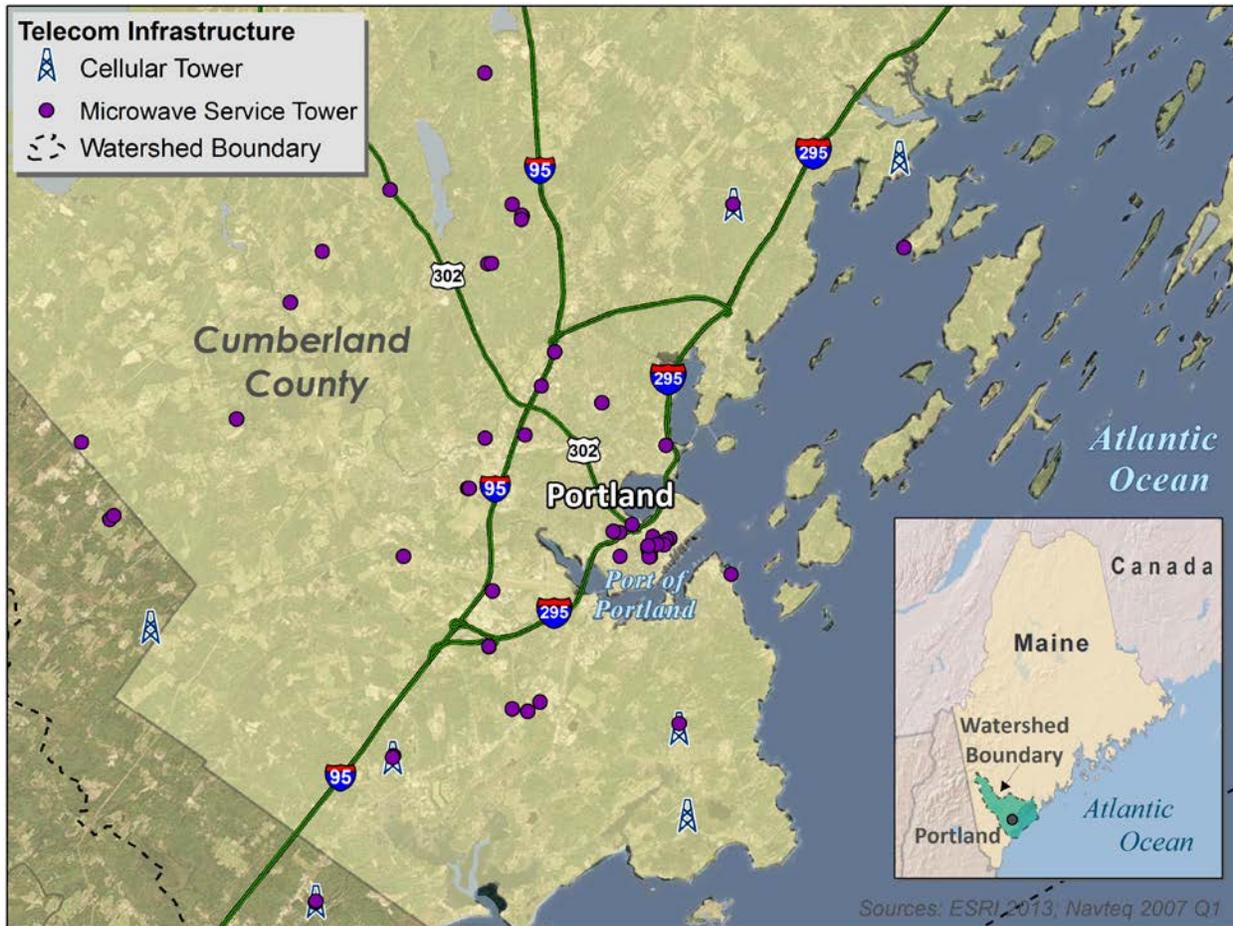


Figure 18 Casco Bay Region Telecommunications Infrastructure

## Current Policy and Planning Response

### Planning and Policy Responses to Climate Change in Maine

For the past two decades, Maine has taken a strong lead in proactive planning for climate change and environmental impacts. As early as 1995, Maine undertook its first statewide GHG emissions inventory. In the same year, the Maine State Planning Office, in conjunction with the U.S. Environmental Protection Agency (EPA), produced the study, *Anticipatory Planning for Sea-Level Rise along the Coast of Maine*,<sup>59</sup> which constituted Maine's first systematic assessment of shoreline vulnerability to accelerated sea level rise associated with global climate change. Appendix B provides a timeline of subsequent planning and policy responses undertaken at both the State and local levels in Maine in response to climate change.

<sup>59</sup> EPA, 1995, *Anticipatory Planning for Sea-Level Rise along the Coast of Maine*, September, [http://papers.risingsea.net/federal\\_reports/maine\\_0.pdf](http://papers.risingsea.net/federal_reports/maine_0.pdf), accessed February 21, 2015.

## Complementary Climate Change Adaptation and Infrastructure Resilience Planning Activities

The Casco Bay RRAP is both linked to, and informed by, several current Maine and DHS activities through direct stakeholder participation, coordination, analytical partnerships, and complementary actions aimed at enhancing the collective effort to address climate change and critical infrastructure within the region. These include the following:

- University of Maine Climate Change Institute’s framework and platform for Climate Adaptation and Sustainability planning for Maine communities;<sup>60</sup>
- University of Maine Climate Change Institute’s *Maine’s Climate Future: 2015* update, which focuses on past, present, and future trends in key indicators of a changing climate specific to Maine, and recent examples of how Maine people are experiencing these changes;<sup>61</sup>
- May 2014 Waterfronts of Portland and South Portland Maine Urban Land Institute Resilience Panel Report,<sup>62</sup> which recommends further evaluation of lifeline infrastructure system climate change risks (e.g., energy and water assets vulnerable to sea level rise and increasing storm surge);
- Throughout 2014, MaineDOT participation in a FHWA-sponsored climate resilience pilot project for integrating vulnerability and criticality assessments into asset management;<sup>63</sup>
- University of Maine Cooperative Extension Service culvert vulnerability and adaptation project to inform decisionmaking, maintenance, and management;<sup>64</sup>
- 2015 DHS pilot studies of infrastructure dependencies and interdependencies throughout the Nation (the Casco Bay Region is one of the pilot locations); and
- DHS-facilitated Maine Climate Change Adaptation Planning Exercise, May 2015.

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<sup>60</sup> Climate Adaptation and Sustainability, 2014, “Planning Framework and Tools for Maine Communities,” University of Maine Climate Change Institute, <http://www.cci-reanalyzer.org/CLAS>, accessed May 23, 2015.

<sup>61</sup> Fernandez, I.J., C.V. Schmitt, S.D. Birkel, E. Stancioff, A.J. Pershing, J.T. Kelley, J.A. Runge, G.L. Jacobson, and P.A. Mayewski, 2015, *Maine’s Climate Future: 2015*, University of Maine, [http://cci.siteturbine.com/uploaded\\_files/climatechange.umaine.edu/files/Maines Climate Future 2015 UpdateFinal-1.pdf](http://cci.siteturbine.com/uploaded_files/climatechange.umaine.edu/files/Maines%20Climate%20Future%202015%20UpdateFinal-1.pdf), accessed April 13, 2015.

<sup>62</sup> Urban Land Institute, 2014, *Waterfronts of Portland and South Portland Maine*, [http://uli.org/wp-content/uploads/ULI-Documents/Portland-ME\\_PanelReport\\_Flo.pdf](http://uli.org/wp-content/uploads/ULI-Documents/Portland-ME_PanelReport_Flo.pdf), accessed February 21, 2015.

<sup>63</sup> FHWA, undated, 2013–2014 Climate Resilience Pilot Descriptions, [http://www.fhwa.dot.gov/environment/climate\\_change/adaptation/ongoing\\_and\\_current\\_research/vulnerability\\_assessment\\_pilots/2013-2014\\_pilots/index.cfm](http://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/vulnerability_assessment_pilots/2013-2014_pilots/index.cfm), accessed May 23, 2015.

<sup>64</sup> University of Maine, undated, “The New Normal: Culverts in Maine Stressed to the Limit,” <http://umaine.edu/mitchellcenter/the-new-normal-culverts-in-maine-stressed-to-the-limit>, accessed May 23, 2015.

# Key Findings

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Public- and private-sector stakeholders in the Casco Bay Region are becoming increasingly aware of the significant threats that climate change may pose to the region. However, aspects of the planning could be improved by better understanding dependencies and interdependencies of critical infrastructure sectors and by securing greater institutional support at multiple levels of government. Improved plans could profoundly affect safety, security, economic prosperity, and quality of life of communities throughout the region.

# Key Finding #1

## Institutional barriers and challenges to meeting regulatory requirements are hindering effective adaptation planning.

The overall lack of institutional structures that enable coordination of planning among agencies and infrastructure operators in different communities is a barrier to effective adaptation planning. As part of a home-rule State, Maine’s communities engage in their own local-level planning. However, impacts from climate change are felt at a much larger scale, requiring coordination among communities within a specific region. Transportation stakeholders, for example, noted that effective flood mitigation planning must occur at the watershed level, which would require coordination among the multiple communities encompassed by a watershed.<sup>65</sup> In addition, water utility providers and representatives from the Casco Bay Estuary Project and the Conservation Law Foundation expressed concern that adaptation in one area of a watershed can lead to unintended negative consequences elsewhere in the watershed—either upstream or downstream.<sup>66</sup> For example, upstream improvements to stormwater drainage or culvert capacity may inadvertently increase storm flows into downstream communities. Preventing these potential conflicts requires broader coordination, which may need to cross political or jurisdictional boundaries. Currently, neither the State of Maine nor the Casco Bay Region has a forum in which to discuss and, when necessary, de-conflict adaptation issues.<sup>67</sup>

### Key Sources That Support Finding #1

Facilitated Workshop Discussions

Challenges in meeting regulatory requirements are also noted as impeding adaptation planning efforts. For example, in response to an increasing number of storms that resulted in power outages and adversely affected the Town of Saco Wastewater System, the utility sought to install a centrally located backup generator. The backup system would provide electricity to multiple pumping stations during a power outage, as it was not financially feasible for the utility to place a generator at each pumping station. However, installation and operation of this centrally located generator would subject the Town of Saco Wastewater System to current public utility regulations as an electric power distributor. The challenge in meeting this regulatory requirement is, for all intents and purposes, preventing the Town of Saco from implementing this adaptation measure.<sup>68</sup>

## Resilience Enhancement Options

To enhance coordination of adaptation planning activities among local communities, the Casco Bay Region stakeholders should consider the following Resilience Enhancement Options:

- The Greater Portland Council of Governments, together with the cities of Portland and South Portland, should form an integrated planning body—the Casco Bay Climate Change Coalition (CBCCC)—that includes members from State and local government agencies, regional planning committees, academic institutions, not-for-profits, and the private sector to begin planning for the potential impacts of climate change.

<sup>65</sup> DHS Transportation Sector Workshop Quick Look Report (QLR)

<sup>66</sup> DHS Water/Wastewater Sector Workshop QLR

<sup>67</sup> Ibid.

<sup>68</sup> Ibid.

- The CBCCC should form planning committees to assess potential impacts and, employing the Five Steps to Climate Resilience from the U.S. Climate Resilience Toolkit (CRT),<sup>69</sup> begin developing a set of adaptation plans using information provided in the NCA 3. Region-specific adaptation plans should focus on the Water/Wastewater, Energy, Transportation,<sup>70</sup> and Telecommunication critical infrastructure sectors, as well as Emergency Services organizations.

- The CBCCC should use the University of Maine Climate Change Institute’s most recent assessment of climate change impacts—*Maine’s Climate Future: 2015*<sup>71</sup>—to inform local adaptation plans and leverage the Institute’s platform for Climate Adaptation and Sustainability (CLAS) as a source of climate data, including future temperature and precipitation projections, together with local land use and other mapping layers.<sup>72</sup>

- The newly formed Region 1 Federal Interagency Climate Preparedness and Resilience Task Force (CPR-TF) should support the CBCCC’s planning sessions. The Region 1 CPR-TF, with subject matter experts from FEMA, EPA, the U.S. Department of Transportation, NOAA, USGCRP, and DHS, provides the following technical assistance:

- Orient CBCCC adaptation planners to the Five-Step Climate Resilience Planning Process.
- Train, instruct, and advise on the use of the Climate Data Initiative (CDI) and CRT to support CBCCC adaptation planning efforts.
- Reach back to climate scientists at USGCRP and NOAA and critical infrastructure subject matter experts at Argonne.

- Adaptation plans developed by the CBCCC should be used to inform ongoing infrastructure planning processes in the region including local level (i.e., city/town) comprehensive plans, capital improvement plans, long-range transportation plans, and NEPA processes, among others. The DHS technical report *Addressing Critical Infrastructure Resilience and Climate Change Adaptation through the National Environmental Policy Act Process* describes how the DHS focus on building resilience among critical infrastructure assets, systems, and networks is uniquely suited to provide valuable information for climate change adaptation considerations among interconnected infrastructure systems through the NEPA planning process.

### National Preparedness Goal Core Capabilities Addressed

Planning
Operational Coordination
Risk Management for Protection Programs and Activities
Community Resilience
Risk and Disaster Resilience Assessment
Threats and Hazard Identification
Infrastructure Systems

<sup>69</sup> U.S. Climate Resilience Toolkit, undated, “Overview: Steps to Resilience,” <https://toolkit.climate.gov/get-started/overview>, accessed February 21, 2015.

<sup>70</sup> The Transportation plan should integrate practices developed during MaineDOT’s participation in the FHWA-sponsored Climate Resilience Pilot Program and practices developed during the University of Maine Cooperative Extension Service culvert vulnerability and adaptation project.

<sup>71</sup> Fernandez, I.J., C.V. Schmitt, S.D. Birkel, E. Stancioff, A.J. Pershing, J.T. Kelley, J.A. Runge, G.L. Jacobson, and P.A. Mayewski, 2015, *Maine’s Climate Future: 2015*, University of Maine, [http://cci.siteturbine.com/uploaded\\_files/climatechange.umaine.edu/files/Maines\\_Climate\\_Future\\_2015\\_UpdateFinal-1.pdf](http://cci.siteturbine.com/uploaded_files/climatechange.umaine.edu/files/Maines_Climate_Future_2015_UpdateFinal-1.pdf), accessed April 13, 2015.

<sup>72</sup> Climate Adaptation and Sustainability, 2014, “Planning Framework and Tools for Maine Communities,” University of Maine Climate Change Institute, <http://www.cci-reanalyzer.org/CLAS/>, accessed May 23, 2015.

## Best Practice: Florida’s Adaptation Action Areas

“Adaptation action area” or “adaptation area” is an optional comprehensive plan designation for the purpose of prioritizing funding for infrastructure needs and adaptation planning for areas that experience coastal flooding and that are vulnerable to the related impacts of rising sea levels. Local governments that adopt an adaptation action area may consider policies within the coastal management element to improve resilience to coastal flooding. Criteria for the adaptation action area may include the following:

- Areas below, at, or near mean higher high water
- Areas that have a hydrological connection to coastal waters
- Areas designated as evacuation zones for storm surge

Source: Section 163.3164(1), Florida Statutes<sup>73</sup>

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<sup>73</sup> Adaptation Action Area policies in Florida include the following: Section 163.3164(1), Florida Statutes (1): “‘Adaptation action area’ or ‘adaptation area’ means a designation in the coastal management element of a local government’s comprehensive plan, which identifies one or more areas that experience coastal flooding as a result of extreme high tides and storm surge and that are vulnerable to the related impacts of rising sea levels for the purpose of prioritizing funding for infrastructure needs and adaptation planning.” From Section 163.3177(6)(g)(10), Florida Statutes: “At the option of the local government, develop an adaptation action area designation for those low-lying coastal zones that are experiencing coastal flooding due to extreme high tides and storm surge and are vulnerable to the impacts of rising sea level. Local governments that adopt an adaptation action area may consider policies within the coastal management element to improve resilience to coastal flooding resulting from high-tide events, storm surge, flash floods, stormwater runoff, and related impacts of sea level rise. Criteria for the adaptation action area may include, but need not be limited to, areas for which the land elevations are below, at, or near mean higher high water, which have an hydrologic connection to coastal waters, or which are designated as evacuation zones for storm surge.” Find in: Florida Department of Economic Opportunity, undated, “Adaptation Planning in Florida,” <http://www.icleiusa.org/action-center/planning/adaptation-planning-in-florida>, accessed February 10, 2015.

## Key Finding #2

### Critical infrastructure is vulnerable to climate change impacts.

Critical infrastructure assets in the Casco Bay Region are vulnerable to point failures of individual nodes, as well as broader systemic failures resulting from climate change.

Coastal electric infrastructure assets are vulnerable to sea level rise and storm surge, which could lead to local power outages impacting dependent infrastructure systems. Analysis of the region's electrical power system revealed that 13 power plants (with a combined generating capacity of 311 MW) and 15 coastal substations could be affected by the storm surge inundation from a Category 2 hurricane. The total reduction in active electrical generation internal to the State of Maine would be approximately 14 percent, resulting in localized power outages.

CMP noted that increasing storm intensity has necessitated a greater effort in removing downed trees from power lines and rights-of-way. In addition, higher seasonal temperatures raise seasonal electricity demand, while simultaneously reducing power plant and transmission line capacity, resulting in the increased potential for rolling brownouts across the region in the coming decades if the electric infrastructure is not adapted. Indirectly, higher temperatures may also be extending the range of invasive species, such as the emerald ash borer, and leading to the spread of disease, such as beech bark disease—both factors that weaken trees and lead to greater power-line damage during storm events.<sup>74,75,76</sup>

Similarly, storm surge and heavy precipitation can adversely affect low-lying roads and causeways, rail lines, and marine infrastructure,<sup>77</sup> thereby disrupting mobility within the region and accessibility to critical facilities. Short-duration, high-intensity rainfall events in Maine have led to dam overtopping because of inadequate spillway capacity, which can directly affect roadways.<sup>78</sup> Other infrastructure vulnerabilities can result from broader or indirect systemic impacts. Sea level rise and resulting increases in coastal aquifer salinity could significantly degrade the quality of drinking-water supplies in the region, and higher seasonal temperatures in 1999 were associated with 1,000 private wells drying up. When combined with heavy runoff, higher temperatures can also lead to algal blooms, which can also negatively affect water quality.<sup>79</sup>

In spite of these vulnerabilities, actions to adapt infrastructure to future climate are inconsistent across sectors and municipalities in the Casco Bay Region. For example, in the Transportation Sector, MaineDOT is currently participating in a FHWA-sponsored climate change resilience project to assess

#### Key Sources That Support Finding #2

Facilitated Workshops  
Storm Surge Modeling  
Electrical Power Analysis  
Waterfronts of Portland and South  
Portland Maine Urban Land Institute  
Resilience Panel Report

<sup>74</sup> DHS Energy Sector Workshop QLR.

<sup>75</sup> Kasson, M.T., 2014, *Relationships among Beech Bark Disease, Climate, Radial Growth Response and Mortality of American Beech in Northern Maine, USA*, May 27, [http://www.researchgate.net/publication/249644023\\_Relationships\\_among\\_beech\\_bark\\_disease\\_climate\\_radial\\_growth\\_response\\_and\\_mortality\\_of\\_American\\_beech\\_in\\_northern\\_Maine\\_USA](http://www.researchgate.net/publication/249644023_Relationships_among_beech_bark_disease_climate_radial_growth_response_and_mortality_of_American_beech_in_northern_Maine_USA), accessed February 4, 2015.

<sup>76</sup> DeSantis, R.D., W.K. Moser, D.D. Gormanson, M.G. Bartlett, and B. Vermunt, 2013, "Effects of Climate on Emerald Ash Borer Mortality and the Potential for Ash Survival in North America," *Agricultural and Forest Meteorology*, April 21, [http://www.fs.fed.us/nrs/pubs/jrnl/2013/nrs\\_2013\\_desantis\\_001.pdf](http://www.fs.fed.us/nrs/pubs/jrnl/2013/nrs_2013_desantis_001.pdf), accessed February 12, 2015.

<sup>77</sup> DHS Transportation Sector Workshop QLR.

<sup>78</sup> Ibid.

<sup>79</sup> DHS Water/Wastewater Sector Workshop QLR.

vulnerabilities to sea level rise and storm surge. Infrastructure managers are taking these impacts into account in order to adapt existing and planned transportation infrastructure to future climate.<sup>80</sup> Conversely, in the Energy Sector, Independent System Operator (ISO) New England, Inc. (ISO New England), is not addressing climate change in its planning activities to determine the grid enhancement requirements necessary to meet future demand given projected temperature increases.<sup>81,82</sup> Major infrastructure projects such as new roadways or electric transmission lines can take decades to plan, design, and build; therefore, climate change must be accounted for early in the planning process to ensure that a resilient built environment exists in the future.

A factor that contributes to the lack of climate change adaptation planning for critical infrastructure in the Casco Bay Region is a deficiency of locally relevant guidance and data. Currently available climate change projections, such as those provided by the National Climate Assessment for New England<sup>83</sup> and *Maine's Climate Future*,<sup>84</sup> provide a valuable understanding of general impacts. However, they lack the spatial resolution and specificity typically needed to directly inform local infrastructure planning, design, and policy decisions. For example, the projections currently available for future precipitation are generally not actionable for climate adaptation, as modeling of precipitation effects at the watershed level is required before flooding risk can be understood and incorporated into infrastructure planning, design, and development programs.<sup>85,86</sup> There is also a perceived absence of guidance from the State as to how best to proceed with adaptation planning. Participants in the Transportation Sector workshop noted that climate modeling produces a range of projections and that guidance from the State is needed to inform specific design decisions.<sup>87</sup> Across sectors it was also widely noted that, because of the complexity of critical infrastructure adaptation planning, agencies often need outside consulting and require additional funding.<sup>88</sup> Thus, without access to locally relevant climate data or clear guidance from the State of Maine, agencies indicate that it will be difficult to pursue effective adaptation planning.

## Resilience Enhancement Options

A detailed understanding is needed of the specific magnitude, timeline, and extent of climate change hazards that the region will experience in the coming decades to guide critical infrastructure adaptation. To address these issues and aid in the better understanding of specific infrastructure vulnerabilities and adaptation measures, the CBCCC, with support from the CPR-TF and infrastructure owners and operators, should consider the following Resilience Enhancement Options:

- Obtain access to downscaled local-level climate projections and develop guidelines to use these data through the CLAS online platform. This information will contribute to a more detailed

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<sup>80</sup> Merrill, S.B., and J. Gates, 2014, *Integrating Vulnerability Assessments and Criticality Analyses into Asset Management at MaineDOT*.

<sup>81</sup> DHS Energy Sector Workshop QLR.

<sup>82</sup> ISO New England, Inc., 2013, *2013 Regional System Plan*, November 7, [www.iso-ne.com/trans/rsp/2013/rsp13\\_final.docx](http://www.iso-ne.com/trans/rsp/2013/rsp13_final.docx), accessed May 12, 2015.

<sup>83</sup> Melillo, J.M., T.C. Richmond, and G.W. Yohe, eds., 2014, *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program, <http://nca2014.globalchange.gov/downloads>, accessed February 16, 2015.

<sup>84</sup> Fernandez, I.J., C.V. Schmitt, S.D. Birkel, E. Stancioff, A.J. Pershing, J.T. Kelley, J.A. Runge, G.L. Jacobson, and P.A. Mayewski, 2015, *Maine's Climate Future: 2015*, University of Maine, [http://cci.siteturbine.com/uploaded\\_files/climatechange.umaine.edu/files/Maines\\_Climate\\_Future\\_2015\\_UpdateFinal-1.pdf](http://cci.siteturbine.com/uploaded_files/climatechange.umaine.edu/files/Maines_Climate_Future_2015_UpdateFinal-1.pdf), accessed April 13, 2015.

<sup>85</sup> DHS Transportation Sector Workshop QLR.

<sup>86</sup> DHS Energy Sector Workshop QLR.

<sup>87</sup> DHS Transportation Sector Workshop QLR.

<sup>88</sup> Ibid.

understanding of local climate impacts and can be used to inform adaptation plans, infrastructure design, and policy decisions.

- Facilitate discussions with ISO New England to obtain a better understanding of climate change impacts on the region’s energy system, with specific focus on generation and transmission of electric power (e.g., reduction in natural gas power plant generation capacity owing to increasing temperatures) and identify planning criteria and technological options for adapting infrastructure to future climate conditions. The California Energy Commission (CEC) is conducting an in-depth study of the vulnerability of the California energy system to climate change that could serve as a model for CBCCC and CPR-TF engagement with ISO New England. The CEC recently held a series of workshops on selecting “Climate Scenarios for the California Energy Sector”. During the CEC workshops, high-resolution (spatial and temporal) regional scenarios were presented to support long-term adaptation planning. The purpose of the CEC workshops was to bring together groups that are developing climate scenarios relevant to California to identify opportunities for coordinating research efforts. The workshops also included technical discussions about the desired characteristics of climate projections for the energy system.
- Develop a Resilient Power Implementation Plan that identifies solutions that will allow the energy system to respond more effectively to disturbances, such as those caused by climate change, and to operate more efficiently. The plan should consider the unique technological and financial challenges of integrating large shares of renewables, in addition to dynamic elements such as storage or demand-side management that facilitate renewable integration and reduce the total system cost.<sup>89</sup> The Clean Energy Group’s Resilient Power Project<sup>90</sup> identifies the following steps to guide implementation of resilient power solutions:

  - Identify the list of top critical facilities in need of protection.
  - Assess the critical power loads that need power protection in each priority facility.
  - Conduct an engineering assessment of critical loads.
  - Develop a viable financial plan with private developers.
  - Develop and supervise an implementation and oversight plan.<sup>91</sup>

National Preparedness Goal Core Capabilities Addressed
Planning
Public Information
Risk and Disaster Resilience Assessment
Threats and Hazard Identification
Critical Transportation
Infrastructure Systems

The City University of New York Smart Distributed Generation (DG) Hub project (see below) and the Metropolitan Washington Council of Governments microgrid planning projects provide examples of similar efforts to foster development of resilient power solutions. Microgrids are especially attractive options for coastal areas susceptible to storm surge and nuisance flooding. If properly built, microgrids can survive flooding and enable buildings or infrastructure systems to

<sup>89</sup> DOE Office of Electricity Delivery and Energy Reliability, undated, “Energy Storage,” <http://energy.gov/oe/services/technology-development/energy-storage>, accessed February 13, 2015.

<sup>90</sup> Clean Energy Group’s Resilient Power Project is designed to help states and municipalities with program and policy information, analysis, finance tools, technical assistance, and best practices to speed the deployment of clean, resilient power systems in their communities. This series of reports describes the continuing efforts of the Clean Energy Group to make resilient power a major part of disaster planning and energy policy—work that is now showing results in new State and local programs to fund resilient power across the country. See Clean Energy Group Resilient Power Project, <http://www.cleanegroup.org/ceg-projects/resilient-power-project>, accessed May 13, 2015.

<sup>91</sup> Sanders, R., and L. Milford, 2015, *Resilient Power: What Cities Should Do, A Guide to Resilient Power Planning*, March, <http://www.cleanegroup.org/assets/2015/Resilient-Cities.pdf>, accessed May 13, 2015.

get back online quickly. For example, the City of Boston is promoting increased use of microgrids in waterfront areas, where storm surges could knock out power systems.<sup>92</sup>

- Incorporate high-resolution precipitation data into hydrological modeling of future climate through watershed-specific intensity duration frequency (IDF) curve development. IDF curves provide a graphical representation of the likelihood that a rainfall event of a given intensity will occur, which is necessary when designing drainage systems and hydraulic structures (e.g., culverts, bridge piers). Projected rainfall and runoff IDF curves will enable today's designs to remain robust in the future.
- Develop a plan to protect critical facilities against long-term sea level rise, storm surges, and intense storm events. The plan should provide a mechanism to assess existing infrastructure vulnerabilities and adapt those systems, as needed, over time. This also requires forward-thinking design practices that account for the projected impacts of climate change in both the redesign of those existing systems and in the planning and design of new and/or replacement infrastructure.

### Smart DG Hub—Resilient Power Project

New York City has seen tremendous growth in solar power in recent years, from 45 installations (1.1 MW) in 2005 to more than 2,600 installations (42.6 MW) in 2015. However, much of this solar generation capacity is disconnected from the city's power grid, which remains vulnerable to unforeseen disruptions or spikes in demand. For example, the impacts of Hurricane Sandy disrupted critical nodes in the power grid, leading to widespread blackouts in large sections of New York City. Although none of the 672 solar arrays that were installed on New York City rooftops within the affected area were damaged by the storm, their power generation capacity could not be utilized by those without power because of their disconnection from the city's power grid. In the aftermath of Hurricane Sandy, it was determined that New York City would benefit from a coordinated focus to incorporate emergency functionality within existing and future distributed generation deployment.

The Smart DG Hub project, led by the City University of New York with Federal, State, and local stakeholders including DOE, DHS, FEMA, the National Renewable Energy Laboratory, and Con Edison, among others, is seeking to ensure broader energy system resilience by integrating distributed solar generation capabilities. By "retrofitting existing systems with inverters that offer 'daylight emergency power,'" Smart DG not only can supply emergency power but also can "play a critical energy-saving role in peak shaving and load shifting when the grid is constrained or when consumers are anticipating heavy energy usage," for example, during heatwaves when energy demand for air conditioning increases significantly. In addition, it can better guard against major disruptions and blackouts resulting from increasing extreme weather events such as hurricane-induced storm surges.

Sources: Clean Energy Group, 2015, *Resilient Cities: Clean Energy to Power Critical Public and Private Facilities*, April 2, <http://www.cleanenergygroup.org/assets/2015/RPP-Resilient-Cities-webinar-slides-4.2.15.pdf>, accessed May 15, 2015; The City University of New York, 2015, "Smart DG Hub: Emergency Power." <http://www.cuny.edu/about/resources/sustainability/SmartDGHubEmergencyPower.html>, accessed May 15, 2015.

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<sup>92</sup> Fitzgerald, M., 2014, "How Boston Is—and Should Be—Preparing for Rising Seas," *The Boston Globe*, April 4, <http://www.bostonglobe.com/magazine/2014/04/04/how-boston-and-should-preparing-for-rising-seas/8mF4YVWgAMzDGQexMF35FK/story.html>, accessed May 13, 2015.

# Key Finding #3

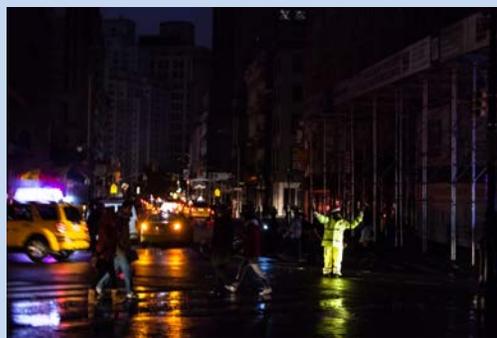
## Critical dependencies and interdependencies exist that can compound climate impacts across multiple infrastructure systems.

Assessing infrastructure resilience requires consideration of many interconnected climatic, socioeconomic, ecological, and technical elements. Examination of these interconnections reveals that disruption or failure of one element can lead to cascading failures in others. These dependencies and interdependencies among infrastructure systems lead to a level of complexity that masks many systemic risks. As a result, an impact on a single node or link—the proverbial “single point of failure” that is often hidden deep within these interconnected systems—can result in significant economic and physical damage on a city-wide, regional, national, or international scale.<sup>93</sup>

### Key Sources That Support Finding #3

Facilitated Workshop Discussions  
Electrical Power Infrastructure Analysis

In October 2012, Hurricane Sandy made landfall on the coast of New Jersey, where storm surges and heavy winds caused widespread damage to infrastructure systems throughout the Northeast. In New York City, storm surge, high winds, and flooding disrupted a small number of substations in lower Manhattan that contributed significantly to a power outage affecting more than 1 million customers, including over 190,000 customers in Manhattan and 158,000 customers in Westchester County. Infrastructure disruptions included five Consolidated Edison substations, 13 networks in Manhattan, one in Brooklyn, and three substations on Staten Island. In addition, four Long Island Power Authority substations were disrupted (primarily affecting the Rockaways area). These point failures of a small number of electrical power system nodes led to cascading failures that affected other critical infrastructure systems. For example, both New Jersey Transit and the [New York] Metropolitan Transportation Authority (MTA) were operationally impacted by power outages; the MTA was not able to provide rail service below 34th Street because of flooding and the lack of power. Similarly, fewer than 40 percent of gas stations in the New York metro area were operational because of the lack of power even three days after the storm, thus affecting the fuel sector as well as transportation.



Nguyen, D., 2012, “Sandy Blackout at Union Square and Broadway,” *Flickr*, October 30 <https://www.flickr.com/photos/zokuga/8142068055>, accessed May 27, 2015 (some rights reserved).

Sources: Heslin, M.F., 2012, “Initial Report of Consolidated Edison Company of New York, Inc., Concerning Network and Load Area Outages Resulting from Superstorm Sandy. Case 09-E-0428—Proceedings on Motion of the Commission as to the Rates, Charges, Rules and Regulations of Consolidated Edison Company of New York, Inc., for Electric Service Reliability Performance Mechanism—Major Outage Metric,” December 13, <http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B27E96B0D-8163-4AA1-8F1E-DF1B3969BD2F%7D>, accessed May 27, 2015; Con Edison, 2012, “Worst Storm Damage Ever Rips Con Edison Equipment,” <http://www.coned.com/newsroom/news/pr20121030.asp>, accessed April 3, 2015; Gibbs, L.I., and C.F. Holloway, 2013, *Hurricane Sandy After Action: Report and Recommendations to Mayor Michael R. Bloomberg*, May, [http://www.nyc.gov/html/recovery/downloads/pdf/sandy\\_aar\\_5.2.13.pdf](http://www.nyc.gov/html/recovery/downloads/pdf/sandy_aar_5.2.13.pdf), accessed May 27, 2015; and Kaufman, S., C. Qing, N. Levenson, and M. Hanson, 2012, *Transportation During and After Hurricane Sandy*, Rudin Center for Transportation, NYU Wagner Graduate School of Public Service, November, <http://wagner.nyu.edu/files/rudincenter/sandytransportation.pdf>, accessed May 27, 2015.

Workshops conducted as part of the Casco Bay RRAP revealed that the region does not have a comprehensive understanding of infrastructure dependencies and interdependencies or the associated cascading effects that could be triggered as a result of disruptions caused by climate change hazards.

<sup>93</sup> Argonne, 2015, Critical Infrastructure Dependencies and Interdependencies Analysis.

Developing this understanding is necessary to developing effective and prioritized adaptation strategies that improve the region’s resilience.

Most critical infrastructure depends, to varying degrees, on the Energy Sector, and especially electricity (which itself depends on other energy sectors for generation, such as natural gas). Water and wastewater facilities rely on electric power to transport and clean water; the Transportation Sector relies on electricity to control traffic operations; and the Telecommunication Sector relies on electric power to run facilities such as cellular phone towers. Many infrastructure nodes, such as water treatment and remote telecommunication facilities, also rely on petroleum products for backup power generation, which, in turn, depend on transportation facilities for access—many of which are vulnerable to climate change hazards. For example, during the telecommunications workshop, participants noted that remote telecommunications sites are becoming more difficult to reach to provide fuel for backup generators during a power outage because of increasingly high-intensity storms that cause erosion of access roads.<sup>94</sup>

## Resilience Enhancement Options

To better understand specific infrastructure vulnerabilities and how both climate change and dependencies and interdependencies influence risk, the CBCCC, with support from the CPR-TF, should participate in ongoing dependency research and analysis with DHS.

The goal of the dependency research and analysis is to better understand climate change risks and cascading impacts on lifeline infrastructure systems and provide the CBCCC with options to inform adaptation of infrastructure systems to these risks. The objectives of the dependency research and analysis include providing CBCCC partners with:

- A scalable approach for identifying and analyzing lifeline system dependencies of critical infrastructure within their sector-specific areas of responsibility.
- Area/region-based analysis identifying resilience capabilities that mitigate dependency issues (e.g., through support to State Threat and Hazard Identification and Risk Assessment [THIRA] planning, enhanced State and local hazard mitigation plans, the identifying of training and exercise needs, or the guiding of future adaptation planning requirements).
- A baseline process and preliminary tools to identify critical infrastructure lifeline dependencies.

Dependency research and assessment efforts should include the following general data collection and analysis tasks and will:

- Develop a characterization of the lifeline infrastructure systems;
- Collect and validate dependency data;
- Develop final products that characterize dependencies; and
- Develop a strategic business case for long-term dependency analysis to inform climate change adaptation planning.

### National Preparedness Goal Core Capabilities Addressed

Planning
Community Resilience
Long-term Vulnerability Reduction
Risk and Disaster Resilience Assessment
Critical Transportation
Infrastructure Systems

<sup>94</sup> DHS Telecommunication Sector Workshop QLR.

# Conclusion

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DHS IP, the State of Maine, and all the stakeholders involved in the Casco Bay RRAP intend for this Assessment Report, along with all associated documents and data, to provide valuable information to address climate change hazards to the electrical power, telecommunications, transportation, and water industries, and to the region at large. IP views the Casco Bay RRAP as the beginning of valuable partnerships that will continue to enhance resilience development in the region.

The Casco Bay RRAP integrates the expertise and knowledge of participants within the region, including emergency planners, responders, and infrastructure providers, to assess gaps and identify possible options to help ensure the long-term resilience of the lifeline infrastructure systems. The Resilience Enhancement Options for the Casco Bay RRAP identify supporting resources that can serve as a starting point to inform Resilience Enhancement Options of critical infrastructure systems within the region. In addition to the resources identified in the individual Key Findings, the following paragraphs describe additional sources for funding or assistance for implementing the Resilience Enhancement Options.

In the year following delivery of this Assessment Report, DHS will be available to provide technical assistance to Federal, State, and local officials; private industry; and other stakeholders to assist them in working together to implement select Resilience Enhancement Options.

In addition, Federal grant funding is available to States, tribal and territorial governments, local governments, not-for-profit organizations, and public-private partnerships to support resilience enhancement activities. For example, **the Homeland Security Grant Program (HSGP) identifies implementation of RRAP-related resilience enhancements as allowable costs for State and urban area grantees.**<sup>95</sup> Together, these activities support implementation of *Presidential Policy Directive 21: Critical Infrastructure Security and Resilience* (PPD-21)<sup>96</sup> and *Presidential Policy Directive 8: National Preparedness* (PPD-8),<sup>97</sup> which recognize that building and sustaining disaster resilience require a combination of organizational resources, equipment, training, and education.

Moreover, **many Resilience Enhancement Options can be implemented without dedicated Federal grant funds.** Communities can incorporate resilience features or principles into existing budgeted investments and planning activities at little or no additional cost. Avenues for advancing Resilience Enhancement Options from the RRAP as well as broader security and resilience improvements include the following:

- *Community infrastructure improvement planning.* Resilience measures can be incorporated or mainstreamed<sup>98</sup> into existing community planning efforts for land use and transportation, or asset management practices. Such plans may include improvements to transportation infrastructure, zoning and style guides for commercial structures, changes to public structures or spaces, or

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<sup>95</sup> FEMA, 2014, “FY 2014 Homeland Security Grant Program (HSGP) Funding Opportunity Announcement,” March 18, <http://www.fema.gov/media-library/assets/documents/92397>, accessed March 20, 2014.

<sup>96</sup> DHS, undated[a], “Strengthening the Security and Resilience of the Nation’s Critical Infrastructure,” <http://www.dhs.gov/strengthening-security-and-resilience-nation%E2%80%99s-critical-infrastructure>, accessed December 17, 2013.

<sup>97</sup> DHS, 2011, “Presidential Policy Directive/PPD-8: National Preparedness,” March 30, <http://www.dhs.gov/presidential-policy-directive-8-national-preparedness>, accessed December 17, 2013.

<sup>98</sup> Mainstreaming climate change adaptation refers to the “process of integrating considerations of climate change adaptation into policy-making, budgeting, implementation and monitoring processes at national, sector and subnational levels.” UNEP, 2011, “Mainstreaming Climate Change Adaptation into Development Planning: A Guide for Practitioners,” United Nations Environment Program: Geneva.

hazard mitigation measures. In addition, redevelopment may offer opportunities to take steps that support development decisions and investments in infrastructure that will enhance the resilience of critical infrastructure systems.<sup>99</sup>

- *Structured approach to risk management.* Many government and industry partners use risk management models that can be applied to critical infrastructure. Effective risk management enables the critical infrastructure community to focus on those threats and hazards that are likely to cause harm and employ approaches that are designed to prevent or mitigate the effects of those incidents.
- *Emergency preparedness plans and exercises.* The inclusion of infrastructure restoration activities in plans and exercises can enhance infrastructure resilience. Exercises that address the loss of essential critical infrastructure services can promote learning and information exchange among public and private partners, result in more effective adaptation during and after incidents, and lead to improvements in emergency preparedness and mitigation plans.<sup>100</sup>
- *Vulnerability identification.* Identifying and analyzing the vulnerabilities of critical infrastructure enables critical infrastructure partners to take action to mitigate the risks they pose.

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<sup>99</sup> DHS, undated[b], *NIPP Supplemental Tool: Incorporating Resilience into Critical Infrastructure Projects*, <http://www.dhs.gov/publication/incorporating-resilience-critical-infrastructure-projects>, accessed January 28, 2014.

<sup>100</sup> DHS, undated[c], *NIPP Supplemental Tool: Executing a Critical Infrastructure Risk Management Approach*, <http://www.dhs.gov/publication/executing-critical-infrastructure-risk-management-approach>, accessed January 28, 2014.

# Key Terms, Acronyms, and Abbreviations

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AR5	Fifth Assessment Report, of the United Nation’s Intergovernmental Panel on Climate Change
Argonne	Argonne National Laboratory
CBCCC	Casco Bay Climate Change Coalition
CBEP	Casco Bay Estuary Project
CDI	Climate Date Initiative
CEC	California Energy Commission
CEQ	Council on Environmental Quality
CLAS	Climate Adaptation and Sustainability
CLF	Conservation Law Foundation
CMP	Central Maine Power
CPR-TF	Climate Preparedness and Resilience Task Force
CRT	Climate Resilience Toolkit
DEP	Department of Environmental Protection (State of Maine)
DG	Distributed Generation
DHS	U.S. Department of Homeland Security
DOE	U.S. Department of Energy
DST	Decision Support Tool
E.O.	Executive Order
EPA	U.S. Environmental Protection Agency
F	Fahrenheit
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FY	Fiscal Year
GHG	Greenhouse Gas
GPCOG	Greater Portland Council of Governments
HSGP	Homeland Security Grant Program
IDF	Intensity-Duration Frequency
IP	Office of Infrastructure Protection
IPCC	United Nations Intergovernmental Panel on Climate Change
IPCCAT	Office of Infrastructure Protection Climate Change Action Team
ISO	Independent System Operator
KM	Kilometer(s)
LMR	Land Mobile Radio

M&NP	Maritime and Northeast Pipeline
MaineDOT	Maine Department of Transportation
MEGIS	Maine Office of Geographic Information Systems
MEMA	Maine Emergency Management Agency
MPH	Mile(s) per Hour
MW	Megawatt(s)
NCA	National Climate Assessment
NCC	National Coordinating Center for Communications
NCCIC	National Cybersecurity and Communications Integration Center
NEPA	National Environmental Policy Act
NIPP	National Infrastructure Protection Plan
NOAA	National Oceanic and Atmospheric Administration
PDI	Power Dissipation Index
PNGTS	Portland Natural Gas Transmission System
PORT	City of Portland
PPD	Presidential Policy Directive
PSA	Protective Security Advisor
PSCD	Protective Security Coordination Division
PUC	Public Utility Commission
PWD	Portland Water District
QLR	Quick Look Report
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RRAP	Regional Resiliency Assessment Program
RST	Regional Support Team
SHSP	State Homeland Security Program
SLAWG	Sea Level Adaptation Working Group
SLR	Sea Level Rise
SME	Subject Matter Expert
SOPO	City of South Portland
THIRA	Threat and Hazard Identification and Risk Assessment
USGCRP	U.S. Global Change Research Program
USM	University of Southern Maine

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# Appendix A: Partner List

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## Federal

- U.S. Department of Homeland Security
  - National Protection and Programs Directorate
    - Office of Infrastructure Protection (IP)
    - Office of Cyber Security and Communications – National Cybersecurity and Communications Integration Center/National Coordinating Center for Communications
  - FEMA, Region I
- National Oceanic and Atmospheric Administration
- U.S. Environmental Protection Agency

## State

- Maine Governor’s Energy Office
- Maine Department of Environmental Protection
- Maine Emergency Management Agency
- Maine Office of Information Technology
- Maine Office of Geographic Information Systems
- Maine Department of Transportation
- Maine Department of Agriculture, Conservation and Forestry
- Maine Turnpike Authority
- Maine Port Authority
- University of Maine, Climate Change Institute
- University of Southern Maine
- University of Maine Extension

## Regional, County, and City Government

- Greater Portland Council of Government
- Cumberland County Emergency Management Agency
- City of South Portland
- City of Portland
- Portland Water District
- Town of Saco Water District

- Town of Brunswick Sewer District
- Town of Freeport
- Southern Maine Planning and Development Commission
- Casco Bay Estuary Partnership
- Portland Jetport

## Private Sector and Not-for-Profit Organizations

### Energy

- Trans-Canada/Portland Natural Gas Transmission System
- Central Maine Power
- Global Petroleum

### Communications

- AT&T Wireless
- Verizon Wireless

### Transportation

- St. Lawrence & Atlantic Railroad
- Casco Bay Lines

### Other

- Conservation Law Foundation

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# Appendix B: Maine's Climate Change Planning and Policy Timeline

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- 1996 The Maine Department of Environmental Protection (DEP) and the Casco Bay Estuary Project (now Casco Bay Estuary Partnership) produce the Casco Bay Plan, outlining wildlife habitat protection, improvements to water quality, and reductions in stormwater runoff pollution, combined sewer overflows, and toxic pollution.
- 2000 The State Planning Office drafts a Climate Action Plan.
- 2001 Governor King joins other northeastern U.S. governors and Eastern Canadian premiers in agreeing to regional greenhouse gas reduction goals.
- 2003 The Maine Legislature enacts the first law to address climate change (Public Law 2003, Chapter 237, An Act to Provide Leadership in Addressing the Threat of Climate Change), calling for a Climate Action Plan (which was subsequently finalized in 2004) for Maine with emission reduction goals at 10 percent below 1990 levels by 2020.
- 2006 The Maine Geological Survey completes a pilot study mapping future flooding associated with sea level rise in Wells, Maine.
- Maine DEP produces *Protecting Maine's Beaches for the Future*, documenting action strategies to create more resilient beaches and coastal communities, including consideration for the potential impacts of sea level rise.
- 2007 The Casco Bay Estuary Partnership and Maine Geological Survey complete a study in Casco Bay using LiDAR data to map existing and potential future coastal wetlands in response to sea level rise.
- Maine and other States adopt legislation to implement the Regional Greenhouse Gas Initiative.
- 2008 Through the Maine Coastal Program, Maine initiates the 5-year Coastal Hazard Resiliency Tools Project with funding from the National Oceanic and Atmospheric Administration (NOAA), and participation through the Maine Geological Survey and Southern Maine Regional Planning Commission.
- Maine takes part in the Nation's first regional greenhouse gas emissions auction.
- 2009 In response to a request from Governor Baldacci, the University of Maine Climate Change Institute drafts *Maine's Climate Future: An Initial Assessment*, examining climate-related changes in Maine ecosystems.
- The Casco Bay Estuary Partnership produces the report *Climate Change in the Casco Bay Watershed: Past, Present, and Future*, describing regional climate change and providing detailed analysis of regional meteorological data, including flood maps of the Portland area.

- 2010 In response to the University of Maine’s 2009 assessment, the State legislature directs the Maine DEP to establish and convene a stakeholder group to evaluate the options and actions available to prepare for and adapt to the impacts of climate change.

The Maine DEP produces *People and Nature, Adapting to a Changing Climate: Charting Maine’s Course*, a report outlining major recommendations related to bringing sea level rise planning tools, models, and technical data to the local decisionmaking level.

The Maine Geological Survey and Southern Maine Regional Planning Commission work with partner communities in Saco Bay to form the first regional Sea Level Adaptation Working Group (SLAWG), which creates the first regionally based vulnerability assessment of resilience of the built and natural environment to sea level rise and storms.

The Maine Natural Areas Program and the Maine Geological Survey, with funding from the U.S. Environmental Protection Agency (EPA), receive a grant to assess the impacts of sea level rise on marshes for southern to mid-coast Maine.

- 2011 The Maine Geological Survey produces the study *Preparing Portland for the Potential Impacts of Sea Level Rise*, which includes a scenario-based vulnerability assessment of impacts on buildings, roads, and wetlands, and recommends potential adaptation techniques.

The Maine Coastal Program, Maine Department of Inland Fisheries and Wildlife, and Maine Geological Survey (and other partners) apply for and receive a NOAA Project of Special Merit, titled *Integrating Science into Policy: Adaptation Strategies for Marsh Migration*.

- 2012 Greater Portland Council of Governments (GPCOG) and NOAA draft the *Casco Bay Environmental Planning Assessment*, discussing the progress of individual municipalities in addressing climate stress, adaptation, and mitigation strategies. A significant finding from the assessment is the need to include climate change hazards such as sea level rise in each municipality’s planning process (e.g., comprehensive plans) and that a framework for doing so should include identification of sea level rise overlay zones to officially designate these areas.

The GPCOG and Maine Geological Survey produce *Adapting to Sea Level Rise in South Portland*, which includes a vulnerability assessment depicting sea level rise scenarios using geographic information systems–based flood inundation mapping.

- 2013 The City of Saco, a member of the SLAWG, amends its Floodplain Management Ordinance to increase required freeboard from 1 to 3 feet for structures in the floodplain for the first time in Maine.

The Town of York develops and passes an Adaptation to Sea Level Rise Chapter in their Comprehensive Plan, the first in Maine.

The Maine Coastal Program, Maine Geological Survey, Maine Bureau of Parks and Lands, and Maine Natural Areas Program (and others) apply for and receive a NOAA Project of Special Merit titled *Changing Shorelines: Adaptation Planning for Maine’s Coastal State Parks*.

The Lincoln County Regional Planning Commission works with the Maine Geological Survey to assess the vulnerability of Lincoln County’s coastal communities to storms and sea level rise; this effort was the first “county-based” approach of its kind in Maine.

Legislation is introduced in the House of Representatives to convene a working group consisting of representatives from State and local governments, not-for-profit organizations, industry, and academia to look at the “high priority” recommendations among the 60 included in the 2010 DEP report.

The EPA produces a Climate Data Report for Portland, Maine, using the Climate Resilience Evaluation and Awareness Tool.

- 2014 The Maine Coastal Program, Maine Geological Survey, Maine Bureau of Parks and Lands, and the Maine Natural Areas Program (and others) apply for and receive a NOAA Project of Special Merit titled *Building Resiliency along Maine’s Bluff Coast* to identify potential future bluff vulnerability in response to shoreline erosion, storms, and sea level rise in the Casco Bay Region.

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