CASCO BAY
CLIMATE CHANGE VULNERABILITY REPORT

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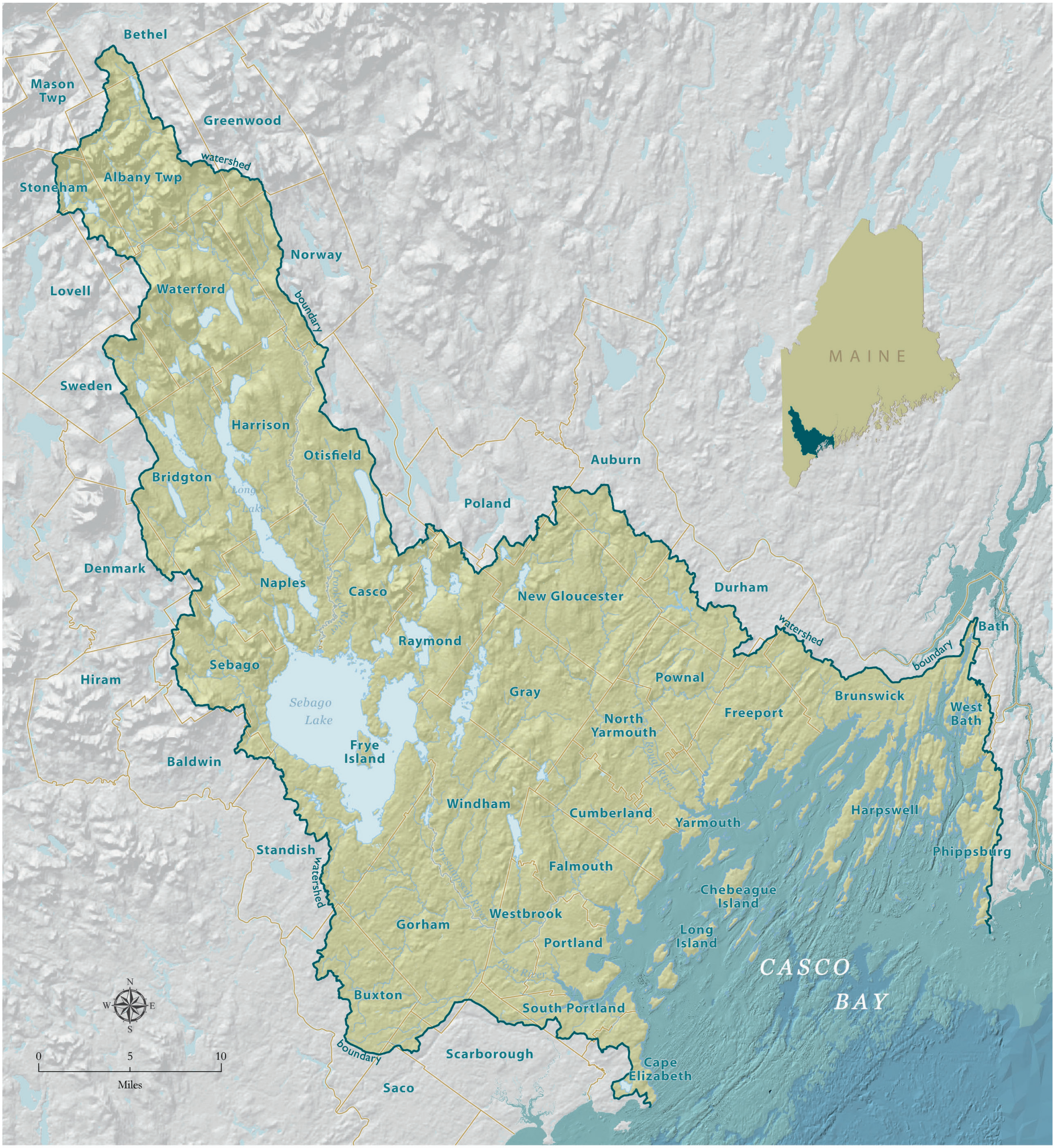

Map of Casco Bay and its watershed. Dark green line indicates watershed boundary.

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On the cover: A September 2015 storm that brought 5.6 inches of rain to Portland, coinciding with an astronomically high tide, caused extensive flooding and damage in Bayside and the Old Port. *Photo by Gabe Souza/Portland Press Herald*

INTRODUCTION

In 2016, Casco Bay Estuary Partnership (CBEP) released its revised Comprehensive Conservation and Management Plan as the *Casco Bay Plan 2016-21* (“the Plan”). The Plan details the Goals, Strategies, and Actions that guide CBEP’s efforts for the next five years to sustain a healthy bay.

The Plan contains four Goals:

Goal 1: Protect, restore and enhance key habitats that sustain ecological health

Goal 2: Reduce nutrient pollution and its impacts, including coastal acidification

Goal 3: Foster resilient communities and their connections to Casco Bay

Goal 4: Mobilize collective knowledge and resources to support Casco Bay

To work toward those Goals, CBEP will implement a total of 32 Actions. The complete Plan is available at www.cascobayestuary.org/planning-for-casco-bays-future.

Recognizing that climate change has important implications for implementation of the Plan, CBEP undertook a risk-based climate change vulnerability assessment. The objective was to facilitate successful implementation of the Plan by adjusting activities as needed to account for climate change-related risks. The assessment considered the potential impacts of seven classes of climate change stressors—warmer summers, warmer winters, warmer water, increasing drought, increasing storminess, sea level rise, and ocean acidification—on Plan implementation.

Section 1: As a foundation for the climate vulnerability assessment, CBEP began by summarizing current scientific evidence of the seven climate stressors within Maine and within the Casco Bay watershed. In 2015, Marina Schauffler of Natural Choices prepared the “Climate Trends in the Casco Bay Region” report presented in Section 1.

Section 2: Focusing on the seven classes of climate change stressors, CBEP then developed a draft list of 79 potential climate change-related risks to implementation of the Plan’s Actions. Following the guidelines of EPA’s *Workbook for Developing Risk-Based Adaptation Plans*, CBEP estimated the probability and consequence of each risk for three timeframes: short (10-20 years), medium (30-40 years), and long (80-100 years).

Peter Taylor of Waterview Consulting managed a peer review process to ensure that the draft list of climate-related risks was complete and accurate, and that the probability/consequence estimates aligned with expert consensus. Based on analysis of the peer review data in consultation with CBEP, Waterview Consulting revised the risks and identified 25 Risks of Primary Concern (RoPCs) for Plan implementation and analyzed linkages between the RoPCs and the Plan Actions.

Section 3: To inform Casco Bay Plan implementation, Waterview Consulting and CBEP next considered the relationships between the Risks of Primary Concern and the Plan’s Actions.

Section 4: The 25 Risks of Primary Concern have the potential to affect CBEP’s ability to meet the goals of the Casco Bay Plan. In this section, CBEP identifies its approach for each risk and details possible adaptation reactions related to that approach.

Section 5: During the peer review process, reviewers provided recommendations about key areas for research related to the Risks of Primary Concern and implementation of the Casco Bay Plan. In addition, Waterview Consulting developed key takeaways and recommendations for Plan implementation. To support implementation, Natural Choices produced in 2015 the Climate Adaptation Resource Guide for Casco Bay Communities presented in Appendix C.

SECTION ONE

Climate Trends in the Casco Bay Region

Overview

The Casco Bay region is vulnerable to all seven of the climate stressors identified by the US Environmental Protection Agency (US EPA): warmer summers; warmer winters; warmer waters; increased drought; increased storminess (evident in higher total precipitation, frequency and intensity); sea level rise; and ocean acidification (US EPA 2014). These climate stressors do not operate in isolation. Compounding their impacts are factors such as population growth, habitat fragmentation and destruction, and resource depletion that can further tax ecosystems and species.

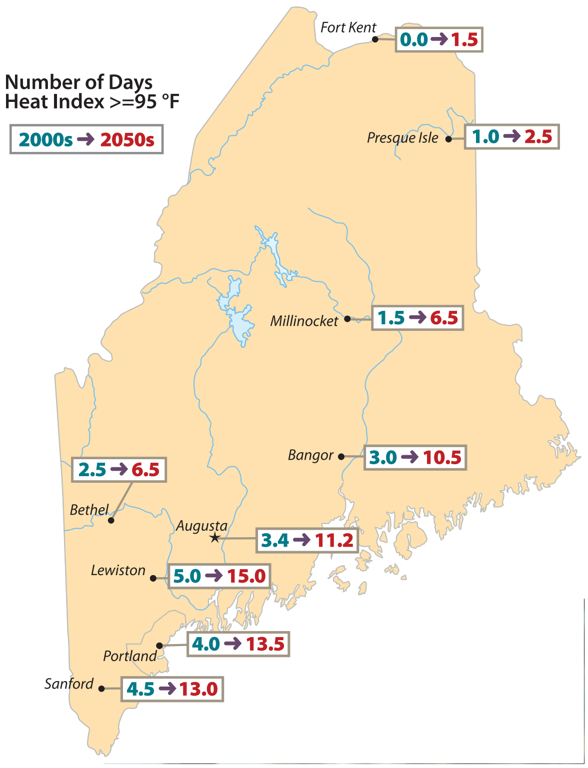
This section summarizes current scientific evidence of these trends within Maine and, where possible, within the Casco Bay watershed (which coincides closely with the geographical boundary of Cumberland County).

Warmer Summers

Between 1895 and 2014, the average annual temperature across Maine warmed by about 3°F (Fernandez et al. 2015). Portland, during this same time period, warmed by about 4°F (National Climatic Data Center). By mid-century, models employed by the Intergovernmental Panel on Climate Change (IPCC) predict that annual air temperatures across Maine will rise another 3 to 5°F (Fernandez et al. 2015). Downscaled climate modeling done for the Casco Bay watershed in 2009 predicts mid-century temperature increases of 2 to 6°F (depending on future greenhouse gas emissions) and end-of-century temperatures in the 3 to 8°F range (Wake et al. 2009). Under a high-emissions scenario, summer temperatures could experience a dramatic change up to 10°F warmer (Wake et al. 2009).

A high-emissions scenario drives the number of days with temperatures over 90°F up to 60 each year, with potentially dangerous impacts on human health and the electricity grid (Wake et al. 2009). Portland's average number of extremely hot days—those with a heat index equal to or greater than 95° F—is expected to increase by mid-century from the current average of 4 to 13.5 days annually (Fernandez et al. 2015). Continued high emissions could raise that number to 35 by the end of the century—with the hottest day for Portland under this scenario reaching 114°F (Wake et al. 2009).

Warming air temperatures and more frequent heat waves pose public health concerns. In the event of heat waves, the Casco Bay region has limited air conditioning and no cooling centers. Higher temperatures can exacerbate unhealthy ground-level ozone, airborne allergens, and the spread of vector-borne diseases like babesiosis, anaplasmosis and Lyme disease. The rising incidence of these diseases, which are linked to a warmer and wetter climate, has transformed the way that Maine residents work and play outdoors.



Source: Maine's Climate Future—2015 Update
http://climatechange.umaine.edu/research/publications/climate-future

Warming air temperatures (in all seasons) will place additional stress on wildlife species already contending with invasive species, habitat loss, pollution and—in some cases—heavy harvesting (Stein et al. 2014). Ecosystem disruptions will affect human communities as well through the diminished capacity of natural systems to provide functions like water filtration and pollination (Stein et al. 2014).

Warmer Winters

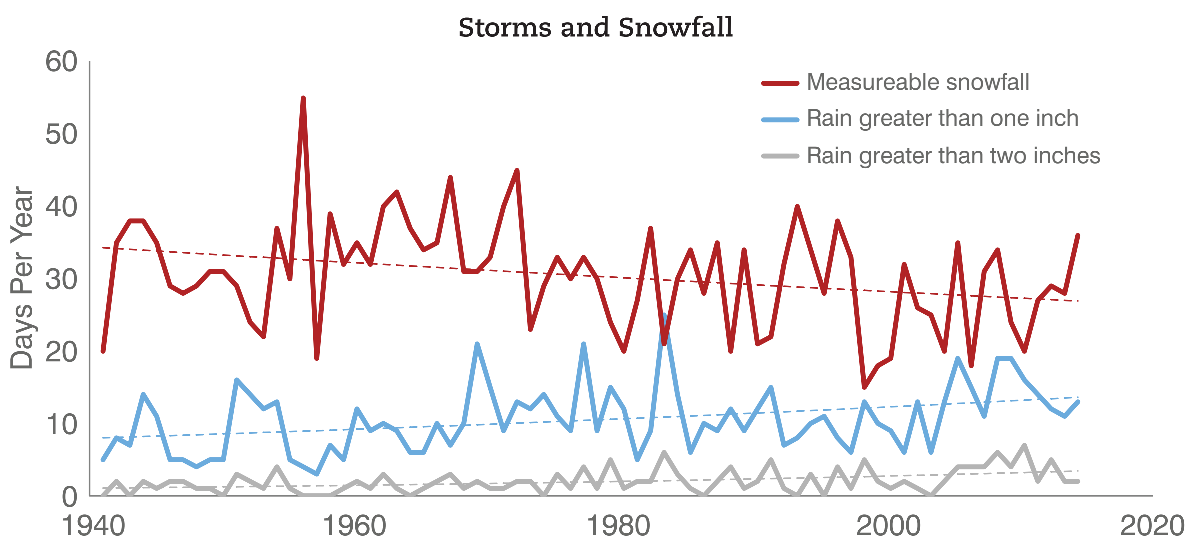
Historical data for the Portland Jetport (from the National Centers for Environmental Information) confirm that air temperatures have been increasing gradually for decades, and that winters are warmer than they were a generation ago (CBEP 2015). Recently, Maine winters have been warming at a faster rate than summers (Fernandez et al. 2015).

Rising minimum temperatures have reduced the number of freezing days and very cold days (with temperatures below zero) (CBEP 2015). By the end of this century, climate scientists anticipate that Portland will have 15 to 30 fewer days with minimum temperatures below 32°F (Wake et al. 2009). Along the coast, days with temperatures below zero could drop from the current 10 days per year to 1 if emissions remain high (Wake et al. 2009).

Days with measurable snowfall have declined about 20 percent in the past 65 years as more winter precipitation arrives as rain (CBEP 2015). Over the last century, the duration of snowpack through Maine's winter has decreased by about two weeks, and climate models suggest that another two weeks could be lost by mid-century (Fernandez et al. 2015). Climate scientists project that total winter snow loss along Maine's southern coast could exceed 40 percent by mid-century (2035-2054) relative to the recent climate (1995-2014) (Fernandez et al. 2015).

Based on historical records, Sebago Lake ice-out in the spring occurs 23 days earlier than it did in 1807 (reflecting a pattern in southern Maine and New Hampshire of ice-outs averaging 16 days earlier from 1850 to 2000) (Wake et al. 2009).

A 2012 study using regional climate models found temperature changes of 2-3°C (3.6-5.4°F.) warmer for the period from 2041 to 2070, with winter changes exceeding 3°C for more than half of the northeastern US (Rawlins et al. 2012). The National Climate Assessment predicts that Maine winters will be wetter as well as warmer, with a 10-20 percent increase in precipitation (Horton et al. 2014).



Source: http://www.cascobayestuary.org/wp-content/uploads/2015/10/Indicator_ClimateChange.pdf

Warmer Waters

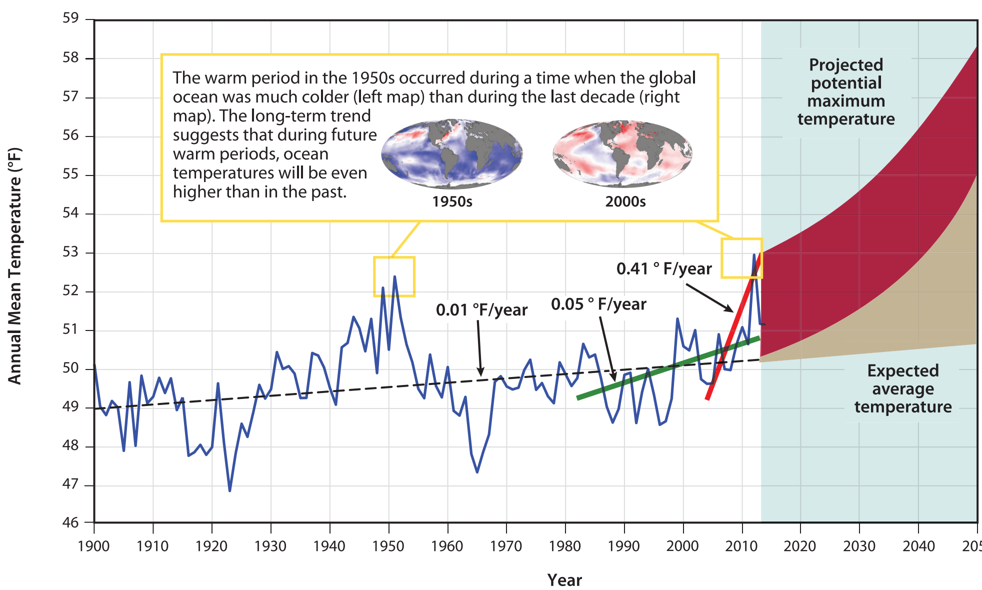
The Gulf of Maine warmed faster between 2004 and 2013 than 99 percent of the world's ocean, according to a recent study (Pershing et al. 2015). During that period, warming within the Gulf of Maine reached a rate of 0.41°F (0.23° C) per year. Since the mid-1990s, water temperatures in Casco Bay have increased about 3°F (CBEP 2015).

In 2012, Casco Bay was subject to an "ocean heat wave"—the largest and most intense such event that the Northwest Atlantic has experienced in three decades—which stretched from North Carolina to Iceland (with especially marked warming in the Gulf of Maine) (Mills et al. 2013). In response to a 1-3°C (1.8-5.4°F) temperature increase (on par with what could be expected by the end of this century), marine species showed marked changes in their seasonal cycles and distribution, abundance, growth and mortality (Mills et al. 2013). During the 2012 heat wave, lobsters moved inshore several weeks earlier than normal—causing a spike in landings that outstripped market demand and led to a price collapse (Mills et al. 2013).

As regional species shift in response to warmer (and more acidic) coastal waters, many traditional fisheries—including the iconic lobster—may be disrupted. To date, some of the most marked shifts in range have occurred in sought-after finfish species like winter flounder, Atlantic cod and silver hake (Mills et al. 2013). As climate change progresses, raising the incidence of temperature extremes in coastal waters, failure to anticipate these events and adjust fisheries management accordingly could exacerbate their economic and social impact (Mills et al. 2013).

Warmer water temperatures—in combination with other factors such as increased CO_2 and runoff from extreme precipitation events—could foster growth of harmful algal blooms in both freshwater lakes and coastal waters (US EPA Office of Water 2013). An extensive outbreak of *Alexandrium fundyense* (red tide) in 2005 caused closures that resulted in $18 million of lost shellfish sales in Massachusetts and Maine (NOAA 2013).

Gulf of Maine Sea Surface Temperature



Source: Maine's Climate Future—2015 Update, http://climatechange.umaine.edu/research/publications/climate-future

Increased Drought

If global emissions remain high, climate scientists anticipate that the frequency of short-term (one- to three-month) droughts across most of New England will increase—changing from an average now of once every 2-3 years to once annually by late in the century (Frumhoff et al. 2007).

From 1996 through September 2015, the coast of Maine (Climate Division 3) has had only two droughts recorded by the Northeast Regional Climate Center—one of 2 months duration in 1999 and one of 9 months duration in 2001-2002 (NRCC 2015). If greenhouse gas emission levels remain high, the Portland area could go from a current average of 4 months of drought in a 30-year period to more than 12 months. If emissions dropped precipitously, little or no change in drought frequency is expected (Wake et al. 2009).

According to the 2010 Cumberland County Hazard Mitigation Plan, the greatest risk of drought is in communities that rely on groundwater wells, river or smaller lake supplies. Those dependent on Sebago Lake (including most of the communities in Greater Portland) have a "fairly low degree of risk to drinking water quantity and quality resulting from drought" (CCEMA 2010, 4-22).

Increased Precipitation and Greater Storm Intensity and Frequency

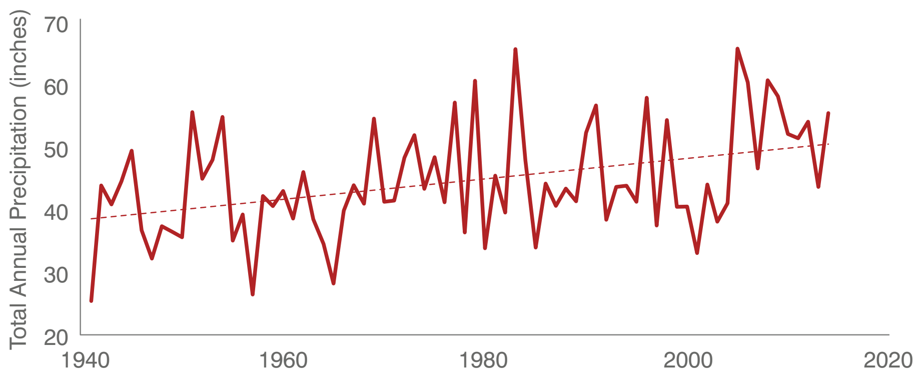
Maine is experiencing increases in both total annual precipitation and extreme precipitation events, raising concerns about flooding, damage to infrastructure like road–stream crossings, increased discharges from combined sewer overflows, and greater stormwater runoff impacts (CBEP 2015).

From 1895 to 2014, annual average precipitation in Maine increased by about 0.50 inches per decade (National Climatic Data Center, 2015). For Portland, the historical rate of increase was about 0.75 inches per decade. Since about 1960, there has been a much more rapid increase, with a rate of 1.92 inches per decade.

In recent decades, the Northeast has experienced a greater recent increase in extreme precipitation than any other US region. The Northeast saw more than a 70 percent increase in the amount of precipitation falling in very heavy events (defined as the heaviest 1 percent of all daily events) between 1958 and 2010 (Horton et al. 2014). Intense rain events typically occurred about once a year in the early 1940s, but are now occurring in Portland about three times a year (CBEP 2015).

Climate models predict that precipitation will continue increasing across the Northeast through at least 2050, with a 4-5 percent increase expected along Maine's southern coast (Fernandez et al. 2015).

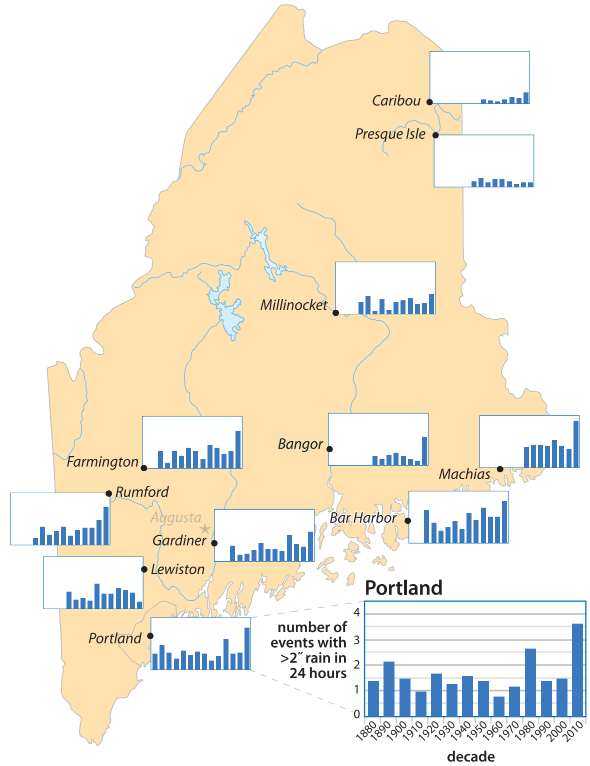
Total Annual Precipitation, Portland Jetport 1941–2014



Source: http://www.cascobayestuary.org/wp-content/uploads/2015/10/Indicator_ClimateChange.pdf

NOAA's storm events database reveals a marked increase in the number of "extreme precipitation" events (categorized as coastal floods, flash floods, floods, heavy rain and tropical storms) within Cumberland County between 1995-2004 and 2005-2014. In the earlier decade, there were 21 days with events, 11 of them involving property damage. In the last decade, that number rose to 55 days, 35 of which involved property damage (NOAA NCDC 2015).

Increases in both annual and extreme precipitation raise the danger of flooding, the leading hazard for Cumberland County (CCEMA, 2010). According to FEMA data, the County had ten disaster declarations between June 2005 and April 2015, all associated with flooding (some with additional storm hazards such as snow, wind and landslides). The County's 2010 Hazard Mitigation Plan identifies four high-priority hazards: flooding, severe winter storms, wildfire and severe summer storms. That Plan identifies 24 "repetitive loss" properties (that have experienced repeated flood damage under the National Flood Insurance Program), all but three of them residential. Due to increased flooding in certain areas, utilities have already been required to relocate transmission lines and other electrical power infrastructure (DeLong 2015).



Extreme Precipitation Events

Source: Maine's Climate Future—2015 Update, http://climatechange.umaine.edu/research/publications/climate-future

Stormwater runoff carries toxic contaminants and excess nitrogen and phosphorus into local waters—lowering dissolved oxygen (leading to fish kills), stimulating harmful algal blooms, altering ecological communities and aggravating coastal acidification in Casco Bay. Release of untreated sewage in extreme precipitation events can carry pathogens into swimming waters, raising risks of waterborne disease (Horton et al. 2014). Two of Casco Bay's most urban swimming beaches have ongoing water-quality challenges, with 20 percent of samples from one beach exceeding the allowable fecal bacteria threshold (CBEP 2015).

Increased precipitation, in combination with warmer temperatures, can aggravate the spread of Lyme disease, babesiosis, anaplasmosis and West Nile Virus (WNV), vector-borne diseases linked to late spring and early summer moisture. In Maine, the arboviruses like WNV and Eastern Equine Encephalitis (EEE) are tied to seasonal increases in abundance of the virus in wild birds and the mosquito population, so they are also tied to midsummer moisture and possibly to temperature. Habitat for the Asian tiger mosquito that can transmit WNV is expected to increase in the Northeast from the current 5 percent to 16 percent within two decades and between 43 and 49 percent by the end of the century (Horton et al. 2014).

NOAA reports that Maine has experienced nine hurricanes in historical records, only five of which made landfall along the coastline. However, Maine has been affected by many lesser tropical storms (mapped at http://coast.noaa.gov/hurricanes/). Hurricane Irene (in 2011) and Hurricane Sandy (in 2012) did not exert their full force in Maine, but they confirmed the Northeast region's vulnerability to heavy rains, storm surge and flooding. Storm surge associated with nor'easters and tropical cyclones poses a particular concern at times of extreme high tides.

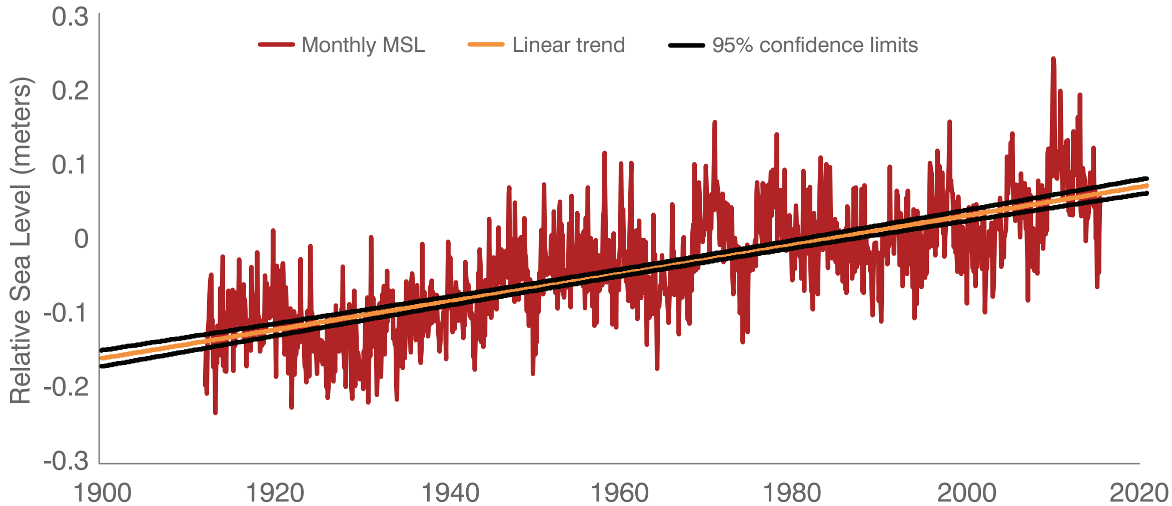
In New York and New Jersey, the storm surge from "Superstorm" Sandy forced water levels up over 11 feet. As a result of Sandy, the Maine Geological Survey released Potential Hurricane Inundation Maps, which approximate potential inundation from Category 1 and 2 hurricanes making landfall at the mean tide level and at high tide (MGS 2015a).

Tropical cyclones have generally grown more intense. Warmer air temperatures and increased water vapor, along with warmer sea-surface temperatures, provide more fuel to tropical storms, increasing their wind speeds (NASA 2015). Warming ocean temperatures could also cause more frequent high-intensity storms carrying more precipitation (Freedman 2013).

Sea Level Rise

Over the past century, Portland's tide gauge has shown an average annual increase in sea level of 1.9 mm per year (7.5 inches per century), close to global changes over that period. Sea level at that site during the past two decades has been rising 130 percent faster than this historical rate (ULI 2014).

Sea Level Trend, Portland Maine, 1912–2015



Data show seasonally corrected average Mean Sea Level, MSL, from 1912 through 2015. Linear prediction and confidence limits based on NOAA analysis.

Data: NOAA Center for Operational Oceanographic Products and Services 2015

Source: http://www.cascobayestuary.org/wp-content/uploads/2015/10/Indicator_ClimateChange.pdf

Based on sea level rise curve scenarios from the US National Climate Assessment, the Maine Geological Survey currently estimates that Casco Bay could potentially experience a 2- to 4-foot rise in sea level by the end of this century. The U.S. Global Change Research Program makes similar projections for the northeastern US (Horton et al 2014). The Maine Geological Survey has statewide potential sea level rise/storm surge inundation maps that depict potential inundation from 1-, 2-, 3.3-, and 6-foot sea level rise scenarios on top of the Highest Annual Tide (MGS, 2015b).

A discussion paper by James Hansen and other climatologists suggests that sub-surface ocean warming could lead to more rapid disintegration of West Antarctic ice sheets, elevating sea levels substantially sooner than previously predicted, with a rise of several meters (upwards of 10 feet) potentially within 50 to 100 years if high levels of greenhouse gas emissions continue (Hansen et al. 2015).

Even modest increases in sea level will increase coastal flooding, erosion, and damage to infrastructure (such as roads, bridges and ports, power and water facilities). Sea level rise and storm surge are a particular concern in densely developed low-lying areas and in settings where erosion threatens the stability of coastal bluffs. Maps identifying bluff areas most vulnerable to erosion are available for some towns bordering Casco Bay: Portland, Yarmouth, Freeport, Brunswick, South Harpswell and Phippsburg (MGS 2015c).

Abrupt sea level changes have already exacerbated local flooding in the Casco Bay region. The highest monthly mean sea levels recorded at Portland since 1912 occurred in January through April 2010 (Slovinsky 2015). A recent study found that Portland had the highest abrupt change in sea levels (on the order of 5 inches) along the entire eastern US coast (Goddard et al. 2015). This rise was attributed to a slowdown in the Gulf Stream combined with a strongly negative North Atlantic Oscillation.

Coastal communities that begin preparing for higher sea levels can save money and resources long-term. According to a 2005 study, every dollar invested in mitigating storm-surge effects on coastal communities saves US taxpayers four dollars in losses from natural hazards (Multihazard Mitigation Council 2005). Numerous communities around Casco Bay (including Cape Elizabeth, Freeport, Harpswell, Portland and South Portland) have undertaken vulnerability assessments—in conjunction with the Maine Geological Survey and Greater Portland Council of Governments (GPCOG)—and some have identified and begun implementing adaptation strategies.

Significant portions of the Portland and South Portland waterfront are highly vulnerable to sea level rise and storm surge, making it cost-effective to pursue short-term actions to protect infrastructure. Casco Bay Estuary Partnership commissioned a study of flood risk in Portland's Back Cove neighborhood that projected flooding would cause hundreds of millions of dollars in cumulative damages by mid-century if no protective actions are undertaken (Merrill et al. 2012).

A vulnerability assessment completed by GPCOG, with data from the Maine Geological Survey, found that with a 2-meter rise in sea level, 9 wastewater facilities in Portland and South Portland would be at risk (Yakovleff 2013a). Many of the urban area's major grocery stores are in settings prone to coastal flooding. Even small increases in sea level rise can increase the recurrence interval of the more destructive storm events, with a 1-foot rise reducing the interval from a 100-year to a 10-year event (Yakovleff 2013a).

Tidal wetlands provide a wide array of social benefits, including flood storage and protection, buffering from storm surge, erosion control, water-quality improvements and wildlife habitat. A Baywide, community-based study led by Casco Bay Estuary Partnership found that sea level rise could increase the damage that tidal restrictions cause to wetlands, reducing their resilience and undermining their structural integrity through increased scouring (Bohlen et al. 2013). The study concluded that many tidal wetlands could migrate into adjacent freshwater wetlands if faced with moderate increases in sea level.

As sea levels rise, salt water can contaminate coastal aquifers. Around Casco Bay, much of the population on islands and peninsulas depends on groundwater from private wells. Oak Ridge National Laboratory did preliminary modeling involving representative bedrock aquifers in the region, and found that even under best-case conditions, wells near shore (particularly on islands and peninsulas) are vulnerable to contamination by saltwater intrusion (Guiang and Allen 2015).

Ocean Acidification

Approximately 26-27 percent of human emissions of CO_2 is being absorbed by the ocean (Le Quéré et al. 2014). When marine waters absorb carbon dioxide, they become more acidic. The ocean is acidifying at a rate at least 100 times faster than at any other time in the past 200,000 years (Hönisch et al. 2012). Waters in the Gulf of Maine have relatively low pH (compared to marine waters farther south on the Eastern Seaboard), making them particularly susceptible to acidification (Walberg et al. 2103). And being relatively cold, they more readily absorb CO_2 (Woodard 2015).

The changes occurring in Casco Bay waters are a result of global ocean acidification (from changes caused by atmospheric CO_2) and coastal acidification, which occurs when excess nitrogen from wastewater, atmospheric deposition and stormwater runoff fuel greater net primary production and subsequent respiration as organic particles sink and decompose. This process results in higher CO_2 and lower pH in commercially valuable benthic areas.

Significant freshwater input along the New England coast can reduce the buffering capacity of its embayments, making them more vulnerable to coastal acidification (Salisbury et al. 2008). One study of Casco Bay during a particularly wet June (2005) found more "corrosive waters" in the Kennebec River plume by the Bay's eastern edge (Gledhill 2015). The threat of corrosive river plumes may intensify in coming years due to increased volume and intensity of precipitation events.

The acidity of Gulf of Maine waters is expected to grow markedly in coming decades, increasing faster than the average for global seas (Gledhill et al 2015). Increasingly acidic waters can impair marine creatures at all levels of the food web, affecting their ability to grow, resist disease and reproduce. The resilience of the Gulf's marine ecosystem has already been compromised by the loss of large predatory fish (Kinsey 2015).

More acidic coastal waters make it especially difficult for juvenile shellfish to build and maintain shells, jeopardizing the future of Maine's shellfish industry and aquaculture operations. Maine is heavily reliant on shellfish, with 87 percent of the value of its commercial fish catch based on species such as lobsters, clams, scallops and oysters (Gledhill et al. 2015).

Research involving juvenile clams from Casco Bay suggests that increased acidification can reduce their probability of settlement and make their shells susceptible to dissolution (Green 2013, Green 2009, Salisbury et al. 2008). In limited studies, finfish have also shown effects from high CO_2 exposure but they appear to be longer-term and sub-lethal (Frommel et al. 2012).

Early research into ocean acidification's effects on zooplankton and phytoplankton appears mixed, and little regional research has been done assessing its effects on macroalgae and sea grass. Research to date has focused primarily on single species at one life stage subject to a single stressor at a fixed level. Future studies will need to account for more ecosystemic complexity—with multiple species and life stages, multiple stressors and variable pH levels (Breitburg et al. 2015).

The Northeast Coastal Acidification Network (NECAN) formed in 2013 to review and assess relevant scientific data, identify knowledge gaps, and set monitoring and research priorities. It has elevated scientific and public understanding of this climate stressor throughout New England, but there remains an urgent need for further monitoring and biological response studies within the region (Gledhill 2015).

Because coastal Maine is very vulnerable to effects of ocean and coastal acidification, the Maine Legislature in 2014 created the Commission to Study the Effects of Coastal and Ocean Acidification to make recommendations on research and adaptation needs to the coastal community. The Commission's report led to the formation in 2016 of a volunteer group called the Maine Ocean and Coastal Acidification (MOCA) Partnership. With the assistance of NECAN, MOCA has been very active in working with stakeholders to follow-up on the Study Commission's recommendations to reduce the impacts or adapt to ocean and coastal acidification.

Anticipating Greater Variability and Uncertainty

Many projected changes in climate variables are described in terms of averages. Yet the increased variability in the climate system raises the prospect of more extreme events—like record-breaking heat, drought and heavy rainfall. The region has already experienced some unexpected extremes, such as a 5-inch spike in sea level in 2009-2010 (Goddard et al. 2010) and an ocean heat wave within the Gulf of Maine in 2012 (Mills et al. 2013).

The increased occurrence of these unusual events makes adaptation more challenging—for both human communities and ecosystems. Greater understanding of climate variability and potential impacts can help communities evaluate and minimize risks.

The climate system itself could pass certain tipping points or thresholds. "A key characteristic of these changes," a National Research Council Committee wrote in 2013, "is that they can come faster than expected, planned, or budgeted for…" (NRC 2013). Abrupt changes in the climate system—happening over decades or even years—have occurred routinely throughout Earth's history.

Several abrupt changes already underway are of particular concern.

- Rapid decline of Arctic sea ice and potential destabilization of the West Antarctic Ice Sheet could cause dramatic increases in global sea levels.
- Extinction rates among terrestrial and marine species are increasing rapidly, and continued warming may accelerate this trend.
- Disruption of the Atlantic meridional overturning circulation (AMOC), the large oceanic conveyor of which the Gulf Stream current is a part, could cause sudden spikes in sea level, disruptions to marine ecosystems, and changes in the ocean's

capacity to store heat and carbon (NRC 2013). A conspicuous region of cooling south of Greenland, possibly linked to melting of the Greenland ice sheet, may be due to a reduction in the AMOC which could weaken further in coming decades with continued melting (Rahmstorf et al. 2015).

While abrupt changes to the climate system cannot be forestalled, monitoring key variables and modeling future scenarios can help identify areas of greatest vulnerability.

SECTION TWO

Climate Risk Assessment

Overview of Risk Assessment Review Process

Casco Bay Estuary Partnership (CBEP) developed a draft list of 79 potential climate change-related risks and associated probability/consequence matrices, and then contracted with Waterview Consulting to (a) conduct a peer review process to ensure that climate change-related risks to implementation of the Casco Bay Plan were fully and accurately considered and (b) determine which risks should be considered as Risks of Primary Concern to be addressed in CBEP's implementation efforts. The peer review process also solicited recommendations on key scientific references and research needs related to the risks.

Waterview Consulting implemented the following process for the risk assessment review:

(1) Prepared draft list of risks for review
Organized and formatted the 79 draft risks identified by CBEP into a review-ready document (Appendix A: Draft List of Climate-Related Risks), including a color-coded consequence/probability matrix for each risk and a legend.

(2) Produced list of potential reviewers
Determined the areas of expertise needed for peer review of the risks (e.g., economics, hydrology, tidal wetland ecology, fisheries, wastewater treatment) and then with input from CBEP identified approximately 100 individuals from academic institutions, government agencies, non-government organizations and the private sector inside and outside of Maine who had advanced degrees or equivalent professional experience in the areas of expertise. We included a minimum of three experts per area of expertise recognizing that not all invitees would participate and because we sought to receive multiple expert viewpoints per topic area.

(3) Created online forms for collecting reviews
Developed, tested, and deployed a web-based system for reviewers to submit their reviews. For each risk, reviewers could provide (a) recommendations to change the probability and/or consequence rankings, and (b) comments, suggestions of key references, and recommendations of critical new research on the topic. Reviewers also submitted overarching comments and recommendations on the risk assessment as a whole.

(4) Solicited reviews
Sent to the approximately 100 experts an invitation by email to participate in the peer review. The invitation included a pdf of the "Draft List of Climate-Related Risks to Implementation of the Casco Bay Plan 2016-2021" along with background information on CBEP, the Plan, and the risk assessment process. It provided a link to the online review forms with instructions for completing them. Reviewers were asked to self-identify which risks were within their expertise, and to provide input only on those risks. The invitation was emailed in early July with a request for responses to be submitted within one month. To further inform the invitees and boost their

response rate, we followed up approximately one week later with a postal mailing that included hard copies of the invitation, the Draft List, and the Plan. Subsequently, we sent email reminders to invitees who had not yet submitted a review through the web-based forms (or by email, as a few chose to do instead). As an incentive, we offered invitees their choice of a CBEP item (water bottle, travel cup, beach towel, or canvas bag) as a gift upon completing a review. We extended the review period by three weeks to increase the response rate, as many invitees had been unavailable due to summer fieldwork and vacations. We received 44 reviews through the online forms and by email, with strong representation across the necessary areas of expertise.

(5) Compiled and analyzed data

Downloaded the data from the online review system and incorporated additional reviewer feedback received by email. Based on reviewers' input, we determined changes to be made in the list of risks, such as revising language in risk descriptions for accuracy or removing risks due to insufficient or opposing scientific evidence. For each risk, we evaluated reviewers' recommendations for increasing or decreasing the short-, medium-, and long-term rankings for probability and consequence. We met with CBEP staff to review preliminary results and then made a presentation to the CBEP Management Committee at its September 2016 meeting, after which we received additional reviews and comments from Committee members. We analyzed the compiled quantitative and qualitative data from all reviews to identify Risks of Primary Concern (RoPCs). We also reviewed the data to identify potential research needs and overarching feedback regarding the risk assessment. Finally, we analyzed relationships between the RoPCs and the Plan Actions to determine how the RoPCs could affect the Actions and how the Actions could help mitigate the RoPCs.

Risks and Risk Matrices

In the early phases of the risk assessment process, CBEP staff sought to develop a comprehensive list of climate change-related effects that might constitute risks to implementation of the Plan. After identifying more than 200 candidate risks, CBEP consolidated and organized them into a draft list of 79 risks to be subjected to peer review. Following the guidelines of EPA's *Workbook for Developing Risk-Based Adaptation Plans*, CBEP ranked (low, medium, high) the probability and consequence of each risk over short, medium, and long timeframes.

Figure 1 provides definitions for the timeframes and the probability and consequence rankings. The 79 draft risks were provided to reviewers in the Draft List of Climate-Related Risks format (Appendix A), along with instructions and definitions. The draft list of risks was divided into five categories aligned with the Plan's Goals: (a) Principally Habitat Related, (b) Principally Water Quality Related, (c) Principally Community Related, (d) Implementation, and (e) Other.

Figure 1. **Definitions of timeframes and probability/consequence rankings**
CBEP used the following definitions in the risk assessment. Reviewers received the definitions for reference.

TIMEFRAME	Short	10-20 years
	Medium	30-40 years
	Long	80-100 years

PROBABILITY	Low	Unlikely
	Medium	Possible; about as likely as unlikely
	High	Probable; more likely than not

CONSEQUENCE	Low	Minor impact that can readily be adapted to with little disruption to ecosystems, communities, or economy.
	Medium	Moderate impact that will require some effort to adapt to. Adaptation is likely to be successful and not impose high costs or threaten Casco Bay Plan goals or other concerns.
	High	Severe impact, may threaten Casco Bay Plan goals, communities, or ecosystems, or adaptation actions are likely to be expensive or disruptive in their own right.

Final List of Risks of Primary Concern

Based on the peer review, we removed 16 potential risks from the list of 79 because either scientific evidence did not support them or they did not qualify as risks to Plan implementation (but rather as potential benefits). We also revised the language of some risk descriptions for accuracy and clarity, and we adjusted the probability/consequence rankings. We then developed, in consultation with CBEP, criteria to define Risks of Primary Concern (RoPCs) based on probability/consequence levels within the overall list of 63 remaining risks. The purpose of defining RoPCs was to enable CBEP to focus its limited resources on the most important risks that pertain to the Plan.

We initially defined RoPCs as those risks that ranked medium/medium, medium/high, high/medium, or high/high in probability/consequence for the short timeframe (10-20 years), which resulted in a set of 25 RoPCs. There were 8 additional risks that did not meet those criteria in the short timeframe but did emerge as very important (high/high, medium/high, or high/medium) in the medium timeframe (30-40 years); we chose to add them as RoPCs because of their significance and because there may be opportunities to mitigate them in the short term. This resulted in 33 risks being preliminarily identified as RoPCs. (Appendix B is a revised version of the full draft list of 79 Risks, including changes made to the risk descriptions and probability/consequence rankings; it also indicates the risks that were removed and the risks that were determined to be RoPCs.)

However, reviewers also recommended that some closely related risks should be consolidated for clarity, accuracy, and consistency. For that reason, some of the initial 33 RoPCs were combined, leading to the following final list of 25 RoPCs (21 short-term and 4 medium-term).

25 Risks of Primary Concern (RoPCs)

RoPCs Principally Related to Habitat

H-1: Warmer waters in rivers and streams in summer exceed thermal tolerances for some native aquatic species, leading to population declines and local extinction.

H-2: Warmer ocean water temperatures cause shifts in species' geographic ranges and the community structure of Casco Bay's ecosystem, leading to declines in some existing fisheries resources and increases in some invasive species, pathogens, pests, and disease vectors.

H-3: Rising seas and increased storm intensities cause greater demand for protection of coastal properties via shoreline hardening (which would reduce habitat value and scope for wetland migration), and therefore the need to facilitate better solutions such as living shorelines.

H-4: More winter precipitation falling as rain, earlier snow melt and less predictable precipitation lead to a shorter and less predictable spring season of high river flows, affecting fish migration.

H-5: Acidification, both in the water column and in tidal flats, caused by global and local factors leads to reduced growth and survival of some species.

H-6: Higher temperatures increase respiration rates in eelgrass, reducing net productivity and increasing mortality. (Medium-term RoPC)

H-7: Climate change leads to changes in marine and coastal food webs, altering species composition, making coastal ecosystems less resilient to other stressors like invasive species, elevated nutrients and habitat destruction, and raising chances of the ecosystem hitting a tipping point. (Medium-term RoPC)

H-8: Sea level rise and altered hydrology in tidal wetlands (due to multiple climate stressors) shifts species composition, causes both gains and losses of tidal wetland area, and makes the wetlands more susceptible to invasion by invasive plants. (Medium-term RoPC)

RoPCs Principally Related to Water Quality

W-1: Higher intensity storms make it more likely that stormwater control devices will prove too small to perform as designed, reducing effectiveness, and degrading downstream water quality.

W-2: Higher water temperatures make the Bay more susceptible to nutrients (via algae growth, thermal stratification, and rapid recycling of nutrients) increasing risk of harmful algae blooms, decreased water clarity, lower dissolved oxygen, and fish kills.

W-3: Large storms increase stormwater volumes and infiltration into aging sewer lines, thus sending larger volumes of more dilute wastewater to treatment plants, reducing effectiveness of nutrient removal.

W-4: Increased runoff and Combined Sewer Overflow (CSO) discharges from more intense storms increase transport of nutrients and other pollutants to downstream waters, including lakes and the Bay, degrading water quality.

W-5: More frequent severe storms and sea level rise increase flooding of coastal and river valley communities, causing release of pollutants into rivers and coastal water.

W-6: More winter precipitation falling as rain, earlier snow melt and less predictable precipitation lead to a shorter and less predictable spring season of high river flows, affecting timing and magnitude of nutrient inputs to the Bay.

W-7: Increased storm intensity and rising seas lead to more erosion from uplands, shores, banks and bluffs, increasing both turbidity and nutrient flows, degrading water quality.

RoPCs Principally Related to Community

C-1: Storm surge and coastal flooding shortens the life of transportation and utility infrastructure, from roads and port facilities to sewer lines and sewage treatment plants, reducing economic productivity and increasing private and public sector costs.

C-2: Rising seas flood stormwater pipes and reduce drainage capacity of stormwater infrastructure, increasing risk of flooding.

C-3: Rising seas make waterfront facilities like piers and other commercial and recreational access points inoperable, or require expensive repairs and investment to maintain functionality, affecting marine industries and quality of life.

C-4: More frequent severe storms and sea level rise increase flooding of coastal and river valley communities, and lead to more frequent catastrophic failure of banks and bluffs, causing economic and social harm.

C-5: Complexity of multiple demands for adaptation to climate change may overwhelm ability of local governments to respond constructively to change.

C-6: Increased probability of failure of culverts due to greater storm intensities requires more frequent culvert replacement, driving up infrastructure costs.

RoPCs Principally Related to Implementation

I-1: Uncertainty about the future of the Bay, due to inability to predict climate impacts caused by multiple interacting stressors, increases both complexity and cost of monitoring programs.

I-2: Unpredictable weather leads to an increased need for monitoring of episodic events like severe storms and their effects, increasing both total and event-triggered monitoring costs.

I-3: Community ability to fund water quality infrastructure and other environmental projects is decreased by need for disaster recovery, infrastructure replacement and costs of climate adaptation. (Medium-term RoPC)

I-4: Multiple climate stressors (warmer summers, winters, and water; increasing drought and storminess; sea level rise; ocean acidification) make it difficult for managers and regulators to understand emerging issues, and to respond quickly and constructively to a changing coastal ocean.

RoPCs with Probability/Consequence Rankings

Figure 2 presents the 25 RoPCs with peer-reviewed probability/consequence rankings in the same format as the draft list of Risks (Appendix A).

Figure 2. Risks of Primary Concern for implementation of the *Casco Bay Plan 2016-2021*
Bold font indicates short-term RoPCs (10-20 years). Regular font indicates medium-term RoPCs (30-40 years).

Risk Theme	Risk ID	Risk Description	Timeframe	Probability	Consequence
Principally **HABITAT** Related	H-1	**Warmer waters in rivers and streams in summer exceed thermal tolerances for some native aquatic species, leading to population declines and local extinction.**	Short Med Long		
	H-2	**Warmer ocean water temperatures cause shifts in species' geographic ranges and the community structure of Casco Bay's ecosystem, leading to declines in some existing fisheries resources and increases in some invasive species, pathogens, pests, and disease vectors.**	Short Med Long		
	H-3	**Rising seas and increased storm intensities cause greater demand for protection of coastal properties via shoreline hardening (which would reduce habitat value and scope for wetland migration), and therefore the need to facilitate better solutions such as living shorelines.**	Short Med Long		
	H-4	**More winter precipitation falling as rain, earlier snow melt and less predictable precipitation lead to a shorter and less predictable spring season of high river flows, affecting fish migration.**	Short Med Long		
	H-5	**Acidification, both in the water column and in tidal flats, caused by global and local factors leads to reduced growth and survival of some species.**	Short Med Long		
	H-6	Higher temperatures increase respiration rates in eelgrass, reducing net productivity and increasing mortality.	Short Med Long		
	H-7	Climate change leads to changes in marine and coastal food webs, altering species composition, making coastal ecosystems less resilient to other stressors like invasive species, elevated nutrients and habitat destruction, and raising chances of the ecosystem hitting a tipping point.	Short Med Long		
	H-8	Sea level rise and altered hydrology in tidal wetlands (due to multiple climate stressors) shifts species composition, causes both gains and losses of tidal wetland area, and makes the wetlands more susceptible to invasion by invasive plants.	Short Med Long		

Risk Theme	Risk ID	Risk Description	Timeframe	Probability	Consequence
Principally **WATER QUALITY** Related	W-1	**Higher intensity storms make it more likely that stormwater control devices will prove too small to perform as designed, reducing effectiveness, and degrading downstream water quality.**	Short Med Long		
	W-2	**Higher water temperatures make the Bay more susceptible to nutrients (via algae growth, thermal stratification, and rapid recycling of nutrients) increasing risk of harmful algae blooms, decreased water clarity, lower dissolved oxygen, and fish kills.**	Short Med Long		
	W-3	**Large storms increase stormwater volumes and infiltration into aging sewer lines, thus sending larger volumes of more dilute wastewater to treatment plants, reducing effectiveness of nutrient removal.**	Short Med Long		
	W-4	**Increased runoff and Combined Sewer Overflow (CSO) discharges from more intense storms increase transport of nutrients and other pollutants to downstream waters, including lakes and the Bay, degrading water quality.**	Short Med Long		
	W-5	**More frequent severe storms and sea level rise increase flooding of coastal and river valley communities, causing release of pollutants into rivers and coastal water.**	Short Med Long		
	W-6	**More winter precipitation falling as rain, earlier snow melt and less predictable precipitation lead to a shorter and less predictable spring season of high river flows, affecting timing and magnitude of nutrient inputs to the Bay.**	Short Med Long		
	W-7	**Increased storm intensity and rising seas lead to more erosion from uplands, shores, banks and bluffs, increasing both turbidity and nutrient flows, degrading water quality.**	Short Med Long		

Figure 2 (Continued). Risks of Primary Concern for implementation of the *Casco Bay Plan 2016-2021*
Bold font indicates short-term RoPCs (10-20 years). Regular font indicates medium-term RoPCs (30-40 years).

Risk Theme	Risk ID	Risk Description	Timeframe	Probability	Consequence
Principally **COMMUNITY** Related	C-1	**Storm surge and coastal flooding shortens the life of transportation and utility infrastructure, from roads and port facilities to sewer lines and sewage treatment plants, reducing economic productivity and increasing private and public sector costs.**	Short Med Long		
	C-2	**Rising seas flood stormwater pipes and reduce drainage capacity of stormwater infrastructure, increasing risk of flooding.**	Short Med Long		
	C-3	**Rising seas make waterfront facilities like piers and other commercial and recreational access points inoperable, or require expensive repairs and investment to maintain functionality, affecting marine industries and quality of life.**	Short Med Long		
	C-4	**More frequent severe storms and sea level rise increase flooding of coastal and river valley communities, and lead to more frequent catastrophic failure of banks and bluffs, causing economic and social harm.**	Short Med Long		
	C-5	**Complexity of multiple demands for adaptation to climate change may overwhelm ability of local governments to respond constructively to change.**	Short Med Long		
	C-6	**Increased probability of failure of culverts due to greater storm intensities requires more frequent culvert replacement, driving up infrastructure costs.**	Short Med Long		

IMPLEMENTATION	I-1	**Uncertainty about the future of the Bay, due to inability to predict climate impacts caused by multiple interacting stressors, increases both complexity and cost of monitoring programs.**	Short Med Long		
	I-2	**Unpredictable weather leads to an increased need for monitoring of episodic events like severe storms and their effects, increasing both total and event-triggered monitoring costs.**	Short Med Long		
	I-3	Community ability to fund water quality infrastructure and other environmental projects is decreased by need for disaster recovery, infrastructure replacement and costs of climate adaptation.	Short Med Long		
	I-4	**Multiple climate stressors (warmer summers, winters, and water; increasing drought and storminess; sea level rise; ocean acidification) make it difficult for managers and regulators to understand emerging issues, and to respond quickly and constructively to a changing coastal ocean.**	Short Med Long		

TIMEFRAME

Short: 10-20 years

Medium: 30-40 years

Long: 80-100 years

PROBABILITY

Low: Unlikely

Medium: Possible; about as likely as unlikely

High: Probable; more likely than not

CONSEQUENCE

Low: Minor impact that can readily be adapted to with little disruption to ecosystems, communities, or economy.

Medium: Moderate impact that will require some effort to adapt to. Adaptation is likely to be successful and not impose high costs or threaten Casco Bay Plan goals or other concerns.

High: Severe impact, may threaten Casco Bay Plan goals, communities, or ecosystems, or adaptation actions are likely to be expensive or disruptive in their own right.

SECTION THREE

Relationship of Risks of Primary Concern to Casco Bay Plan Actions

Correlation of Risks of Primary Concern with Plan Actions

The primary goal of the climate change risk assessment was to identify how implementation of the 32 Actions in the *Casco Bay Plan 2016-2021* might be affected by future climate change. To achieve that goal, we analyzed correlations of the Risks of Primary Concern (RoPCs) with Plan Actions, including how Actions may be threatened by each RoPC and how Actions may help to alleviate RoPCs.

Twelve of the 32 Actions are threatened with impairment by the RoPCs. Among the 12,

- Actions 1.1A and 1.2A, which focus on habitat conservation and restoration, are each threatened by 14-15 RoPCs, reflecting the fact that the long-term success of these two Actions could be greatly influenced by changing environmental conditions, and
- the other 10 are threatened by only 1-4 RoPCs, most of which relate to funding availability.

Thirteen of the 32 Actions are not threatened by the RoPCs but could help to alleviate the RoPCs. Seven of the 32 Actions are not closely correlated with the RoPCs either as being threatened or alleviating them; they may build capacity toward future alleviation of RoPCs.

The following narrative describes the findings for each Action, and these correlations are summarized in Figure 3.

GOAL 1: Protect, restore and enhance key habitats that sustain ecological health

Strategy 1.1: Conserve significant coastal habitats and areas that protect water quality, such as riparian corridors, wetlands and forests adjoining headwater streams
Strategy 1.2: Restore and enhance coastal habitats and habitat connectivity that are important to sustaining the health of Casco Bay

Action 1.1A: Maintain Casco Bay Estuary Partnership Habitat Protection Fund

Potential negative effects of RoPCs on Action:

- Many of the habitat- and water quality-related RoPCs have the potential to impair the anticipated benefits of habitat protection projects. *RoPCs H-1, H-2, H-4, H-5, H-6, H-7, H-8, W-1, W-2, W-3, W-4, W-5, W-7*
- Shoreline hardening could permanently reduce the area of high-quality coastal habitat available for protection. *RoPC H-3*
- Competing demands for climate change adaptation at the community level could reduce capacity and/or funding available to pursue habitat protection. *RoPC I-3*

Potential positive or negative effect of RoPCs on Action:

- The increasing need for culvert replacement could be beneficial for Action 1.1A, if culvert replacement creates opportunities for habitat protection. However, if culvert replacement occurs at sites where habitat protection is not possible or desirable, it could impair Action implementation by reducing available funding. *RoPC C-6*

Potential positive effect of this Action on RoPCs:

- Habitat protection is a relatively straightforward process with wide-ranging environmental benefits, meaning it can serve as a hedge against the inability of people to address particular, complex environmental issues. *RoPCs C-5, I-4*

Action 1.1B: Assist Habitat Protection Efforts

Potential negative effect of RoPCs on Action:

- N/A

Potential positive effect of this Action on RoPCs:

- N/A

Action 1.2A: Lead Coastal Habitat Restoration Efforts

Potential negative effect of RoPCs on Action:

- Many of the habitat- and water quality-related RoPCs have the potential to reduce the viability and anticipated benefits of habitat restoration projects. *RoPCs H-2, H-4, H-5, H-6, H-7, H-8, W-1, W-2, W-3, W-4, W-5, W-6, W-7*
- Shoreline hardening could permanently reduce the area of high-quality coastal habitat available for restoration and also limit the long-term viability of nearby restoration projects. *RoPC H-3*
- Unpredictable changes in weather and climate could make it necessary to implement more expensive and complex monitoring programs for restoration projects. *RoPCs I-1, I-2*
- Competing demands for climate change adaptation at the community level could reduce capacity and/or funding available to pursue habitat restoration. *RoPC I-3*

Potential positive or negative effect of RoPCs on Action:

- The increasing need for culvert replacement could be beneficial for Action 1.2A, if culvert replacement creates opportunities for habitat restoration. However, if culvert replacement occurs at sites where habitat restoration is not possible or needed, it could impair Action implementation by reducing available funding. *RoPC C-6*

Potential positive effect of Action on RoPCs:

- Habitat restoration is a relatively straightforward process with wide-ranging environmental benefits, meaning it can serve as a hedge against the inability of people to address particular, complex environmental issues. *RoPCs C-5, I-4*

Action 1.2B: Coordinate Efforts to Restore Aquatic Habitat Connectivity

Potential negative effect of RoPCs on Action:

- Warmer freshwater habitats and shifts in seasonal precipitation patterns could reduce the anticipated benefits of restoring aquatic habitat connectivity. *RoPCs H-1, H-4*

Potential positive or negative effect of RoPCs on Action:

- The increasing need for culvert replacement could be beneficial for Action 1.2B, if culvert replacement creates opportunities for restoring aquatic habitat connectivity. However, if culvert replacement occurs at sites that are not beneficial to aquatic habitat connectivity, it could impair Action implementation by reducing available funding. *RoPC C-6*

Potential positive effect of Action on RoPCs:

- Restoring aquatic habitat connectivity is a relatively straightforward process with wide-ranging environmental benefits, meaning it can serve as a hedge against the inability of people to address particular, complex environmental issues. *RoPCs C-5, I-4*

Action 1.2C: Train Habitat Restoration Practitioners

Potential negative effect of RoPCs on Action:

- N/A

Potential positive effect of Action on RoPCs:

- This Action could help to alleviate many of the RoPCs by increasing practitioners' knowledge and ability to incorporate the RoPCs into planning and implementation of habitat restoration projects. *RoPCs H-1, H-2, H-3, H-4, H-5, H-6, H-7, H-8, W-1, W-2, W-4, W-5, W-6, W-7, C-5, C-6, I-1, I-2, I-4*

Action 1.2D: Study Novel Methods to Enhance Ecosystem Functioning

Potential negative effect of RoPCs on Action:

- Competing costs associated with climate change adaptation could cause communities to lack the funding needed to apply the novel methods developed in this Action. *RoPC I-3*

Potential positive effect of Action on RoPCs:

- This Action could help alleviate many of the RoPCs by finding solutions to issues associated with the RoPCs (e.g., shoreline hardening, acidification, excess nutrients) and educating people about the solutions. *RoPCs H-3, H-5, H-7, W-1, W-2, W-3, W-4, W-5, W-6, W-7, C-5, I-4*

GOAL 2: Reduce nutrient pollution and its impacts, including coastal acidification

Strategy 2.1: Fill the gaps in scientific understanding of Casco Bay's nutrient sources, processes and impacts that are needed to guide policy and management decisions
Strategy 2.2: Encourage use of green infrastructure to reduce nutrient pollution from runoff
Strategy 2.3: Advance policies and regulations that minimize nutrient pollution and coastal acidification
Strategy 2.4: Seek long-term solutions for funding stormwater management and constructing stormwater infrastructure

Action 2.1A: Assess Casco Bay's Nutrient Sources, Cycles and Impacts

Potential negative effect of RoPCs on Action:

- Unpredictable changes in weather and climate could make it necessary to implement more expensive and complex monitoring programs. *RoPCs I-1, I-2*

Potential positive effect of Action on RoPCs:

- This Action will help build a foundation of information that is needed to understand and alleviate several risks. *RoPCs H-5, H-7, W-1, W-2, W-3, W-4, W-6, W-7, C-5, I-4*

Action 2.1B: Improve Understanding of Water Movement within Casco Bay

Potential negative effect of RoPCs on Action:

- Unpredictable changes in weather and climate could make it necessary to implement more expensive and complex monitoring programs. *RoPCs I-1, I-2*
- Competing costs associated with climate change adaptation could cause communities to lack the funding support this Action's monitoring effort. *RoPC I-3*

Potential positive effect of Action on RoPCs:

- This Action will help build a foundation of information that is needed to understand and alleviate several risks. *RoPCs H-5, W-2, W-4, W-5, W-7*

Action 2.2A: Work Collaboratively to Reduce Nutrient Pollution within a Priority Watershed

Potential negative effect of RoPCs on Action:

- Other infrastructure costs associated with climate change adaptation could reduce the funding that communities and agencies have available to put toward green infrastructure. *RoPCs C-1, C-6, I-3*

Potential positive effect of Action on RoPCs:

- This Action will help build a foundation of information and public awareness to understand and alleviate several risks. *RoPCs H-5, H-7, W-1, W-2, W-3, W-4, W-5, W-7, C-5, I-4*

Action 2.2B: Share Innovative Stormwater Solutions

Potential negative effect of RoPCs on Action:

- Other infrastructure costs associated with climate change adaptation could reduce the funding that communities and agencies have available to put toward innovative stormwater solutions. *RoPCs C-1, C-6, I-3*

Potential positive effect of Action on RoPCs:

- This Action will help build a foundation of information and public awareness to understand and alleviate several risks. *RoPCs H-7, W-1, W-3, W-4, C-2, C-5, I-4*

Action 2.3A: Form a Stakeholder-Based Group to Study Impacts of Nutrients and Costs of Nutrient Management

Potential negative effect of RoPCs on Action:

- Other infrastructure costs associated with climate change adaptation could reduce the funding that communities and agencies have available to put toward nutrient management. *RoPCs C-6, I-3*

Potential positive effect of Action on RoPCs:

- This Action will help build a foundation of information and public support to understand and alleviate several risks. *RoPCs H-5, H-7, W-1, W-2, W-3, W-4, W-5, C-5, I-4*

Action 2.3B: Reduce Combined Sewer Overflow Discharges

Potential negative effect of RoPCs on Action:

- Other infrastructure costs associated with climate change adaptation could reduce the funding that communities and agencies have available to put toward reducing CSO discharges. *RoPCs C-1, C-6, I-3*

Potential positive effect of Action on RoPCs:

- This Action will help build a foundation of information and public support to understand and alleviate several risks. *RoPCs H-5, H-7, W-1, W-2, W-3, W-4, C-5, I-4*

Action 2.4A: Help Address Stormwater and Water Infrastructure Finance Challenges

Potential negative effect of RoPCs on Action:

- N/A

Potential positive effect of Action on RoPCs:

- This Action will help build a foundation of information and public support to understand and alleviate several risks. *RoPCs H-5, H-7, W-1, W-2, W-3, W-4, C-1, C-2, C-5, I-3, I-4*

Action 2.4B: Monitor Implementation of Portland's Stormwater Service Charge

Potential negative effect of RoPCs on Action:

- N/A

Potential positive effect of Action on RoPCs:

- This Action will help build a foundation of information and public support to understand and alleviate several risks. *RoPCs H-5, H-7, W-1, W-2, W-3, W-4, C-1, C-2, C-5, I-3, I-4*

GOAL 3: Foster resilient communities and their connections to Casco Bay

Strategy 3.1: Strengthen appreciation for the cultural, ecological and economic values of Casco Bay
Strategy 3.2: Improve local policies and practices to better protect the Bay
Strategy 3.3: Help communities prepare for climate change impacts and resulting economic, cultural and ecological disruptions

Action 3.1A: Highlight Casco Bay's Economic Importance

Potential negative effect of RoPCs on Action:

- N/A

Potential positive effect of Action on RoPCs:

- This Action could help build information and public support to understand and alleviate all RoPCs. *All RoPCs*

Action 3.1B: Expand and Publicize Volunteer Opportunities

Potential negative effect of RoPCs on Action:

- N/A

Potential positive effect of Action on RoPCs:

- A larger, better-informed volunteer base could be a valuable resource to overcome the increased cost and complexity of monitoring associated with climate change. *RoPCs I-1, I-2*

Action 3.1C: Encourage Experiential Learning Programs to Engage Students With Casco Bay

Potential negative effect of RoPCs on Action:

- N/A

Potential positive effect of Action on RoPCs:

- N/A (Although this Action is generally beneficial for addressing many RoPCs over the long term, it does not closely correlate with them.)

Action 3.1D: Offer Small Grants for Community-based Projects

Potential negative effect of RoPCs on Action:

- N/A

Potential positive effect of Action on RoPCs:

- N/A (Although this Action is generally beneficial for addressing many RoPCs over the long term, it does not closely correlate with them, except if individual funded community-based projects alleviate particular RoPCs.)

Action 3.2A: Provide Technical Assistance to Casco Bay Communities
Action 3.2B: Create and Promote a Municipal Self-Assessment Tool to Encourage Adoption of Local Policies That Protect Casco Bay

Potential negative effect of RoPCs on Actions:

- N/A

Potential positive effect of Actions on RoPCs:

- These Actions will provide local communities with information and assistance to respond constructively to climate change. *RoPCs C-5, I-4*
- By extension, they will indirectly help alleviate many other RoPCs.

Action 3.2C: Help Portland Create a Solution for Dredged Material Disposal

Potential negative effect of RoPCs on Action:

- Costs of repairing and maintaining waterfront facilities in the face of climate change may limit capacity and funding available for dredging. *RoPC C-3*

Potential positive effect of Action on RoPCs:

- N/A

Action 3.3A: Foster Climate Preparedness among Local Decision Makers
Action 3.3B: Promote Climate Adaptation Best Practices That Incorporate Sound Climate Science

Potential negative effect of RoPCs on Actions:

- N/A

Potential positive effect of Actions on RoPCs:

- These Actions will provide local communities with information and assistance to respond constructively to climate change. *RoPCs C-5, I-4*
- By extension, they will indirectly help alleviate many other RoPCs.

GOAL 4: Mobilize collective knowledge and resources to support Casco Bay

Strategy 4.1: Serve as an information hub on Casco Bay issues and initiatives
Strategy 4.2: Provide an organizational anchor for initiatives that benefit the Bay
Strategy 4.3: Expand the scope and coordination of Bay-related environmental monitoring

Action 4.1A: Gather and Share Casco Bay Information
Action 4.1B: Report on the State of the Bay
Action 4.1C: Share Scientific and Community Information to Inform Relevant Policy Decisions
Action 4.2A: Lead Place-Based Planning to Benefit Habitat and Water Quality
Action 4.2B: Host Technical Working Groups on Emerging Issues

Potential negative effect of RoPCs on Actions:

- N/A

Potential positive effect of Actions on RoPCs:

- Actions 4.1A-4.2B will provide local communities with information and assistance to respond constructively to climate change. *RoPCs C-5, I-4*
- By extension, they will indirectly help alleviate many other RoPCs. Working Groups hosted through Action 4.2B will focus on specific RoPCs.

Action 4.2C: Seek Resources to Support Programs That Benefit the Bay
Action 4.3A: Coordinate a Casco Bay Monitoring Network
Action 4.3B: Facilitate Improved Research on Changes in Casco Bay
Action 4.3C: Expand Monitoring of Casco Bay Tributaries

Potential negative effect of RoPCs on Actions:

- N/A

Potential positive effect of Actions on RoPCs:

- N/A (While Actions 4.2C-4.3C do not directly alleviate the RoPCs, they build capacity to do so more effectively in the future.)

Figure 3 correlates each risk with the Plan Actions that it may affect, estimates the time frame of the RoPC's potential impact, and considers the relationship (impair, facilitate, alleviate) between the Action and the RoPC.

Figure 3. Correlation of Risks of Primary Concern with the Actions of the *Casco Bay Plan 2016-2021*

Bold font: Short-term RoPCs (10-20 years) Regular font: Medium-term RoPCs (30-40 years)
X = Risk may impair Action (+) = Risk may facilitate Action A = Action may alleviate Risk

GOAL:	1: Habitat						2: Water Quality								3: Community									4: Knowledge/Resources											
Strategy:	1.1		1.2				2.1		2.2		2.3		2.4		3.1				3.2			3.3		4.1			4.2			4.3					
Action:	A	B	A	B	C	D	A	B	A	B	A	B	A	B	A	B	C	D	A	B	C	A	B	A	B	C	A	B	C	A	B	C	Risk Theme	Risk ID	Risk Description
	X			X	A										A																		Principally **HABITAT** Related	**H-1**	**Warmer waters in rivers and streams in summer exceed thermal tolerances for some native aquatic species, leading to population declines and local extinction.**
	X		X		A										A																		Principally **HABITAT** Related	**H-2**	**Warmer ocean water temperatures cause shifts in species' geographic ranges and the community structure of Casco Bay's ecosystem, leading to declines in some existing fisheries resources and increases in some invasive species, pathogens, pests, and disease vectors.**
	X		X		A	A									A																		Principally **HABITAT** Related	**H-3**	**Rising seas and increased storm intensities cause greater demand for protection of coastal properties via shoreline hardening (which would reduce habitat value and scope for wetland migration), and therefore the need to facilitate better solutions such as living shorelines.**
				X	A										A																		Principally **HABITAT** Related	**H-4**	**More winter precipitation falling as rain, earlier snow melt and less predictable precipitation lead to a shorter and less predictable spring season of high river flows, affecting fish migration.**
	X		X		A	A	A	A	A		A	A	A	A	A																		Principally **HABITAT** Related	**H-5**	**Acidification, both in the water column and in tidal flats, caused by global and local factors leads to reduced growth and survival of some species.**
	X		X		A										A																		Principally **HABITAT** Related	H-6	Higher temperatures increase respiration rates in eelgrass, reducing net productivity and increasing mortality.
	X		X		A	A	A		A	A	A	A	A	A	A																		Principally **HABITAT** Related	H-7	Climate change leads to changes in marine and coastal food webs, altering species composition, making coastal ecosystems less resilient to other stressors like invasive species, elevated nutrients and habitat destruction, and raising chances of the ecosystem hitting a tipping point.
	X		X		A										A																		Principally **HABITAT** Related	H-8	Sea level rise and altered hydrology in tidal wetlands (due to multiple climate stressors) shifts species composition, causes both gains and losses of tidal wetland area, and makes the wetlands more susceptible to invasion by invasive plants.
	X		X		A	A	A		A	A	A	A	A	A	A																		Principally **WATER QUALITY** Related	**W-1**	**Higher intensity storms make it more likely that stormwater control devices will prove too small to perform as designed, reducing effectiveness, and degrading downstream water quality.**
	X		X		A	A	A	A	A		A	A	A	A	A																		Principally **WATER QUALITY** Related	**W-2**	**Higher water temperatures make the Bay more susceptible to nutrients (via algae growth, thermal stratification, and rapid recycling of nutrients) increasing risk of harmful algae blooms, decreased water clarity, lower dissolved oxygen, and fish kills.**
	X		X			A	A		A	A	A	A	A	A	A																		Principally **WATER QUALITY** Related	**W-3**	**Large storms increase stormwater volumes and infiltration into aging sewer lines, thus sending larger volumes of more dilute wastewater to treatment plants, reducing effectiveness of nutrient removal.**
	X		X		A	A	A	A	A	A	A	A	A	A	A																		Principally **WATER QUALITY** Related	**W-4**	**Increased runoff and Combined Sewer Overflow (CSO) discharges from more intense storms increase transport of nutrients and other pollutants to downstream waters, including lakes and the Bay, degrading water quality.**
	X		X		A	A		A							A																		Principally **WATER QUALITY** Related	**W-5**	**More frequent severe storms and sea level rise increase flooding of coastal and river valley communities, causing release of pollutants into rivers and coastal water.**
			X		A	A	A								A																		Principally **WATER QUALITY** Related	**W-6**	**More winter precipitation falling as rain, earlier snow melt and less predictable precipitation lead to a shorter and less predictable spring season of high river flows, affecting timing and magnitude of nutrient inputs to the Bay.**
	X		X		A	A	A	A							A																		Principally **WATER QUALITY** Related	**W-7**	**Increased storm intensity and rising seas lead to more erosion from uplands, shores, banks and bluffs, increasing both turbidity and nutrient flows, degrading water quality.**

Figure 3 (Continued). Correlation of Risks of Primary Concern with the Actions of the *Casco Bay Plan 2016-2021*

Bold font: Short-term RoPCs (10-20 years) Regular font: Medium-term RoPCs (30-40 years)
X = Risk may impair Action (+) = Risk may facilitate Action A = Action may alleviate Risk

GOAL:	1: Habitat						2: Water Quality								3: Community									4: Knowledge/Resources											
Strategy:	1.1		1.2				2.1		2.2		2.3		2.4		3.1				3.2			3.3		4.1			4.2			4.3					
Action:	A	B	A	B	C	D	A	B	A	B	A	B	A	B	A	B	C	D	A	B	C	A	B	A	B	C	A	B	C	A	B	C	Risk Theme	Risk ID	Risk Description
									X	X		X			A																		Principally **COMMUNITY** Related	C-1	**Storm surge and coastal flooding shortens the life of transportation and utility infrastructure, from roads and port facilities to sewer lines and sewage treatment plants, reducing economic productivity and increasing private and public sector costs.**
									A	A			A	A	A																			C-2	**Rising seas flood stormwater pipes and reduce drainage capacity of stormwater infrastructure, increasing risk of flooding.**
															A						X													C-3	**Rising seas make waterfront facilities like piers and other commercial and recreational access points inoperable, or require expensive repairs and investment to maintain functionality, affecting marine industries and quality of life.**
															A																			C-4	**More frequent severe storms and sea level rise increase flooding of coastal and river valley communities, and lead to more frequent catastrophic failure of banks and bluffs, causing economic and social harm.**
	A		A	A	A	A	A		A	A	A	A	A	A	A				A	A		A	A	A	A	A	A	A						C-5	**Complexity of multiple demands for adaptation to climate change may overwhelm ability of local governments to respond constructively to change.**
	(+)		(+)	(+)	A				X	X	X	X	A	A	A																			C-6	**Increased probability of failure of culverts due to greater storm intensities requires more frequent culvert replacement, driving up infrastructure costs.**
			X		A		X	X							A	A																	**IMPLEMENTATION**	I-1	**Uncertainty about the future of the Bay, due to inability to predict climate impacts caused by multiple interacting stressors, increases both complexity and cost of monitoring programs.**
			X	X	A		X	X							A	A																		I-2	**Unpredictable weather leads to an increased need for monitoring of episodic events like severe storms and their effects, increasing both total and event-triggered monitoring costs.**
	X		X	X		X		X	X	X	X	X	A	A	A																			I-3	Community ability to fund water quality infrastructure and other environmental projects is decreased by need for disaster recovery, infrastructure replacement and costs of climate adaptation.
	A		A	A	A	A	A		A	A	A	A	A	A	A				A	A		A	A	A	A	A	A	A						I-4	**Multiple climate stressors (warmer summers, winters, and water; increasing drought and storminess; sea level rise; ocean acidification) make it difficult for managers and regulators to understand emerging issues, and to respond quickly and constructively to a changing coastal ocean.**

SECTION FOUR

Management of Risks

Overview

The 25 Risks of Primary Concern (RoPCs) have the potential to affect the ability of the Casco Bay Estuary Partnership (CBEP) to meet the goals of the Casco Bay Plan. The four general approaches for responding to specific risks are Mitigate; Transfer; Accept; Avoid. In this section, CBEP identifies its approach for each risk and details possible adaptation reactions related to that approach.

Habitat-Related Risks

H-1 Warmer waters in rivers and streams in summer exceed thermal tolerances for some native aquatic species, leading to population declines and local extinction.

Response Type: Mitigate

Warmer waters are already having an effect in Maine on cold-water fish like brook trout. Impacts on other fish, including anadromous species, are likely to increase in decades to come.

Increases in air temperature will increase stream temperatures, but stream temperature reflects more than air temperature. Stream temperatures are influenced by surrounding land uses, presence of sunlight and shade on streams, and groundwater inflow. Thus while we are unable to completely eliminate increasing stream temperatures, we can reduce or delay their severity and impacts.

We can:

- Protect and restore cold water refugia, including areas of groundwater discharge to streams and rivers;
- Work to improve fish passage between tributary streams and larger waters like lakes and rivers, increasing access of cold-water species to cooler waters during the warmest part of the summer;
- Protect riparian and floodplain forests surrounding headwater streams, brooks, and rivers, to increase shading of the streams;
- Encourage use of stormwater control technologies that reduce the probability of discharge of heated waters from asphalt surfaces or retention ponds directly to vulnerable streams.

We can also mitigate the impact of stream temperature on populations of fish species of concern by supporting those populations in other ways. For example, one way to reduce the impact of rising temperatures on anadromous fish is to restore fish passage to our streams and rivers. Increases in migratory fish populations due to fish passage improvements would mask emerging changes due to elevated temperature. And the substantially larger populations possible—especially on our larger rivers—would be both less vulnerable to extinction, and more able to adapt to changing conditions.

Local communities could change ordinances to provide better protection of riparian zones, improve culverts near stream-river junctions, and extend protections to groundwater discharge areas, but such changes are likely to be controversial.

Relationship to the Casco Bay Plan:
Responses to this RoPC can be implemented as part of Strategies 1.1 (Habitat Protection) and 1.2 (Habitat Restoration) of the Casco Bay Plan. Recognition of this RoPC may influence work with local communities under Strategy 3.3 (Prepare for Climate Change).

H-2 Warmer ocean water temperatures cause shifts in species' geographic ranges and the community structure of Casco Bay's ecosystem, leading to declines in some existing fisheries resources and increases in some invasive species, pathogens, pests, and disease vectors.

Response Type: Mitigate

It is hard to overstate the importance of climate impacts on species ranges in shaping the marine resource economy of Maine in coming decades. The northern shrimp fishery has been closed since 2014, principally because the species has shifted its range northward. Lobstermen report increasing numbers of black sea bass turning up in their traps, and the State approved a limited fishery for this mid-Atlantic species in 2014. Scientists have expressed concern that Maine's lobster fishery may be susceptible to rapid declines like those in southern New England, where the American lobster is all but commercially extinct. In 2016, lobster represented 73.9% of the value of all fisheries in Maine, and the prosperity of Maine's island and small coastal communities is highly dependent upon lobster.

We can do little at the Casco Bay scale to affect shifts in the ranges of marine species, which reflect changing ocean conditions developing at regional and continental scales. We can, however, take steps to minimize impact of these shifts on fisheries, coastal economies, and coastal ecosystems. We can reduce the impact of ecosystem change on coastal communities by working with those communities to facilitate economic adaptation. For example, we can work to facilitate emerging fisheries or support development of locally owned, environmentally sound aquaculture businesses.

Numerous invasive marine species are already present in Casco Bay. Some invasives, like the green crab, the common periwinkle, and the orange sheath tunicate (*Botrylloides violaceus*) are found in significant numbers throughout the Bay. Invasives are already imposing significant impacts on coastal ecosystems and fisheries.

Unfortunately, our ability to block invasive species in the marine environment is limited. Several invasives of concern are already present in the Gulf of Maine, but are not known to have established in Casco Bay. Such species may not yet have been introduced to Bay waters, or conditions in the Bay (such as cold winters) may limit their numbers. Either way, options for active management to reduce the probability of their arrival are few.

We can:

- Monitor presence and abundance of invasive species, so we know what is present and identify emerging threats;
- Provide education for boat owners, marina operators and others about impacts of invasive species, and actions they can take to reduce their spread;
- Seek tools to manage populations or reduce economic and ecological impacts of invasives.

Finally, we can mitigate the impact of invasive species on the health of Casco Bay by protecting the Bay's health in other ways—from reducing nutrient pollution to protecting important coastal habitats.

Relationship to the Casco Bay Plan:
CBEP's Strategy 3.3 (Prepare for Climate Change) provides an avenue for addressing this risk, principally by working with communities to diversify the economy of coastal communities and reduce their vulnerability to shifts in abundance of any one marine species. Monitoring of invasives should be an integral part of Strategy 4.3 (Bay monitoring).

H-3 Rising seas and increased storm intensities cause greater demand for protection of coastal properties via shoreline hardening (which would reduce habitat value and scope for wetland migration), and therefore the need to facilitate better solutions such as living shorelines.

Response Type: Mitigate

CBEP is already working with the Maine Coastal Program and other partners to facilitate environmentally preferable strategies for protecting eroding shorelines in Maine. This effort, which is expected to last several years, will develop and test "living shorelines" technologies that work in Maine. The initiative will also involve working with regulatory agencies to seek solutions to regulatory barriers that sometimes provide disincentives for landowners to use creative approaches to protecting their property.

Shorelines can also be protected against hardening over a period of decades by legal means, including:

- Direct fee acquisition of shoreline properties;
- Use of easements (conservation easements, rolling easements) to limit shoreline construction;
- Shoreline protection policies that limit construction of hardened shorelines;
- Shoreline protection policies that limit construction of residences and infrastructure in vulnerable locations.

Policy change may be needed as part of a coordinated response to this RoPC.

Relationship to the Casco Bay Plan:
Directly related to Action 1.2.D (Study and test novel methods to enhance ecosystem functioning.) Directly related to work with communities to protect the Bay (Strategy 3.2), and to prepare for climate change (Strategy 3.3). Some shoreline protection strategies could be supported by Action 1.1.A (Habitat Protection Fund) and 1.1.B (Assist habitat protection).

H-4 More winter precipitation falling as rain, earlier snow melt and less predictable precipitation lead to a shorter and less predictable spring season of high river flows, affecting fish migration.

Response Type: Accept/Mitigate

We can do little to affect seasonality of river flows at the local scale, and we are likely to have to accept the impacts such changes may have on migratory fish. However, impacts at the population level can be mitigated by supporting anadromous fish populations in other ways.

As with efforts to mitigate the impact of rising stream and river temperatures on migratory fish (see RoPC H-1) we can continue to work to restore and maintain access of migratory fish to their breeding habitats and protect water quality in the lake and riverine habitat, where many migratory species are most vulnerable.

Relationship to the Casco Bay Plan:
Responses to this RoPC can be implemented as part of Strategies 1.1 (Habitat Protection) and 1.2 (Habitat Restoration), particularly Action 1.2.B (Restore Aquatic Habitat Connectivity), of the Casco Bay Plan. Many efforts to address water quality under Goal 2 (Water Quality) may also help mitigate this risk.

H-5 Acidification, both in the water column and in tidal flats, caused by global and local factors leads to reduced growth and survival of some species.

Response Type: Mitigate

While we can do little at the local level to reduce the magnitude of acidification caused by global CO_2 levels, we can work to combat local processes that exacerbate the problem. High nutrient levels in the Bay contribute to growth of planktonic algae, which often leads to increased production of algae and, indirectly, CO_2. That CO_2, in turn, produces local acidification that just adds to the global phenomenon. One of the most effective ways we can reduce the impact of acidification on Casco Bay is to reduce nutrient loading to the Bay. Excess nutrients have many other negative effects on the Bay's health, so reducing nutrients would have numerous other benefits.

Other actions to reduce the impact of acidification on the Bay and on our communities could include:

- Support efforts to improve understanding of coastal acidification and its impacts on the Bay and on important local fisheries, including aquaculture;
- Experiment with ways to reduce impacts of acidification on key resources, like shellfish;
- Work with communities to identify strategies for diversifying local economies.

Relationship to the Casco Bay Plan:
Almost all of the Actions under Goal 2 (Water Quality) contribute to mitigating this RoPC. Studies of ways to reduce impact of acidification may be included under Action 1.2.D (Study and test novel methods to enhance ecosystem functioning). Working with local communities on climate change is addressed in Goal 3 (Community).

H-6 Higher temperatures increase respiration rates in eelgrass, reducing net productivity and increasing mortality.

Response Type: Mitigate/Accept

In coming years, eelgrass in Casco Bay is likely to be confronted with multiple stressors, from green crab population booms (like the one that caused extensive loss of eelgrass in 2013) to poor water clarity due to elevated nutrient levels in the Bay. The type of long-term reductions in net eelgrass productivity expressed in this RoPC are likely to slow growth and recovery of eelgrass, and thus act synergistically with other stressors to make it increasingly difficult in the future to maintain healthy eelgrass in the Bay.

We have few options for avoiding this risk, but we can seek ways to reduce or delay impacts of the loss of eelgrass by working to protect existing eelgrass beds, improve water quality and seek opportunities to enhance eelgrass populations via restoration, replanting, and integration of eelgrass into "living shorelines" projects.

In the long term, if eelgrass productivity does decline, we will need to reevaluate the viability of simple restoration and planting projects, in light of slower plant growth. In another generation, we may need to consider options that may be controversial today, such as importing more heat-tolerant eelgrass genotypes from the mid-Atlantic or creating eelgrass "reserves" to maintain local sources of plant material for natural recruitment and restoration.

Relationship to the Casco Bay Plan:
Responses to this RoPC can be implemented as part of Strategies 1.1 (Habitat Protection) and 1.2 (Habitat Restoration) of the Casco Bay Plan. Recognition of this RoPC may influence work with local communities under Strategy 3.3 (Prepare for Climate Change).

H-7 Climate change leads to changes in marine and coastal food webs, altering species composition, making coastal ecosystems less resilient to other stressors like invasive species, elevated nutrients and habitat destruction, and raising chances of the ecosystem hitting a tipping point.

Response Type: Accept

Climate change will act synergistically with other stressors, making the Bay more susceptible to other challenges. Thus a key part of responding to a changing climate must be to protect the Bay's health in other ways. A healthier Bay will respond more constructively to change than will a Bay already facing challenges. Climate change does not overshadow other efforts to protect the Bay; it makes them even more important.

The challenge for Casco Bay in coming decades is not just climate change, but coastal change—the synergistic effect of multiple stressors affecting the coast simultaneously with a changing climate. The principal local response to coastal change, perhaps paradoxically, thus must be to focus even more strongly on how we reduce and eliminate other threats to the Bay's health.

The other way to respond to this RoPC will be to put more resources into understanding and monitoring the Bay. Better monitoring will help us detect and characterize change as it begins, providing more time to respond—both to protect the Bay itself and to assist coastal communities with adapting to a changing Bay, and with better information to do so. Better science will help us identify more effective strategies for protecting the health and resilience of the Bay as it continues to change.

Relationship to the Casco Bay Plan:
This RoPC was well recognized by the CBEP community while the *Casco Bay Plan 2016-2021* was being drafted. It underlies many of the priorities expressed in that Plan, especially interest in exploring novel methods to enhance ecosystem function in Goal 1, a focus on nutrients in Goal 2, community engagement in Goal 3, and improving monitoring and science in Goal 4.

H-8 Sea level rise and altered hydrology in tidal wetlands (due to multiple climate stressors) shifts species composition, causes both gains and losses of tidal wetland area, and makes the wetlands more susceptible to invasion by invasive plants.

Response Type: Accept

Casco Bay's tidal wetlands will change in numerous ways in coming decades. With thousands of acres of tidal wetlands scattered in hundreds of sites around the Bay, a comprehensive response to these changes is all but impossible. Luckily, most changes are likely to be gradual, allowing us to develop and evaluate strategies for responding to this RoPC as we come to understand them better.

Initial studies suggest that loss of tidal wetlands in Casco Bay due to sea level rise in the next 50 to 100 years are likely to be less severe than losses projected to our south. The geomorphology of Casco Bay and the relatively undeveloped nature of most of its shoreline gives many of our wetlands space to move, at least for a while. But in the long run—exactly when depends on the rate of sea level rise—Casco Bay's steep shorelines mean most Casco Bay wetlands will have nowhere to go.

In coming years it will be important to consider what we understand about the future of Casco Bay wetlands in designing and implementing coastal restoration and protection projects. There may be little point in investing in wetland restoration if the restored marsh has an expected lifetime of only a few decades. Conversely, forecasts for the Gulf of Maine suggest severe population bottlenecks for saltmarsh sparrows by the middle of the century. Casco Bay's tidal wetlands, while small by regional standards, are relatively resilient to moderate sea level rise. They may provide a valuable refuge for these salt marsh breeding birds through the decades of the mid twenty-first century.

In the interim, we can work to improve our understanding of changes in Casco Bay's tidal wetlands and experiment with restoration methods. We have already used simple models to characterize future wetland loss, and we are in the process of establishing sentinel monitoring sites in Casco Bay tidal wetlands to allow us to track changes in our salt marshes. We can continue to assess the potential of methods that are being tested elsewhere for improving the resilience of our tidal wetlands.

Relationship to the Casco Bay Plan:
Response to this RoPC is closely aligned with Actions in Goal 1 and Goal 4.

Water Quality-Related Risks

W-1 Higher intensity storms make it more likely that stormwater control devices will prove too small to perform as designed, reducing effectiveness, and degrading downstream water quality.

Response Type: Mitigate

The consequences of this risk can be mitigated by use of climate-responsive designs for stormwater control devices. However, this effort is likely to be slow, as climate responsive designs are not well understood or broadly accepted by the development community.

A particularly promising approach to mitigating this risk will be to expand use of "Low Impact Development" and "Green Infrastructure" approaches to stormwater management. As these design philosophies integrate site hydrology and natural processes into site design, and make more extensive use of small, decentralized stormwater management tools, they are more resilient than traditional designs.

Because of the relatively slow rate of population growth in our region, a high proportion of our developed landscape was urbanized decades ago, before the advent of modern stormwater design criteria. Thus many stormwater control devices are undersized by today's standards. Moreover, the structures are aging and may provide little water quality benefit. Climate change will just make that situation worse. Adaptation to this RoPC thus will also entail efforts to install stormwater controls in existing developed landscapes.

CBEP can support these efforts by:

- Working with communities to increase awareness of the impact of stormwater on Casco Bay;
- Encouraging adoption of stormwater control measures in general, and encouraging designs that incorporate forecasts and uncertainties about future storm intensities into present-day designs;
- Facilitating use of climate-responsive designs and technologies like green infrastructure and low impact development;
- Helping to address long-term funding needs for water infrastructure.

Relationship to the Casco Bay Plan:
Responses to this risk align closely with actions under Goals 2 and 3 of the Casco Bay Plan.

W-2 Higher water temperatures make the Bay more susceptible to nutrients (via algae growth, thermal stratification, and rapid recycling of nutrients), increasing risk of harmful algae blooms, decreased water clarity, lower dissolved oxygen, and fish kills.

Response Type: Mitigate

This RoPC makes it more important than ever to focus on reducing nutrient loads entering the Bay. The combination of climate change and a growing human population in the Casco

Bay watershed make risks to the health of the Bay due to nutrient enrichment one of the most concerning long-term threats to the health of the Bay. (See also the related RoPC H-7).

Relationship to the Casco Bay Plan:
The CBEP community was well aware of this risk when drafting the *Casco Bay Plan 2016-2021*. Addressing this risk is reflected throughout the structure of the Plan, but especially in Goals 2 and 4.

W-3 Large storms increase stormwater volumes and infiltration into aging sewer lines, thus sending larger volumes of more dilute wastewater to treatment plants, reducing effectiveness of nutrient removal.

Response Type: Mitigate

Wastewater treatment plant engineers and operators can take steps to reduce nutrient concentrations in each plant's effluent, but if water volumes increase due to changes in precipitation patterns, so will total discharges of nutrients to the Bay. Plant upgrades that allow substantial reductions in effluent nutrient concentrations, however, can be costly.

Potential responses include:

- Support efforts to reduce volumes of water entering sewer lines by reducing inflow and infiltration into sewer systems and assessing benefits of storm sewer separation (while weighing the nutrient removal benefits of providing even partial treatment for stormwater);
- Continue to reduce the average nutrient concentrations in treatment plant effluent;
- Continue to reduce other sources of nutrients entering the Bay (see RoPC W-2 and H-7).

Relationship to the Casco Bay Plan:
Reductions in nutrient loading to the Bay achieved via the Actions in Goal 2 will reduce or delay impacts of increased loads due to climate change. Little of the Plan, however, focuses directly on wastewater treatment practice. Action 2.3.A involves wastewater treatment plant operators (among others) in discussions on how to manage nutrient loads to the Bay. Certain approaches to reduce CSO discharges (Action 2.3.B) can also reduce flow of surface or groundwater to wastewater plants. Efforts to address water infrastructure finance needs (Action 2.4.A) will help identify the resources necessary for long-term investments in sewer and wastewater systems to address this RoPC.

W-4 Increased runoff and Combined Sewer Overflow (CSO) discharges from more intense storms increase transport of nutrients and other pollutants to downstream waters, including lakes and the Bay, degrading water quality.

Response Type: Mitigate

Nutrient enrichment is likely to be among the most important threats to the health of the Bay in coming years. And runoff—in our region principally from urban areas—is among the most important sources of nutrients. More rain and larger storms both tend to wash more nutrients to the Bay, and climate forecasts suggest both more rain and more intense storms in the future.

While we can do little at the local level to affect future precipitation patterns, we can work to reduce the yield of nutrients—especially nitrogen—entering the Bay per unit rainfall.

We can reduce the impact of increased runoff by (among other strategies):

- Implementing better stormwater management programs at the local level;
- Installing "stormwater retrofits" into existing developed landscapes where existing stormwater infrastructure is inadequate or does a poor job of removing nitrogen;
- Encouraging the use of stormwater control approaches—like "green infrastructure"—that reduce nitrogen flow to downstream waters;
- Educating the public and policy makers about the effects of runoff on the Bay;
- Encouraging homeowners to avoid or minimize the use of fertilizers on their lawns;
- Continuing to reduce the frequency and size of combined sewer overflow events.

Relationship to the Casco Bay Plan:
Many of the Actions identified in Goal 2, especially under Strategies 2.2 and 2.3 are immediately relevant to mitigating the impact of this RoPC.

W-5 More frequent severe storms and sea level rise increase flooding of coastal and river valley communities, causing release of pollutants into rivers and coastal water.

Response Type: Transfer

The primary way to reduce the impacts of this RoPC should be to reduce risks of flooding of coastal and river valley communities, thus reducing risk of release of pollutants. A secondary approach will be to move pollutants out of flood-prone areas in advance of storms. Communities, businesses, and residents can take steps to move vulnerable assets (and associated pollutants) out of harm's way, via investment in flood protection infrastructure and gradual disinvestment in vulnerable assets. Zoning, insurance, planning and risk management policies can create disincentives for placing vulnerable assets or potential pollutants into flood-prone areas.

CBEP and our partners can support these efforts via outreach and education, especially by communicating the best available science to help communities assess the magnitude of storm-related risks. We can also encourage coastal and river valley communities to invest in infrastructure or disinvest in vulnerable assets to reduce potential flooding impacts.

CBEP can play a role in publicizing flood risks and the benefits of various flood risk mitigation strategies.

Relationship to the Casco Bay Plan:
Responses to this RoPC are included as part of Strategy 3.3. Recognition of this RoPC may place a greater priority on communicating with coastal and floodplain communities about the possible health and environmental impacts of pollutants that enter rivers and the Bay during floods.

W-6 More winter precipitation falling as rain, earlier snow melt and less predictable precipitation lead to a shorter and less predictable spring season of high river flows, affecting timing and magnitude of nutrient inputs to the Bay.

Response Type: Accept

Shifts in timing of river and stream flow over the past several decades are well documented in Maine. We can do little at the watershed scale to avoid or reduce these shifts in timing, and the implications for coastal ecosystems are not well understood. Consequently, any action to address this RoPC is premature. The best responses available to us involve overall efforts to protect and enhance the health of the Bay, especially working to reduce nutrient loading to the Bay and protect water quality.

Relationship to the Casco Bay Plan:
Many Actions included in the Plan can indirectly reduce the potential negative consequences of this risk.

W-7 Increased storm intensity and rising seas lead to more erosion from uplands, shores, banks and bluffs, increasing both turbidity and nutrient flows, degrading water quality.

Response Type: Mitigate

A high proportion of erosion from uplands is caused or exacerbated by human activity, such as construction, agriculture, logging, clearing land, poor landscaping practices, and so on. Legal and policy tools, from zoning and permit requirements under state and federal law, to Department of Agriculture conservation programs, help reduce soil erosion. Such tools will continue to be important for limiting erosion in the future.

On the other hand, erosion of shores and banks is a normal process, and thus responding to possible increases in their erosion must be measured and responsible, considering the interplay of sediment erosion, deposition and transport in the context of the geomorphology of Casco Bay and its tributaries.

A number of strategies can mitigate the severity of this RoPC, including:

- Support efforts to reduce soil erosion, including education, policy development, and enforcement of existing policies;
- Reduce land cleared of vegetation during site development. Existing vegetation significantly reduces erosion, and can provide other important services, including water quality benefits and habitat for wildlife;
- Work to develop environmentally sound approaches to shoreline protection (see RoPC H-3), where appropriate;
- Reduce other water quality challenges that will exacerbate or act synergistically with increased sediment inputs to the Bay and other local waters;
- Expand use of stormwater management practices like green infrastructure that reduce nutrient loading to the Bay.

Relationship to the Casco Bay Plan:
This RoPC is closely related to efforts to reduce nutrient pollution to the Bay, incorporated into Goal 2 of the Plan. Certain Actions under Goal 3 are also relevant for assisting local government with developing robust policies to reduce soil erosion.

Community-Related Risks

C-1 Storm surge and coastal flooding shorten the life of transportation and utility infrastructure, from roads and port facilities to sewer lines and sewage treatment plants, reducing economic productivity and increasing private and public sector costs.

Response Type: Transfer/Mitigate

To a large extent, other organizations—especially local government, businesses, and homeowners—will absorb these costs. Costs can be reduced by planning for climate change and taking appropriate actions to reduce or mitigate climate impacts. CBEP can support these efforts by facilitating access to the best available information on future risks.

Relationship to the Casco Bay Plan:
Directly related to Actions 3.3.A and 3.3.B. Indirectly related to Strategy 4.3 (Environmental Monitoring).

C-2 Rising seas flood stormwater pipes and reduce drainage capacity of stormwater infrastructure, increasing risk of flooding.

Response Type: Accept/Transfer

A major storm in September of 2015 dropped several inches of rain in Portland during an unusually high astronomical tide. The storm, which flooded portions of Forest Avenue and Marginal Way, showed what can happen when tides and rainfall conspire to overload capacity of urban drainage infrastructure. Climate forecasts suggest more intense storms in future, while rising seas are likely to reduce drainage capacity. Responses to increased risk of short-term urban flooding include redesigning stormwater conveyances to carry more water, elevating roadway intersections and other infrastructure above flood levels, or accepting infrequent flooding of vulnerable areas.

Relationship to the Casco Bay Plan:
CBEP Actions related to stormwater management (under Goal 2) and climate adaptation (under Strategy 3.3) are relevant to reducing flood risk.

C-3 Rising seas make waterfront facilities like piers and other commercial and recreational access points inoperable, or require expensive repairs and investment to maintain functionality, affecting marine industries and quality of life.

Response Type: Transfer

This is a significant long-term risk to the character of waterfront, water-dependent, and island communities in our region. Businesses and local communities will have the primary role in addressing this risk. CBEP communities and partners can play a supporting role in helping waterfronts to adapt to climate change and sea level rise by facilitating adaptation efforts, encouraging climate preparedness, and sharing credible scientific assessments of emerging risks.

Relationship to the Casco Bay Plan:
Actions under Strategy 3.3 may be relevant to assisting landowners and local communities with planning for and adapting to this RoPC.

C-4 More frequent severe storms and sea level rise increase flooding of coastal and river valley communities, and lead to more frequent catastrophic failure of banks and bluffs, causing economic and social harm.

Response Type: Accept/Transfer/Mitigate

This is a complex risk that embeds a variety of mechanisms by which a changing climate may generate economic and social harm. Control of this risk is also complex, and will generally prove site and situation specific. Thus, the best near-term approach to addressing this RoPC will be to carefully assess local risks, and develop plans to help reduce community exposure to related harm.

Relationship to the Casco Bay Plan:
Strategy 3.3 provides ways to facilitate local planning to identify and ameliorate risks.

C-5 Complexity of multiple demands for adaptation to climate change may overwhelm ability of local governments to respond constructively to change.

Response Type: Accept

This risk will be influenced both by the severity of future climate impacts and by the capacity of communities to respond constructively to impacts that do occur. The best way to address this risk may be to work to mitigate other climate risks while also supporting the ability of communities (including local governments) to understand, prepare for, and respond to climate-induced changes. For example, communities can work to develop or maintain robust governance structures, support civil discourse, or increase community conversations and connections to increasing social capital.

Relationship to the Casco Bay Plan:
Strategy 3.3 provides ways to facilitate local planning to identify and ameliorate risks. No actions in the Plan are directly related to protecting social capital or the ability of communities to respond constructively to change.

C-6 Increased probability of failure of culverts due to greater storm intensities requires more frequent culvert replacement, driving up infrastructure costs.

Response Type: Mitigate

Owners of potentially affected infrastructure should be encouraged to design structures for the climate of the future, not the climate of the past. While larger culverts are initially more expensive than smaller structures, designs should be based on an estimate of lifetime costs. Appropriate cost-benefit analysis should be based on a realistic assessment of future failure probabilities. Mechanisms are needed to incorporate trends, forecasts, and uncertainty into design practice (e.g., regularly updated flood return frequency analyses, and engineering guidance on incorporating climate change into design practice).

Relationship to the Casco Bay Plan:
Action 1.2.B emphasizes a focus on aquatic connectivity, but it is directly related to addressing the ecological harm associated with undersized (and thus vulnerable) culverts.

Implementation-Related Risks

I-1 Uncertainty about the future of the Bay, due to inability to predict climate impacts caused by multiple interacting stressors, increases both complexity and cost of monitoring programs.

Response Type: Accept

CBEP needs to build broad-based coalitions and institutional frameworks to facilitate long-term monitoring and long-term funding of monitoring. This is likely to require reducing investment in some other activities, as well as finding novel ways of funding long-term monitoring.

Relationship to the Casco Bay Plan:
Strategy 4.3 is directly related to this RoPC.

I-2 Unpredictable weather leads to an increased need for monitoring of episodic events like severe storms and their effects, increasing both total and event-triggered monitoring costs.

Response Type: Accept

See discussion of RoPC I-1.

Relationship to the Casco Bay Plan:
Strategy 4.3 is directly related to this RoPC.

I-3 Community ability to fund water quality infrastructure and other environmental projects is decreased by need for disaster recovery, infrastructure replacement and costs of climate adaptation.

Response Type: Accept

This risk is relatively long-term. The principal near-term strategy for addressing this RoPC will be to encourage climate adaptation planning.

Relationship to the Casco Bay Plan:
Strategy 3.3 can help address this RoPC.

I-4 Multiple climate stressors (warmer summers, winters, and water; increasing drought and storminess; sea level rise; ocean acidification) make it difficult for managers and regulators to understand emerging issues, and to respond quickly and constructively to a changing coastal ocean.

Response Type: Mitigate

CBEP can and should continue to work with regulators and policy makers to ensure that responses of regulatory and legal structures keep up with changing climate. The long-term response to this RoPC is likely to include legal and policy innovation.

Relationship to the Casco Bay Plan:
Not clearly related to any specific Actions in the Plan, but closely allied with CBEP's mission.

SECTION FIVE

Recommendations for Further Research and Implementation

Recommendations for Further Research

During the peer review process, reviewers were asked for recommendations about key areas for research or monitoring related to the RoPCs and Plan implementation. They identified the following needs:

(1) Socioeconomic research into local climate change impacts and adaptation strategies

Little is known about how people and communities around the Bay will be affected socioeconomically by climate change, or about climate change adaptation approaches that may be most beneficial and feasible. Research into this topic could inform future initiatives by CBEP and other government and non-government entities.

(2) Predicted summer maximum water temperatures and effects on eelgrass

Studies show that eelgrass respiration outpaces photosynthesis at temperatures above 25°C, and declines in eelgrass can be precipitated by several weeks of exposure to summertime temperatures above that threshold. However, wind-driven upwelling can drop water temperatures significantly compared to the surface. Predictions of sustained maximum water temperatures at depth are needed to project impacts of climate change on eelgrass meadows.

(3) Effects of phenological changes on reproduction and ecosystem resilience

There are two research needs within this topic: (a) For species in this region, to what extent are spawning timing and other reproductive characteristics genetically cued versus plastic, adaptive traits that respond to environmental conditions? (b) How does changing phenology differentially affect species, and how do those effects link to coastal ecosystem resilience?

(4) Effects of climate change on species and food webs

One potential area of research would involve transplants of southern populations of various species (for example, mussels) into Casco Bay and monitoring survival, growth, and fecundity. In addition, mesocosm experiments could be conducted with a focus on food webs. This research would provide insight into the potential for species to persist under climate change and how ecological communities might be affected.

Recommendations for Implementation

The peer review process generated a trove of expert insights on climate change to help guide implementation of the *Casco Bay Plan 2016-2021*. The key takeaways from the process include the following:

- The draft list of 79 climate change-related risks produced by CBEP covered all the key risks.
- Based on the peer review, a list of 25 Risks of Primary Concern (RoPCs) has been identified and can be used in future CBEP efforts.
- Twelve of the 32 Actions in the Plan are threatened with impairment by the RoPCs.
- Actions 1.1A and 1.2A, which focus on habitat protection and conservation, are threatened by the most RoPCs.
- Thirteen Actions are not threatened by the RoPCs and could help to mitigate some RoPCs.
- Seven Actions are not closely correlated with the RoPCs either as being threatened or mitigating them, although they may build capacity toward future mitigation of RoPCs.
- The most relevant and important risks for Plan implementation lie in the human response to climate change, not in the climatic changes themselves.

Based on our analysis, we make the following recommendations regarding implementation of the Casco Bay Plan in the face of climate change:

Recommendation 1: Explicitly consider the RoPCs in the processes and methods used to implement Actions 1.1A and 1.2A.

Recommendation 2: Carry out all Actions with a focus on equipping local governments and stakeholders with information and tools to proactively, efficiently, and effectively adapt to climate change—without overwhelming them.

Recommendation 3: Consider adding a new Action focused on keeping abreast of successful integrative approaches to climate change adaptation being used elsewhere and identifying opportunities to apply new and enhanced approaches to Casco Bay.

CBEP is poised through its *Casco Bay Plan 2016-2021* to play a vital role in equipping the people of Casco Bay with the information, capacity, and tools they need to be resilient and adapt to climate change. Findings of the climate risk assessment offer guidance for successful implementation of the Plan in the face of a changing climate. Appendix C provides a list of resources and organizations that can support Casco Bay watershed communities in their efforts to anticipate and plan for the far-reaching impacts of climate change.

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The authors are responsible for any errors or omissions in this report.

Appendix A: Draft List of Climate-Related Risks

This appendix includes the draft list of 79 climate-related risks developed by CBEP in the format that it was provided to reviewers (see Section 2). The reviewers also received instructions and definitions (see Figure 1 on page 17).

Risks Related Principally to **HABITAT**

Risk #	Risk Description	Timeframe	Probability	Consequence
1	Warmer temperatures cause higher evapotranspiration, increased risk of drought, altered wetland hydrology, and changes in species composition of coastal wetlands, decreasing ecosystem health and making restoration projects riskier.	Short Med Long		
2	Higher summer temperatures lead to increased mortality of intertidal organisms during exposure at low tide, complicating restoration efforts and affecting coastal fisheries.	Short Med Long		
3	Higher temperatures increase respiration rates in eelgrass, reducing net productivity and reducing abundance.	Short Med Long		
4	Increased evapotranspiration concentrates salt in the high marsh, creating salt pannes, placing restoration projects at risk, and reducing habitat quality.	Short Med Long		
5	Warmer temperatures alter phenology of reproduction in marine organisms and plants, affecting composition and reducing resilience of coastal ecosystems.	Short Med Long		
6	Warmer waters in summer exceed thermal tolerances for cold-adapted aquatic native species like brook trout and Atlantic salmon, leading to population declines and local extinction.	Short Med Long		
7	Warmer winter temperatures reduce winter mortality of potentially harmful organisms, including pathogens, pests, disease vectors, epiphytes on eelgrass, and invasive species (such as green crabs) thus increasing risk of significant ecosystem change.	Short Med Long		
8	Rising temperatures lead to changes in lobster reproduction, behavior and abundance.	Short Med Long		
9	Warmer water temperatures increase metabolic rate of commercial shellfish, leading to more rapid growth and higher productivity.	Short Med Long		
10	Warmer waters will shift the wild shellfish harvest from soft-shell clams toward quahogs, affecting management of intertidal fisheries, the livelihoods of local harvesters, and shellfish markets.	Short Med Long		
11	Changes in temperature cause shifts in marine community structure and make Casco Bay more susceptible to non-native species.	Short Med Long		
12	Warmer temperatures and other climate changes shift ranges of marine species (including commercially important species) north, leading to loss of existing fisheries resources, and novel fisheries opportunities.	Short Med Long		
13	Warmer waters reduce the viability of populations of cod and other commercially and ecologically important fish such as sturgeon, alewife, blueback, cusk, and stripers, affecting both ecosystem health and coastal fisheries.	Short Med Long		
14	Higher water temperatures and changes in other timing cues like winter cold and spring freshets alter reproductive timing for marine organisms (such as shellfish and rockweed) in an unpredictable manner, with secondary effects on coastal ecosystems.	Short Med Long		
15	Altered hydrology (due to multiple climate stressors) shifts species composition and makes wetlands and other coastal ecosystems more susceptible to invasion by invasive plants.	Short Med Long		

16	Warmer waters in the spring and changes in timing of spring peak flows affects key life stages of diadromous species (spawning, rearing, outmigration) including alewife, shad, blueback herring, smelt, and eels, reducing population viability.	Short Med Long	
17	Geomorphic adjustment of stream and river channels to altered flow regime (caused by increased severity of storms) reduces in-stream habitat quality and alters hydrology of floodplain wetlands, reducing health and resilience of coastal habitats.	Short Med Long	
18	Increased storm damage eliminates eelgrass beds and reduces areas that may be suitable for eelgrass restoration.	Short Med Long	
19	Multiple climate stressors cause salinity in estuaries and tidal creeks to change and become less predictable, potentially making them less hospitable to marine species.	Short Med Long	
20	Coastal rivers, streams and wetlands see rises in groundwater and baseflow elevations in response to rising seas, complicating restoration design and planning.	Short Med Long	
21	Rising seas and increased storm intensities increase demand for shoreline hardening, thus reducing habitat value of the shoreline and reducing scope for wetland migration.	Short Med Long	
22	Rising seas increase water depth over existing eelgrass, reducing light availability, and causing the eelgrass beds to shift landward.	Short Med Long	
23	Rising seas reduce the area and alter the period of inundation of intertidal areas, reducing productivity and economic viability of intertidal fisheries (e.g., clams), and shifting relative abundance of intertidal organisms.	Short Med Long	
24	Sea level rise causes both gains and losses of tidal wetland area; as well as shifts in species composition within wetlands in response to rising water levels and increased salinity.	Short Med Long	
25	Rising seas cause inundation and loss of tidal flats and other intertidal areas leading to a reduction in feeding, roosting and nesting habitats for migratory shorebirds.	Short Med Long	
26	Acidification, both in the water column and in tidal flats, reduces recruitment and growth of tidal flat infauna, including commercially important softshell clams, and leads to changes in dominant species.	Short Med Long	Uncertain Uncertain Uncertain
27	Increased CO2 in the water column (related to acidification) increases productivity of eelgrass and macroalgae, with potential beneficial effects on habitat structure.	Short Med Long	
28	Acidification causes understaturation of carbonate minerals, reducing growth of marine organisms with calcareous skeletons and altering coastal food webs and reducing ecosystem health.	Short Med Long	
29	Sea level rise, acidification, and non-native species threaten blue mussel and oyster reefs and bars, degrading water quality by reducing filtering of Bay waters, and making ecological restoration or enhancement projects more difficult.	Short Med Long	
30	Poor functioning of byssal threads in increasingly acidic water reduces abundance and growth of mussels, placing both aquaculture and restoration efforts at risk, reducing abundance of molluscan filter feeders in the Bay and thus reducing water quality.	Short Med Long	Uncertain Uncertain Uncertain
31	Climate change leads to unpredictable changes in marine and coastal food webs, reducing species diversity, and making coastal ecosystems less resilient to other stressors like invasive species, elevated nutrients and habitat destruction.	Short Med Long	
32	Interest in water storage to plan for drought or retain flood waters reduces community willingness to remove dams, affecting efforts to restore river connectivity and diadromous fishes.	Short Med Long	

33	More winter precipitation falling as rain, earlier snow melt and less predictable precipitation lead to a shorter and less predictable spring season of high river flows, affecting fish migration.	Short Med Long		
34	Drought, increased air temperature, and more severe storms increase the risk of failure of habitat restoration projects.	Short Med Long		
35	Increased storm intensity and rising seas lead to more erosion from uplands, shores, banks and bluffs, contributing sediments that help tidal wetlands keep up with rising seas.	Short Med Long		
36	Increased storm intensity and rising seas lead to more erosion from uplands, shores, banks and bluffs, smothering aquatic habitats like stream channels and eelgrass beds.	Short Med Long		

Risks Related Principally to **WATER QUALITY**

Risk #	Risk Description	Timeframe	Probability	Consequence
37	Higher water temperatures make the Bay more susceptible to nutrients (via algae growth, thermal stratification, and rapid recycling of nutrients) increasing risk of harmful algae blooms, decreased water clarity, lower dissolved oxygen, and fish kills.	Short Med Long		
38	Warmer temperatures cause increased rate of decomposition, thus increasing release of nutrients, CO2 and methane from tidal wetlands and coastal sediments, reducing water quality and increasing greenhouse gas emissions.	Short Med Long		
39	Longer tourist and boating season resulting from warmer temperatures leads to additional illegal discharges of wastes from recreational boats and heavier use of permitted overboard discharges, increasing loading of pollutants to the bay.	Short Med Long		
40	More winter precipitation falling as rain, earlier snow melt and less predictable precipitation lead to a shorter and less predictable spring season of high river flows, affecting timing and magnitude of nutrient inputs to the Bay.	Short Med Long		
41	Warmer temperatures lengthen the growing season, triggering increased use of fertilizers & pesticides on lawns, gardens, and ornamental plants, increasing annual nutrient loads entering local waters.	Short Med Long		
42	Reduced snow cover due to warmer winters leads to less use of winter deicing products, improves the efficiency of green infrastructure and reduces maintenance costs.	Short Med Long		
43	Warmer winters and earlier increases in water temperatures lead to an earlier spring phytoplankton bloom, desynchronizing timing of key life history events in coastal waters and reducing ecosystem health.	Short Med Long		 Uncertain Uncertain
44	Drought, increased air temperature, and more severe storms increase the risk of mortality of plants used in green infrastructure projects, increasing project costs and reducing water quality benefits.	Short Med Long		
45	Less predictable precipitation and increased evapotranspiration lead to increased risk of low base flow conditions in streams and rivers, threatening water quality and causing mortality of fish and aquatic invertebrates.	Short Med Long		
46	Pollution sources may build up on land during periods with little rain, leading to higher pollutant concentrations in the first flush of subsequent storms.	Short Med Long		
47	Increased agricultural needs for water as a consequence of increased temperatures and drought, result in increased water withdrawals from streams, exacerbating low flow conditions; and threatening both water quality and stream organisms.	Short Med Long		
48	Higher intensity storms make it more likely that stormwater control devices will prove too small to perform as designed, reducing effectiveness, and degrading downstream water quality.	Short Med Long		
49	Large storms increase stormwater volumes and infiltration into aging sewer lines, thus sending larger volumes of more dilute wastewater to treatment plants, reducing effectiveness of nutrient removal.	Short Med Long		
50	Increased probability of large storms increases Combined Sewer Overflow (CSO) discharges.	Short Med Long		
51	Increased runoff from more intense storms increases transport of nutrients and other pollutants to downstream waters, including lakes and the Bay, degrading water quality.	Short Med Long		

52	Increased storm intensity and rising seas lead to more erosion from uplands, shores, banks and bluffs, increasing both turbidity and nutrient flows, degrading water quality.	Short Med Long
53	Large freshwater pulses following large storms increase probability of haline stratification of Bay waters, especially near the mouth of the Presumpscot River, increasing risk of low dissolved oxygen in bottom waters.	Short Med Long
54	Intense storm and resulting stream flow spikes result in trash being washed downstream, polluting coastal waters and requiring cleanup efforts.	Short Med Long
55	Septic systems experience increased failure due to wet weather conditions or increasing elevation of the groundwater table due to sea level rise, leading to increased water pollution and risk of exposure to water-borne pathogens.	Short Med Long
56	Geomorphic adjustment of stream and river channels to altered flow regime (caused by increased severity of storms) exports sediment and nutrients to the Bay.	Short Med Long
57	Increased CO2 in the water column (related to acidification) increases productivity of phytoplankton, reducing water quality and increasing risk of low dissolved oxygen and acidification.	Short Med Long
58	More frequent severe storms and sea level rise increase flooding of coastal and river valley communities, causing release of pollutants into rivers and coastal water.	Short Med Long

Risks Related Principally to **COMMUNITY**

Risk #	**Risk Description**	Timeframe	**Probability**	**Consequence**
59	Warmer waters facilitate pathogen persistence and transmission, increasing disease risk of swimming and eating shellfish (e.g., increased risk of *Vibrio haemolytica* in shellfish).	Short Med Long		
60	Increasing temperatures lengthen the tourism season, and reduce winter heating costs, increasing both tourism and migration of climate refugees to Maine, leading to higher seasonal and year-round populations.	Short Med Long		
61	Changing risks of exposure to phytotoxins via consumption of shellfish (e.g., increased risk of domoic acid exposure) increases related health risks to humans.	Short Med Long		
62	Increased frequency of storms reduces time on the water for fishermen, and increases risk of damage to boats and equipment, reducing financial viability of fishing industries.	Short Med Long		
63	Increased probability of failure of culverts due to greater storm intensities requires more frequent culvert replacement, driving up infrastructure costs.	Short Med Long		
64	More frequent severe storms and sea level rise increase flooding of coastal and river valley communities, leading to economic and social harm.	Short Med Long		
65	Increasing storm intensity and rising seas lead to coastal properties becoming cost-prohibitive to insure, reducing resilience of coastal communities to storms and other natural disasters.	Short Med Long		
66	Rising seas flood stormwater pipes and reduce drainage capacity of stormwater infrastructure, increasing risk of flooding.	Short Med Long		
67	Rising seas make waterfront facilities like piers and other commercial and recreational access points inoperable, or require expensive repairs and investment to maintain functionality, affecting marine industries and quality of life.	Short Med Long		
68	Chronic tidal flooding extends to new areas, leading to economic costs to prevent, reduce or repair flood damage.	Short Med Long		
69	Complexity of multiple demands for adaptation to climate change may overwhelm ability of local governments to respond constructively to change.	Short Med Long		
70	Climate stressors lead to a loss of historic fisheries (e.g. groundfish, lobster) and a shift towards new fisheries opportunities (e.g., aquaculture) with indirect negative effects on tourism, recreation and transportation.	Short Med Long		
71	Increased risks of drought and saltwater intrusion into coastal wells (especially on islands) triggers a need for additional investment in drinking water infrastructure, increasing costs and stressing communities.	Short Med Long		
72	Storm surge and coastal flooding shortens the life of transportation and utility infrastructure, from roads and port facilities to sewer lines and sewage treatment plants, reducing economic productivity and increasing private and public sector costs.	Short Med Long		
73	Increased storm intensity and rising seas lead to more frequent catastrophic failure of banks and bluffs, putting property and lives at risk.	Short Med Long		

Risks Related to **IMPLEMENTATION**

Risk #	Risk Description	Timeframe	Probability	Consequence
74	Unpredictable weather leads to an increased need for monitoring of episodic events like severe storms and their effects, increasing both total and event-triggered monitoring costs.	Short Med Long		
75	Uncertainty about the future of the Bay, due to inability to predict climate impacts caused by multiple interacting stressors, increases both complexity and cost of monitoring programs.	Short Med Long		
76	Community interest in funding water quality infrastructure and other environmental projects is decreased by need for disaster recovery, infrastructure replacement and costs of climate adaptation.	Short Med Long		

OTHER Risks

Risk #	Risk Description	Timeframe	Probability	Consequence
77	Increasing temperatures alter the invertebrate (and fish) communities used to define Maine's biological water quality criteria, allowing long-term decline in ecosystem health to be masked by changing assessment methods.	Short Med Long		
78	Rising seas lead to changes in patterns of water circulation in the Bay, influencing water quality, distribution of planktonic larvae, and other nearshore phenomena.	Short Med Long		
79	Effects of all seven stressors make it difficult for regulators to understand emerging issues, and to respond quickly and constructively to a changing coastal ocean.	Short Med Long		

Appendix B:

Updated Risk List and Matrices After Peer Review

This appendix presents the list of 79 climate-related risks after it was updated based on the peer review (see Section 2). It includes revised language in the Risk Descriptions and revised rankings of probability and consequence.

In addition, the following categories of risks based on the peer review are indicated:

- **Bold font**: Risk of Primary Concern in the short term (10-20 years)
- Regular font: Risk of Primary Concern in the medium term (30-40 years)
- *Italicized font*: Did not rank as Risk of Primary Concern
- Gray background: Removed from the list of risks

This updated risk list was subsequently streamlined by consolidating some risks to produce the final list of Risks of Primary Concern presented in Figure 2 (see page 22).

RISKS RELATED PRINCIPALLY TO HABITAT

Risk #	Risk Description	Timeframe	Probability	Consequence
1	Warmer temperatures cause higher evapotranspiration, increased risk of drought, altered wetland hydrology, and changes in species composition of coastal wetlands, decreasing ecosystem health and making restoration projects riskier.	Short		
		Med		
		Long		
2	*Higher summer temperatures lead to increased mortality of intertidal organisms during exposure at low tide, complicating restoration efforts.*	Short		
		Med		
		Long		
3	Higher temperatures increase respiration rates in eelgrass, reducing net productivity and reducing abundance.	Short		
		Med		
		Long		
4	Increased evapotranspiration concentrates salt in the high marsh, creating salt pannes, placing restoration projects at risk, and reducing habitat quality.	Short		
		Med		
		Long		
5	Warmer temperatures alter phenology of reproduction in marine organisms and plants, affecting composition and reducing resilience of coastal ecosystems.	Short		
		Med		
		Long		
6	**Warmer waters in summer exceed thermal tolerances for cold-adapted aquatic native species like brook trout and Atlantic salmon, leading to population declines and local extinction.**	Short		
		Med		
		Long		
7	**Warmer winter temperatures reduce winter mortality of potentially harmful organisms, including pathogens, pests, disease vectors, and invasive species (such as green crabs and nuisance algae) thus increasing risk of significant ecosystem change.**	Short		
		Med		
		Long		
8	Rising temperatures lead to changes in lobster reproduction, behavior and abundance.	Short		
		Med		
		Long		
9	Warmer water temperatures increase metabolic rate of commercial shellfish, leading to more rapid growth and higher productivity.	Short		
		Med		
		Long		
10	Warmer waters will shift the wild shellfish harvest from soft-shell clams toward quahogs, affecting management of intertidal fisheries, the livelihoods of local harvesters, and shellfish markets.	Short		
		Med		
		Long		
11	**Changes in temperature cause shifts in marine community structure and make Casco Bay more susceptible to non-native species.**	Short		
		Med		
		Long		
12	**Warmer temperatures and other climate changes shift ranges of marine species (including commercially important species) north, leading to loss of existing fisheries resources, and novel fisheries opportunities.**	Short		
		Med		
		Long		
13	**Warmer waters reduce the viability of populations of cod and other commercially and ecologically important fish such as sturgeon, alewife, blueback, cusk, and stripers, affecting both ecosystem health and coastal fisheries.**	Short		
		Med		
		Long		
14	Higher water temperatures and changes in other timing cues like winter cold and spring freshets alter reproductive timing for marine organisms (such as shellfish and rockweed) in an unpredictable manner, with secondary effects on coastal ecosystems.	Short		
		Med		
		Long		
15	Altered hydrology (due to multiple climate stressors) shifts species composition and makes wetlands and other coastal ecosystems more susceptible to invasion by invasive plants.	Short		
		Med		
		Long		

16	Warmer waters in the spring and changes in timing of spring peak flows affects key life stages of diadromous species (spawning, rearing, outmigration) including alewife, shad, blueback herring, smelt, and eels, reducing population viability.	Short		
		Med		
		Long		
17	Geomorphic adjustment of stream and river channels to altered flow regime (caused by increased severity of storms) reduces in-stream habitat quality and alters hydrology of floodplain wetlands, reducing health and resilience of coastal habitats.	Short		
		Med		
		Long		
18	Increased storm damage eliminates eelgrass beds and reduces areas that may be suitable for eelgrass restoration.	Short		
		Med		
		Long		
19	Multiple climate stressors cause salinity in estuaries and tidal creeks to change and become less predictable, potentially making them less hospitable to marine species.	Short		
		Med		
		Long		
20	*Coastal rivers, streams and wetlands see rises in groundwater and baseflow elevations in response to rising seas, complicating restoration design and planning.*	Short		
		Med		
		Long		
21	**Rising seas and increased storm intensities increase demand for shoreline hardening, thus reducing habitat value of the shoreline and reducing scope for wetland migration.**	Short		
		Med		
		Long		
22	*Rising seas increase water depth over existing eelgrass, reducing light availability, and causing the eelgrass beds to shift landward.*	Short		
		Med		
		Long		
23	Rising seas reduce the area and alter the period of inundation of intertidal areas, reducing productivity and economic viability of intertidal fisheries (e.g., clams), and shifting relative abundance of intertidal organisms.	Short		
		Med		
		Long		
24	Sea level rise causes both gains and losses of tidal wetland area; as well as shifts in species composition within wetlands in response to rising water levels and increased salinity.	Short		
		Med		
		Long		
25	*Rising seas cause inundation and loss of tidal flats and other intertidal areas leading to a reduction in feeding, roosting and nesting habitats for migratory shorebirds.*	Short		
		Med		
		Long		
26	**Acidification, both in the water column and in tidal flats, reduces recruitment and growth of tidal flat infauna, including commercially important softshell clams, and leads to changes in dominant species.**	Short	?	
		Med	?	
		Long	?	
27	Increased CO2 in the water column (related to acidification) increases productivity of eelgrass and macroalgae, with potential beneficial effects on habitat structure.	Short		
		Med		
		Long		
28	*Acidification causes undersaturation of carbonate minerals, impairing some marine species and altering coastal food webs and ecosystem processes.*	Short		
		Med		
		Long		
29	Sea level rise, acidification, and non-native species threaten blue mussel and oyster reefs and bars, degrading water quality by reducing filtering of Bay waters, and making ecological restoration or enhancement projects more difficult.	Short		
		Med		
		Long		
30	*Poor functioning of byssal threads in increasingly acidic water reduces abundance and growth of mussels, placing both aquaculture and restoration efforts at risk, reducing abundance of molluscan filter feeders in the Bay and thus reducing water quality.*	Short	?	
		Med	?	
		Long	?	
31	Climate change leads to unpredictable changes in marine and coastal food webs, reducing species diversity, and making coastal ecosystems less resilient to other stressors like invasive species, elevated nutrients and habitat destruction.	Short		
		Med		
		Long		
32	*Interest in water storage to plan for drought or retain flood waters reduces community willingness to remove dams, affecting efforts to restore river connectivity and diadromous fishes.*	Short		
		Med		
		Long		

33	**More winter precipitation falling as rain, earlier snow melt and less predictable precipitation lead to a shorter and less predictable spring season of high river flows, affecting fish migration.**	Short Med Long		
34	*Drought, increased air temperature, and more severe storms increase the risk of failure of habitat restoration projects.*	Short Med Long		
35	Increased storm intensity and rising seas lead to more erosion from uplands, shores, banks and bluffs, contributing sediments that help tidal wetlands keep up with rising seas.	Short Med Long		
36	*Increased storm intensity and rising seas lead to more erosion from uplands, shores, banks and bluffs, smothering aquatic habitats like stream channels and eelgrass beds.*	Short Med Long		

RISKS RELATED PRINCIPALLY TO WATER QUALITY

Risk #	Risk Description	Timeframe	Probability	Consequence
37	**Higher water temperatures make the Bay more susceptible to nutrients (via algae growth, thermal stratification, and rapid recycling of nutrients) increasing risk of harmful algae blooms, decreased water clarity, lower dissolved oxygen, and fish kills.**	Short		
		Med		
		Long		
38	*Warmer temperatures cause increased rate of decomposition, thus increasing release of nutrients, CO2 and methane from tidal wetlands and coastal sediments, reducing water quality and increasing greenhouse gas emissions.*	Short		
		Med		
		Long		
39	*Longer tourist and boating season resulting from warmer temperatures leads to additional illegal discharges of wastes from recreational boats and heavier use of permitted overboard discharges, increasing loading of pollutants to the bay.*	Short		
		Med		
		Long		
40	**More winter precipitation falling as rain, earlier snow melt and less predictable precipitation lead to a shorter and less predictable spring season of high river flows, affecting timing and magnitude of nutrient inputs to the Bay.**	Short		
		Med		
		Long		
41	*Warmer temperatures lengthen the growing season, triggering increased use of fertilizers & pesticides on lawns, gardens, and ornamental plants, increasing annual nutrient loads entering local waters.*	Short		
		Med		
		Long		
42	Reduced snow cover due to warmer winters leads to less use of winter deicing products, improves the efficiency of green infrastructure and reduces maintenance costs.	Short		
		Med		
		Long		
43	*Warmer winters and earlier increases in water temperatures lead to an earlier spring phytoplankton bloom, desynchronizing timing of key life history events in coastal waters and reducing ecosystem health.*	Short		
		Med		?
		Long		?
44	*Drought, increased air temperature, and more severe storms increase the risk of mortality of plants used in green infrastructure projects, increasing project costs and reducing water quality benefits.*	Short		
		Med		
		Long		
45	*Less predictable precipitation and increased evapotranspiration lead to increased risk of low base flow conditions in streams and rivers, threatening water quality and causing mortality of fish and aquatic invertebrates.*	Short		
		Med		
		Long		
46	*Pollution sources may build up on land during periods with little rain, leading to higher pollutant concentrations in the first flush of subsequent storms.*	Short		
		Med		
		Long		
47	*Increased agricultural needs for water as a consequence of increased temperatures and drought, result in increased water withdrawals from streams, exacerbating low flow conditions; and threatening both water quality and stream organisms.*	Short		
		Med		
		Long		
48	**Higher intensity storms make it more likely that stormwater control devices will prove too small to perform as designed, reducing effectiveness, and degrading downstream water quality.**	Short		
		Med		
		Long		
49	**Large storms increase stormwater volumes and infiltration into aging sewer lines, thus sending larger volumes of more dilute wastewater to treatment plants, reducing effectiveness of nutrient removal.**	Short		
		Med		
		Long		
50	**Increased probability of large storms increases Combined Sewer Overflow (CSO) discharges.**	Short		
		Med		
		Long		
51	**Increased runoff from more intense storms increases transport of nutrients and other pollutants to downstream waters, including lakes and the Bay, degrading water quality.**	Short		
		Med		
		Long		

52	**Increased storm intensity and rising seas lead to more erosion from uplands, shores, banks and bluffs, increasing both turbidity and nutrient flows, degrading water quality.**	Short Med Long
53	*Large freshwater pulses following large storms increase probability of haline stratification of Bay waters, especially near the mouth of the Presumpscot River, increasing risk of low dissolved oxygen in bottom waters.*	Short Med Long
54	*Intense storm and resulting stream flow spikes result in trash being washed downstream, polluting coastal waters and requiring cleanup efforts.*	Short Med Long
55	*Septic systems experience increased failure due to wet weather conditions or increasing elevation of the groundwater table due to sea level rise, leading to increased water pollution and risk of exposure to water-borne pathogens.*	Short Med Long
56	*Geomorphic adjustment of stream and river channels to altered flow regime (caused by increased severity of storms) exports sediment and nutrients to the Bay.*	Short Med Long
57	*Increased CO2 in the water column (related to acidification) increases productivity of phytoplankton, reducing water quality and increasing risk of low dissolved oxygen and acidification.*	Short Med Long
58	**More frequent severe storms and sea level rise increase flooding of coastal and river valley communities, causing release of pollutants into rivers and coastal water.**	Short Med Long

RISKS RELATED PRINCIPALLY TO COMMUNITY

Risk #	Risk Description	Timeframe	Probability	Consequence
59	*Warmer waters facilitate pathogen persistence and transmission, increasing disease risk of swimming and eating shellfish (e.g., increased risk of Vibrio haemolytica in shellfish).*	Short Med Long		
60	*Increasing temperatures lengthen the tourism season, and reduce winter heating costs, increasing both tourism and migration of climate refugees to Maine, leading to higher seasonal and year-round populations.*	Short Med Long		
61	*Changing risks of exposure to phytotoxins via consumption of shellfish (e.g., increased risk of domoic acid exposure) increases related health risks to humans.*	Short Med Long		
62	*Increased frequency of storms reduces time on the water for fishermen, and increases risk of damage to boats and equipment, reducing financial viability of fishing industries.*	Short Med Long		
63	**Increased probability of failure of culverts due to greater storm intensities requires more frequent culvert replacement, driving up infrastructure costs.**	Short Med Long		
64	**More frequent severe storms and sea level rise increase flooding of coastal and river valley communities, leading to economic and social harm.**	Short Med Long		
65	Increasing storm intensity and rising seas lead to coastal properties becoming cost-prohibitive to insure, reducing resilience of coastal communities to storms and other natural disasters.	Short Med Long		
66	**Rising seas flood stormwater pipes and reduce drainage capacity of stormwater infrastructure, increasing risk of flooding.**	Short Med Long		
67	**Rising seas make waterfront facilities like piers and other commercial and recreational access points inoperable, or require expensive repairs and investment to maintain functionality, affecting marine industries and quality of life.**	Short Med Long		
68	Chronic tidal flooding extends to new areas, leading to economic costs to prevent, reduce or repair flood damage.	Short Med Long		
69	**Complexity of multiple demands for adaptation to climate change may overwhelm ability of local governments to respond constructively to change.**	Short Med Long		
70	*Climate stressors lead to a loss of historic fisheries (e.g. groundfish, lobster) and a shift towards new fisheries opportunities (e.g., aquaculture) with indirect negative effects on tourism, recreation and transportation.*	Short Med Long		
71	*Increased risks of drought and saltwater intrusion into coastal wells (especially on islands) triggers a need for additional investment in drinking water infrastructure, increasing costs and stressing communities.*	Short Med Long		
72	**Storm surge and coastal flooding shortens the life of transportation and utility infrastructure, from roads and port facilities to sewer lines and sewage treatment plants, reducing economic productivity and increasing private and public sector costs.**	Short Med Long		
73	Increased storm intensity and rising seas lead to more frequent catastrophic failure of banks and bluffs, putting property and lives at risk.	Short Med Long		

RISKS RELATED TO **IMPLEMENTATION**

Risk #	Risk Description	Timeframe	Probability	Consequence
74	**Unpredictable weather leads to an increased need for monitoring of episodic events like severe storms and their effects, increasing both total and event-triggered monitoring costs.**	Short		
		Med		
		Long		
75	**Uncertainty about the future of the Bay, due to inability to predict climate impacts caused by multiple interacting stressors, increases both complexity and cost of monitoring programs.**	Short		
		Med		
		Long		
76	Community interest in funding water quality infrastructure and other environmental projects is decreased by need for disaster recovery, infrastructure replacement and costs of climate adaptation.	Short		
		Med		
		Long		

OTHER RISKS

Risk #	Risk Description	Timeframe	Probability	Consequence
77	*Increasing temperatures alter the invertebrate (and fish) communities used to define Maine's biological water quality criteria, allowing long-term decline in ecosystem health to be masked by changing assessment methods.*	Short		
		Med		
		Long		
78	*Rising seas lead to changes in patterns of water circulation in the Bay, influencing water quality, distribution of planktonic larvae, and other nearshore phenomena.*	Short		
		Med		
		Long		
79	**Multiple climate stressors (warmer summers, winters, and water; increasing drought and storminess; sea level rise; ocean acidification) make it difficult for managers and regulators to understand emerging issues, and to respond quickly and constructively to a changing coastal ocean.**	Short		
		Med		
		Long		

Appendix C:

Climate Adaptation Resource Guide for Casco Bay Communities

Prepared by Natural Choices in December 2015; Contact information updated by CBEP in May 2017

Tookits and Viewers

Adaptation Toolkit for Public Officials
http://www.maine.gov/dep/sustainability/climate/adaptation-toolkit/public-official.html

Gulf of Maine Council Climate Network Community Toolkit
http://www.gulfofmaine.org/2/climate-network-community-toolkit/

New England Environmental Finance Center Climate Change Tools
http://efc.muskie.usm.maine.edu/pages/climate%20change_tools.html

Sustain Southern Maine Climate Change Resources
http://sustainsouthernmaine.org/developing-our-action-plan-climate-change/

Envisioning Change: Mapping Sea-level Rise in Casco Bay
http://media.usm.maine.edu/~slc/

Climate Solutions Mapping Project for Maine
http://climatesolutionsme.org/

NOAA's Digital Coast Sea-Level Rise Viewer
http://coast.noaa.gov/digitalcoast/tools/slr

Surging Seas Sea Level Viewer
http://sealevel.climatecentral.org/

Maine Geological Survey Sea-Level Rise/Storm Surge Viewer
http://www.maine.gov/dacf/mgs/hazards/slr_ss/index.shtml

Maine Beginning with Habitat Viewer
http://webapps2.cgis-solutions.com/beginningwithhabitat/

Maine Beginning with Habitat Toolbox
http://www.beginningwithhabitat.org/toolbox/about_toolbox.html

Maine Coastal Program--Coastal Erosion and Sea Level Rise Resources
http://www.maine.gov/dacf/mcp/environment/coastal-erosion.htm

Maine Coastal Program Resources for Local Climate Change Planning
http://www.maine.gov/dacf/municipalplanning/technical/climate.shtml

Maine Stream Habitat Viewer
http://mapserver.maine.gov/streamviewer/streamdocDisclaimer.html

Community Resilience Tools
http://www.seagrant.umaine.edu/extension/coastal-community-resilience

EPA Water Utility Response On-the-Go (Mobile)
http://watersgeo.epa.gov/responseotg/

EPA's RAINE Database (Resilience and Adaptation in New England)
http://www.epa.gov/raine/searching-raine-database

Environment America's Extreme Weather Map
http://environmentamerica.org/page/ame/hitting-close-home-global-warming-fueling-extreme-weather-across-us

Organizations Working on Climate Adaptation within the Region

Casco Bay Estuary Partnership
The Partnership supports climate adaptation throughout the Casco Bay watershed through training programs, research, publications and other collaborative actions (featured in its Casco Bay Plan 2016-2021). It also helps support the ocean acidification monitoring station at Southern Maine Community College. Climate-related publications include:

- Climate Trends in the Casco Bay Region (2015)
- Climate Change in the Casco Bay Watershed: Past, Present Future (2009)
- Geomorphology and the Effects of Sea Level Rise on Tidal Marshes in Casco Bay (2012)
- Sea Level Rise and Casco Bay's Wetlands: A Look at Potential Impacts (a report with maps targeted to each of ten different municipalities around the Bay—in the CBEP Publications Library)
- State of the Bay 2015 Climate Change Indicator

Contact: Marti Blair, 207-780-4306, cbep@maine.edu

Casco Bay Regional Resiliency Assessment Program
This cooperative, non-regulatory program to assess the resilience of critical infrastructure, led by the Department of Homeland Security Office of Infrastructure Protection, involved gathering and analyzing data (e.g., facility vulnerability assessments and modeling). A regional resiliency report was completed for the Casco Bay region and can be found here.

Cumberland County Emergency Management Agency
Cumberland County EMA is charged with developing and periodically updating the county's Hazard Mitigation Plan. This Plan is reviewed and approved by the Maine Emergency Management Agency and the Federal Emergency Management Agency (FEMA) before being formally adopted by towns. In the final stages of the Plan process, CCEMA staff members attend select board meetings in every community—providing an opportunity for discussion of climate adaptation planning. By signing the Plan, communities are eligible to have competitive projects funded at 75 percent through FEMA.

The Cumberland County Hazard Mitigation Plan was updated in 2017. CCEMA's planner, Margaret Cushing, led this process in cooperation with municipalities throughout the county. She is the primary CCEMA staff person dedicated to hazard mitigation: the other six employees focus on response to disasters.

Contact: Margaret Cushing, 207-892-6785, cushing@cumberlandcounty.org

Cumberland County Soil and Water Conservation District
CCSWCD helps to coordinate the Interlocal Stormwater Group (ISWG), a regional partnership in which 14 municipalities share strategies for reducing stormwater pollution and complying with related Clean Water Act permits. ISWG communities work cooperatively to educate youth, municipal officials, developers and citizens about water quality and stormwater.

Contact: Jami Fitch, 207-892-4700, jfitch@cumberlandswcd.org

Friends of Casco Bay
Friends of Casco Bay's 2015 report, A Changing Casco Bay, covers impacts of nitrogen pollution and coastal acidification, and includes actions that individuals can take to make a difference.

Contact: Mary Cerullo, 207-799-8574, mcerullo@cascobay.org

Greater Portland Council of Governments
Through its Sustain Southern Maine initiative, GPCOG completed a regional sea-level rise vulnerability assessment and shared climate change adaptation recommendations.

A Casco Bay Environmental Planning Assessment completed by GPCOG in 2012 summarizes planning activities and land-use regulations based on a survey of ten communities bordering Casco Bay. Sections of that plan most relevant to climate adaptation include shoreland zoning, stormwater management, impervious surface limits, LID techniques, drinking water protection and floodplain management. This report is being updated and will be finalized in July 2017.

The Cumberland County Climate and Energy Plan, prepared by GPCOG and adopted by the Cumberland County Commissioners in 2012, outlines ways that municipalities and communities can reduce energy use and minimize greenhouse gas emissions.

GPCOG frequently assists communities around the region with adaptation planning, and is currently working with Chebeague Island to assess the vulnerability to sea-level rise of a current and potential wharf site. Summaries of three past coastal resiliency projects—in Cape Elizabeth, Freeport and South Portland, are available on the environmental planning page of the GPCOG website.

Contact GPCOG at 207-774-9891 or 1-800-649-1304.

Gulf of Maine Research Institute
GMRI is exploring new technologies and business models to sustain the long-term health of the region's coastal economy in the face of significant fisheries changes. It recently received a $6.5 million grant from NASA to create a new educational program to upgrade the technical infrastructure at its center for interactive learning, enabling classrooms in Maine and nationwide to investigate how climate change is affecting their local region and the rest of the world. The new programming will be offered by the 2018-2019 school year.

Its scientists are tracking temperature changes within the Gulf of Maine and their impact on marine species. A recent article in Science magazine highlight the Gulf's warming and its impact on cod populations. Other projects related to adaptation at GMRI include an aquatic survey to monitor the Casco Bay ecosystem, sampling fish and plankton near the Presumpscot River estuary over a ten-year period; and Gulf of Maine Lobster Forecasting

Contact: Elijah Miller, 207-228-1667, emiller@gmri.org

Island Institute
Island Institute currently has three projects that relate to climate adaptation in Casco Bay. A new pilot project is testing ocean acidification remediation at Paul Dobbins' Ocean Approved kelp farm off Chebeague Island. Island Institute scientist Susie Arnold and Nichole Price from Bigelow Laboratory are deploying sensors for pH, CO_2, dissolved oxygen, temperature and salinity in and around the kelp farm to determine if kelp has the capacity to locally remediate ocean acidification (and whether it is beneficial to collocate kelp and shellfish).

Island Institute is partner in a Coastal Community Grant Program project (supported by the Maine Coastal Program) in which Greater Portland Council of Governments is helping Chebeague Island conduct a sea-level rise vulnerability assessment.

The Institute is also working with island communities on economic diversification in light of fisheries changes. It is offering a six-month Aquaculture Cohort program introducing island residents to shellfish and seaweed aquaculture (with about half of the registrants currently coming from Casco

Bay). Participants in this Institute project may also elect to participate in a Maine Sea Grant "Aquaculture in Shared Waters" training program.

Contacts: Susie Arnold, Marine Scientist and Nick Battista, Marine Programs Director, 207-594-9209, sarnold@islandinstitute.org and nbattista@islandinstitute.org

Maine Coastal Program
The Maine Coastal Program (MCP), housed at the Maine Department of Agriculture, Conservation and Forestry provides funds to regional councils and communities around Casco Bay through two competitive grants program. Municipalities in Maine can apply each year to help fund municipal and regional projects in Maine's coastal zone through the Coastal Community Grant Program and Shore and Harbor Planning Grant Program.

With support from MCP, South Portland updated its comprehensive plan language; Cape Elizabeth completed a stormwater study of its town center and revised its shoreland zoning ordinance; and Yarmouth, Freeport and Brunswick received introductory presentations on sea-level rise. Chebeague conducted a vulnerability assessment of its ferry landing at the Stone Pier, and a review of its comprehensive plan (in conjunction with GPCOG).

The MCP has a webpage of resources on planning for climate variability and one on coastal erosion and sea level rise. It lists past projects funded through its Coastal Community Grant Program.).

Contacts: Ruta Dzenis (Coastal Community Grants), 207-287-2851, ruta.dzenis@maine.gov. Claire Enterline (Shore and Harbor Management Grants), 287-1493, claire.enterline@maine.gov.

Maine Geological Survey
Maine Geological Survey (MGS), in conjunction with the Maine Coastal Program (MCP) and Regional Planning Organizations, has worked with roughly half of the municipalities bordering Casco Bay (specifically Cape Elizabeth, South Portland, Portland, Freeport, Harpswell and Phippsburg) to complete sea-level rise vulnerability assessments using a scenarios-based approach. Additional assessments of mainland communities bordering Casco Bay are included in the Sustain Southern Maine Sea Level Rise Vulnerability Assessment. Phippsburg worked with MGS and MCP on a study of marsh migration and road impacts that involved extensive public outreach.

MGS has several upcoming projects of relevance to Casco Bay communities:

- A NOAA Project of Special Merit, titled Building Resiliency along Maine's Bluff Coast, is focusing on Casco Bay bluff erosion hazards--helping municipalities learn new ways of managing bluffs and reexamine their commitment to setbacks. This project is being done in conjunction with Cumberland County Soil and Water Conservation District.
- Through a 2-year NOAA Coastal Management Fellowship project, MGS and MCP is engaging municipalities with a resiliency self-assessment, in addition to using existing incentives to participate or increase their scores in the National Flood Insurance Program Community Rating System. Currently only Cape Elizabeth (Class 9) and Portland (Class 8) are participating in this incentive based program (which provides a 5 percent discount for each class-level increase) based on policies such as shoreland zoning with open space provisions; meeting or exceeding state freeboard standards; building code standards; comprehensive plans and MS4 stormwater measures.
- MGS has created statewide GIS layers that can viewed online (http://www.maine.gov/dacf/mgs/hazards/coastal/index.shtml) showing existing highest annual tide; scenarios of sea-level rise or storm surge with layers for 1-foot, 2-foot, 1 meter and 6-feet; and a hurricane inundation layer for Category 1 and 2 storm events.

Contact: Peter Slovinsky, 207-287-2801, peter.a.slovinsky@maine.gov

Maine Sea Grant
In addition to its Coastal Community Resilience website, Maine Sea Grant has several resources to help municipalities and landowners with climate preparedness.

- Maine Property Owner's Guide to Managing Flooding, Erosion and Other Coastal Hazards website: http://www.seagrant.umaine.edu/coastal-hazards-guide

Maine Audubon
In conjunction with Manomet Center for Conservation Sciences and others, Maine Audubon has completed two studies of climate change and biodiversity, available online at http://maineaudubon.org/publications-resources/. Maine Audubon helped found the Stream Smart Program, which provides ongoing trainings for public works directors, contractors, planners, engineers, landowners and conservation volunteers and professionals on how to build and upgrade road-stream crossings in ways that sustain wildlife habitat, improve public safety (especially as more extreme precipitation events occur), and minimize risk of washouts and storm damage.

Contact: Sarah Haggerty, 207-781-2330 x225, shaggerty@maineaudubon.org

Manomet Center for Conservation Sciences
Manomet has prepared climate adaptation plans for two sites in the Casco Bay watershed (Maquoit Bay and in the Sebago Lake watershed) and has published a list of funding resources for climate adaptation work. More information and publications are available at https://www.manomet.org/program/climate-services/climate-change-adaptation.

Contact: Eric Walberg, 207-721-9040, ewalberg@manomet.org

Maine Coast Heritage Trust
MCHT's booklet, Conservation Options: A Guide for Maine Landowners, offers an array of strategies for open space protection. It also has a flyer on the Public Benefits of Conserved Lands.

Contact: Warren Whitney, 207-729-7366, wwhitney@mcht.org

Maine Department of Environmental Protection Water Bond Funds
The Maine Department of Environmental Protection has begun disbursing funds from a $10 million Water Bond that voters approved in November 2014. More than $5 million is dedicated to funding vital public improvement projects including stream crossing or culvert upgrades, and $400,000 is set aside for state wetland restoration. Projects are intended to reduce the risk of culvert failure; incorporate provisions for climate change, flood protection and resiliency; remove barriers to fish passage; and restore wetlands that provide wildlife habitat. RFP information is on the Maine DEP website.

Contact: Bill LaFlamme, 207-215-9237, william.n.laflamme@maine.gov

Maine Department of Inland Fisheries and Wildlife (MDIFW)
In 2015, MDIFW collaborated with more than 100 conservation partners to revise Maine's Wildlife Action Plan, several sections of which relate to climate change adaptation. Table 3-3 on page 13 of Element 3 lists links to PDFs containing Species of Greatest Conservation Need and habitat information for four different sub-categories of climate change. The Conservation Actions chapter has additional climate-related recommendations.

Contact DIFW at 207-287-8000

Natural Resources Council of Maine
NRCM hosts climate-related forums, encourages business engagement (see http://www.nrcm.org/projects-hot-issues/clean-air-clean-energy/federal-climate-and-energy-issues/become-a-maine-businesses-for-climate-action/).

Contact: Dylan Voorhees, 207-430-0112, dvoorhees@nrcm.org

New England Environmental Finance Center (NEEFC)
The New England Environmental Finance Center helps communities in New England develop capacity to plan and finance climate adaptation and resiliency programs.

The NEEFC's report Climate Adaptation and Resiliency Planning for New England Communities: First Steps and Next Steps (2016) includes a process guide for communities including tools and financing options related to climate change adaptation and resiliency planning and financing. NEEFC developed a financing options directory of federal and state funding and financing sources for climate adaptation projects in each New England state. See the Executive Summary here and read the Full Report here.

NEEFC also developed the COAST model to help cities and towns estimate the costs of projected sea level rise and storm surge damages, as well as the avoided costs of various adaptation measures. Click here to access the COAST tool.

Contact: Martha Sheils, 207-228-8164, Martha.sheils@maine.edu

NOAA Coastal Services Center
In addition to its sea level-rise viewer, NOAA's Digital Coast site offers many other adaptation resources, including on-site trainings and webinars.

Contact: Rebecca Newhall, 978-281-9237, Rebecca.newhall@noaa.gov

NOAA National Centers for Environmental Information, Eastern Region Office
The Regional Climate Services Office provides various resources to assist planning and decision-making, including a quarterly Climate Impacts and Outlook bulletin for the Gulf of Maine region and monthly webinars related to regional weather and climate.

Contact: Ellen Mecray, 508-824-5116, ext. 263, ellen.l.mecray@noaa.gov

The Nature Conservancy Maine Chapter
TNC's Maine Chapter has habitat restoration projects underway in both inland and nearshore portions of the Casco Bay watershed, as well as a marine program (exploring a potential permit banking strategy for ground fisheries and working to increase more volunteer monitoring of diadromous fish runs along the coast).

It has two habitat restoration specialists who work statewide, who work helping communities to increase the size of culverts to enhance fish passage, improve stream function, maintain habitat diversity and better withstand large storms. Its staff is also working on projects to increase nearshore resilience through eelgrass planting, saltmarsh restoration and oyster cultivation. Ongoing monitoring of these experimental sites will help provide guidance for more far-reaching efforts. TNC also participates in the Stream Smart Program, helping to change the state's culture of road-building and maintenance, and in the statewide Stream Connectivity Work Group.

TNC also works on policy measures to advance climate adaptation such as carbon credits and sustainable energy.

Contact: Jeremy Bell, 207-729-5181, jbell@tnc.org

University of Maine Climate Change Institute
The University of Maine Climate Change Institute conducts research and graduate education focused on variability of Earth's climate, ecosystems, and other environmental systems, and on the interaction between humans and the natural environment. The Institute has numerous resources to help understand climate trends and impacts, and houses information sources such as Maine's Climate Future 2015 Update and tools such as the Climate Reanalyzer. The Institute is developing a Climate Futures initiative to further bridge science and tools to provide decision-support frameworks for planning and management in a changing climate.

Contact: Betty Lee, 207-581-2190, bliqcs@maine.edu

USFWS Gulf of Maine Coastal Program Habitat Resilience
The U.S Fish and Wildlife Service (USFWS) Gulf of Maine Coastal Program has completed a resilience literature review that looks at the intersection of ecological and social resilience in adaptive management. The report identifies important ecological and social factors that foster greater resiliency, including overlapping governance and strong organizational relationships, diversity and ecological variability, and understanding of ecosystem functions.

The Gulf of Maine Coastal Program contributes to building more resilient landscapes and communities through its habitat protection and restoration programs (e.g., providing technical assistance to replace culverts with structures that restore passage for aquatic species and protect municipal infrastructure).

Contact: Jed Wright, 207-781-8364 (ext.12), jed_wright@fws.gov

Wells Reserve Coastal Training Program
The CTP at Wells National Estuarine Research Reserve offers science-based trainings to local and regional decision-makers on topics such as land use, climate change (sea-level rise) and green infrastructure.

Contact: Dr. Christine Feurt, 207-646-1555 ext. 111, cfeurt@wellsnerr.org

Model Municipal Projects and Products

Cape Elizabeth rewrote its shoreland zoning ordinance to add 3 vertical feet over the Highest Astronomical Tide in its development review (http://www.capeelizabeth.com/government/rules_regs/ordinances/zoning/zoning.pdf). With funding support from the Maine Coastal Program, it has also created a new stormwater plan for its town center that could serve as a model for other communities. It will be available by the end of 2015: contact Town Planner Maureen O'Meara at Maureen.omeara@capeelizabeth.org.

South Portland has completed a detailed vulnerability assessment with assistance from GPCOG, made significant strides with mitigation measures, and put language on sea-level rise into its comprehensive plan (http://www.southportland.org/files/4113/7279/7365/Final_Plan_Adopted_10-15-12_without_Appendices.pdf)

Georgetown (which lies just outside the Casco Bay watershed boundary) received support from the Maine Coastal Program to complete a Climate Change Adaptation Report that could serve as a model for other communities. Providing a thorough overview of threats and detailed localized responses, it includes recommendations at both municipal and individual levels. It is online at http://gtownconservation.com/wp-content/uploads/2015/08/Georgetown-Adaptation-Report-ALL-chapters-FINAL-8.75x11.25-v10forPDFonlineV2.pdf.

Harpswell provides all new town residents with A Resident's Conservation Guide to Casco Bay, a short handbook that offers guidance on Bay-sensitive landscaping, pest management, boating practices and household actions. The guide (online at http://www.harpswell.maine.gov/vertical/Sites/%7B3F690C92-5208-4D62-BAFB-2559293F6CAE%7D/uploads/A_Residents_Conservation_Guide_to_Casco_Bay_Rev_1.3_120613_-_on-line.pdf). Harpswell also developed an Open Space Plan that helps guide development to appropriate areas while fostering preservation of twelve "focus areas" that are critical to water resources, wildlife and commercial fish species. The Plan is online at http://www.harpswell.maine.gov/index.asp?SEC=33C20AD8-07E9-4F5C-9AE7-A26DC9701C19&Type=B_BASIC.

Key Characteristics of Climate-Smart Conservation

Link actions to climate impacts
Conservation strategies and actions are designed specifically to address the impact of climate change in concert with existing threats; actions are supported by an explicit scientific rationale.

Embrace forward-looking goals
Conservation goals focus on future, rather than past, climatic and ecological conditions; strategies take a long view (decades to centuries) but account for near-term conservation challenges and needed transition strategies.

Consider broader landscape context
On-the-ground actions are designed in the context of broader geographic scales to account for likely shifts in species distributions, to sustain ecological processes, and to promote collaboration.

Adopt strategies robust to uncertainty
Strategies and actions ideally provide benefit across a range of possible future conditions to account for uncertainties in future climatic conditions, and in ecological and human responses to climate shifts.

Employ agile and informed management
Conservation planning and resource management is capable of continuous learning and dynamic adjustment to accommodate uncertainty, take advantage of new knowledge, and cope with rapid shifts in climatic, ecological, and socioeconomic conditions.

Minimize carbon footprint
Strategies and projects minimize energy use and greenhouse gas emissions, and sustain the natural ability of ecosystems to cycle, sequester, and store carbon.

Account for climate influence on project success
Considers how foreseeable climate impacts may compromise project success; generally avoids investing in efforts likely to be undermined by climate-related changes unless part of an intentional strategy.

Safeguard people and nature
Strategies and actions enhance the capacity of ecosystems to protect human communities from climate change impacts in ways that also sustain and benefit fish, wildlife, and plants.

Avoid maladaptation
Actions taken to address climate change impacts on human communities or natural systems do not exacerbate other climate-related vulnerabilities or undermine conservation goals and broader ecosystem sustainability.

(From the National Wildlife Federation's Climate-Smart Conservation, 2014)

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