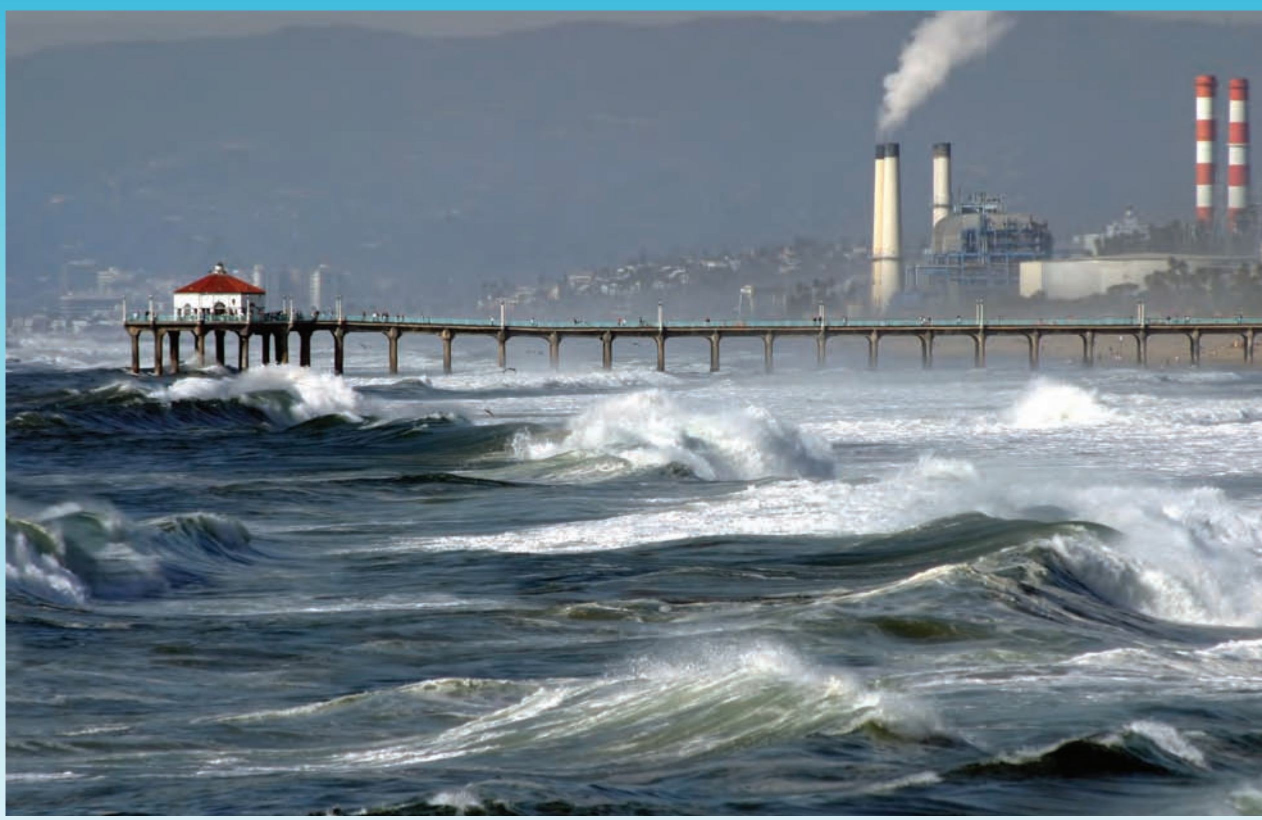
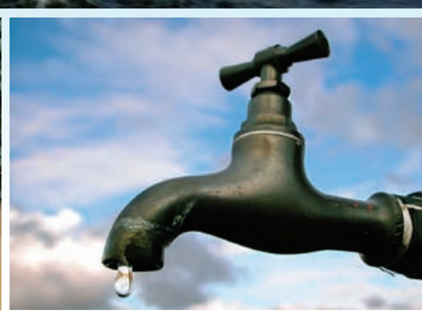
Thirsty for Answers

Preparing for the Water-related Impacts of Climate Change in American Cities

August 2011





NRDC
THE EARTH'S BEST DEFENSE

Principal Authors
Mark Dorfman
Michelle Mehta

Contributing Authors
Ben Chou
Steve Fleischli
Kirsten Sinclair Rosselot

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About NRDC

The Natural Resources Defense Council is an international nonprofit environmental organization with more than 1.3 million members and online activists. Since 1970, our lawyers, scientists, and other environmental specialists have worked to protect the world's natural resources, public health, and the environment. NRDC has offices in New York City, Washington, D.C., Los Angeles, San Francisco, Chicago, Montana, and Beijing. Visit us at *www.nrdc.org*.

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Foreword

We Can Do Something About Climate Change

The ferocious tsunami that devastated Japan's coast earlier this year, the massive floods across the midwestern United States, and the continuing droughts in the American Southwest are tragic reminders that we have an uneasy relationship with water. Water can take life just as easily as it gives it. While we can't prevent certain natural disasters like earthquakes, we can minimize at least some of the damage from many water-related calamities by dealing with climate change and its impacts now.

What can humans do about things that appear to be massive forces of nature? We can continue our efforts to reduce our carbon output and slow a trend that is far from inevitable, rather than capitulate to those who are trying to dismantle the federal government's authority to regulate carbon pollution. We can also prepare for climate change, in the event that some impacts are inevitable due to past and ongoing emissions.

Paradigm shifts such as this don't come easily. But if we do nothing to address climate change, water supplies will be at risk in many parts of the United States, ocean levels will rise 30 to 55 inches (or more), and our infrastructure and economy will be threatened.

Nowhere is action more important than at a local level. That's why cities around the world are confronting the challenges of climate change, both by reducing carbon emissions and by building resiliency into their planning.

The new R20 Regions of Climate Action, of which I am a co-founder, is a formal global alliance created to develop and implement low-carbon and climate-resilient projects through cooperation among subnational governments around the world, nongovernmental organizations, corporations, and educational institutions. As the R20 charter notes, local and regional governments "play a key role in rising to the climate challenge and are responsible for the majority of the actions required to halt climate change as well as to adapt to its impacts." Moreover, promoting climate resilience and adaptation will result in significant cost savings and generate economic benefits and opportunities.

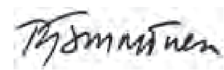
As this NRDC report shows, many U.S. cities, often supported by state policy action, have a shared vision and are building climate resilience into their everyday planning:

- Chicago has developed a climate action plan, which includes a critical vulnerability assessment.
- New York City has launched the Climate Change Adaptation Task Force and the New York Panel on Climate Change to develop strategies to secure the city's infrastructure.
- San Francisco, Seattle, and Phoenix have taken steps to prepare for water shortages.
- Miami is working with surrounding communities to develop a preparedness strategy.
- Norfolk, Virginia, has hired a consultant to conduct a flood vulnerability assessment.

Certainly more can and should be done, and more U.S. cities need to get on board. But it is important to recognize that there are solutions to these threats, and that it will take a multi-pronged attack to confront the most serious challenge facing humanity.

The lessons here are many. In the near term, we must do all we can to aid those communities that will suffer from the impacts of our influence on the natural environment. In the long term, we must heed the powerful truth that every community and economy is dependent on our water resources—and that we must simultaneously combat and prepare for climate change to protect these resources.

People are thirsty for answers. And with thoughtful leadership, many cities are finding them.



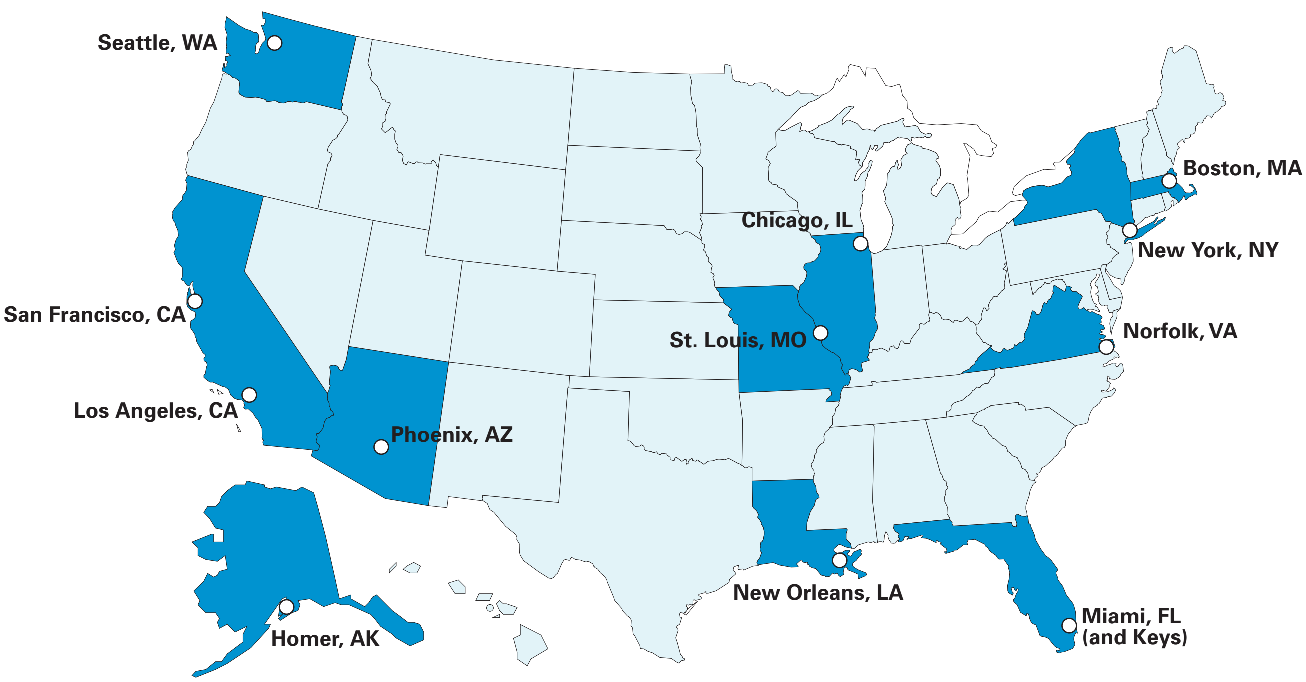
Terry Tamminen

Terry Tamminen *was the secretary of the California Environmental Protection Agency under Governor Schwarzenegger and is today an author, lecturer, and strategist on energy and the environment. He is the president of Seventh Generation Advisors and serves as an operating adviser for Pegasus Capital Advisors. His latest book,* Cracking the Carbon Code: The Keys to Sustainable Profits in the New Economy *(Palgrave), shows how to find the low-carbon products and services that save money, get ahead of regulations, and preserve resources for generations to come.*

Executive Summary

Communities across the United States—regardless of region—face significant water-related vulnerabilities because of climate change. Coastal cities such as New York, Miami, and San Francisco anticipate serious challenges from sea level rise. Southwestern cities such as Phoenix face water shortages. Midwest cities such as Chicago and St. Louis expect more intense storms and floods. Even Homer, Alaska, with a population of less than 6,000, is not immune to the impacts of climate change. NRDC urges cities to prepare for these challenges by taking action at the local level to increase a community's resilience to the water-related impacts of climate change.

Figure ES.1: The 12 U.S. cities profiled in this report



For the first time, our report compiles findings from climate researchers about local, water-related climate changes and impacts to major cities across the United States. While there may be some uncertainty as to the rate of warming or sea level rise, there is no uncertainty that these changes are taking place, and that they are taking place in our backyards. Fortunately, many measures exist to help communities prepare, and this report documents efforts cities are taking to become more resilient. Indeed, many cities highlighted in this report are leading the way, although more can and should be done, particularly in places that have not yet begun the process of identifying their own water-related vulnerabilities. This report is intended to highlight the importance of understanding vulnerabilities facing cities as well as the importance of preparing for change.

WATER-RELATED VULNERABILITIES

NRDC examined more than 75 scientific studies, as well as data and reports generated by government agencies and nonprofit organizations, to summarize the water-related impacts of climate change on 12 cities in the United States (see Figure ES.1). Each chapter of the report examines one

Table ES.1: Water-related climate changes and impacts

	Rising sea levels	Increased annual precipitation	More frequent and intense storm events	Increased flooding	Decreased annual precipitation	Water supply challenges (e.g., Increased droughts, early snowmelt)	Increased erosion	Increased saltwater intrusion	Increased impacts to fisheries
Boston	Highly likely	Likely	Highly likely	Highly likely		Possible			
Chicago		Highly likely	Highly likely	Highly likely		Possible			
Homer		Highly likely				Possible	Possible		Likely
Los Angeles	Highly likely		Possible	Highly likely	Likely	Highly likely	Possible	Highly likely	
Miami & Keys	Highly likely		Highly likely	Highly likely	Likely	Highly likely	Highly likely	Highly likely	Highly likely
New Orleans	Highly likely		Likely	Highly likely					Likely
New York City	Highly likely	Likely	Highly likely	Highly likely		Likely	Likely	Likely	
Norfolk	Highly likely	Likely	Likely	Highly likely					
Phoenix					Likely	Highly likely			
San Francisco	Highly likely		Possible	Highly likely	Likely	Highly likely	Highly likely	Highly likely	Likely
Seattle	Highly likely	Likely	Likely	Highly likely		Highly likely	Likely		Highly likely
St. Louis		Highly likely	Highly likely	Likely					

Source: NRDC

This chart summarizes climate changes and impacts that are very likely to occur (red), likely to occur (orange), or possible (yellow), based on scientific articles and reports reviewed by NRDC.[1] If a box is not checked, it does not necessarily mean that the city is not vulnerable to the corresponding climate change or impact. Rather, it means that we did not find well-documented local research or data studying or making a determination about that change or impact.

● Highly likely
● Likely
● Possible

Floodwaters inundate midwestern cities in summer 2011.

of these cities in detail, and key findings are summarized in Table ES.1.

RISING SEAS

Most of the coastal cities in this report are threatened by flooding and storm surges caused and exacerbated by rising seas. In fact, Miami ranks number one worldwide in terms of assets exposed to coastal flooding, and the Norfolk–Virginia Beach metropolitan area ranks tenth. Rising seas will likely destroy a significant portion of coastal wetlands off the coast of New Orleans, further robbing that city of hurricane protection and potentially leaving it sitting on land almost completely surrounded by the open waters of the Gulf of Mexico. Meanwhile, the very existence of the Florida Keys is at stake; under even one of the most optimistic climate scenarios, 38 percent of the Keys risk inundation.

The West Coast does not fare much better. By mid-century, projected sea level rise relative to the 2000 level ranges from approximately 12 to 18 inches (31 to 46 centimeters) for Los Angeles and San Francisco and 3 to 22 inches (8 to 56 centimeters) for Seattle. All three areas have important coastal transportation infrastructure, from ports to airports to rail lines, that are vulnerable to the effects of rising seas. In some cities rising seas also threaten freshwater supplies. For instance, saltwater intrusion could affect the quality of New York City's water supply because rising sea levels would send saltwater farther up the Hudson River and Delaware River estuaries during high tides. Salinity, which is already a problem in the Sacramento–San Joaquin River Delta in California, is very likely to increase as a result of sea level rise, which would degrade the quality and reliability of the freshwater supply pumped from the southern edge of the delta. In Miami, rising sea level, combined with extraction of freshwater faster than it is being recharged, makes the Biscayne Aquifer susceptible to saltwater intrusion.

Finally, recent research posits that the Intergovernmental Panel on Climate Change (IPCC) estimates for sea level rise, upon which many studies summarized in this report are grounded, are too conservative. Indeed, observed changes in sea level rise have exceeded predictions by about 50 percent. Thus, a newer model projects that by 2100, sea levels will be, on average, 1 to 1.4 meters (3.3 to 4.6 feet) higher than they were in 1990.[2]

MORE STORMS AND FLOODING

The Midwest and East Coast are at the highest risk for more frequent and intense storms. In Chicago, for instance, the frequency of intense storm events, which cause very heavy downpours, is likely to increase as much as 50 percent by 2040, and 80 percent to 160 percent by 2100. More intense rainfall events are expected in New York City and Norfolk, Virginia, as well.

Along the Atlantic, the combination of sea level rise and more intense rainfall is expected to lead to significant flooding by tropical storms and nor'easters that did not cause significant flooding in the past. For New York City, what we today call a100-year flood (one that has about a 1 percent chance of occurring in any given year) could occur every 35 to 55 years by mid-century. Such flooding poses an increased risk of damage to the dense and low-lying infrastructure of New York City and the important naval and civilian ports located in and around Norfolk.

> ***"The risks of continuing 'business as usual' are greater than the risks associated with strong efforts to limit and adapt to climate change."***
> – National Academy of Sciences

In the Midwest, heavier rainfall is likely to cause increased stream flows as more rain falls on increasingly saturated soils. St. Louis, which lies at the confluence of three major rivers and has seen increased development in the floodplains behind its levees, is particularly vulnerable. Without infrastructure improvements, more intense rain in Chicago is expected to increase the number of combined sewer overflows (CSO) that discharge a mix of untreated sewage and stormwater into the Chicago River and Lake Michigan.

A DRIER WEST

In the West, a combination of higher temperatures, decreased precipitation, and decreased snowpack have implications for water supply for people and aquatic life.

In California, loss of spring snowpack in the Sierra Nevada mountain range, from which Californians get much of their water, is very likely. In the worst-case climate change scenario, stream flows in Southern California could decrease by 41 percent. Even small increases in temperature with no change in precipitation alter the timing of flow patterns for rivers in California substantially, with more water flowing in the rivers during the winter and less flowing during the dry season, when agricultural and urban demand is highest.

Climate change is likely to alter the timing of peak flows that supply water to Seattle and Phoenix as well. In watersheds supplying Seattle, warming average winter temperatures are projected to steadily decrease the amount of precipitation falling as snow over the course of the 21st century, thereby reducing snowpack and causing spring and summer runoff from melting snows to decline or disappear just when demand is peaking. In watersheds that supply Phoenix, the same pattern could occur if temperatures warm enough to cause winter precipitation to fall as rain instead of snow.

These changes pose a challenge to water supply managers. They must balance the needs of a thirsty human population —whose demand for drinking and landscape irrigation water is greatest during the dry summer months—with the need to ensure sufficient water for other essentials, such as wildlife habitats, hydroelectricity, and shipping locks.

DECREASED WATER QUALITY

The impacts of a changing climate and rising atmospheric carbon dioxide concentrations are likely to affect water quality and aquatic life in a number of ways. In Chicago, for instance, an increased threat of CSOs into Lake Michigan carries with it an increased risk of waterborne disease outbreaks. The combination of increased nutrient runoff into Chesapeake Bay waters from more frequent rainfall events, higher dissolved carbon dioxide concentrations, and higher temperatures will likely lead to more frequent and intense algal blooms. Warmer waters could also increase the frequency and duration of harmful algal blooms around Seattle, as well as cause problems for the area's cold-water fish such as summer sockeye and chinook salmon.

Warmer waters and rising atmospheric carbon dioxide concentrations are detrimental to the coral reefs off the coast of Miami and the Florida Keys: under even an optimistic global warming scenario, almost half the coral cover is predicted to disappear by the end of the century. Acidification of the waters in Puget Sound off the coast of Seattle affects shellfish there as well. These impacts could have devastating implications for aquatic life and dependent local economies.

HOW CITIES ARE BECOMING MORE RESILIENT TO WATER-RELATED VULNERABILITIES

The level of carbon dioxide in the atmosphere has reached the point where at least some impacts are inevitable and irreversible. Preparing for these changes is therefore a crucial component of any city's climate change action plan. In this way, a community can become more resilient to the effects of climate change. As explained by the International Council for Local Environmental Initiatives (ICLEI), "resilience is the capacity of a community to respond creatively, preventatively, and proactively to change or extreme events, thus mitigating crisis or disaster."

Each of the cities highlighted in this report has taken some form of action to prepare for the impacts of climate change and become more resilient. That said, some are much further along in their planning than others and should be commended. Perhaps one of the most important elements of a robust climate plan is a solid vulnerability assessment, something a few cities in our report have excelled at.

- In 2007, the city of Chicago formed the Chicago Climate Task Force to develop a climate action plan. A crucial component of the plan was a vulnerability assessment, including regional climate modeling. The research provides a foundation upon which to determine how to respond to climate change.

- In 2008, New York City's Mayor Michael Bloomberg launched the Climate Change Adaptation Task Force and the New York City Panel on Climate Change (NPCC) to develop adaptation strategies to secure the city's infrastructure from the effects of climate change. To carry out these tasks, the NPCC prepared a vulnerability assessment that presents climate trends and projections for New York City and identifies potential risks to the city's critical infrastructure posed by climate change.
- Seattle benefits by being home to the University of Washington Climate Impacts Group, an interdisciplinary research group studying the effects of climate change, particularly on the Pacific Northwest region. In 2009 the group released the impressive Washington Climate Change Impacts Assessment, an evaluation of climate change impacts on Washington State, including the Puget Sound region where Seattle is located. Such a detailed assessment of how Seattle is likely to be affected by climate change helps the city understand the actions it needs to take to become more resilient.

"Action at the local level is the most effective method of reducing, mitigating, and preventing disasters. Local governments can reduce the impact of disasters on their communities by increasing their community's resilience." – ICLEI

Many other efforts are under way to increase readiness for the effects of climate change. Cities in the West, including San Francisco, Seattle, and Phoenix, are preparing for potential water supply shortages by developing local and alternative sources such as gray water, stormwater, and recycled water. Miami-Dade County in Florida has joined forces with three neighboring counties in many preparedness efforts. For instance, they are working with university scientists and other experts to reach a consensus of regional sea level rise projections that will be used for planning purposes. Norfolk has hired a Dutch coastal engineering firm, Fugro, to conduct a citywide flood vulnerability analysis, which will be used to enhance the city's current flood mitigation program and inform the development of a robust, cost-effective program for the future. These are just a few of the efforts—which we applaud—that are detailed throughout this report and that serve as examples for other communities across the country.

Indeed, many communities lag behind those noted above in terms of climate preparedness. St. Louis, for instance, lacks city-specific information on vulnerabilities to climate change, and its greenhouse gas emissions inventory and sustainability plan is still in the development stage. Los Angeles, as well, currently lacks a local or regional vulnerability assessment.

Green roof of Chicago Cultural Center reduces stormwater runoff.

CONCLUSIONS AND RECOMMENDATIONS

This report shows that climate change, which is happening on a global scale, has local impacts in communities across the United States. Some of the most serious impacts will be water-related, such as flooding of critical infrastructure due to rising seas, and longer droughts due to less snowpack and less rain. Fortunately, increasingly accurate downscaled modeling is helping cities to better understand their vulnerabilities and the ways in which they can prepare for change. Among other things, cities can:

- fully assess water-related vulnerabilities to climate change, including future water availability, precipitation, drought, runoff patterns, sea level rise, and flooding risks;
- assess water supply vulnerabilities and prepare for changes in available water resources;

- pursue nonstructural solutions and exploit natural protective features to address problems such as sea level rise and flooding;
- explore creative legal options to address problems such as sea level rise and flooding;
- prioritize the development of clean and efficient energy;
- think about climate change vulnerability in terms of emergency preparedness and risk management planning;
- create dedicated sources of funding for climate change preparedness;
- pursue regional partnerships for climate change research and planning;
- provide ample opportunity for participation by local stakeholders;
- take advantage of resources designed to help, such as the Climate Adaptation Knowledge Exchange (*http://www.cakex.org/*) and ICLEI–Local Governments for Sustainability (*http://www.iclei.org/*).

Local planning is key. But, in the end, only effective implementation of measures to both mitigate and adapt to climate change can ensure that our communities are best prepared to face the coming challenges relating to their water resources.

ENDNOTES

1 See Background and Methodology section for more information about likelihood.

2 Vermeer, M., and Rahmstorf, S., "Global Sea Level Linked to Global Temperature," *Proceedings of the National Academy of Sciences* 106, 21527-21532 (2009).

Background and Methodology

Communities worldwide are threatened with a variety of impacts from climate change. In this report, we chose to focus on targeted, local impacts to 12 cities in the United States. We chose these 12 cities in part because much of the country's population lives in these cities and because they represent a broad sampling of the country's regions: the Pacific Northwest, Southwest, Northeast, Gulf region, Southeast, Midwest, and noncontiguous United States. Further, a lot of research on the impacts of climate change has been focused on these cities. Thus, it is not that other cities—like Lincoln, Nebraska, or Memphis, Tennessee—are not facing climate change, but that much more research was available regarding specific, local impacts to the cities in this report.

OBSERVED CLIMATE CHANGES

Local climate changes are the result of global and regional changes caused by increasing concentrations of greenhouse gasses in the atmosphere.

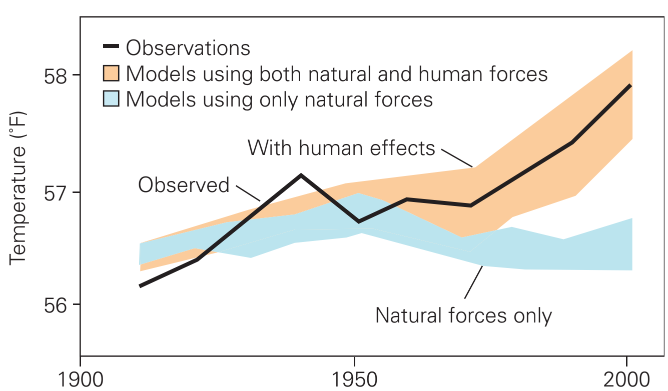
Higher air and water temperatures: In its most recent report, the IPCC stated that between 1906 and 2005, global surface air temperatures increased by a range of 1.01° to 1.66°F (0.56° to 0.92°C) and that there is a greater than 90 percent chance that the increase is primarily due to human activities (see Figure B.1).[1] The U.S. Global Change Research Program reported that in the past 50 years, average temperatures have risen more than 2°F (1.1°C) in the United States.[2] Observations reflect that the average ocean temperature has risen as well.[3]

Sea level rise: Eustatic sea level rise is the combination of the thermal expansion of the oceans due to a warmer atmosphere and the melting of land-based polar and glacial ice. Relative sea level rise is the net effect of eustatic influences and the subsidence or emergence of land over time. Subsiding land adds to eustatic sea level rise; emergence negates it (see Figure B.2).

The average rate of global sea level rise was 0.07 inch (1.8 mm) per year between 1961 and 2003. The rate of sea level rise was faster than average between 1993 and 2003: about 0.12 inch (3.1 mm) per year.[4]

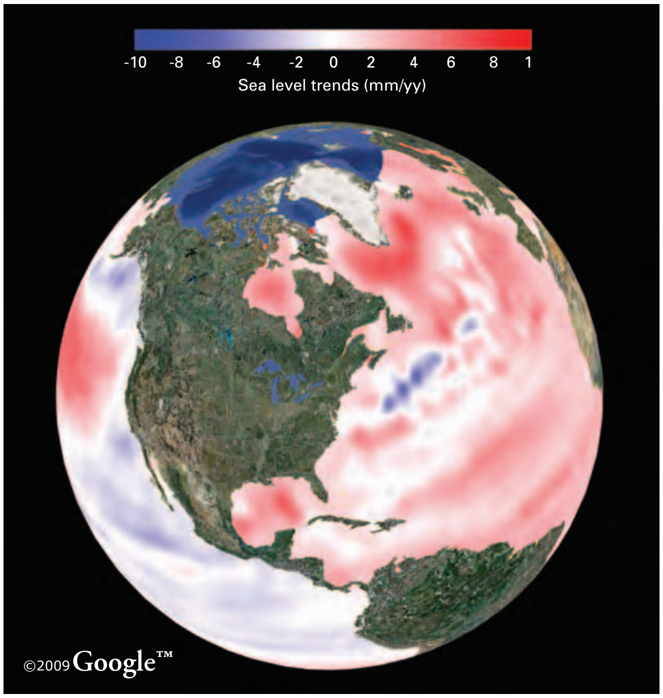
More intense storms: Warmer air fuels the intensity of storms because of its increased capacity to hold moisture; chronically higher air temperatures eventually raise water temperatures, which also fuel storms. Atlantic hurricanes in the United States originate off the coast of West Africa. Higher sea surface temperatures in that region of the ocean are associated with more intense hurricanes. If the sea surface warming trend continues in that region, hurricane rainfall

Figure B.1: 20th-century global temperature observations and general circulation model results



Source: Horton et al. (see Appendix A)

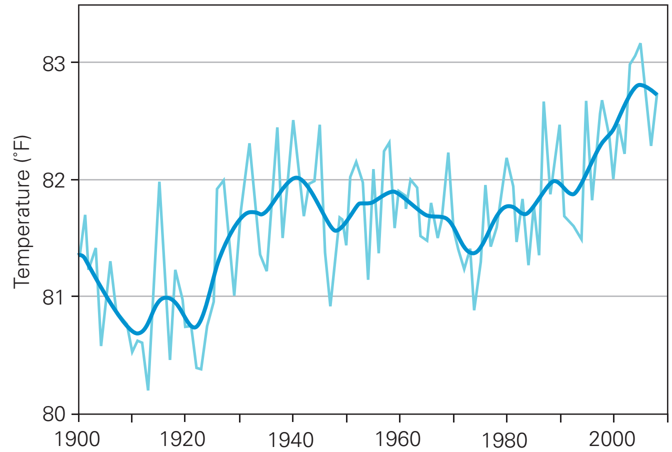
Figure B.2: Global sea level trends



Land subsidence and emergence is one factor leading to variations in sea level rise around the world.

Source: NOAA (see Appendix A)

Figure B.3: Sea surface temperatures where Atlantic hurricanes develop, August through October



Higher sea surface temperatures in this region are associated with more intense hurricanes.

Source: Adapted from U.S. Global Change Research Program (see Appendix A)

levels and wind speeds will likely increase as a result (see Figure B.3).

According to data collected by the International Disaster Database, the frequency of disastrous storms and floods has increased over the past 100 years, particularly in the past three decades.[5] Extreme storms reached a peak in the mid-1990s, but floods appear to be occurring at a steadier rate (see Figure B.4). Given the extreme storms and floods that have occurred recently, 2011 may turn out to be another peak year. Indeed, April 2011 was the wettest on record for the Central climate region, which includes Illinois.[6] March 2011 was the second-wettest March on record for Washington, the fifth-wettest for Oregon, and the ninth-wettest for California.[7]

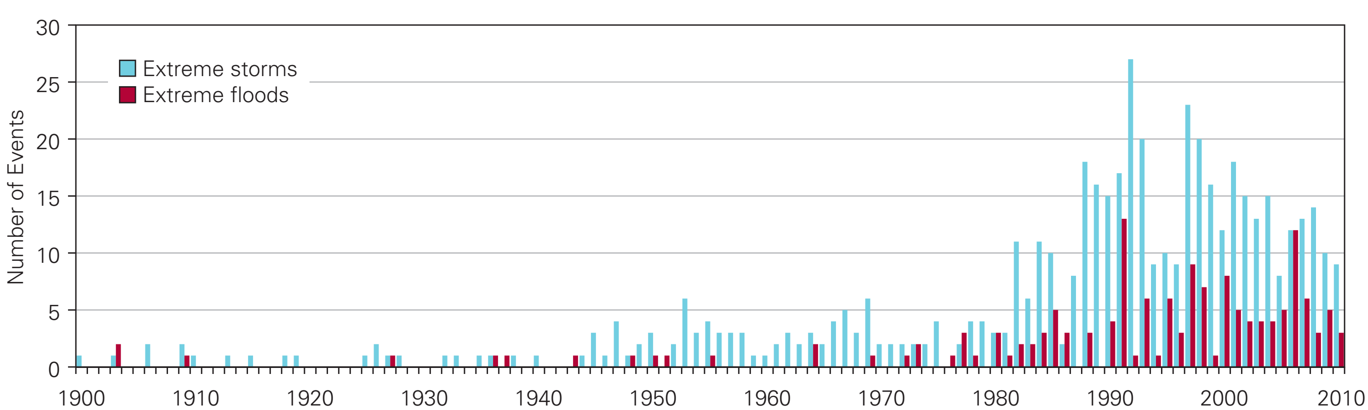
TYPES OF CLIMATE CHANGE IMPACTS

This report discusses a variety of impacts to the built and natural environment that climate change can cause or contribute to, including these:

Sea level rise can lead to saltwater intrusion into aquifers. Freshwater flowing toward the ocean, whether at the earth's surface or underground, normally prevents saltwater from moving too far inland. Since freshwater is less dense than saltwater, it forms the top layer of a coastal aquifer. When freshwater is pumped from the aquifer, the underlying saltwater tends to rise 40 feet for every foot that the water table is lowered.[8] The combination of freshwater withdrawals from aquifers and rising sea levels increases the likelihood that the saltwater layer in coastal aquifers will move closer to the surface.

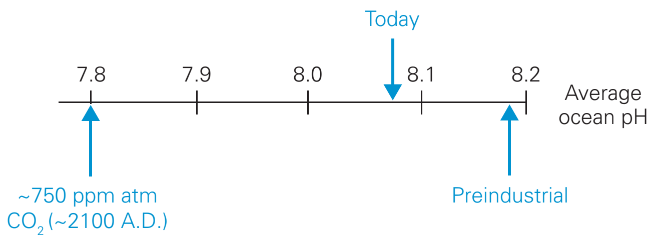
Floods affect infrastructure. Infrastructure includes various components of the built environment, including energy utilities, transportation systems, communication

Figure B.4: Number of extreme storms and floods per year in the United States, 1900–2010



Source: NRDC/Data from EM-DAT: the International Disaster Database (see Appendix A)

Figure B.5: Change in ocean pH



Source: Virginia Institute of Marine Science (see Appendix A)

networks, and drinking water and sewer systems. Flooding can damage sensitive electrical components needed to operate these systems and can accelerate the deterioration of metal or concrete infrastructure, particularly when the corrosive effects of saltwater are involved. Flooded roads and railways can cause transportation delays and may require extra expenditures for maintenance pumps. Runoff from floods can increase turbidity in drinking water supplies and increase the costs of filtration. Landfills saturated with floodwaters could leach toxic contaminants into surrounding soils and waterways.

Hydrologic changes affect water supply availability. Climate change will have a significant impact on the sustainability of water supplies in the coming decades, increasing the risk that supplies will not be able to keep pace with withdrawals in many areas of the United States. Two of the principal reasons for the projected water constraints are shifts in precipitation and in potential evapotranspiration. Moreover, in many places, water is already used in quantities that exceed local supply and replenishment. The impacts of climate change will greatly increase the number of areas where renewable water supply will be lower than withdrawal, thereby increasing the number of areas vulnerable to future water shortages.[9]

Ocean acidification impacts coral reefs and shellfish. The pH of ocean waters has decreased by about 0.1 since preindustrial times (see Figure B.5). Each tenth of a pH point represents a tenfold change in acidity. Living corals begin to die off in acidic waters, and the calcium carbonate shells of mollusks, including some commercial shellfish, become weak, resulting in higher rates of mortality.[10]

Warmer air and water temperatures affect aquatic life. Higher air temperatures can degrade water quality by concentrating pollutants through increased water evaporation rates. Chronically warmer surface air temperatures eventually lead to warmer ocean waters, which can adversely affect aquatic flora and fauna. Warmer waters also increase the frequency and duration of harmful algal blooms and cause problems for cold-water fish such as salmon.

ESTIMATING CLIMATE CHANGES

IPCC SCENARIOS

Climate change is a function of the concentration of heat-trapping greenhouse gases (GHG) in the atmosphere, including carbon dioxide and methane (the primary constituent of natural gas). While some people and governments are proactively reducing their GHG emissions, others take a more wait-and-see approach. No one knows for certain how this will play out over the course of the 21st century and beyond, so in order to plan for potential climate changes through 2100, scientists, politicians, resource managers, concerned citizens, and other stakeholders must consider a range of scenarios that result in a range of potential climate changes. The IPCC's

IPCC Climate Change Scenarios[11]

A1 A future world of very rapid economic growth, with a global population that peaks in the mid-21st century and declines thereafter. This world is characterized by the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family has three groups that describe alternative directions of technological change in the energy system: fossil intensive (**A1FI**), non-fossil intensive (**A1T**), or balanced across all sources (**A1B**), where *balanced* is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates will apply to all energy supply and end-use technologies.

A2 A very heterogeneous world where the underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continually increasing population. Economic development is primarily regionally oriented, and per capita economic growth and technological change are more fragmented and slower than in other scenarios.

B1 A convergent world with the same global population pattern as in the A1 storyline (peaking in mid-century and declining thereafter), but characterized by rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

B2 A world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continually increasing global population, but at a rate lower than that of A2, and with intermediate levels of economic development and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is oriented toward environmental protection and social equity, it focuses on local and regional levels.

climate change scenarios are referenced throughout this report as either "higher" or "lower" emissions scenarios or by the shorthand designations used to refer to the IPCC's family of socioeconomic scenarios (see sidebar, p. 9).

Computer models: Predictions of climate change are based largely on general circulation models and other global climate models that use mathematics to describe the complex interactions and feedback loops in the transfer of heat and moisture among the land, ocean, and atmosphere. The models cannot replicate every factor that contributes to climatic phenomena and require some simplifications and assumptions. Therefore, researchers tend to use a series of models before drawing conclusions. Projections for later in the 21st century have greater uncertainty than do projections for earlier in the century.

Downscaling: Global climate models have a resolution of hundreds of miles and therefore are too coarse to make climate projections at the level of cities. Dynamic and statistical downscaling are techniques that increase the resolution of global climate models to make assessments of climate change impacts at the regional and local levels.

METHODOLOGY

The information contained in each city chapter is based on available research pertaining to each city or, sometimes, region. We attempted to focus solely on local data and relied on regional data only where local data were lacking. Where available, we sought information from peer-reviewed scientific journals supplemented with information from local government sources.

LAYOUT OF CITY-SPECIFIC CHAPTERS

Each chapter begins with a summary overview of the major climate changes projected for that particular city and their potential impacts on local water resources. We then provide context by describing the city's physical attributes, geographic location, water resources, and typical climate. This is followed by separate sections discussing specific climate changes and their potential impacts on the city's water resources and infrastructure. The sections vary by city but generally include the following topics:

- sea level rise, coastal flooding, and saltwater intrusion (in this section, flooding is described as a result of sea level rise generally, even in the absence of storm events, and is often called tidal flooding);
- storm events, precipitation, and coastal and inland flooding (where possible in this section, we describe coastal flooding as that occurring during storms, often called surge flooding);
- air and water temperature, water quality, and water supply.

Each chapter closes with an "Action" section that describes notable local efforts to prepare for the impacts of climate change. We also include any state, county, and city climate plans and greenhouse gas reduction measures as context, and as recognition that cities act within a larger governmental context.

In describing potential climate changes and impacts on water resources, we use descriptors similar to those used by IPCC: "very likely," "likely," and "possible." IPCC used specific probabilities for each of these designations, but many research reports do not quantify the information they present, nor do they specifically state likelihood. In those cases, NRDC used its best judgment when describing the likelihood of a given impact, based on how frequently it is mentioned in various reports.

ENDNOTES

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2 Karl, T.R.; Melillo, J.M.; and Peterson, T.C., "Global Climate Change Impacts in the United States," *National Climate Change*, United States Global Change Research Program (2009), *http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf*.

3 IPCC, note 1.

4 IPCC, note 1.

5 EM-DAT: The International Disaster Database, maintained by the Centre for Research on the Epidemiology of Disasters, *www.emdat.be*. For a storm or flood to be entered into the disaster database, at least one of the following criteria must be fulfilled: 10 or more people reported killed, 100 or more people reported affected, declaration of a state of emergency, or call for international assistance.

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11 Verbatim from Nakićenović, N., and Swart, R., *Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, U.K., and New York, N.Y. (2000), as presented in Pyke, C.R., and Najjar, R., "Climate Change and the Chesapeake Bay," Chesapeake Bay Program, Scientific and Technical Advisory Committee (2008).

CHAPTER 1

New York City, New York

Major water-related effects of climate change on New York City include sea level rise, more frequent and intense storm events, and increased flooding. With a dense and low-lying infrastructure, these impacts could cause major disruptions to water, sewer, power, health, and transportation networks. The city, however, is working on several comprehensive initiatives to prepare for climate change and to ensure that those efforts are well informed and well coordinated.

New York City's dense infrastructure is vulnerable to sea level rise, storm surges, and flooding.

Figure 1.1: New York City and surrounding area

Source: Map Resources/NRDC

AREA OVERVIEW

New York city is the most populous city in the United States with an estimated 8.2 million inhabitants. The city's five boroughs—Manhattan, Brooklyn, Bronx, Queens, and Staten Island—cover 305 square miles of land and 165 square miles of water (see Figure 1.1). The average elevation is 33 feet (10 meters) above sea level. New York City has relatively hot and humid summers (with an average high of 82°F, or 28°C) and cold winters (with an average low of 28°F, or −2.2°C).

Almost 40 percent of New York City's land is occupied by residential structures, almost 33 percent is open space and vacant land, and the remainder is occupied by commercial, institutional, public, or mixed-use structures.[1] New York's five boroughs share a 578-mile waterfront along seven main freshwater, estuarine, and marine waterways: the Hudson, Harlem, and East rivers, New York Harbor, Long Island Sound, Jamaica Bay, and the Atlantic Ocean. Less than 3,000 acres of New York City's original estimated 224,000 acres of freshwater wetlands that existed before the American Revolution remain today. Of the original 16,000 acres of tidal wetlands in Jamaica Bay, only 4,000 acres remain.

New York City has one of the densest infrastructures in the world, with 6,000 miles of streets, 90,000 miles of underground electricity distribution lines, 7,000 miles of water mains, and 6,600 miles of sewer pipes. Many parts of the city's infrastructure are in low-lying areas and would be difficult and expensive to relocate. Further, due to the age of some of the infrastructure, it may not be able to handle projected stresses of climate change.[2]

POTENTIAL CLIMATE CHANGES AND THEIR IMPACTS

The following sections describe projected water-related climate changes and impacts to New York City throughout the 21st century. For a general explanation of how increased greenhouse gases affect our climate and seas, and typical resulting impacts of climate change, see the Background and Methodology section.

Table 1.1: Summary of water-related climate changes and impacts in New York City throughout the 21st century

	Rising sea levels
	Increased flooding
	More frequent and intense storm events
	Increased annual precipitation
	Increased saltwater intrusion
	Increased erosion
	Water supply challenges due to increased droughts

Highly likely   Likely   Possible

Source: NRDC

SEA LEVEL RISE, COASTAL FLOODING, AND SALTWATER INTRUSION

Occurrence

Sea level in New York City is very likely to rise throughout the 21st century. The central range of climate model outputs demonstrates that, compared with sea levels at the end of the 20th century, levels in the New York City area could rise 2 to 5 inches (5 to 13 centimeters) by 2020, 7 to 12 inches (18 to 30 centimeters) by the 2050s, and 12 to 23 inches (30 to 58 centimeters) by the 2080s. Under a rapid ice melt scenario, the ranges increase to about 5 to 10 inches (13 to 25 centimeters) in 2020, 19 to 29 inches (48 to 74 centimeters) in the 2050s, and 41 to 55 inches (104 to 140 centimeters) in the 2080s.[3]

Impacts

Sea level rise in low-lying New York is likely to cause coastal flooding.[4] In a densely populated urban environment like New York City, flooding from sea level rise has the potential to greatly affect infrastructure elements. For instance, power-

Figure 1.2: New York City power plants

Locations of New York City power plants relative to 10-foot elevation contour (portions in blue).

Source: Zimmerman and Faris (see Appendix A)

generating plants are traditionally sited at or close to shorelines because they require massive quantities of water to cool their generators (see Figure 1.2). Water intake and discharge pipes are potentially sensitive to flooding due to sea level rise.[5]

The flow of wastewater from the discharge pipes at New York City's 14 wastewater treatment facilities and combined sewer overflows relies on gravity. Rising sea levels could reduce the ability of these pipes to function properly, causing sewage backups.[6] Without pumps to force treated effluent or sewage-contaminated stormwater out of the discharge pipes, rising seas could cover pipe openings, forming a blockage that could extend a distance up into the pipes. If discharges cannot exit, they have nowhere to go except back in the direction from which they came—potentially flooding through storm drains into streets or back into the wastewater treatment plants.

Further, New York City used in-city landfills for many decades. In-city landfills are now closed, but those located in low-lying areas are subject to flooding. If inundated, these facilities could create water quality problems because many are located near shorelines and relied on closure technologies that did not take into account the possibility of rapidly rising seas.[7]

The city's water supply also could be affected by rising sea levels, which will send saltwater further up the Hudson and Delaware river estuaries during high tides. Also, generally speaking, the age and composition of New York City's infrastructure, including the underground drinking water distribution pipes within city limits, may make them more susceptible to the corrosive effects of saltwater.[8] Although saltwater intrusion may compromise the 69 groundwater wells that make up the Groundwater System in the borough of Queens, none of these wells has been operational since 2008.[9]

Higher sea levels can also inundate low-lying areas, including freshwater wetlands and salt marshes, and cause higher rates of beach erosion. In New York, sea level rise and land subsidence are contributing to the narrowing of beaches and the landward shift of barrier islands. One article found that, holding other variables constant (such as beach profiles and wave climates), erosion rates for a range of study sites were roughly proportional to sea level rise. Thus, "rates of beach erosion would double or triple at the case study sites by the 2020s, increasing 3 to 6 times by the 2050s, and 4 to 10 times by the 2080s, relative to the 2000s." To compensate, the researchers found that beach replenishment (adding more sand) would be needed and would probably remain a viable option through mid-century. After the latter half of the century, however, the volume of sand needed to counteract erosion would grow substantially, by 5 to 26 percent.[10]

In Jamaica Bay, the natural buildup of salt marshes is unlikely to keep pace with the accelerated rates of erosion associated with continued sea level rise.[11] This erosion threatens the many benefits provided by the Jamaica Bay salt marshes, including critical wildlife habitat, flooding mitigation, shoreline erosion control, filtration of pollutants from the water, reduction of carbon dioxide in the atmosphere, and recreational opportunities.[12]

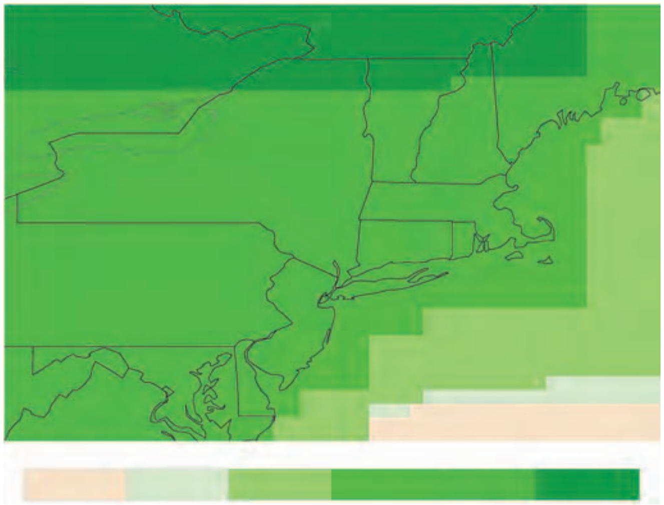
Higher sea levels can inundate low-lying areas, including freshwater wetlands and salt marshes. In Jamaica Bay, the natural buildup of salt marshes is unlikely to keep pace with the accelerated rates of erosion associated with continued sea level rise.

STORM EVENTS, PRECIPITATION, AND COASTAL AND INLAND FLOODING

Occurrence

It is very likely that increasingly powerful storms, such as hurricanes and nor'easters, will hit New York's coastline.[13] Hurricanes strike New York City and the surrounding region infrequently but can produce large storm surges and wind damage. They are usually of short duration. Nor'easters occur more frequently than hurricanes in the region and tend to take place during cooler parts of the year. Although nor'easters generally produce smaller surges and weaker winds than hurricanes, their impacts can be large. They often remain in the region for multiple days, bringing an extended period of high winds and high water that often coincides

Figure 1.3: Precipitation change for the 2080s



Percentage change in precipitation across the northeastern United States, including New York City, for the 2080s, relative to a 1971–2000 baseline.

Source: Horton et al. (see Appendix A)

with high tides.[14] Further, nor'easters generally affect a larger region than do hurricanes.

Mean annual precipitation in New York City is more likely than not to increase. Climate models project increases of 0 to 5 percent by the 2020s, 0 to 10 percent by the 2050s, and 5 to 10 percent by the 2080s (see Figure 1.3).[15] Even if projections for mean annual precipitation are not as certain as some other effects, it is the intensity and frequency of extreme events that will have significant impacts, particularly at coastal locations, due to the combined effect of intense storms and higher sea levels.

Heavy rainfall events are also expected to increase. Rainfall events exceeding 1 inch in 24 hours currently occur on about 13 days out of the year. Due to climate change, these events could increase by 1 day per year by the 2020s, 2 more days per year by the 2050s, and 1 to 3 more days by the 2080s, relative to a late-20th-century baseline. For rainfall events exceeding 2 inches in 24 hours, the baseline is 3 days per year. The increase of these events could be up to 1 more day per year throughout the century. Rainfall events exceeding 4 inches in 24 hours currently occur during about 7 hours out of the year. The increase for these extreme events could be up to 2 more hours by the 2020s and up to 5 more hours by the 2080s.[16]

Coastal flooding associated with these extreme events is predicted to increase as the 21st century progresses. For instance, for coastal floods caused by storm surges, by mid-century a traditional 10-year flood could occur every 5 to 6 years, and a traditional 100-year flood could occur every 35 to 55 years.[17] Also by mid-century, flood heights associated with both a 10-year flood and a 100-year flood could increase by up to a foot (see Table 1.2). Figure 1.4 demonstrates potential 100-year flood zones for lower Manhattan under two different projections of sea level rise. The southern tip, with expensive real estate within the financial district, is particularly flood-prone.

Storm events of increased frequency, intensity, and duration and the attendant flooding and shoreline erosion would likely render New York City more vulnerable to increased damage to its infrastructure, especially in low-lying areas or along the shoreline.

The coastal inundation zone from nor'easters is very likely to increase from 6.7 feet (2 meters) above late-20th-century sea levels to 8.2 feet (2.5 meters) by the 2050s due to sea level rise.[18]

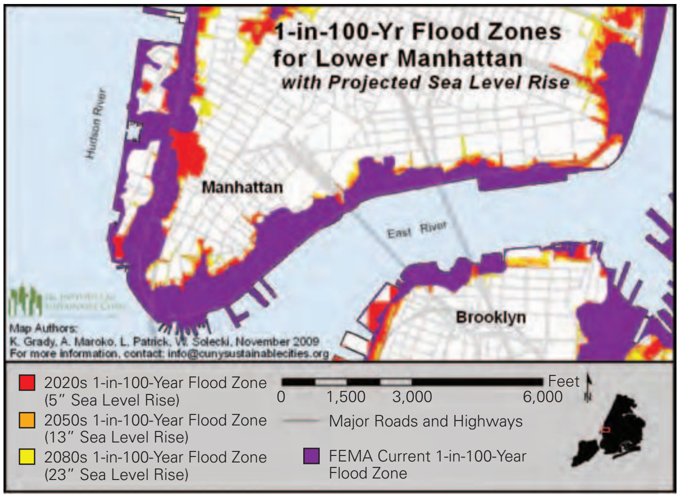
Finally, by the 2080s, shoreline erosion rates could be 2 to 4 times the erosion rates of the 2020s, and 4 to 10 times those of the 2000s.[19] Long Island and northern New Jersey beaches could move landward as much as 2.8 to 11.8 feet (0.85 to 3.6 meters) per year by the 2080s.[20]

Table 1.2: Predicted changes in extreme flood events

	2020s		2050s		2080s	
Event Baseline	**Recurrence**	**Flood Heights**	**Recurrence**	**Flood Heights**	**Recurrence**	**Flood Heights**
Traditional 1-in-10-year flood, associated with 6.3-foot flood heights	Once every 8 to 10 years	6.5 to 6.8 feet	Once every 5 to 6 years	7 to 7.3 feet	Once every 1 to 3 years	7.4 to 8.2 feet
Traditional 1-in-100-year flood, associated with 8.6-foot flood heights	Once every 65 to 80 years	8.8 to 9 feet	Once every 35 to 55 years	9.2 to 9.6 feet	Once every 15 to 35 years	9.6 to 10.5 feet

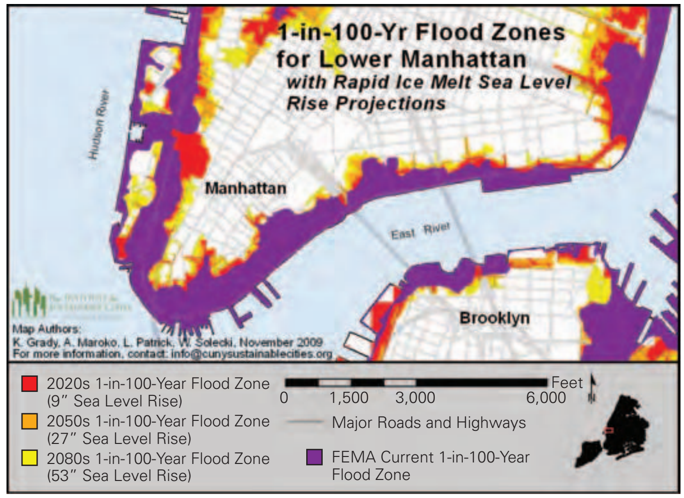
Source: Adapted from Horton et al. (see Appendix A)

Figure 1.4: 100-year flood projections for lower Manhattan



Note: This map is subject to limitations in accuracy as a result of the quantitative models, data sets, and methodology used in its development. The map and data should not be used to assess actual coastal hazards, insurance requirements, or property values or be used in lieu of Flood Insurance Rate Maps issued by FEMA.

Interpretation: The floodplains delineated above in no way represent precise flood boundaries but rather illustrate three distance areas of interest: 1) areas currently subject to the 1-in-100-year flood that will continue to be subject to flooding in the future, 2) areas that do not currently flood but are expected to potentially experience the 1-in-100-year flood in the future, and 3) areas that do not currently flood and are unlikely to do so in the time-line of the climate projection scenarios used in this research (end of the current century).



Note: This map is subject to limitations in accuracy as a result of the quantitative models, data sets, and methodology used in its development. The map and data should not be used to assess actual coastal hazards, insurance requirements, or property values or be used in lieu of Flood Insurance Rate Maps issued by FEMA.

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The southern tip of Manhattan, with expensive real estate within the financial district, is particularly flood-prone.

Impacts

New York City depends heavily on its 578-mile shoreline. Power-generating facilities and wastewater treatment plants are traditionally located near shorelines because of their water intake and discharge requirements. Two international airports within city limits are at waterfront locations. Other elements of the transportation system, like roads, railways, and tunnels, are in low-lying areas. Storm events of increased frequency, intensity, and duration and the attendant flooding and shoreline erosion would likely render New York City more vulnerable to increased damage to its infrastructure, especially in low-lying areas or along the shoreline.

For instance, New York's wastewater treatment plants are located primarily at low elevations at the city's shorelines. During dry weather, the wastewater treatment plants can fully treat 1.5 times their design capacity and can partially treat about 2 times their design capacity. However, during heavy rainfall events when urban runoff exceeds a plant's capacity, untreated sewage mixed with stormwater is released into the city's waterways through combined sewer overflows or outfalls (CSOs).[21] CSOs are a major source of contamination in waterways. The locations of CSOs and wastewater treatment plants in New York City are shown in Figure 1.5.

More frequent flooding episodes associated with storm events, exacerbated by sea level rise, would adversely affect major transportation arteries, including highways and rail and air transportation, and the viability of waterfront structures. Many facilities are located underground or in coastal or river floodplains; the elevation of New York City's subway stations ranges from 91 feet (28 meters) above sea level to 180 feet (55 meters) below.[22]

More generally, increased flooding would also affect streets, basements, sewer systems, communications equipment, and electrical support facilities such as relays, wiring, and switches associated with fiber-optic cable.[24] In total, by 2070 the greater New York City metro area is projected to have $1.7 trillion to $2.1 trillion in property at risk from coastal flooding due to storm surges and damage from high winds.[25]

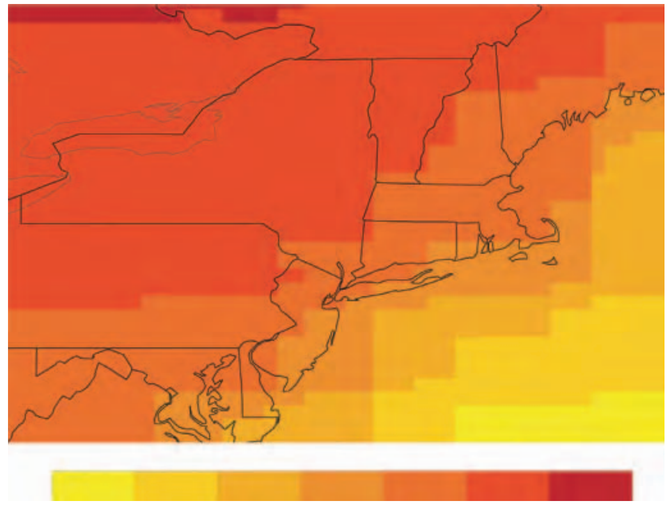
Figure 1.5: Locations of wastewater treatment plants, combined sewer outfalls, and drainage areas in the New York City area, 2008

Source: NYC Dept. of Environmental Protection (see Appendix A)

The Ripple Effects of Water-related Vulnerabilities

A New York City rainstorm on August 8, 2007, provides an example of how vulnerable the subway system is to extensive flooding. The storm resulted in a near system-wide outage of the subways during the morning rush hour. Workers had to remove 16,000 pounds of debris from tracks and repair or replace induction stop motors, track relays, resistors, track transformers, and electric switch motors. Such massive, costly, and debilitating floods may become more frequent from storms induced by climate change (Zimmerman and Faris).

Figure 1.6: Temperature change for the 2080s



Average annual temperature change (°F) across the northeastern United States, including New York City, for the 2080s, relative to a 1971–2000 baseline.

Source: Horton et al. (see Appendix A)

Finally, an increase in CSOs is not the only way in which increased storm events and flooding can affect water quality. Episodic runoff from more frequent and extreme storm events can increase nutrient loads in waterways, causing taste and odor problems in drinking water, and can increase eutrophication rates in reservoirs. Runoff can also increase infectious bacteria and pathogen loads in reservoirs.[26]

INCREASED AIR AND WATER TEMPERATURES AND WATER SCARCITY

Occurrence

Warmer temperatures are highly likely in New York City and the surrounding region (see Figure 1.6). Mean annual temperatures are projected to increase by 1.5° to 3°F (0.8° to 1.7°C) by the 2020s, 3° to 5°F (1.7° to 2.8°C) by the 2050s, and 3° to 7.5°F (1.7° to 4.2°C) by the 2080s. The frequency and duration of heat waves, defined by the New York City Panel on Climate Change (NPCC) as three or more consecutive days with maximum temperatures above 90°F (32°C), are also expected to increase. In contrast, extreme cold events, defined by the NPCC as the number of days per year with a minimum temperature at or below 32°F (0°C), are expected to become rarer.[26]

Droughts are more likely than not to become more severe and more frequent over the course of the 21st century.[27]

Impacts

By the end of the 21st century, the effect of higher temperatures, especially during the summer months, on evaporation is expected to outweigh any increases in precipitation, leading to more drought. Severe drought frequency is projected to be essentially unchanged for the 2020s but is expected to increase thereafter. For the 2050s, the frequency will be approximately doubled, and by the 2080s the frequency will be about 5 times greater than the late-20th-century baseline.[28] Drought incidence increases under other precipitation scenarios as well: One study posited that a 7°F (3.9°C) temperature increase with no change in precipitation amount would more than double, to 15 percent, the proportion of the year that New York City is in a water supply crisis, and a 3.2°F (1.8°C) increase in temperature combined with a 20 percent decrease in precipitation would increase the time in crisis to about 35 percent.[29]

Rising temperatures may also exacerbate degradation of materials used in the water supply system.[30] Repeated fluctuations between extreme hot and cold temperatures add stress to structures each time they expand and contract. High temperatures can speed up chemical reactions, such as the corrosive oxidation of metals. Droughts can also

Warmer air temperatures translate to warmer temperatures in the city's natural waters. Warmer water temperatures affect aquatic life by reducing the amount of dissolved oxygen the water can hold. Low oxygen levels can lead to stress-related fish diseases and fish kills. Higher temperatures can favor infectious microorganisms and pathogens in recreational waters.

decrease average reservoir storage and cause increased strain and degradation of infrastructure materials.[31]

The Catskill and Delaware watersheds provide 90 percent of New York City's water. While increased rainfall could increase the water supply from the Catskill reservoir watershed, rising temperatures could decrease the supply in the reservoir due to evapotranspiration, which acts to lower stream levels and soil moisture content.[32]

Warmer air temperatures also translate to warmer temperatures in the city's natural waters. Warmer surface waters may lead to increased costs for facilities that rely on these waters for transferring heat from industrial processes.[33] Warmer water temperatures also affect aquatic life by reducing the amount of dissolved oxygen the water can hold. Low oxygen levels can lead to stress-related fish diseases and fish kills. Higher temperatures can favor certain infectious microorganisms and pathogens in recreational waters. The concentration of waterborne pollutants in surface waters and reservoirs can also increase through greater evapotranspiration.

New York City, as part of its comprehensive sustainability plan, PlaNYC, is undertaking both climate change mitigation and adaptation efforts. The city is working on several comprehensive, citywide initiatives to ensure that future actions on climate change adaptation are both well informed and well coordinated.

New York State Sea Level Adaptation

On December 31, 2010, the New York State Sea Level Rise Task Force approved a formal Report to the Legislature outlining a plan of action to protect New York's coastal communities and natural resources from sea level rise. The task force recommended, among other things, that New York place increased reliance on "non-structural measures and natural protective measures to reduce impacts from coastal hazards, where applicable (NY DEC)."These nonstructural solutions—which the task force acknowledged "must play a major role in a statewide response"—include elevation and relocation of structures; conservation of natural protective features such as barrier islands, tidal wetlands, and dunes; and increased use of green infrastructure and low-impact development (NY DEC). The task force also recommended the amendment of laws and regulations to "address sea level rise and prevent further loss of natural systems that reduce risk of coastal flooding (NY DEC)."Some of the specific regulatory objectives include restricting hard structures (such as sea walls), prioritizing nonstructural and soft shoreline protection measures, providing buffers and setbacks for new development, and requiring local planning to establish areas for migration of natural protective features (NY DEC).

Although approved by the task force, these recommendations were met with some dissent. In particular, the city of New York disagreed with these specific recommendations, arguing that such policies were premature due to a perceived lack of thorough scientific, environmental, and economic analysis in a dense urban context (NY DEC).

ACTION: MITIGATING AND PREPARING FOR CLIMATE CHANGE

New York City, as part of its comprehensive sustainability plan, PlaNYC, is undertaking both climate change mitigation and adaptation efforts. To date, most of the adaptation actions implemented have occurred on a department by department basis; however, the city is working on several comprehensive, citywide initiatives to ensure that future actions on climate change adaptation are both well informed and well coordinated.

STATE, REGIONAL, AND CITY PLANS AND GREENHOUSE GAS REDUCTION MEASURES

In August 2009, Governor David Paterson signed an executive order establishing the goal of reducing statewide greenhouse gas emissions by 80 percent, relative to 1990 levels, by 2050.[34] The New York State Climate Action Council released its interim report on the policies and strategies necessary to achieve this goal for public comment in November 2010 and is working on finalizing its report.[35]

New York City released its long-term sustainability plan, PlaNYC, in April 2007 and adopted the goal of a 30 percent reduction in citywide greenhouse gas emissions, relative to 2005 levels, by 2030.[36] To support this midterm goal, in October 2007 Mayor Michael Bloomberg signed Executive Order 109, which mandates greenhouse gas reductions of 30 percent below fiscal year 2006 levels by 2017 for municipal facilities and operations. The actions and policies necessary to accomplish this reduction are discussed in the Energy Conservation Steering Committee's "Long-Term Plan to Reduce Energy Consumption and Greenhouse Gas Emissions of Municipal Buildings and Operations."[37]

Notable Local Adaptation Efforts

In 2008 the New York City Department of Environmental Protection (NYC DEP), the agency responsible for managing the city's water supply, sewer, and wastewater treatment

The High Line repurposed a piece of industrial infrastructure as public green space, reducing the amount of stormwater than runs off the site into the sewer system.

systems, released the NYC DEP Climate Change Task Force's Climate Change Assessment and Action Plan. The Action Plan contains a range of tasks and actions across the nine NYC DEP bureaus, including:

- working with climate scientists to improve regional climate change projections;
- determining potential climate change impacts on water systems through modeling and estimating costs associated with these impacts;
- identifying and implementing appropriate response strategies; and
- inventorying and reducing greenhouse gas emissions from operations.

The NYC DEP is also involved in several ongoing efforts that will increase water system resiliency in the face of climate change, such as:

- increased water conservation through rebate programs;
- implementation of low-impact development strategies;
- maximization of water supplies from existing facilities;
- conversion of combined sewers into high-level storm sewers (HLSS) that capture and transport rainfall directly to waterways, thereby reducing the volume of stormwater flowing into the sewer system; and
- infrastructure improvements to enhance reliability of water distribution systems.

Furthermore, NYC DEP is working on actions that will address climate change over the long term, such as:

- development of a methodology for including climate change impacts in the City Environmental Quality Review process;
- consideration of future sea and tide levels in sewer design and siting of outfalls;
- inclusion of climate change as a risk when prioritizing projects; and
- identification of vulnerable infrastructure and inclusion of flood protection measures in capital improvement funding cycles.[38]

To address potential flooding issues, NYC DEP has raised pump motors, circuit breakers, and controls at the Rockaway Wastewater Treatment Plant from 25 feet (7.6 meters) below sea level to 14 feet (4.3 meters) above sea level.[39]

Also in 2008, Mayor Bloomberg convened the NPCC, which advises the mayor on issues related to climate change and adaptation and provides support to the New York City Climate Change Adaptation Task Force. The panel is composed of climate, legal, insurance, and risk management experts and is modeled after the IPCC. The work of the task force builds upon earlier adaptation efforts, such as those of NYC DEP's Climate Change Task Force. Among its ongoing activities, the NPCC has developed three documents to assist the Adaptation Task Force:

- the Climate Risk Information (CRI) workbook, which contains climate change projections in order to ensure that the impacts identified and the strategies developed by task force members are based on the same information;
- the Adaptation Assessment Guidebook (AAG), which provides an eight-step process by which task force members can identify at-risk infrastructure and develop appropriate adaptation strategies; and
- the Climate Protection Levels (CPL) workbook, which addresses the potential for climate change to affect current regulations and design standards.

These resources will aid the Adaptation Task Force in identifying risks to the city's infrastructure and developing coordinated adaptation strategies to address these risks.[40]

In May 2010 the NPCC released its adaptation report, "Climate Change Adaptation in New York City: Building a Risk Management Response," to lay a foundation for adaptation planning. The panel made several recommendations, such as promoting flexible adaptation pathways—strategies that can change over time as climate risk assessment, evaluation of adaptation strategies, and monitoring occur. One example of a flexible, or iterative, adaptation pathway identified by the NPCC is a plan for the Thames River in London, where the Greater London Authority has designed escalating responses (e.g., raise existing defenses, construct new barriers) that are triggered by sea level rise. The panel also recommended implementing strategies that have near-term benefits and that also build long-term resilience, such as greenhouse gas mitigation and emergency preparedness. Many of these recommended actions have already been undertaken, either by the Adaptation Task Force or by city departments.[41]

The Department of City Planning (DCP) released Vision 2020, the city's comprehensive waterfront plan, in March 2011. One of the eight goals of Vision 2020 is to identify potential adaptation strategies that build climate resilience in the face of sea level rise and more intense storm events. The DCP discusses the necessity of a combination of retreat (e.g., rolling easements), accommodation (e.g., flood proofing existing structures), and protection (e.g., seawalls) strategies to build resilience, given the city's diverse and extensive waterfront. Over the next three years, the city will:

- establish a strategic planning process for climate resilience by updating PlaNYC;
- study best practices for increasing climate resilience to flooding and storm surge;
- incorporate climate change and sea level rise projections into infrastructure design standards in waterfront areas;
- work with the Federal Emergency Management Agency (FEMA) to update flood insurance rate maps to more accurately reflect current flooding risks; and
- integrate climate change projections into emergency planning and preparedness.[42]

Furthermore, the 2011 PlaNYC update reaffirms the city's commitment to strategies that build climate resilience. In addition to the strategies discussed in Vision 2020, these include the creation of green corridors and green infrastructure and capital investment in wastewater and stormwater infrastructure that will better equip the city to handle extreme precipitation events.[43]

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CHAPTER 2
Boston, Massachusetts

Situated on Boston Harbor where a number of rivers empty into the Atlantic Ocean, the city of Boston has irregular contours and is exposed on many sides to water. While hook-shaped Cape Cod affords some protection from storms, infamous nor'easters tend to take a direct path toward Boston. A projected increase in the frequency and intensity of storms, combined with land subsidence and sea level rise, could increase flooding in Boston. Recognizing these potential impacts, Boston is taking a number of steps to become a more resilient city.

Increased sea level rise, storms, and flooding threaten Boston's coastal development and infrastructure.

Figure 2.1: Boston and surrounding area

Source: Map Resources/NRDC

AREA OVERVIEW

The city of Boston, home to about 617,000 people, lies on the western and northern edges of Boston Harbor and sits across the Charles River from the city of Cambridge (see Figure 2.1). The Charles River flows into Back Bay and the Inner Harbor adjacent to Logan Airport, the region's busiest. The Neponset River forms part of the city's southern border. The city anchors the larger Metropolitan Boston area, comprising about 100 municipalities such as Cambridge and Lowell.

Land use varies from densely populated urban areas in the east, residential areas in the center, and undeveloped farmland and some urban sprawl on the fringes. The area is characterized by a climate with four distinct seasons, including warm and humid summers and cold and snowy winters. The mean summer temperature is 72°F (22°C) and the mean winter temperature is 29°F (–2°C). Boston experiences annual precipitation of 42 inches (106 centimeters), divided between rain and snow and distributed relatively evenly throughout the year. The area is prone to nor'easter storms.

Relative sea level in Boston has increased approximately 11.8 inches (0.3 meter) since 1900—half due to climate change and half due to natural land subsidence.

Drinking water for the city of Boston is provided by the Massachusetts Water Resources Authority (MWRA), which draws on surface water from two major reservoirs in the central portion of the state—the Quabbin and Wachusett reservoirs—as well as the Ware River.[1] The Quabbin Reservoir is approximately 530 feet higher in elevation than the mean elevation of the city, which allows for gravitational flow through most of the water distribution system; pumps are not needed.[2]

Table 2.1: Summary of water-related climate changes and impacts in Boston throughout the 21st century

Likelihood	Impact
Highly likely	Rising sea levels
Highly likely	More frequent and intense storm events
Highly likely	Increased flooding
Likely	Increased annual precipitation
Possible	Water supply challenges due to increased droughts

Highly likely · Likely · Possible

Source: NRDC

POTENTIAL CLIMATE CHANGES AND THEIR IMPACTS

The following sections describe projected water-related climate changes and impacts to Boston throughout the 21st century. For a general explanation of how increased greenhouse gases affect our climate and seas, and typical resulting impacts of climate change, see the Background and Methodology section.

SEA LEVEL RISE AND COASTAL FLOODING

Occurrence

Boston sits on land that is subsiding at an estimated rate of 0.06 inch (1.5 mm) per year, or 6 inches (0.15 meter) over the past 100 years.[3] Relative sea level in Boston has increased approximately 11.8 inches (0.3 meter) since 1900—half due to climate change and half due to natural land subsidence.[4] (Relative sea level rise is a measure of the combined effect of absolute sea level rise, caused by melting land-based ice and expansion of the ocean due to warming, and land subsidence.) Studies published in 2008 estimated that by 2100, sea levels in Boston could rise another 2 to 3.3 feet (0.6 to 1 meter) due to climate change and natural land subsidence (see Figure 2.2).[5]

However, these studies, like many others in this report, rely on IPCC scenarios of sea level rise that many now believe are too conservative. More recent estimates project, on average, a sea level 3.3 to 4.6 feet (1 to 1.4 meters) higher than 1990 levels by 2100.[6] Thus, the above projections for Boston are also too conservative.[7]

Impacts

Higher relative sea levels increase the flood potential of storm surges. If relative sea levels in the Boston area rise by 3 feet (0.9 meter), then the elevation of a 100-year storm surge measured in 2005 at 9.5 to 9.8 feet (2.9 to 3 meters) rises in 2050 to 10.5 to 11.2 feet (3.2 to 3.4 meters). By 2050, the recurrence of a 2005 100-year flood event is every 3 years or less. By 2100 the elevation of a 2005 100-year storm surge rises to 12.5 to 13.8 feet (3.8 to 4.2 meters), and recurrence comes less than every 2 years.[8] Further, new estimates of sea level rise project an increase of more than 3 feet by 2100.[9]

Coastal infrastructure, such as Logan Airport and port facilities in Boston's Inner Harbor, will be at risk of flooding.[10] A number of Boston's landmarks and transportation infrastructure will be at risk for future flooding as well (see Figure 2.3).

STORM EVENTS AND FLOODING

Occurrence

By 2100 annual precipitation in the Boston area could increase by 5.9 percent to 23 percent, depending on the climate change scenario.[11] The frequency and intensity of severe storms in winter and summer are expected to increase.[12]

Impacts

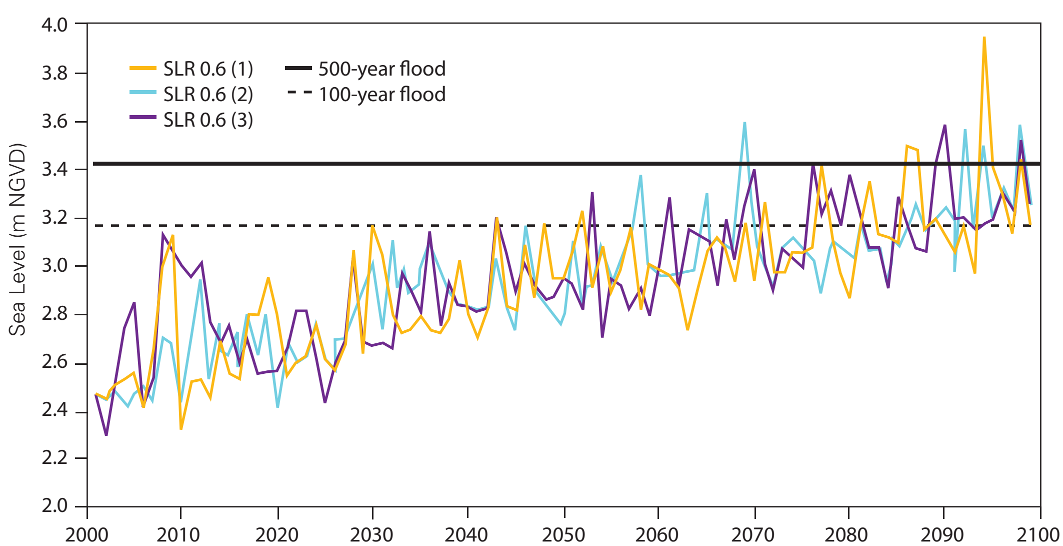
Cities like Boston, situated along the coast with concentrated development along riverbanks and coastal shorelines, are at high risk from floods.[13] Coastal flooding in Boston is often a result of nor'easters or low-pressure areas that come ashore with winds from the northeast. Indeed, a nor'easter that may have been a 100-year (or even rarer) storm hit the greater Boston area in 1978 and caused $550 million (in year 2000 dollars) in flood damage and incurred $95 million in emergency costs.[14]

If current growth and land use practices remain unchanged while relative sea levels rise 3.3 feet (1 meter) by the end of the century, a 100-year storm surge could cost the city of Boston about $36 billion (in year 2000 dollars) in damages to residential, commercial, and industrial structures and in emergency response costs.[15] Homes built in the area's 100- and 500-year floodplains could see flood damage of $7,000 to $18,000 each. Over the course of the 21st century, river flooding could affect twice as many properties at twice the overall cost of past floods.[16]

As with coastal flooding from sea level rise, flooding from storm events would likely affect highly developed areas and transportation infrastructure, including Logan Airport (at an elevation of just 20 feet, or 6.1 meters, and surrounded by water on three sides) in East Boston.[17] Flood damage could snarl traffic, leaving motorists stuck for about

River flooding could affect water treatment plants and increase the concentration of pathogens washing onto recreational beaches, possibly increasing the number of days when beaches are closed or under a no-swim advisory.

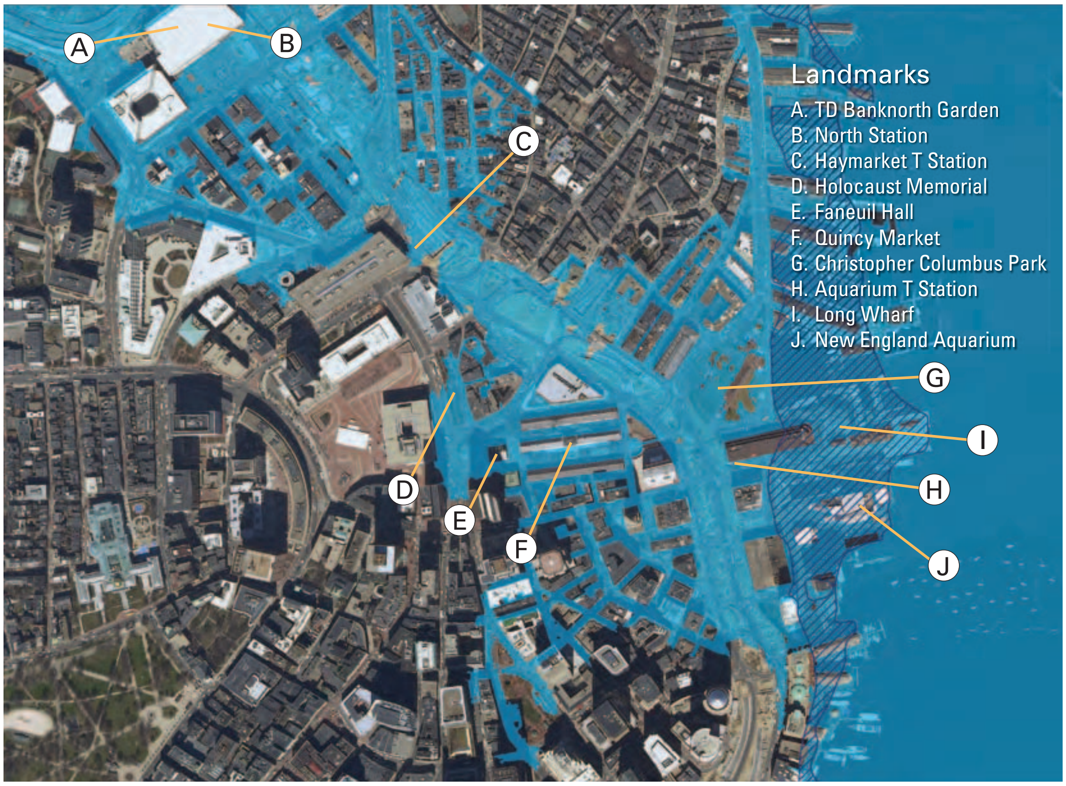
Figure 2.2: Projected sea level rise in Boston



Possible annual maximum sea levels from 2000 to 2100 (in meters), over three scenarios, and frequency of exceeding 100- and 500-year flood levels. These are conservative estimates.

Source: Adapted from Kirshen et al. (see Appendix A)

Figure 2.3: Future projected flood zone



Current 100-year flood zone
Projected 100-year flooded area (higher-emissions scenario)

Source: Union of Concerned Scientists (see Appendix A)

Future 100-year flood zone (lighter blue) under a higher-emissions scenario for the waterfront/Government Center area of Boston. Under a lower-emissions scenario, the flood zone elevation would be about 0.5 foot lower, but still 2 feet higher than the current 100-year flood zone (darker, crosshatched blue).

80 percent more hours and resulting in 82 percent more canceled road trips.[18]

Inland flooding could also increase: Climate models show that 20 percent increases in rainfall combined with higher temperatures would lead to increases in stream flows by 15 percent to 23 percent, giving rise to potential inland flooding.[19] River flooding could affect water treatment plants[20] and increase the concentration of pathogens washing onto recreational beaches, possibly increasing the number of days when beaches are closed or under a no-swim advisory.

INCREASED TEMPERATURE, WATER SUPPLY, AND WATER QUALITY

Occurrence

By 2030, air temperature in Boston could increase by 2° to 2.3°F (1.1° to 1.3°C). By 2100, temperatures could increase by 5.2° to 8.6°F (2.9° to 4.8°C).[21] The number of days above 90°F (32 °C) each year could double to at least 30 days.[22]

Impacts

The city of Boston's water supply is far enough inland and at a high enough elevation so as not to be at serious risk from climate change over the course of this century. Even if warmer temperatures and demographic changes increase demand, the reliability of the MWRA water system should remain manageable.[23] In terms of water quality, however, flooding does have the potential to affect some water treatment plants.

Further, warmer temperatures are likely to affect water quality. Research demonstrated that an air temperature increase of 4.3°F (2.4°C) would lower dissolved oxygen in Boston's rivers by 0.5 milligram per liter, a significant decrease. Decreased levels of dissolved oxygen make it difficult for rivers to support fish and plant life. The Assabet River in metropolitan Boston, for instance, is already listed by state environmental authorities as unsuitable for fish, wildlife, and certain recreational activities such as swimming and boating because of low dissolved oxygen levels; further decreases could contribute to further decline of fish and plant life.[24]

Higher temperatures also extend the growing season by one or two months, so plants pull water from soil for a longer period of time and deliver it to leaves, where it evaporates in a process known as transpiration. A drop in soil moisture levels reduces the amount of water that can percolate through soil to replenish surface water or groundwater.[25]

ACTION: MITIGATING AND PREPARING FOR CLIMATE CHANGE

Boston has been one of the leading cities in the United States in terms of climate change mitigation; the 2007 adoption of a green building standard that requires large projects to be LEED certifiable, the first of its kind nationwide for a major city, is but one example.[26] In recent years the city has begun to develop a focused and comprehensive strategy for adaptation. We offer a brief glimpse into these activities in our discussion below.

STATE, REGIONAL, AND CITY PLANS AND GREENHOUSE GAS REDUCTION MEASURES

In August 2008, Governor Deval Patrick signed into state law the Global Warming Solutions Act (GWSA). The GWSA requires the Executive Office of Energy and Environmental Affairs (EOEEA), in collaboration with other state agencies and the public, to set statewide goals to reduce greenhouse gas (GHG) emissions to levels 10 percent to 25 percent below a 1990 baseline by 2020, and to reduce emissions by 80 percent below this baseline by 2050.[27] In December 2010, the state set a 25 percent reduction target for GHG emissions by 2020 and outlined energy efficiency strategies for meeting this goal and the 2050 goal in the Massachusetts Clean Energy and Climate Plan for 2020.[28]

In April 2010, the Climate Action Leadership Committee, established by Mayor Thomas Menino, released a report titled "Sparking Boston's Climate Revolution," which called for reducing Boston's greenhouse gas emissions by at least 25 percent below a 1990 baseline by 2020 and meeting an 80 percent reduction by 2050.[29]

NOTABLE LOCAL ADAPTATION EFFORTS

The city of Boston has been examining the potential impacts of climate change for quite some time. In the late 1980s and early 1990s, the MWRA scrapped plans to lower the elevation of the Deer Island Wastewater Treatment Plant because of concerns about sea level rise.[30] In 2004 a report titled "Climate's Long-term Impacts on Metro Boston" (CLIMB) was released. The report analyzed the potential socioeconomic impacts to the Boston area from climate change and evaluated the monetary and environmental costs associated with three adaptive scenarios: one that assumes no adaptive steps except for rebuilding property and infrastructure damaged by climate-related events; one that includes some preemptive actions, such as shoreline hardening measures; and one that includes aggressive preemptive actions like floodproofing new and existing structures in floodplains. Noting that Boston is particularly vulnerable to coastal and river flooding and water quality issues, CLIMB concluded that adopting a proactive strategy now to deal with climate change impacts would be the least costly scenario and would provide the greatest environmental benefits over the long term.[31]

In 2007 Mayor Menino signed an executive order requiring the development of an integrated plan that outlines actions to reduce risks from climate change impacts. The order also included a provision requiring new and major renovations of municipal facilities to include considerations of the risk of climate change impacts on the project and related infrastructure through 2050.[32]

"Sparking the Climate Revolution" also noted several ongoing adaptation efforts. The Office of Emergency Preparedness is working on an update to Boston's Comprehensive Emergency Management Plan that will integrate climate change concerns. The Boston Water and Sewer Commission will be including climate change impacts, notably sea level rise and storm intensity changes, into long-range capital planning for the city's sewer and stormwater system.[33] Furthermore, some waterfront projects have taken proactive efforts to mitigate flood risks associated with sea level rise. In 2009, in response to sea level rise concerns, Spaulding Rehabilitation Hospital designed its new Charlestown Navy Yard facility to have a ground floor 3 feet higher than usual, electrical and mechanical systems on the roof instead of in the basement, and no critical care facilities on the first floor.[34] More recently, the $3 billion, 23-acre Seaport Square project, in consultation with the Boston Redevelopment Authority, made design adjustments to reduce flooding risks from future sea level rise, such as locating primary building entrances and ground floor elevations above the 500-year flood level.[35]

Boston was selected in November 2010 to participate in the Climate Resilient Communities program developed by ICLEI USA. Participants in the program receive access to adaptation resources and technical support to guide adaptation planning.[36] In addition, the Metro Boston Consortium for Sustainable Communities, which includes 55 municipalities in the Boston area, will be using a $4 million grant from the U.S. Department of Housing and Urban Development, in part to develop a regional climate change adaptation strategy.[37] This strategy will include specific policies and measures to reduce vulnerability to future hazards and impacts associated with climate change.[38]

> ***"Doing nothing to prepare for climate change will result in the greatest amount of damage and the highest possible costs to governments and residents in the Boston region. In contrast, investing now in measures to adapt to and protect against the changing climate will significantly reduce the amount of damage from global warming and lower the costs of adaptation."*** — CLIMB Report

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CHAPTER 3
Norfolk, Virginia

Norfolk and other areas in the Hampton Roads section of the lower Chesapeake Bay are sinking. Sinking land compounds the effects of rising seas, which include high-tide flooding of coastal areas where major naval and civilian ports are sited. The area has garnered much attention lately for flooding issues associated with sea level rise and land subsidence. Due to the vast amount of infrastructure and assets and the number of people at risk in the region, many government agencies and organizations are involved in adaptation planning.

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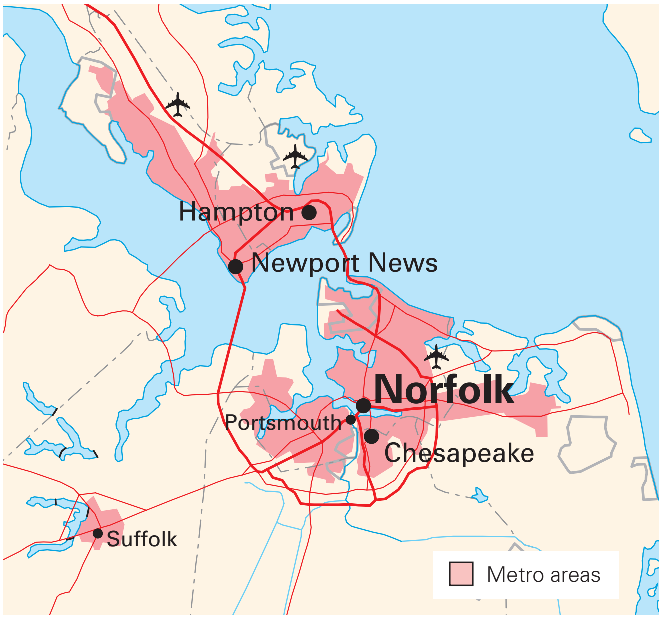
The rate of annual sea level rise in Norfolk is the highest along the eastern coast.

AREA OVERVIEW

Norfolk is Virginia's second-largest city, with a population of more than 240,000. It is surrounded by water on three sides—the Chesapeake Bay (the largest estuary in the United States), the James River, and the Elizabeth River. Norfolk lies at the heart of Hampton Roads, a nautical term used to describe the sheltered, deepwater port at the confluence of the James River and the Chesapeake Bay, as well as the larger metropolitan region (see Figure 3.1).

Norfolk is considered the geographical as well as the financial and cultural center of the region. It hosts strategic military and transportation facilities including the Norfolk Naval Base/Naval Station Norfolk, the world's largest naval base; the Norfolk Naval Shipyard, part of the Little Creek

Figure 3.1: Norfolk and surrounding area



Source: Map Resources/NRDC

Naval Amphibious Base; and Norfolk International Terminals, the Port of Virginia's largest terminal.[1] Other military and federal facilities are located throughout the region (see Figure 3.6).

Norfolk experiences hot and humid summers but mild winters. The annual average high temperature is 68°F (20°C) and the annual average low is 51°F (11°C). Rainfall is steady throughout the year, adding up to a yearly average of 46 inches

Norfolk is Virginia's second-largest city, with a population of more than 240,000. It is surrounded by water on three sides—the Chesapeake Bay (the largest estuary in the United States), the James River, and the Elizabeth River.

(117 centimeters). Snowfall is rare. Hurricanes and tropical storms pass by the area but do not often make landfall.

Norfolk's water supply comes from eight surface-water reservoirs that it owns in and around the city: Lake Whitehurst, Little Creek Reservoir, Lake Lawson, Lake Smith, Lake Wright, Lake Burnt Mills, Western Branch Reservoir, and Lake Prince. A ninth, Lake Taylor, is currently inactive.[2]

POTENTIAL CLIMATE CHANGES AND THEIR IMPACTS

The following sections describe projected water-related climate changes and impacts to Norfolk throughout the 21st century. For a general explanation of how increased greenhouse gases affect our climate and seas, and typical resulting impacts of climate change, see the Background and Methodology section.

Table 3.1: Summary of water-related climate changes and impacts in Norfolk throughout the 21st century

Highly likely	Rising sea levels
Highly likely	Increased flooding
Likely	Increased annual precipitation
Likely	More frequent and intense storm events

Highly likely · Likely · Possible

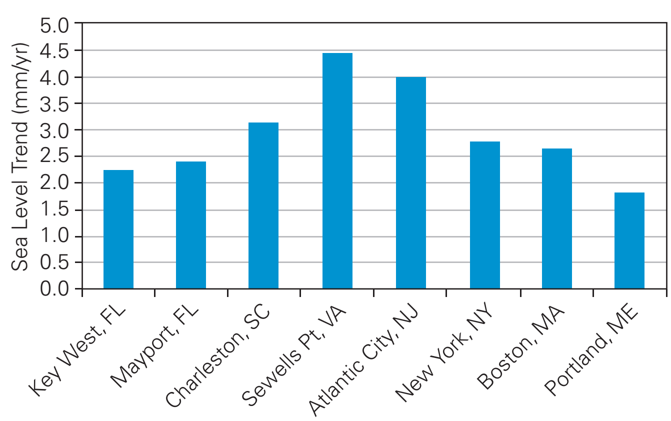
Source: NRDC

SEA LEVEL RISE, COASTAL FLOODING, AND SALTWATER INTRUSION

Occurrence

The rate of annual sea level rise measured at Sewells Point in Norfolk is the highest of all stations along the U.S. East Coast—nearly 4.5 millimeters per year (see Figures 3.2 and 3.3). It is not clear whether this rate is more likely to hold steady through the 21st century or to increase further.[3] Relative sea level in Norfolk has steadily risen 14.5 inches (0.37 meter) over the past 80 years (see Figure 3.3) and is projected to increase by another 1.3 to 5.2 feet (0.39 to 1.6 meters) by 2100.[4] Extreme projections go as high as 7.4 feet (2.3 meters) by 2100.[5] Anywhere from about one-third to slightly more than

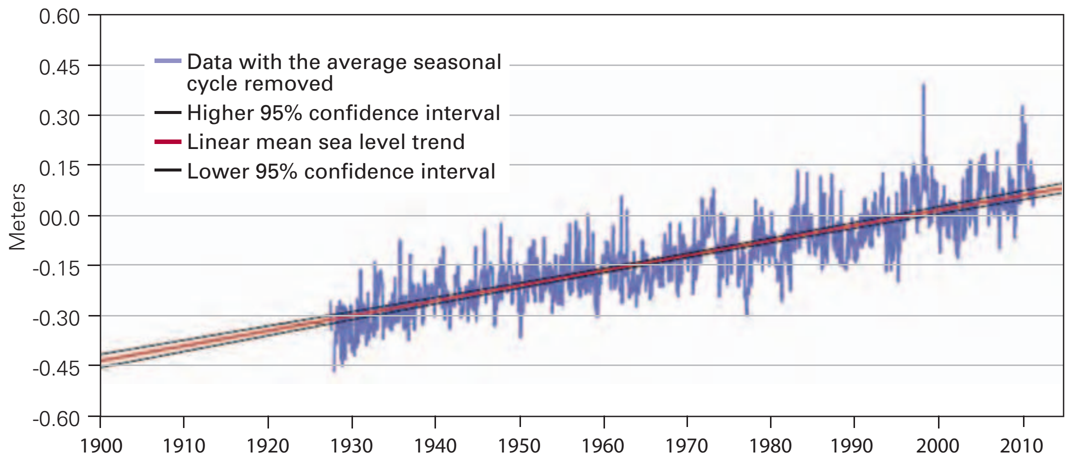
Figure 3.2: Relative sea level trends along the U.S. East Coast



Sewells Point in Norfolk has the fastest rate of sea level rise on the Eastern Seaboard.

Source: Boon et al. (see Appendix A)

Figure 3.3: Historic sea level rise at Sewells Point, Norfolk, Virginia, 1927–2006



Source: NOAA (see Appendix A)

one-half of the sea level rise in the Hampton Roads area is due to local land subsidence.[6]

The land in Norfolk and the rest of Hampton Roads is subsiding for a combination of reasons. First, the area sits on the leading edge of a passive tectonic plate, which causes gradual land subsidence. Second, the area also lies on the edge of a bowl-shaped depression known as the Chesapeake Bay Impact Crater. Third, the area is rebounding downward after being elevated while the massive Laurentide ice sheet weighed down the land to the north during the last ice age. And fourth, the area is settling due to withdrawals of groundwater from underlying aquifers more quickly than they can be recharged.[7] The Scientific and Technical Advisory Committee of the Chesapeake Bay Program reports average subsidence rates of about 0.6 inch (1.4 centimeters) per decade.[8] Land subsidence is expected to continue into the 21st century, exacerbating the effects of sea level rise due to thermal expansion of the oceans and melting ice cover.[9]

Impacts

Flooding due to sea level rise is likely to be a priority issue for Norfolk in the 21st century.[10] Most of the city is at an elevation of 16.4 feet (5 meters) or less with a very shallow slope.[11] By 2100, much of Norfolk could be underwater if not protected by an extensive levee system.[12] Important transportation infrastructure vulnerable to sea level rise includes the Hampton Roads Bridge Tunnel connecting the cities of Hampton and Norfolk along Interstate 64. According to the Organization for Economic Cooperation and Development, the Norfolk–Virginia Beach metropolitan area ranks 10th in the world in the value of assets exposed to increased flooding from sea level rise.[13] However, more than half the insurance companies operating in the mid-Atlantic region are reducing or eliminating new coastal coverage in Norfolk and other areas in Hampton Roads.[14]

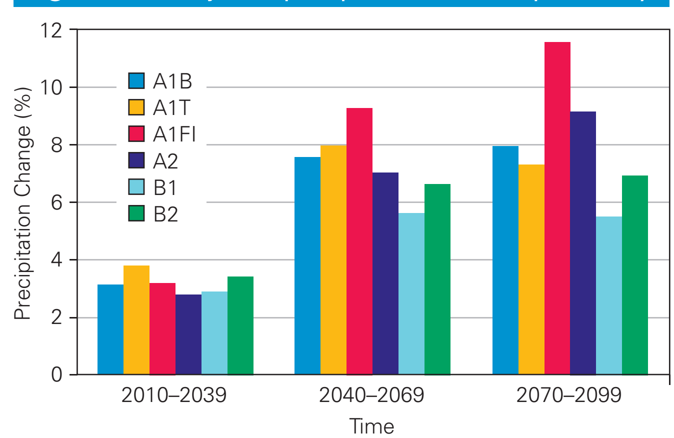
With increased sea level rise, the characteristics of Norfolk's land surface are expected to change. For instance, with a 3.3-foot (1-meter) rise in sea level, undeveloped dry land is expected to decrease by 22 percent, as wetlands move inland in areas not protected by seawalls and other barriers.[15] Norfolk's eight reservoirs are at higher elevations than the surrounding area. The impact of sea level rise, if any, on Norfolk's reservoirs is not clear at this time, but water supply officials told NRDC there are currently no water supply–related climate change mitigation plans.[16]

STORM EVENTS AND COASTAL AND INLAND FLOODING

Occurrence

The Virginia Governor's Commission on Climate Change projects that an 11 percent increase in overall annual precipitation is likely by 2100.[17] Many climate change models also predict an increase in precipitation intensity in the mid-Atlantic region by the end of the 21st century. Although seasonal predictions are less certain, winter and spring rainfall will likely increase (see Figure 3.4).[18]

Figure 3.4: Projected precipitation in Chesapeake Bay



Annual mean precipitation of the Chesapeake Bay watershed for six IPCC scenarios averaged over the four highest-ranked climate models. A1 and A2 are higher GHG emissions scenarios, and B1 and B2 are lower GHG emissions scenarios.

Source: Adapted from Pyke et al. (see Appendix A)

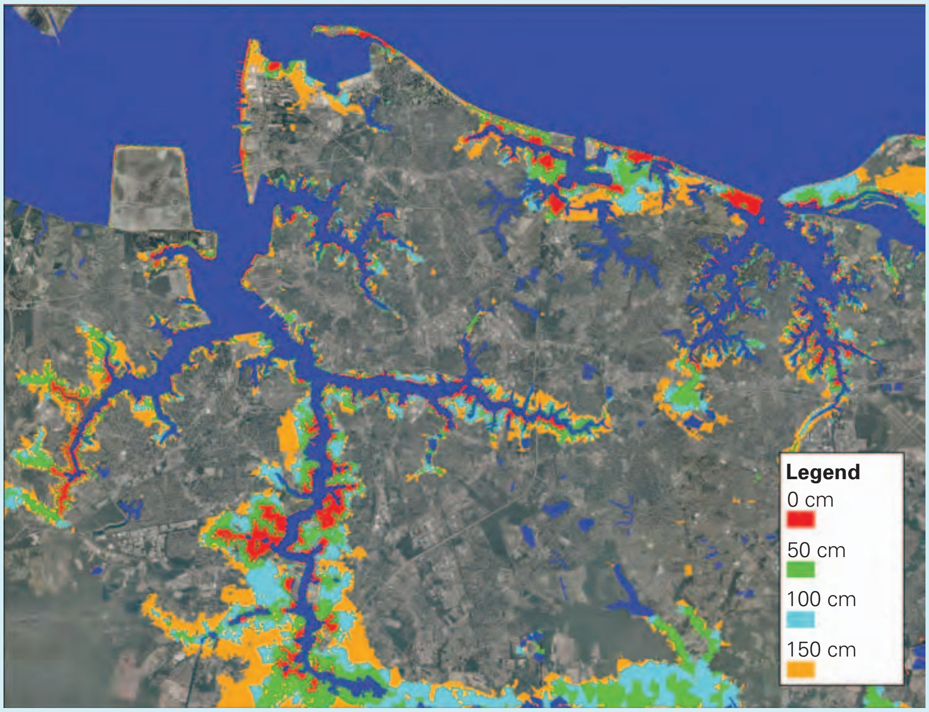
Naval Impacts

To a large extent, Norfolk's economy is based on industries associated with coastal locations. For instance, the U.S. Navy provided direct economic impact of more than $14.6 billion in the Hampton Roads region in 2008.[1] Norfolk is home to three major Navy facilities, as well as the Port of Virginia's Norfolk International Terminal. All of these facilities are vulnerable to storm surge flooding. Temporary work stoppages or permanent transfer of these facilities because of flood damage could have a ripple effect on Norfolk's economy.[2] Flood damage to Navy facilities could also impair the readiness of U.S. military forces.[3]

The largest naval facility in Norfolk—in fact, the largest in the United States—is the Naval Station Norfolk, also known as Norfolk Naval Base. Its extensive shoreline infrastructure supports surface and submarine vessels, and its 8,300-foot airstrip supports fixed-wing and rotary-wing aircraft. The 4,300-acre site has more than 500 buildings with a plant replacement value of more than $4.2 billion. With an average elevation of 8 to 10 feet (2.4 to 3 meters) above mean sea level, the site already experiences storm-related flooding, which the Navy anticipates will be exacerbated by sea level rise (see Figure 3.5). Repeated flood-related damage is expected to make infrastructure maintenance more expensive. Climate change–related impacts that the Navy projects for this site include extreme tides and storm surges that will disrupt utilities and damage piers, increased dredging requirements due to silting from heavy precipitation, flood damage to the airstrip, and shoreline erosion.[4]

To address such impacts, the Navy released a road map to guide policy, strategy, and investment plans related to climate change. According to Rear Admiral David Titley, director of Task Force Climate Change and Oceanographer of the Navy, "Climate change will affect the type, scope, and location of future Navy missions, so it's essential that naval force structure and infrastructure are delivered at the right time and at the right cost. That will depend upon a rigorous assessment of future requirements and capabilities and an understanding of the timing, severity, and impact of the changing climate, based on the best available science."[5]

Figure 3.5: Comparison of projected inundation areas if a hurricane similar to Isabel were to strike Norfolk at varying degrees of sea level rise



Source: Noblis

The red zones show the approximate flooded areas after the actual hurricane in 2003. The green, blue, and orange zones show the additional flooded areas predicted by the model if the same type of hurricane were to hit Norfolk when seas are 1.6 feet (0.5 meter), 3.3 feet (1 meter), or 4.9 feet (1.5 meters) higher, respectively, than they were in 2003.

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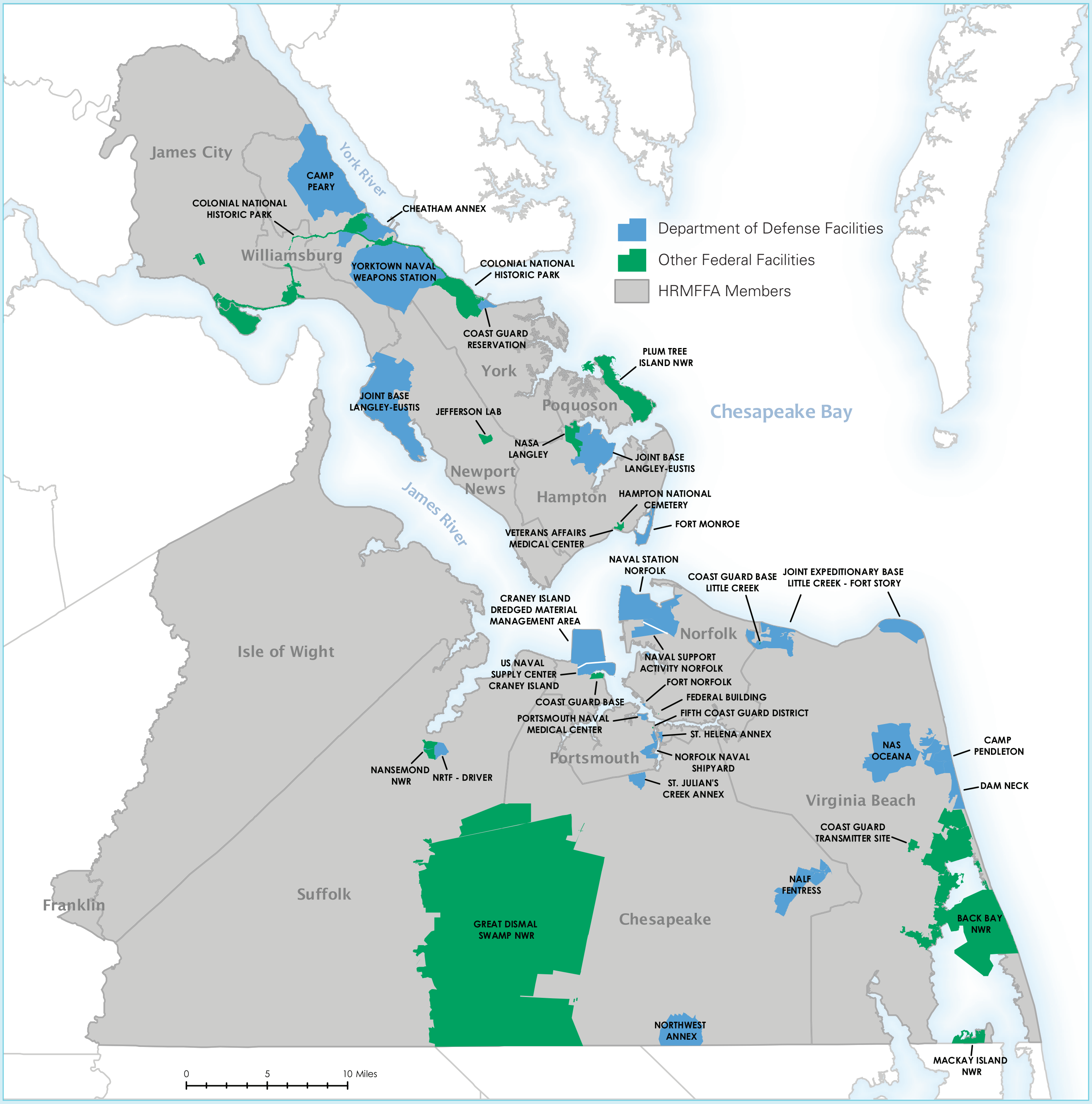
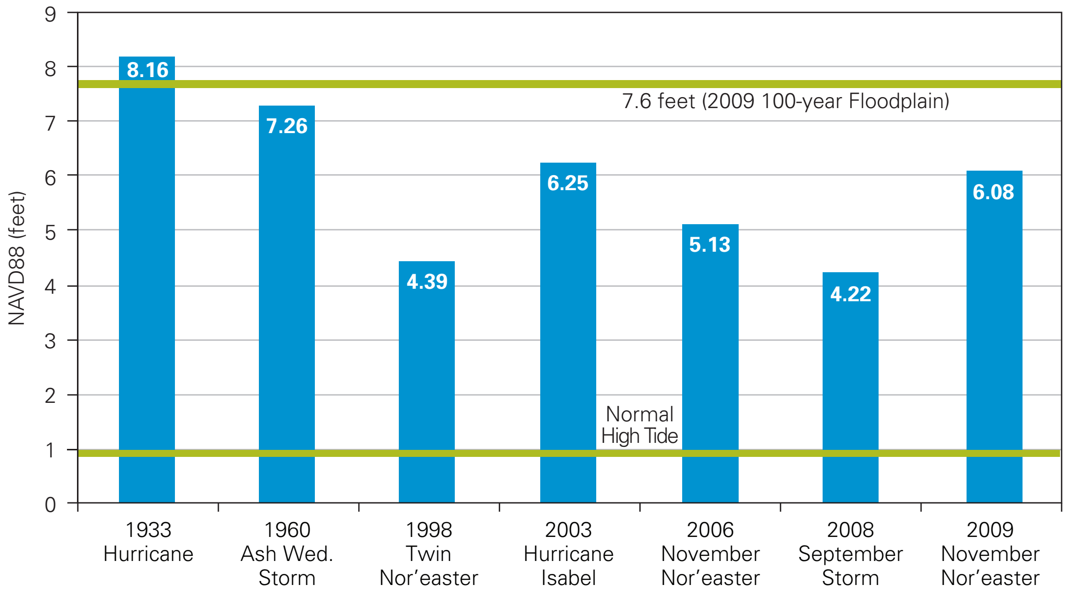
Figure 3.6: Military and other federal facilities in Norfolk and greater Hampton Roads



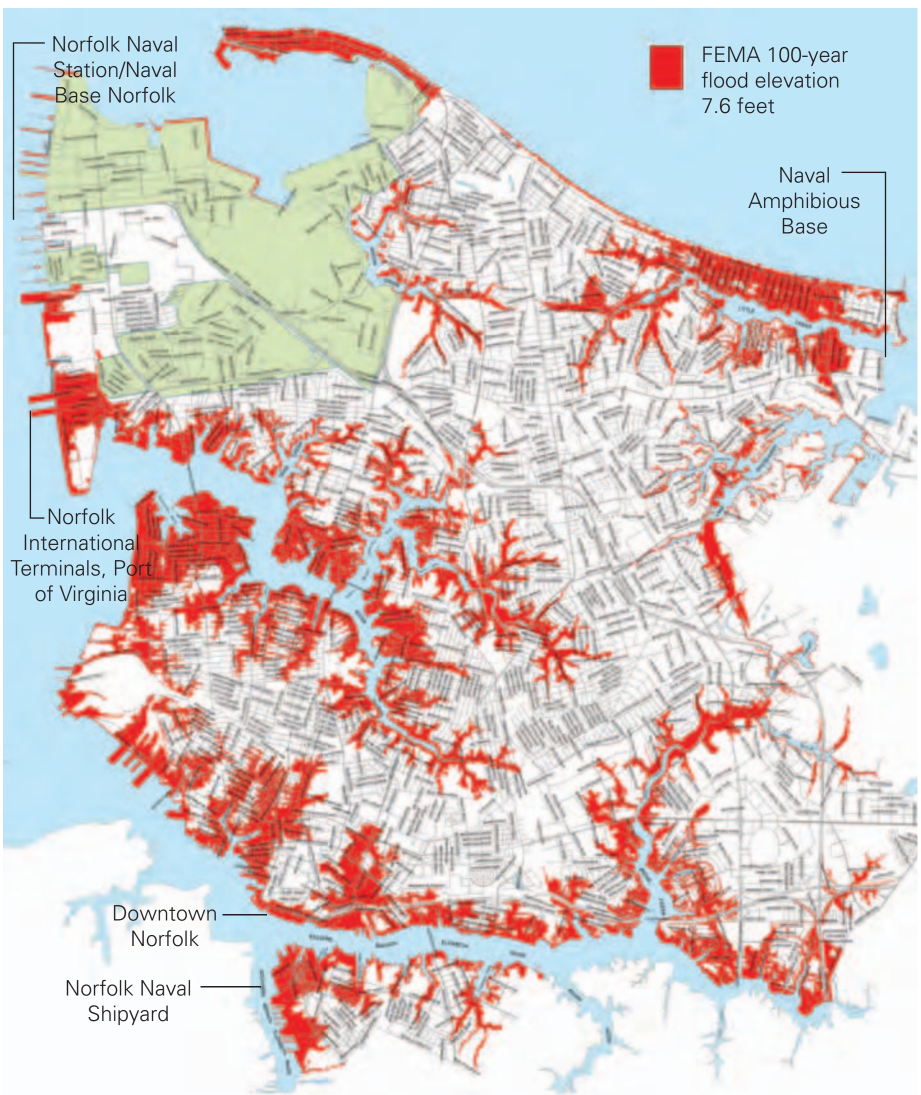
Source: Hampton Roads Planning District Commission

Figure 3.7: Storm tide elevations at Sewells Point, Norfolk



Source: Adapted from Lentz (see Appendix A)

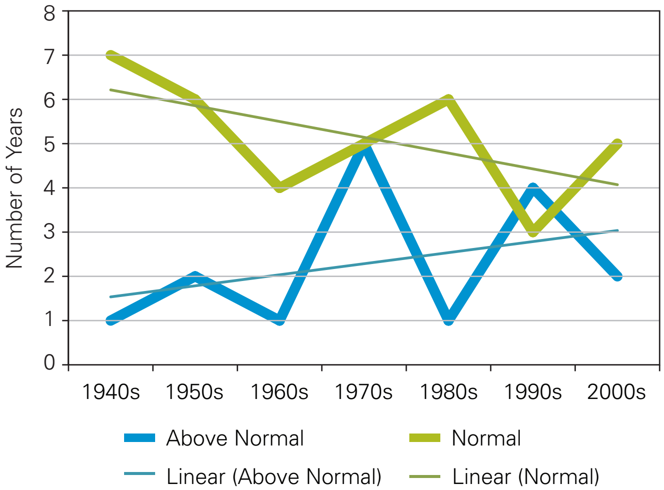
Figure 3.8: FEMA flood hazard map for Norfolk



In 2009 FEMA increased Norfolk's base flood elevation to 7.6 feet, 0.3 foot higher than its 1980 prediction.

Source: FEMA/Lentz (see Appendix A)

Figure 3.9: Number of normal rainfall years and number of above-normal rainfall years per decade



Source: NRDC/Data from USGS (see Appendix A)

Looking at the number of wetter years versus normal rainfall years per decade, there is a general trend toward more wet years and fewer normal years (see Figure 3.9).[19]

Indeed, the trend toward wetter years is already visible when assessing the amount of runoff entering the Chesapeake Bay during a 73-year period from 1937 to 2010. The number of years with above-normal rainfall levels increased by about 50 percent (from 7 to 10 wetter-than-normal years) during the latter half of that time period compared with the first half. In the future, as heat waves and precipitation intensity increase, it is plausible that greater extremes of streamflow will result.[20]

Impacts

Increased storm intensity will affect storm surges in the area. Over the past 80 years, five of the seven most significant storm surges in Norfolk have occurred since 1998 (see Figure 3.7). This trend is expected to continue particularly because of continued sea level rise and local land subsidence.[21] This combination is also expected to lead to significant flooding by tropical storms and nor'easters that did not cause significant flooding in the past.[22] For instance, Hurricane Isabel, which hit Norfolk on September 17, 2003, caused a storm tide of 6.25 feet (1.9 meters). The surge destroyed 17 homes, damaged more than 1,600 others, and felled more than 4,000 trees.[23] Probably because of the combination of sea level rise and land subsidence, Hurricane Isabel caused as much damage as the "storm of the century" 1933 Chesapeake-Potomac Hurricane had 70 years earlier, despite the fact that Isabel's storm surge was almost 2 feet (0.6 meter) lower.[24]

The more populated and developed sections of Norfolk and their associated transport systems (e.g., coastal roads, railways, and runways) are at high risk from storm surge flooding (see Figure 3.8).[25] Utility infrastructure and stormwater systems will be challenged with larger and more intense flows and natural forces.[26]

More intense rainfall could also have water quality impacts. More intense rainfall leads to increased runoff, which elevates bacteria and algae levels. This can raise the risk of waterborne diseases as well as some forms of water pollution, particularly sediment concentration and nutrient pollutants.[27]

INCREASED TEMPERATURE

Occurrence

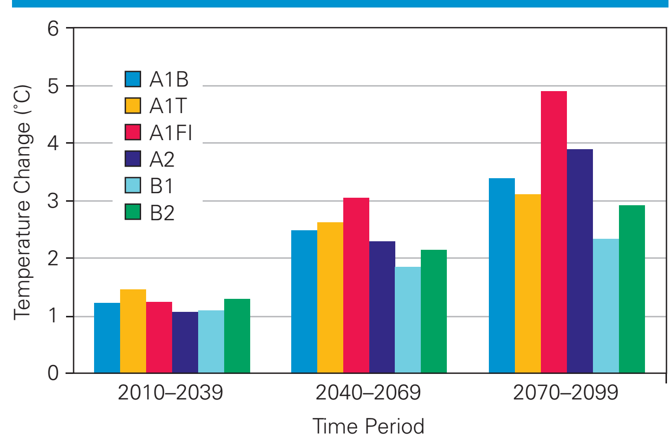
Multi-model projections of annual average temperature suggest an increase of 3.1° to 3.8°F (1.7° to 2.1°C) for the Chesapeake Bay area by 2050,[28] and 3.6° to 9°F (2° to 5 °C) of warming by 2100 (see Figure 3.10). One climate scenario predicts that heat waves in the mid-Atlantic region will also increase by 2100.[29]

Impacts

The combination of increased nutrient pollution of Chesapeake Bay waters from more frequent rainfall events, higher dissolved carbon dioxide concentrations, and higher temperatures will likely lead to more frequent and intense blooms of algae. Algal blooms can, in turn, decrease dissolved oxygen as they decay, causing more intense and frequent episodes of hypoxia.[30]

The impact of increased temperature, if any, on Norfolk's reservoirs is not clear at this time, but water supply officials told NRDC there are currently no water supply–related climate change mitigation plans.[31]

Figure 3.10: Projected temperatures in Chesapeake Bay



Annual mean temperature in the Chesapeake Bay watershed for six IPCC scenarios averaged over the four highest-ranked climate models. A1 and A2 are higher GHG emissions scenarios, and B1 and B2 are lower GHG emissions scenarios.

Source: Adapted from Pyke et al. (see Appendix A)

ACTION: MITIGATING AND PREPARING FOR CLIMATE CHANGE

Much of the recent attention to Norfolk and the Hampton Roads area of Virginia has focused on flooding issues associated with sea level rise and land subsidence. Given the vast amount of infrastructure, assets, and people at risk in the region, many government agencies and organizations are involved in adaptation planning. Our discussion below is merely an overview and is not meant to be fully comprehensive of all work being conducted on these issues.

STATE, REGIONAL, AND CITY PLANS AND GREENHOUSE GAS REDUCTION MEASURES

In 2007 the Governor's Commission on Climate Change was established to identify actions necessary to meet the 2007 Virginia Energy Plan's greenhouse gas (GHG) emissions

Figure 3.11: Repetitive flooding loss sites

Source: Lentz (see Appendix A)

goal of a reduction to 2000 levels by 2025 (30 percent below business-as-usual projections for 2025).[32] In 2008 the commission released its final report, "A Climate Change Action Plan," to support achievement of this emissions target.[33]

The city of Norfolk is currently working on a carbon footprint inventory that will include a GHG emissions reduction target and strategies for achieving this goal. This work is expected to be completed by 2012.[34]

NOTABLE LOCAL ADAPTATION EFFORTS

While Norfolk does not have a comprehensive plan for addressing climate change impacts (and is not planning on developing one), the city is currently working on an update to its general plan, plaNorfolk 2030, which will include climate change impact considerations such as sea level changes.[35] Most of the city's adaptation efforts thus far have been spearheaded by the Public Works Department.

To date, Norfolk's flood mitigation work has largely been composed of ad hoc response strategies and minor improvements to and maintenance of the city's 60-year-old drainage system, which was originally designed to handle smaller storms than what it is now handling.[36] To decrease flooding risk, the city requires the finished floor of new structures to be at least 1 foot above the 100-year base flood elevation; however, many existing structures do not meet this standard and are vulnerable. FEMA's Hazard Mitigation Program provides limited funding to raise or acquire repetitive loss structures (flood-prone structures), to try to reduce damages from future disasters (see Figure 3.11). In the past 5 years, the city has raised 24 structures at an average cost of $146,000 each.[37] In response to tidal flooding, Norfolk has also raised

Climate change planning is dependent on good information about projected climate changes and their impacts. Accordingly, the Hampton Roads region is working on obtaining funding for better information to support future planning efforts.

Source: U.S. Navy/Christopher B. Stoltz

The Department of Defense is evaluating climate change's impacts on military installations.

several roads. To combat flooding associated with rainfall and poor drainage, the city has designed new and replacement facilities to handle a 10-year storm versus the 2-year storm that much of the existing drainage system was initially designed to handle.[38]

Norfolk has hired a Dutch coastal engineering firm, Fugro, to conduct a citywide flood vulnerability analysis that will be used to enhance the city's current flood mitigation program and inform the development of a robust, cost-effective program for the future.[39] The city will utilize the flood forecast model to evaluate the costs associated with implementing various flood mitigation mechanisms and the economic damages avoided by installing these mechanisms. It is expected that this plan will be completed by the end of 2011, with implementation occurring over the next few years.[40]

The Hampton Roads Planning District Commission (HRPDC), which represents the 16 local governments in the area, is working on several initiatives regarding sea level rise. The HRPDC Elizabeth River Restoration Program Steering Committee is planning to look at potential flooding of industrial and contaminated sites that may be inundated or flooded due to sea level rise.[41] Regional emergency management personnel are updating the region's hazard mitigation plans to include climate change considerations. HRPDC is also involved in a study to determine the vulnerability of population, housing, transportation, and infrastructure to sea level rise and storm surge.[42] In addition, the commission recently partnered with Old Dominion University to conduct an economic impact analysis of sea level rise in the Hampton Roads region.[43]

Climate change planning is dependent on good information about projected climate changes and their impacts. Accordingly, the Hampton Roads region is working on obtaining funding for better information to support future planning efforts.[44] For example, the Chesapeake Inundation Prediction System (CIPS) uses very high resolution hydrodynamic models; very high resolution elevation data (LiDAR), which provides more accurate flood predictions; and emerging GIS and visualization capabilities for integrated, high-resolution results.[45]

The U.S. military and the intelligence community have recognized that climate changes poses a risk: The National Intelligence Council concluded that "global climate change will have wide-ranging implications for U.S. national security interests over the next 20 years,"[46] and the 2010 Quadrennial Defense Review further recognized the risk that climate change poses to military operations and installations worldwide. As a result, the Strategic Environmental Research and Development Program (SERDP), a partnership among the Department of Defense, Environmental Protection Agency, and Department of Energy, has launched several studies to evaluate the environmental and ecological impacts on military installations posed by climate change. One such study focuses specifically on the development of a risk assessment framework to evaluate changes in risk to coastal military installation assets and mission capabilities in the Hampton Roads region due to climate change impacts.[47] In 2009 the Chief of Naval Operations (CNO) presented climate change–related issues potentially impacting naval installations and operations to the CNO Executive Board, which then established the Navy's Task Force Climate Change (TFCC). In 2010, TFCC released the U.S. Navy Climate Change Roadmap to guide Navy policy, strategy, and investment plans related to a changing global climate. The document prioritizes the development of recommendations for Navy investments to meet climate change challenges, including the protection of coastal installations vulnerable to sea level rise and water resource challenges for fiscal years 2011 and 2012.[48]

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CHAPTER 4

Miami, Florida

Miami is one of the most vulnerable cities in the world to climate change. Sea level rise has the potential to cause shoreline and infrastructure damage from flooding, and the city's sole natural source for drinking water is threatened by saltwater intrusion. The likelihood of more intense storms magnifies these effects. In fact, Miami ranks number one worldwide in terms of assets exposed to damage from coastal flooding. The good news, however, is that the city, county, and region are pulling together to actively prepare for the effects of climate change.

AREA OVERVIEW

Miami sits in southeast Florida near the tip of the Florida peninsula, where the Miami River meets the Atlantic Ocean (see Figure 4.1). The city has a diverse population of more than 400,000. Greater Miami's 5.4 million people make it the largest metropolitan area in the southeastern United States. The Port of Miami is the busiest cruise-ship port in the world. Two national parks are close by: Biscayne National Park and Everglades National Park.[1]

Miami receives about 54 inches (137 centimeters) of rain annually, most of which falls during the summer season of June through September. High temperatures during the rainy season cause more than half of the rainfall to evaporate before it can be used. Water demand is highest during the drier winter and spring months, when tourism peaks.[2] Miami is no stranger to severe weather, particularly hurricanes: Hurricane Andrew caused $26.5 billion in damage in 1992, and Hurricane Wilma caused more than $1 billion in damage in 2005.[3]

Miami ranks number one worldwide in assets exposed to coastal flooding, according to the OECD.

Figure 4.1: Miami and surrounding area

Source: Map Resources/NRDC

The drinking water source for most of Florida is the Floridan Aquifer, but in south Florida this aquifer is deep and brackish. In southeast Florida, the Biscayne Aquifer sits above the Floridan Aquifer and is the drinking water source for Miami-Dade and Broward counties and parts of Palm Beach County.[4]

POTENTIAL CLIMATE CHANGES AND THEIR IMPACTS

The following sections describe projected water-related climate changes and impacts to Miami throughout the 21st century. For a general explanation of how increased greenhouse gases affect our climate and seas, and typical resulting impacts of climate change, see the Background and Methodology section.

SEA LEVEL RISE, COASTAL FLOODING, AND SALTWATER INTRUSION

Occurrence

The projected sea level rise for Miami, at current rates of global warming, is 1.5 to 2.3 feet (0.5 to 0.7 meter) by mid-century and 3 to 5 feet (0.9 to 1.5 meters) by 2100.[5] Given that the average elevation of land in Miami is just 6 feet (1.8 meters) above mean high water, Miami is highly vulnerable to the effects of global sea level rise.[6]

Impacts

Figure 4.2 shows the land area vulnerable to sea level rise of 2.3 feet, or 0.7 meter. The vulnerable zone (gray) essentially engulfs almost all of Miami's developed areas (red).[7] Infrastructure that could be impacted in this zone include power generating facilities (including one nuclear reactor near Miami), prisons, nursing homes, hospitals, airports, low-income housing complexes, solid waste disposal sites, assisted livings facilities, gas stations, shopping centers, public schools, hazardous-material cleanup sites, religious establishments, hotels, and historic structures.

Sea level rise could also affect Miami's drinking water, causing it to become brackish.[8] The Biscayne Aquifer is located just a few feet belowground. Like the rest of southeast Florida, it is composed of very porous limestone, which facilitates easy movement of water throughout this underground substrate. Rising sea level, combined with extraction of freshwater faster than it is being recharged, makes the aquifer susceptible to saltwater intrusion. A 2010 report prepared by the International Council for Local Environmental Initiatives (ICLEI) stated that "as sea level rises, hydrostatic pressure will cause the saltwater front to move further inland, threatening contamination of drinking water wells with saltwater."[9]

The porous nature of the underground limestone substrate makes the use of surface levees and dikes less effective at protecting drinking water sources from saltwater intrusion.[10] Such intrusion could necessitate expensive, energy intensive desalination plants to make the water potable.

Table 4.1: Summary of water-related climate changes and impacts in Miami and the Florida Keys throughout the 21st century

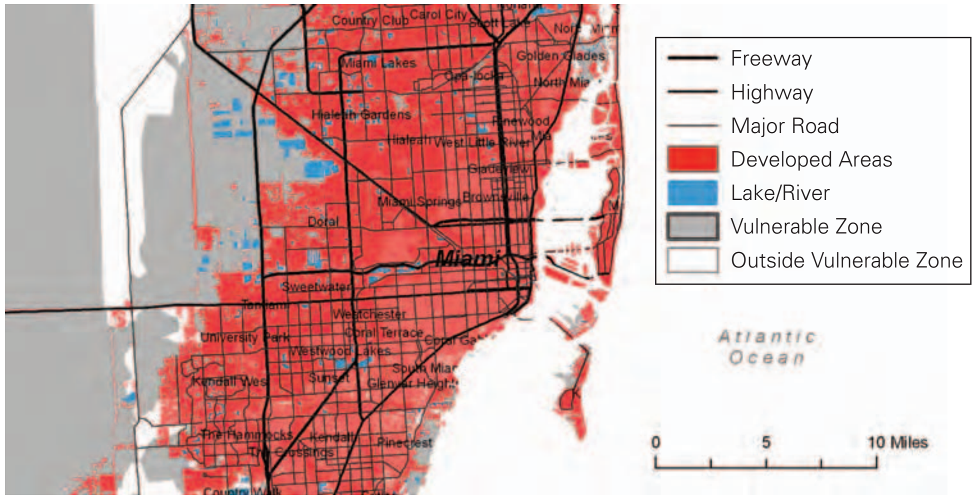
(Highly likely)	Rising sea levels
(Highly likely)	Increased flooding
(Highly likely)	Increased saltwater intrusion
(Highly likely)	More frequent and intense storm events
(Highly likely)	Increased erosion
(Highly likely)	Water supply challenges due to increased droughts
(Highly likely)	Increased impacts to fisheries
(Likely)	Decreased annual precipitation

Highly likely · Likely · Possible

Source: NRDC

Sea level rise is expected to cause saltwater intrusion farther into Miami's estuaries, coastal wetlands, and tidal rivers as well as its groundwater aquifers. It could also leave many of Miami's sandy beaches and parts of the nearby Everglades, including the sensitive habitats that depend on that ecosystem, underwater by mid-century. These impacts would cause Miami's tourism economy to suffer.[11]

Figure 4.2: Miami's zone of vulnerability to a 0.7-meter sea level rise



Source: Adapted from Stanton and Ackerman (see Appendix A)

STORM EVENTS, COASTAL AND INLAND FLOODING, AND BEACH EROSION

Occurrence

Annual rainfall in southeast Florida is likely to decrease by 10 to 20 percent in the coming decades.[12] However, as with many other areas along the East Coast, while the frequency of storms in Miami may decrease on an annual basis, storms that do occur, including tropical storms and hurricanes, may be more intense.[13]

Impacts

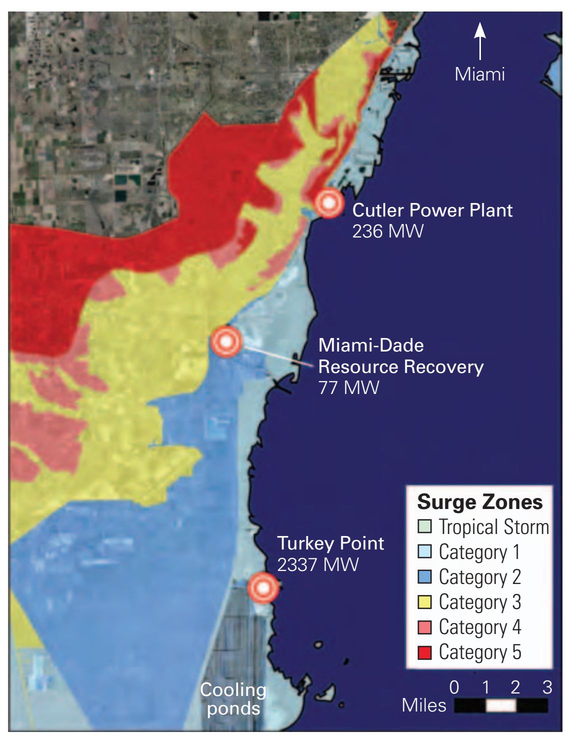
Sea level rise, even at the more modest projected levels, will bring greater risk of flooding, particularly in combination with more intense storms.[14] Miami is especially at risk for flooding from storm surges.[15] The human and economic cost of coastal flooding due to storm surge and damage from high winds in Miami is potentially enormous. According to research by the Organization of Economic Cooperation and Development (OECD), under present-day conditions, Miami ranks number one worldwide in assets exposed to coastal flooding and fourth in terms of population exposed (after Mumbai, Guangzhou, and Shanghai).[16] Greater Miami currently has more than $400 billion in property value at risk from coastal flooding, and that value could rise to $3.5 trillion by 2070.[17] This includes Miami's largest power plant, the 2,337-megawatt Turkey Point nuclear facility. The smaller Cutler Power Plant and Miami-Dade Resource Recovery Plant are located well within the area that is already at risk from storm surges (see Figure 4.3).[18]

Florida's porous limestone substrate helps reduce flooding during rainfall events by absorbing runoff. However, the porous quality of the substrate also facilitates a strong connection between the sea and groundwater, so a rise in sea level will cause the water table to rise closer to the surface. This will reduce the substrate's capacity to absorb stormwater and could increase the likelihood of inland flooding.[19]

Beach erosion that results from rough seas during hurricanes, storms, and periods of high wind, exacerbated by rising sea levels, will likely increase.[20] Wide beaches have significant benefits for storm damage reduction: According to a guide by the NOAA Coastal Services Center, "During storms with elevated water levels and high waves, a wide beach performs as an effective energy absorber with the wave energy dissipated across the surf zone and wide beach rather than impacting on the upland structures."[21] Wide beaches also benefit Miami's tourist economy because of their obvious recreational value.[22]

To counter the impacts of beach erosion, sand renourishment may have to occur more frequently. However, this labor-intensive process comes at a price: Between 1976 and 1981, a beach renourishment project that replenished a 10-mile stretch of beach to a width of about 100 feet cost $64 million.[23]

Figure 4.3: Miami-area power plants at risk from storm surges



Source: Stanton and Ackerman (see Appendix A)

The Florida Keys

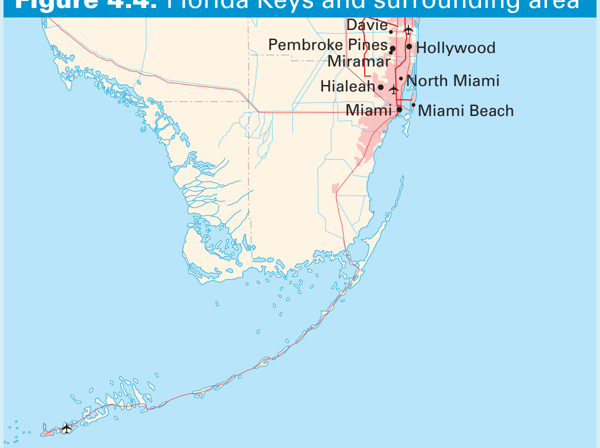
Sea level rise threatens the very existence of the Florida Keys, and higher water temperatures and ocean acidification threaten the viability of the only living coral reef ecosystem in the continental United States.

The Keys are a string of about 1,700 islands in Monroe County that span 220 miles. They stretch in an arc from Biscayne National Park, about 10 miles due south of downtown Miami, to Key West and the Dry Tortugas National Park (see Figure 4.4). Parallel to the Keys on the Atlantic side lies the third-largest barrier reef in the world.[1] In 1908, recognizing the beauty and value of the Florida Keys, President Theodore Roosevelt created the Key West National Wildlife Refuge. Today the economy of the Keys depends primarily on tourism and to a lesser extent on commercial fishing. Yet by 2100, "terrestrial protected areas and the endemic organisms found in this low-lying island chain are likely to be extinct or clinging to an increasingly precarious existence as the sea rises around them," according to The Nature Conservancy.[2]

Loss of land: Sea level rise (estimates for the region are 3 to 5 feet, or 0.9 to 1.5 meters, by 2100[3]) delivers a one-two punch to the Keys, owing to their low elevation (an average of 4 to 7 feet, or 1.2 to 2.1 meters, above current sea level) and their high water-to-land ratio (any point on land is within 4 miles of water).[4] Estimates of the potential loss of land area in the Keys range from 38 percent (at a value of $11 billion) to 92 percent ($35 billion).[5] Climate change is also projected to cause more severe storms and hurricanes in the region, exacerbating the impact of rising sea levels on shorelines as well as on mangroves and sea grasses.

Loss of living coral reef: Florida Keys coral reefs also get a one-two punch from rising atmospheric carbon dioxide concentrations. Atmospheric carbon dioxide not only raises air and water temperatures but also lowers the pH of ocean water as it dissolves into it. Both warmer and more acidic seawater can kill living corals. Warmer temperatures can cause coral polyps to discharge their symbiotic algae partners; acidic conditions make it more difficult for them to grow as well as weaken their calcium carbonate skeletons, making them more susceptible to erosive forces. Under the more pessimistic climate change scenarios, under which global temperatures increase by at least 7.2°F (4°C) by 2100 and ocean pH decreases from the norm of 8.1 to 7.7 or below, coral cover is likely to be

Figure 4.4: Florida Keys and surrounding area



Source: Map Resources/NRDC

© Wiki user Molasses11

Ocean acidification threatens coral reef ecosystems.

completely wiped out in the Keys. Even under a more optimistic scenario, where global temperatures increase by 4.5°F (2.5°C) and ocean pH does not fall below 8, almost half the coral cover is predicted to disappear by the end of the century.[6] Either of these scenarios would have devastating impacts on the marine life of the reef and the people who depend on it for food and tourism income.

Prior to the onset of climate change, the close proximity of coral reefs to populated areas of the Florida Keys was already making them susceptible to pollution, particularly sewage contamination from septic tanks. Florida's Sanitary Wastewater Management Plan, approved by the Board of County Commissioners in June 2000, required centralized sewer facilities throughout the Florida Keys by July 1, 2010. The Keys' major municipalities have been, or are close to being, fully sewered, but unincorporated areas still rely on septic tanks.

Brackish water supply: The Florida Keys have already begun adjusting to the reality of a brackish drinking water source. Since 1939 the Florida Keys Aqueduct Authority (FKAA) has drawn drinking water from wells in nearby Miami-Dade County. These wells tap the heavily used Biscayne Aquifer, which is increasingly threatened by saltwater intrusion exacerbated by sea level rise. In addition, climate change is projected to increase droughts and heat waves, both of which can reduce water volume in the Biscayne Aquifer, further aggravating saltwater intrusion. In anticipation of restrictions on its use of the Biscayne Aquifer, FKAA began drawing water from the deeper and brackish Floridan Aquifer in January 2010. FKAA desalinates the brackish water using reverse osmosis.

Actions: The Florida Reef Resilience Program released its climate action plan for 2010–15 for the Florida Keys National Marine Sanctuary.[7] In 2008 Monroe County's Board of Commissioners instituted a Green Initiative Task Force to recommend practices and techniques to protect the environment and mitigate climate change. The U.S. Fish and Wildlife Service is incorporating sea level rise estimates in its management planning. The city of Key West is beginning to factor sea level rise into its engineering and construction decisions.[8]

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The U.S. Fish and Wildlife Service is incorporating sea level rise estimates in its management planning. The city of Key West is beginning to factor sea level rise into its engineering and construction decisions.

INCREASED TEMPERATURE AND DROUGHT

Occurrence

In the "business-as-usual" scenario of steadily increasing greenhouse gas (GHG) emissions, temperatures in Miami are expected to increase between 4.5° and 9°F (2.5° to 5°C) by mid-century. Moreover, heat waves—generally considered to be three or more consecutive days with maximum temperatures above 90°F (32°C)—are expected to increase in duration and number (see Figure 4.5).[24] Miami's climate could surpass that of hot, humid Bangkok, where temperatures climb above 90°F more than two-thirds of the year.[25] These hotter temperatures combined with less annual rainfall could bring longer droughts to south Florida.[26]

Impacts

A number of conditions come together to negatively affect Miami's water supply. Hotter and drier conditions, summertime heat waves that increase evapotranspiration and reduce soil moisture content and groundwater levels, and a projected increase in Florida's population will decrease supply and increase demand for water.[27]

ACTION: MITIGATING AND PREPARING FOR CLIMATE CHANGE

Recognizing some of the serious predictions for its region, the city of Miami and Miami-Dade County, together with other southeast Florida counties, are investing many resources in planning for climate change impacts. The county, especially, is a driver for robust adaptation planning.

The initiatives discussed below represent just a fraction of the region's efforts.

STATE, REGIONAL, AND CITY PLANS AND GREENHOUSE GAS REDUCTION MEASURES

Florida has pledged to reduce the GHG emissions of state agencies and departments to 2000 levels by 2017, 1990 levels by 2025, and 80 percent of 1990 levels by 2050. To reach these and other goals related to climate change, in 2007 the state released an Energy and Climate Change Action Plan.[28]

Miami-Dade County has committed to the U.S. Cool Counties Program, which includes the regional goal of reducing GHG emissions by 80 percent of 2008 levels by 2050. In 2006 the county established a Climate Change Advisory Task Force (CCATF). The CCATF made recommendations to the county regarding mitigation and adaptation efforts, many of which were incorporated into the county's sustainability plan, called GreenPrint, which was released in February 2011.[29] A crucial component of GreenPrint is the county's Climate Change Action Plan.[30]

In 2009, Miami-Dade County entered into the Southeast Florida Regional Climate Change Compact with Broward, Palm Beach, and Monroe counties in order to coordinate policy positions, scientific research, and mitigation and adaptation efforts. In the compact, the counties pledge to develop a regional action plan.[31]

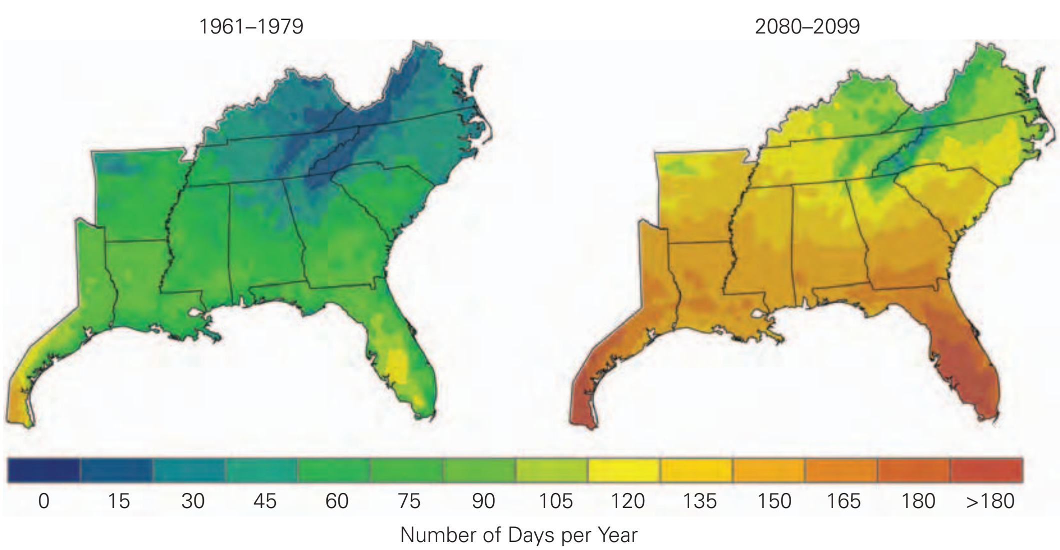
The city of Miami pledged to reduce GHG emissions to 25 percent of 2006 levels citywide by 2020 and to 25 percent of 2007 governmental levels by 2015. To implement these goals, the city released MiPlan: City of Miami's Climate Action Plan.[32]

NOTABLE LOCAL ADAPTATION EFFORTS

In MiPlan, the city recognizes the need to prepare for climate change impacts. It proposes the following specific actions: "Incorporate climate change into long-term planning, including the likely impacts of sea level rise on current and future infrastructure, flood mitigation, water supply risk, and health impacts of increased temperatures," and "Increase water management efforts including water conservation, pollution prevention, and water resource planning."[33]

Like MiPlan, the Miami-Dade County's GreenPrint plan sets forth strategies for how the area can prepare for the

Figure 4.5: Number of days with peak temperature over 90˚F



Source: Adapted from U.S. Global Change Research Program (see Appendix A)

Sand renourishment projects help combat beach erosion.

effects of climate change, with a higher level of detail than MiPlan. On water-related effects, GreenPrint's adaptation strategies include the following:

- develop planning maps and tools for Miami-Dade County based on consensus of SE FL Climate Change Compact planning scenarios;
- continue existing local surface water, groundwater, and saltwater intrusion modeling projects, incorporating expected climate change impacts (i.e., changes in temperature, precipitation, sea level rise, etc.) and integrating with regional water modeling projects from the South Florida Water Management District and other SE FL Climate Change Compact partners;
- examine the implications of sea level rise on vulnerable facilities (i.e., solid waste facilities, and water and wastewater utilities) ; and
- develop mechanisms for organizations to integrate potential climate change impacts into capital and operational decisionmaking.[34]

The counties that are part of the Compact have made important progress on the first strategy—working together with university scientists and other experts to come to a consensus of regional sea level rise projections to be used for planning purposes. The work group will release a white paper with its projections for the years 2030 and 2060 and will meet at least every two years to determine whether the figures need to be updated on the basis of evolving scientific information.[35]

One of the biggest challenges for the region, in terms of preparing for sea level rise, relates to the hydrology of southeast Florida. As discussed earlier, the Biscayne Aquifer is particularly susceptible to saltwater intrusion. One of the ways to combat saltwater intrusion is to add more freshwater to the aquifer. But because the aquifer level is already high, adding more freshwater would exacerbate flooding. Part of the region's planning efforts will address how to deal with these competing priorities. As they lay the groundwork for this type of determination, planners will endeavor to gather as much data as possible about the hazards the region can expect to see. [36]

Miami-Dade County and the region are also leveraging their resources to enlist the assistance of federal agencies, such as the National Oceanic and Atmospheric Administration (NOAA), the U.S. Geological Survey (USGS), the National Park Service (Miami is flanked by two national parks), and the Army Corps of Engineers.[37]

As part of an alternative water supply plan, the county's Water and Sewer District is working on the construction of the largest reclaimed water facility in Florida. This project will allow Miami-Dade County to reclaim highly purified wastewater for the specific purpose of reducing withdrawals from the Biscayne Aquifer. The project is anticipated to produce 170 million gallons per day by 2027.[38]

In part because Miami-Dade County has been such a driver for adaptation planning, the city of Miami works on adaptation issues primarily by participating in the county's efforts. For instance, the city gave input to the CCATF and on the GreenPrint plan.[39]

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CHAPTER 5

New Orleans, Louisiana

Given the havoc wreaked upon New Orleans by Hurricane Katrina in 2005, most people are well aware that much of the city lies below sea level. What many people may not be aware of is that with each passing year, the region is sinking further. New Orleans is one of the most vulnerable cities in the United States to the impacts of climate change, due to its low elevation, land subsidence rates, sea level rise, and prediction of more intense hurricanes.[1] As the city rebuilds in the wake of Katrina, it is trying to make itself more resilient to the effects of climate change, land subsidence, and wetland loss.

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New Orleans continues to be at serious risk of flooding from sea level rise, land subsidence, and intense storms.

Figure 5.1: New Orleans and surrounding area

Source: Map Resources/NRDC

Table 5.1: Summary of water-related climate changes and impacts in New Orleans throughout the 21st century

Highly likely	Rising sea levels
Highly likely	Increased flooding
Likely	More frequent and intense storm events
Likely	Increased impacts to fisheries

Highly likely · Likely · Possible

Source: NRDC

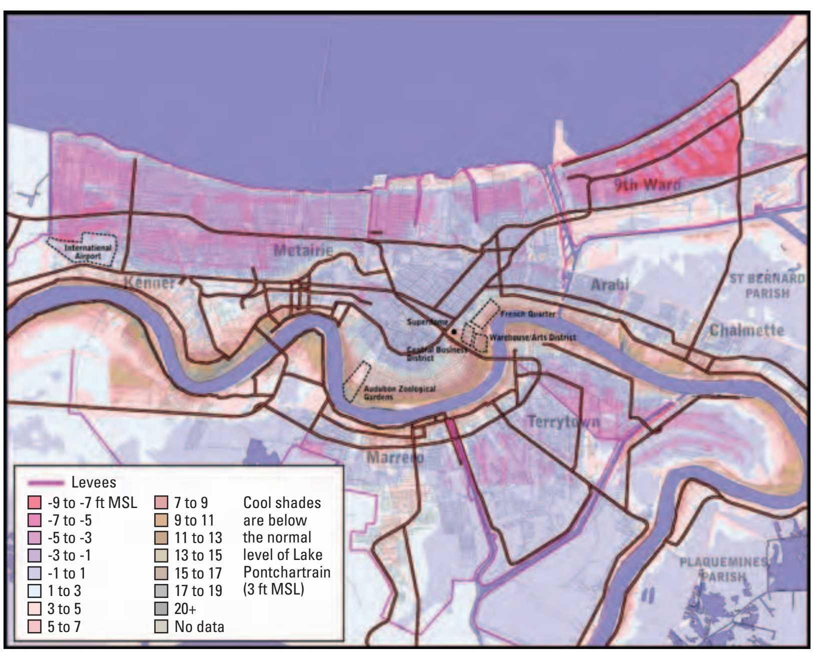
AREA OVERVIEW

The city of New Orleans, founded in 1718, is the largest in Louisiana with a population of about 344,000. The Mississippi River winds through the city and the massive Lake Pontchartrain forms its northern border (see Figure 5.1).

New Orleans has a humid subtropical climate, with mild winters and hot, humid summers. The yearly average low is about 60°F (16°C) and the yearly average high is 78°F (26°C). The city sees an average of 64 inches (163 centimeters) of rain a year and is extremely vulnerable to hurricanes.

Because much of the city lies below sea level (see Figure 5.2), an extensive system of drainage canals and pumping stations is needed to pump stormwater out of the city. The Sewerage and Water Board of New Orleans manages surface and subsurface canals and pumping stations that pump most of the stormwater over the flood-protection levees into Lake Pontchartrain and a smaller portion into the Intracoastal Waterway and Industrial Canal.[2] Drinking water is drawn from the Mississippi River.[3]

Figure 5.2: New Orleans elevation map



Source: ©2005 Tim Vasquez/Stormtrack.org. Reproduction and distribution permitted; this copyright notice may not be removed.

POTENTIAL CLIMATE CHANGES AND THEIR IMPACTS

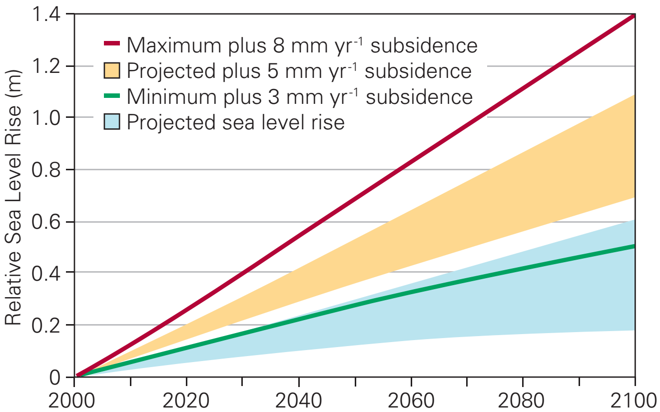
The following sections describe projected water-related climate changes and impacts to New Orleans throughout the 21st century. For a general explanation of how increased greenhouse gases affect our climate and seas, and typical resulting impacts of climate change, see the Background and Methodology section.

SEA LEVEL RISE, COASTAL FLOODING, AND SALTWATER INTRUSION

Occurrence

Sea levels in the New Orleans area are likely to increase by 1 to 4.6 feet (0.3 to 1.4 meters) by 2100 based on the range of estimates of absolute sea level rise and subsidence of the local land (see Figure 5.3). Local land is subsiding due to human activity and natural effects including soil oxidation and tectonic activity.[4] These conditions give much of the Louisiana coast a relative sea level rise rate that is among the highest in the nation.

Figure 5.3: Projected sea level rise in New Orleans



Relative sea level rise in the New Orleans area over the course of the 21st century based on combinations of high and low estimates of absolute sea level rise and local land subsidence rates.

Source: Blum and Roberts (see Appendix A)

Impacts

Rising seas will likely wipe out a significant portion of the coastal wetlands in the Mississippi River Deltaic Plain, where wetland loss rates are already among the highest in the world. Mississippi River flood-protection levees, some in place since the 18th century, rob the surrounding wetlands of replenishing seasonal sediments that would help counteract natural and man-made subsidence and erosion.[5] Additional human activities such as the dredging of ship channels, oil and gas production, and the siting of industrial facilities exacerbate wetland loss.[6] Wetland vegetation thrives in shallow waters but cannot survive as water depth and salinity increase. Wetlands without vegetation lose their ability to damp the energy of storm surges and waves, thus increasing the likelihood of flooding further inland in places—like metropolitan New Orleans—that have historically depended on these wetlands for protection.

Without inputs of sediment, an additional 3,900 to 5,200 square miles of wetlands will be under water by the end of the 21st century.[7] If the impacts of relative sea level rise on wetlands are not checked, metropolitan New Orleans could eventually sit on land almost completely surrounded by the open waters of the Gulf of Mexico (see Figure 5.4).

Loss of Louisiana's coastal wetlands not only would be a loss of natural flood protection but would impact the vast array of plants and animals that they support, many of which are tied to economic activity including fishing, timber, agriculture, tourism, and recreation.[8] The combined value of infrastructure and biological productivity associated with Louisiana's wetlands exceeds $100 billion.[9]

STORM EVENTS AND COASTAL AND INLAND FLOODING

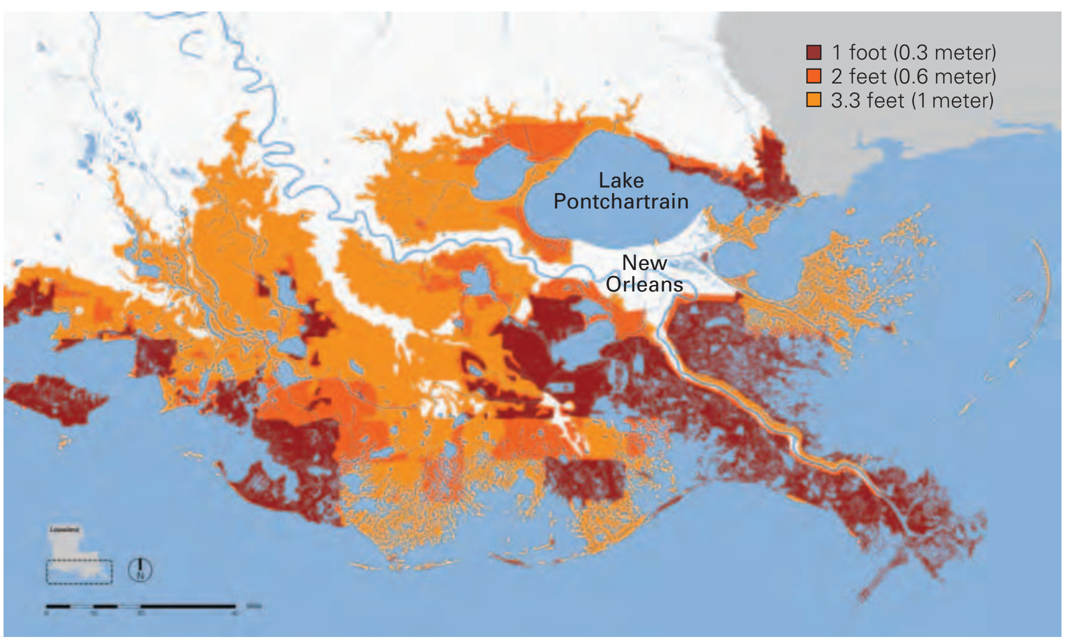
Occurrence

The number of extreme precipitation events has already increased in the southeastern United States over the past century.[10] In the future, as ocean temperatures rise, New Orleans will likely continue to experience more intense precipitation events and hurricanes.[11]

Impacts

Because of New Orleans's low elevation, stormwater and rain must be pumped out of the city.[12] Rainstorms with severe intensity have caused significant flooding in New Orleans in the past,[13] and any increase in precipitation intensity is likely to exacerbate the situation.

Figure 5.4: Potential wetland submersion by 2100



Source: Adapted from Carbonell and Meffert (see Appendix A)

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Hurricane Katrina floodwaters in downtown New Orleans.

Further, more intense hurricanes could be devastating to the city, as evidenced by Hurricane Katrina. The storm surge from Katrina, a Category 3 hurricane, was so devastating to coastal wetlands that the impact "represented about 50 years of projected wetland loss," according to Dr. Douglas Meffert.[14] After Katrina passed over New Orleans, about 80 percent of the city was flooded, with some areas covered by as much as 20 feet (6 meters) of water.[15] For just the 95,000 single-family homes with some extent of flood damage (that is, excluding commercial and industrial facilities), the estimated repair cost was between $8 billion and $10 billion, of which $3 billion to $6 billion was expected to be uninsured.[16] The storm surge from a Category 5 hurricane could cause flooding of more than 34 feet (10.5 meters) within the city by the end of the 21st century, depending on flood mitigation systems in place at the time.[17]

If left to nature, the vast network of wetlands surrounding New Orleans would absorb much of the energy from storm surges and waves, and the sediment collected from the vast watershed of the Mississippi River and deposited in the delta would keep erosion of critical wetlands in check. But decades of human activity, including the channeling of the Mississippi River and extraction of subterranean oil and gas, have contributed to significant erosion and subsidence of these natural buffers.

Decades of human activity, including the channeling of the Mississippi River and extraction of subterranean oil and gas, have contributed to significant erosion and subsidence of critical wetlands that act as natural buffers to storms.

New Orleans is a port city, and the Port of New Orleans is a major source of jobs and revenue for the city and the state. It is the country's foremost importer of rubber and coffee, employing more than 160,000 people, generating $8 billion in annual revenue, and paying $800 million in state taxes. Flooding of port facilities could have a devastating economic impact on New Orleans, the state of Louisiana, and the nation.[18]

ACTION: MITIGATING AND PREPARING FOR CLIMATE CHANGE

In Louisiana, the city of New Orleans is leading the way in mitigating and adapting to climate change. State-level efforts, or the lack thereof, are included below for comparison purposes.

Hurricane Katrina and the resulting levee failures flooded nearly 80 percent of New Orleans. The city's efforts to rebuild have focused largely on preventing a repeat of this disaster as well as creating a more sustainable and environmentally conscious New Orleans. Much of the work outlined below achieves the city's general sustainability objectives in the near term; over the long term these actions will also serve to help build community resilience to the impacts of climate change. Indeed, the survival of New Orleans and its heritage is largely dependent on the implementation of these adaptation actions.

STATE, REGIONAL, AND CITY PLANS AND GREENHOUSE GAS REDUCTION MEASURES

The state of Louisiana has not adopted a greenhouse gas emissions reduction goal; however, in 2009 the state legislature created the Climate Change Policy Commission to develop "a comprehensive policy for the state of Louisiana for climate change."[19] The commission has never met, and a bill to extend the life of the Louisiana Climate Change Policy Commission died in the Louisiana House of Representatives in 2010.[20]

On March 15, 2001, the New Orleans City Council set the goal of a 10 percent reduction in municipal greenhouse gas emissions from 1998 levels by 2015.[21] The actions and policies recommended to meet this reduction were outlined in the city's Baseline Greenhouse Gas Emissions Profile.[22] Due largely to the devastating impacts of Hurricane Katrina and the population loss that followed, municipal greenhouse gas emissions were reduced nearly 30 percent from 1998 levels by 2007.[23] In 2008 New Orleans released GreeNOLA, a sustainability action plan for the city as it rebuilds. In this plan, the city proposed strategies for achieving a 30 percent reduction in municipal greenhouse gas emissions from 2005 levels by 2020.[24]

NOTABLE LOCAL ADAPTATION EFFORTS

The widespread flooding that occurred as a result of levee failures during Hurricane Katrina exposed the city's extreme vulnerability to flooding hazards caused by heavy precipitation events, storm surge, and sea level rise. In the wake of Katrina, the city adopted a Multiple Lines of Defense Strategy for flood protection. This approach includes coastal wetlands restoration, construction of protective structures such as flood gates and levees, nonstructural strategies, and emergency response planning.[25]

The Coastal Protection and Restoration Authority of Louisiana, in conjunction with the U.S. Army Corps of Engineers and other agencies, is working on projects to restore the coastline (including freshwater redistribution, bank restoration, and marsh creation), which can provide protection to communities like New Orleans from storm surge.[26] The city is currently working with the Bayou Land Resource Conservation & Development Council on a project to use artificial floating islands to protect and stabilize marsh shorelines in the Bayou Sauvage National Wildlife Refuge.[27]

The U.S. Army Corps of Engineers implemented the Hurricane and Storm Damage Risk Reduction System (HSDRRS) to repair and improve the city's flood protection to withstand a 100-year flood. The HSDRRS was designed with a 50-year project life and takes into account sea level rise, climate change, and land subsidence.[28]

The Coastal Protection and Restoration Authority of Louisiana, in conjunction with the U.S. Army Corps of Engineers and other agencies, is working on projects to restore the coastline (including freshwater redistribution, bank restoration, and marsh creation), which can provide protection to communities like New Orleans from storm surge.

New Orleans is also employing other structural strategies to build climate resilience. New public facilities, especially public safety and emergency facilities, are being designed to withstand 500-year storm events. The city, through the Hazard Mitigation Grant Program, is providing funding to elevate existing residential structures as well as to demolish flood-damaged residential structures and build new elevated structures on the same site.[29] The city's Master Plan and accompanying Comprehensive Zoning Ordinance project will use zoning to control the placement, construction, and design of new development in addition to the expansion and renovation of existing structures.[30] In addition to these larger city planning efforts, the greater New Orleans area recently began work on a sustainable integrated water management strategy to reduce flood hazards, use stormwater as a resource, and minimize soil subsidence, among other goals.[31]

ENDNOTES

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CHAPTER 6

Chicago, Illinois

While an increase in average temperatures presents the challenge of rising sea levels to marine coastal cities, Great Lakes coastal cities like Chicago may face falling lake levels by the end of this century. Average annual rainfall levels and storm intensity are expected to increase in Chicago, causing an increased risk of flooding and sewage overflows into Lake Michigan. In 2008, to increase its readiness for climate change, the city launched the Chicago Climate Action Plan, which includes efforts to both mitigate and adapt to climate change.

AREA OVERVIEW

Chicago, the nation's third-largest city with a population of approximately 2.8 million, draws many commercial and recreational benefits from its position on the southwest shores of Lake Michigan (see Figure 6.1). Tourism and real estate along the lakeshore supplement the city's primary economic base of manufacturing and transportation of goods. The Chicago River, which links Lake Michigan and the Mississippi River Basin, flows through downtown Chicago alongside the city's famous skyscrapers.

Dense development along the Chicago River is vulnerable to increased flooding.

Figure 6.1: Chicago and surrounding area

Source: Map Resources/NRDC

Table 6.1: Summary of water-related climate changes and impacts in Chicago throughout the 21st century

	Increased annual precipitation
	More frequent and intense storm events
	Increased flooding
	Decreased Lake Michigan levels
	Water supply challenges due to increased droughts

Highly likely | Likely | Possible

Source: NRDC

The so-called Windy City has four seasons. Winter temperatures average a high of about 31°F (–1°C) and a low of 16°F (–9°C). Winter skies are often cloudy, and frequent windy snowstorms average a total of about 38 inches (96.5 centimeters) per year. Midwest summers are hot and humid, with an average high of 84°F (29°C) and a low of 66°F (19°C).

Lake Michigan is the second-largest Great Lake, covering an area of 22,000 square miles, and has an average depth of 280 feet.[1] Cities along Lake Michigan, including Chicago, utilize this vast resource for their potable water needs. The City's Department of Water Management draws a billion gallons of drinking water every day, primarily from Lake Michigan. The Metropolitan Water Reclamation District of Greater Chicago (MWRD) treats the city's sewage and stormwater runoff at seven treatment facilities, handing a combined generation of wastewater of 1.4 billion gallons a day. During times of heavy rainfall, untreated wastewater and stormwater runoff is sometimes diverted into Lake Michigan.

Given the mass of water held by the Great Lakes and the capacity of water to absorb or lose large amounts of energy without a corresponding change in temperature, the lake system exerts a considerable influence on the regional climate. It may, at least temporarily, moderate the extreme weather events projected to accompany global warming.[2] Even so, projections for the impacts of climate change on Chicago are severe.

POTENTIAL CLIMATE CHANGES AND THEIR IMPACTS

The following sections describe projected water-related climate changes and impacts to Chicago throughout the 21st century. For a general explanation of how increased greenhouse gases affect our climate and seas, and typical resulting impacts of climate change, see the Background and Methodology section.

LAKE MICHIGAN WATER LEVEL CHANGE

Occurrence

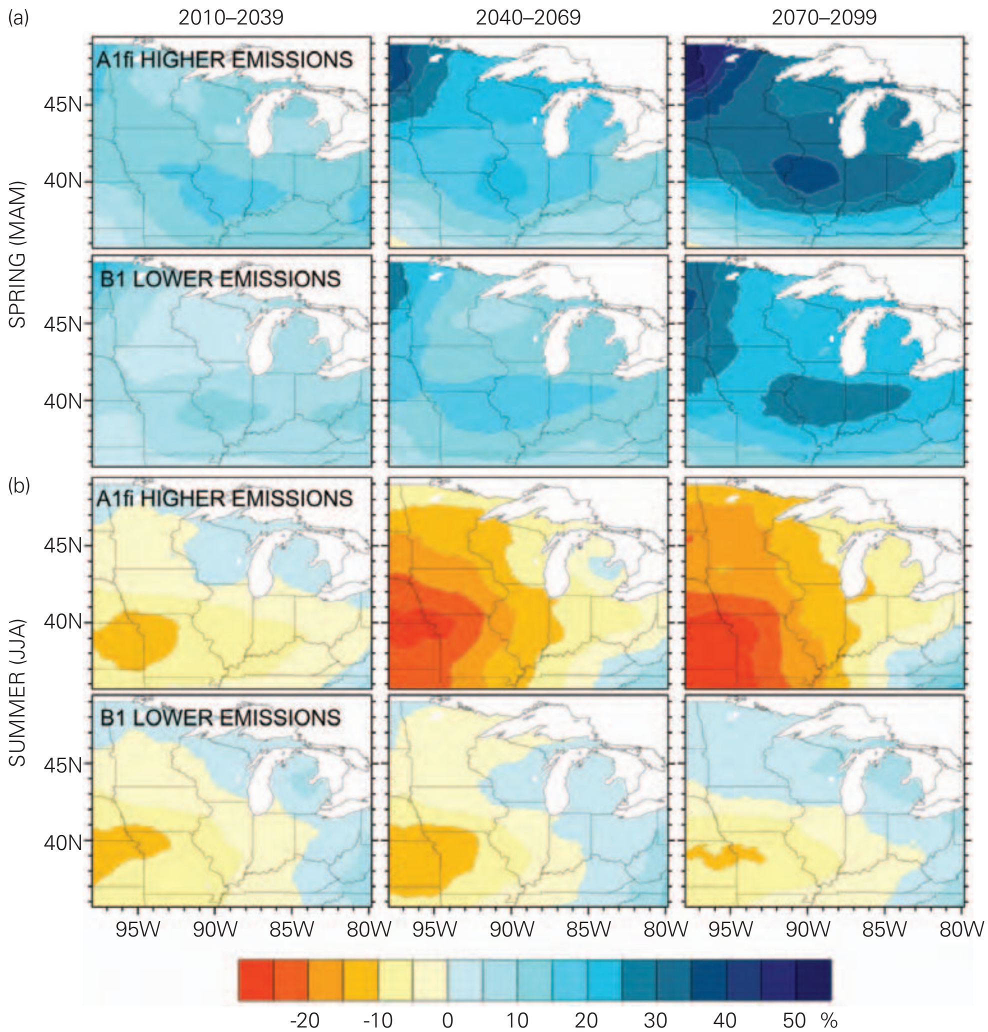
Research is generally in agreement that Lake Michigan's water level is likely to decline, although there is some variability as to the extent of that decline. Predictions range from a long-term drop of 4.5 to 5 feet (1.4 to 1.5 meters) by 2090[3,4] to a more modest drop of 1.5 feet (0.5 meter) by the end of the century.[5]

However, predicting precise changes in lake levels rests on a complex set of variables. Some, such as heavy rainfall and runoff, act to increase lake levels; others, like higher air and water temperatures and a longer growing season, cause them to decrease. The timing and duration of rain events and hot weather over the coming decades will influence the ultimate change in lake levels.

Impacts

Reduced lake levels could increase the overall costs of lake water use. Drinking water supply costs could increase due to expansion of intake pipes and greater pumping requirements to reach lower water levels, and increased water treatment to remove turbidity caused by wave action. Container ships would need to reduce loads to avoid grounding in shallower waters, requiring more trips and increased costs. Commercial navigation would require increased harbor and channel dredging; recreational boating marinas and channels would also require dredging.[6] In all, economic impacts for a drop of 5 feet (1.5 meters) range between \$3.5 billion and \$35 billion (in 1988 dollars).[7]

Figure 6.2: Projected changes in spring and summer precipitation under higher- and lower-emissions scenarios relative to 1961–1990 averages



Source: Hayhoe et al. (see Appendix A)

However, lower lake levels might also have some positive impacts. Recreational beach size and season would expand, and flood and erosion risks to buildings could be reduced as their distance from the water increases.[8]

PRECIPITATION, STORM EVENTS, AND FLOODING

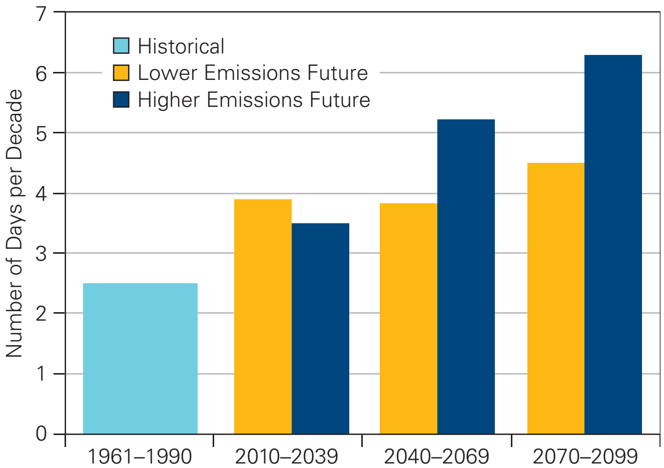
Occurrence

Both the quantity and intensity of precipitation are projected to increase in Chicago due to climate change. Projected increases are smaller in the early part of the 21st century, becoming larger toward 2100. Between 2010 and 2069, average annual rainfall could increase by 5 to 10 percent, though springtime increases could be on the order of 20 percent in the last two decades of that period. During the late century (2070 to 2099), average annual rainfall could reach 43 to 45 inches (109 to 114 centimeters)—a 20 percent increase over late-20th-century levels (see Figure 6.2). Most models agree that winter and spring will see increased precipitation; autumn and summer changes are less certain.[9] A larger portion of winter precipitation will likely fall as rain rather than snow, while summer seasons may see intense storms between extended dry periods. In fact, some of these changes are already occurring: more winter precipitation is falling as rain than as snow, and snow is melting earlier in the spring.[10]

The frequency of intense storm events with very heavy downpours—more than 2.5 inches (6 centimeters) in a 24-hour period—is likely to increase as much as 50 percent between 2010 and 2039, and 80 to 160 percent by 2100. In other words, by the end of the century, the frequency of very heavy precipitation events could increase from about once every 4 years to once every 2 years (see Figure 6.3).[11]

By 2100, average annual river and stream flows are projected to increase, though seasonal changes will vary. Winter and summer maximum flows are projected to increase by 3 to 18 percent and 7 to 13 percent, respectively. Wintertime increases will be due to a combination of less seasonal precipitation falling as snow and accumulated snow melting a

Figure 6.3: Projected changes in the frequency of extreme precipitation events exceeding 2.5 inches in 24 hours



Source: Adapted from Hayhoe et al. (see Appendix A)

month early. As a result, spring maximum flows, traditionally stemming from melting winter snows, are expected to decrease by 2 to 5 percent. Summertime increases will be due to more spring rainfall and intense summer storms.[12]

Impacts

Intense storms with very heavy precipitation and strong winds increase the risk of flooding and wave damage. In the Great Lakes region, storm surges as high as 8 feet (2.4 meters) with waves as high as 10 to 24 feet (3 to 7.3 meters) have enough force to move objects weighing many tons.[13] The potential impacts of floods and strong waves include shoreline erosion, contaminated drinking and recreational waters, damaged roads and bridges, crop damage, and property loss.[14]

Due to Chicago's combined stormwater and sewage collection system, rainfall exceeding as little as 0.67 inch (1.7 centimeters) in 24 hours can result in combined sewer overflows (CSOs) that discharge a mix of untreated sewage and stormwater into the Chicago River and Lake Michigan.[15] During these rainfall events, discharges from 303 of the 369 Chicago-area CSO outfalls have the potential to impact Lake Michigan in this way.[16] In 2009 alone, 2,036 discharge events occurred.[17] Without improvements to the stormwater system, increased precipitation is thus likely to cause an increase in CSOs and a higher risk of waterborne disease outbreaks at Lake Michigan.[18] On the other hand, green infrastructure techniques such as replacing impervious area with street trees, bioswales, rain gardens, and porous pavement result in a measurable reduction in the volume of water entering the sewer system, and a corresponding reduction in the number of CSOs.[19]

Projected increases in temperature and floods also have economic consequences. For instance, road materials that can better withstand these conditions cost twice as much

Chicago's Devastating Floods

Climate change will increase episodes of intense rainfall and, unfortunately, their often devastating impacts. Examples of these impacts were seen in the aftermath of record-breaking rainstorms on September 13, 2008, and July 17–18, 1996, in Chicago and its suburbs. In 2008 6.7 inches (17 centimeters) of rain fell in Chicago in a 24-hour period. The storm caused massive urban flooding, and 10,000 homes had to be evacuated. The storm led to $155 million in property damage.[1] Twelve years earlier, almost 17 inches (43 centimeters) of rainfall in a 24-hour period was reported in Aurora, Illinois, 40 miles west of downtown Chicago.[2]
Six people died, more than 4,300 people had to be evacuated, and 35,000 homes experienced flood damage. The total estimated cost, including losses and recovery actions, was $645 million, making this flood Illinois's second-most costly weather disaster on record. The damage was detailed as follows in an article by Stanley Chagnon: "Extensive damages and travel delays occurred on metropolitan transportation systems (highways and railroads). Commuters were unable to reach Chicago for up to 3 days and more than 300 freight trains were delayed or rerouted. Communities dealt with removal of flood-damaged materials, as well as damage to streets, bridges, and sewage treatment and water treatment plants. Reduced crop yields in adjacent rural areas represented a $67 million loss of farm income. Conflicts between communities developed over blame for the flooding due to inadequate storage capacity resulting in new regional flood planning. Federal and state aid ultimately reached $265 million, 41 percent of the storm costs. More than 85,000 individuals received assistance, and 222 structures have been relocated under the federal Hazard Mitigation Grant Program at a cost of $19.6 million."[3]

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Table 6.2: Projected temperature changes for late-21st-century Chicago

		2070 to 2099	
	1961 to 1990	Lower emissions scenario	Higher emissions scenario
Summer mean temperature	72˚F (22.4˚C)	77˚F (24.8˚C)	83˚F (28.2˚C)
Highest temperature per year	99˚F (37.3˚C)	107˚F (41.8˚C)	117˚F (47.1˚C)
Frequency of hot days per year*	14.8 days	36.3 days	72.2 days
Frequency of very hot days per year*	2 days	8.4 days	30.5 days
Intensity of heat waves*	94˚F (34.3˚C)	95˚F (35.1˚C)	97˚F (36.1˚C)
Duration of heat waves	2.9 days	5.3 days	9.8 days
Length of heat wave season	68.6 days	108 days	137.7 days

*"Hot days" = maximum temperature ≥90°F (32°C), and "very hot days" = maximum temperature ≥100°F (38°C). The intensity of heat waves is the average daily maximum temperature on consecutive days ≥ 90°F (32 °C).

Source: Adapted from Vavrus and Van Dorn (see Appendix A)

as traditional materials.[20] A storm in 2007 that left thousands of Chicagoans without power cost the city and the Chicago Park District more than $6 million to remove damaged trees, repair damaged homes and other buildings, and clean up flooded basements, streets, and viaducts. At least 7,144 home claims and 1,027 vehicle claims resulted from this storm.[21]

INCREASED TEMPERATURE AND DROUGHT EVENTS

Occurrence

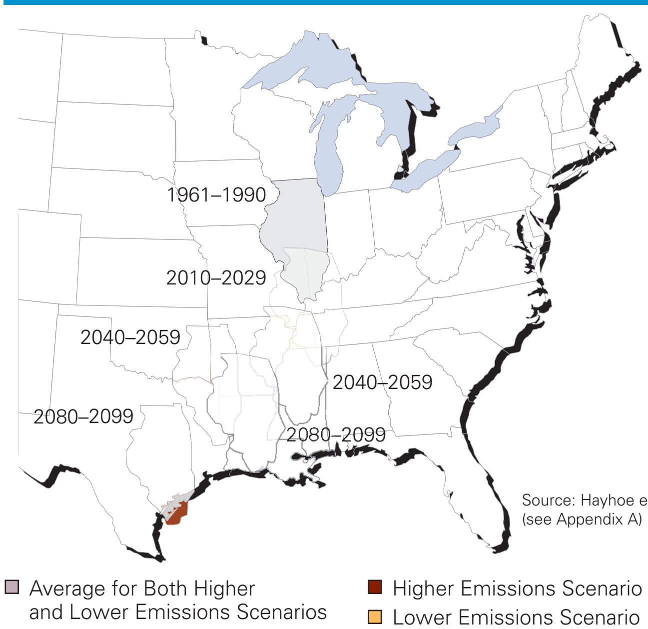
Compared with the latter half of the 20th century, annual temperatures in Chicago are expected to increase about 2.5ºF (1.4ºC) between 2010 and 2039, 3.6º to 5.4ºF (2º to 3ºC) by mid-century, and 5.4º to 9ºF (3º to 5ºC) between 2070 and 2099.[22]

The frequency, duration, and intensity of heat waves are also expected to increase, particularly starting in mid-century, though some summers may still be relatively mild.[23] The time of year in which heat waves occur could also increase. Typically there is a 69-day window in which heat waves occur; this could increase by 2 months by 2100 under the higher-emissions scenario (see Table 6.2).[24]

Another way of describing changes in annual average summer temperatures is through "climate migration." By 2100, depending on efforts made to reduce greenhouse gas emissions, Illinois summers could feel like summers in east Texas or Arkansas today (see Figure 6.4).

In warmer winters, precipitation is more likely to fall as rain than as snow.[25] Warmer summertime temperatures combined with potentially longer summertime dry periods make summer droughts more likely.[26]

Figure 6.4: Illinois's projected "climate migration" due to changes in summer average temperatures and rainfall



Source: Hayhoe et al. (see Appendix A)

Impacts

Warmer temperatures, especially in summer, will increase demand for drinking water. Warmer temperatures also cause power-generating plants to draw more surface waters for cooling due to increased demand for electricity to run air-conditioning systems.

Warmer water and air temperatures increase evaporation from the lake surface, which can concentrate waterborne pollutants and create conditions more favorable to water-borne diseases. Because of concentrated nutrients, algae blooms may occur more frequently, leading to higher water treatment costs and more frequent beach closures. Warmer waters at the lake surface could reduce mixing between surface and deep waters. Mixing is important to plankton, the basis of the aquatic food chain, because surface waters provide high oxygen concentrations and deep waters provide high nutrient concentrations.

Reduced lake levels and warmer waters could adversely affect wetlands and wildlife habitats. Cold-water fish such as walleye and trout may migrate away from current habitats, to be replaced by invasive species that thrive under warmer conditions. Native plants in riverine habitats and wetlands that provide ecological benefits such as stormwater filtration and storm buffering may decline due to lower water levels and drier summers.[27]

Increased annual temperatures are expected to reduce ice cover on Lake Michigan. Between 1973 and 2008 there was record-low ice cover on the lake.[28] Average annual ice cover could fall to near zero before 2050.[29] Reduced ice cover can have both positive and negative impacts. On the positive side, shipping, recreational boating, swimming, and sport fishing seasons could expand, the width of beaches could increase, and ice jams and associated flooding could decrease. On the negative side, increased evaporation from the lake could lead to lower water levels, possibly requiring the dredging of shallow channels and harbors, a shorter sport ice fishing season, and an increase in the concentration of water pollutants.

ACTION: MITIGATING AND PREPARING FOR CLIMATE CHANGE

Chicago has compiled an excellent assessment of the impacts it can expect to see due to climate change. It is moving forward with efforts to mitigate greenhouse gas emissions and prepare for inevitable impacts such as increased rain and flooding, although more work is needed to decrease combined sewer overflows.

STATE, REGIONAL, AND CITY PLANS AND GREENHOUSE GAS REDUCTION MEASURES

In October 2006 Governor Rudy Blagojevich signed an executive order that created the Illinois Climate Change Advisory Group (ICCAG). The ICCAG is tasked with recommending actions to meet the greenhouse gas emissions reduction goals set by the governor in February 2007: reduction to 1990 levels by 2020 and 60 percent below 1990 levels by 2050.[30]

In 2007 Cook County joined the Cool Counties Stabilization Initiative. Participating counties pledge to reduce global warming emissions to 80 percent below their current levels by 2050.[31]

The city of Chicago launched the Chicago Climate Action Plan (CCAP) in September 2008.[32] CCAP is the city's framework for reducing greenhouse gas emissions to 25 percent below 1990 levels by 2020 and 80 percent below 1990 levels by 2050. It outlines 26 actions to mitigate greenhouse gases as well as nine actions to adapt to climate changes already occurring and calls upon a range of governmental bodies—local, regional, and national—to improve policies.[33]

NOTABLE LOCAL ADAPTATION EFFORTS

One of Chicago's main challenges will be how to deal with increased stormwater, flooding, and CSOs as a result of increased precipitation. The city has a stormwater management ordinance in place, and since January 2008 the ordinance has addressed at least 265 development projects, resulting in a 20 percent increase in permeable area per site and a total increase of 55 acres of permeable surface area. The city has also installed at least 120 green alleys, resulting in the conversion of more than 32,000 square feet of impervious surfaces to pervious surfaces.[34] This conversion allows rain to infiltrate into groundwater, decreasing runoff that must be handled by aging treatment plants. The city discusses this and other adaptation measures in its 2008–2009 Progress Report.[35]

The city has also created a sewer model that, for purposes of analysis, breaks the city into hundreds of "sewersheds." The model can help determine how these sewersheds are performing under different precipitation conditions and pinpoint areas where capital improvements or green infrastructure solutions should be prioritized. Among other things, the city can then target neighborhoods for rebates or other incentives where stormwater improvements are most needed. Currently the model and improvements to the sewer system are based primarily on historic rain patterns.[36] The model is a useful tool, and to better prepare for climate change it should account for future precipitation patterns based on climate change scenarios.

Chicago's MWRD also has responsibility for controlling CSOs in the city. Currently its efforts have been inadequate to control routine CSOs, which cause the Chicago River and Lake Michigan to be in violation of water quality standards. Increased precipitation caused by climate change will only exacerbate these problems.

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Chicago's stormwater ordinance helps reduce sewage overflows into Lake Michigan.

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CHAPTER 7

St. Louis, Missouri

St. Louis generally suffers from a lack of local information on projected climate changes and impacts to water resources. However, information for the Upper Mississippi River Basin and the Midwest region of the country suggests St. Louis will likely experience more frequent heavy rainfall events, with potentially high river crests that could cause flooding, as seen in the summer of 2011. Floodplain development and a lack of coordinated climate change planning make St. Louis even more vulnerable.

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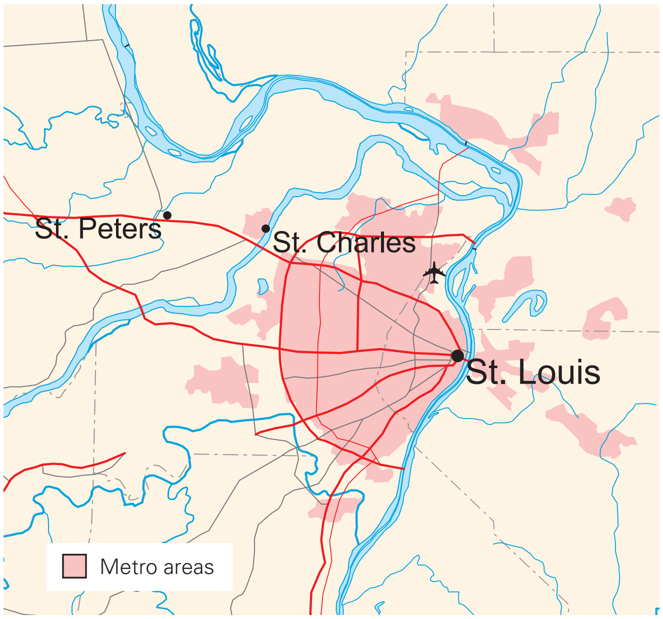
St. Louis, located at the confluence of the Mississippi and Missouri rivers, is vulnerable to increased flooding.

Figure 7.1: St. Louis and surrounding area



Source: Map Resources/NRDC

AREA OVERVIEW

With a population of 320,000, St. Louis is the second-largest city in Missouri, after Kansas City. The city anchors the greater St. Louis area, with a population of 2.8 million. It sits at an elevation of 100 to 200 feet (30 to 60 meters) at the confluence of the Illinois, Missouri, and Mississippi rivers—the southern end of the Upper Mississippi River Basin (see Figures 7.1 and 7.2). St. Louis experiences four distinct seasons, with rainy springs, hot and humid summers, mild falls, and cold and snowy winters. The average annual high and low temperatures are 66°F (19°C) and 50°F (8°C), respectively. The average annual precipitation is 39 inches (98 centimeters). The city of St. Louis Water Division supplies drinking water from two treatment plants sited on the Missouri River.

POTENTIAL CLIMATE CHANGES AND THEIR IMPACTS

The following sections describe projected water-related climate changes and impacts to St. Louis throughout the 21st century. For a general explanation of how increased greenhouse gases affect our climate and seas, and typical resulting impacts of climate change, see the Background and Methodology section.

Unlike many other cities in this report, there is not much local data on climate impacts for St. Louis. Therefore, this chapter draws on regional information from the Midwest and the Upper Mississippi River Basin.

PRECIPITATION, STORM EVENTS, AND FLOODING

Occurrence

The Midwest has already seen a rise in precipitation and heavy rain events. Since the middle of the 20th century, overall precipitation has increased 10 to 20 percent in the region.[1]

Table 7.1: Summary of water-related climate changes and impacts in St. Louis throughout the 21st century

(Highly likely)	More frequent and intense storm events
(Highly likely)	Increased annual precipitation
(Likely)	Increased flooding

Highly likely   Likely   Possible

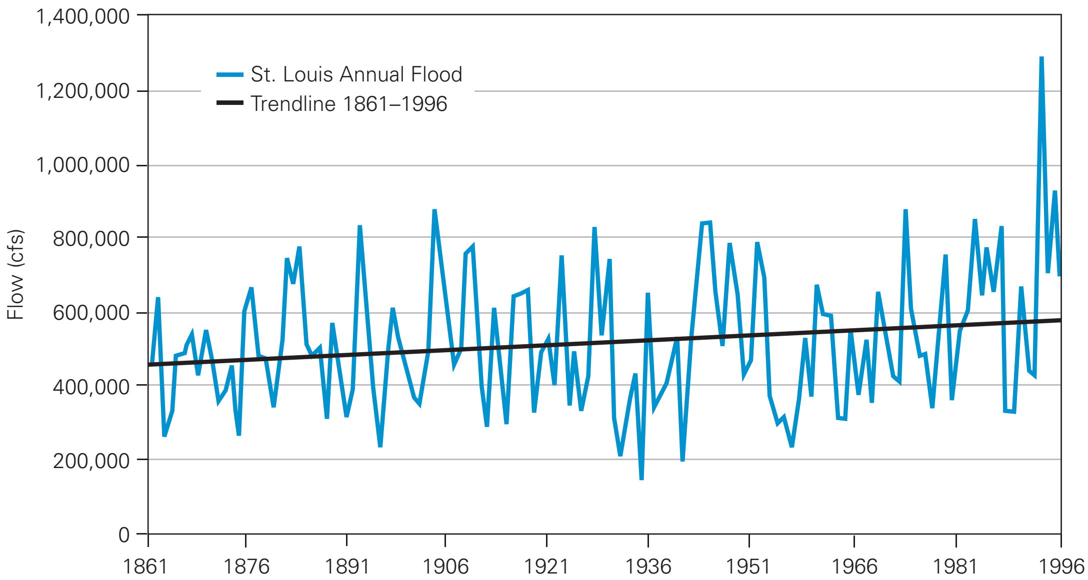
Source: NRDC

Figure 7.2: Upper Mississippi River Basin

Source: Saint Mary's University of Minnesota, GeoSpatial Services, 2011

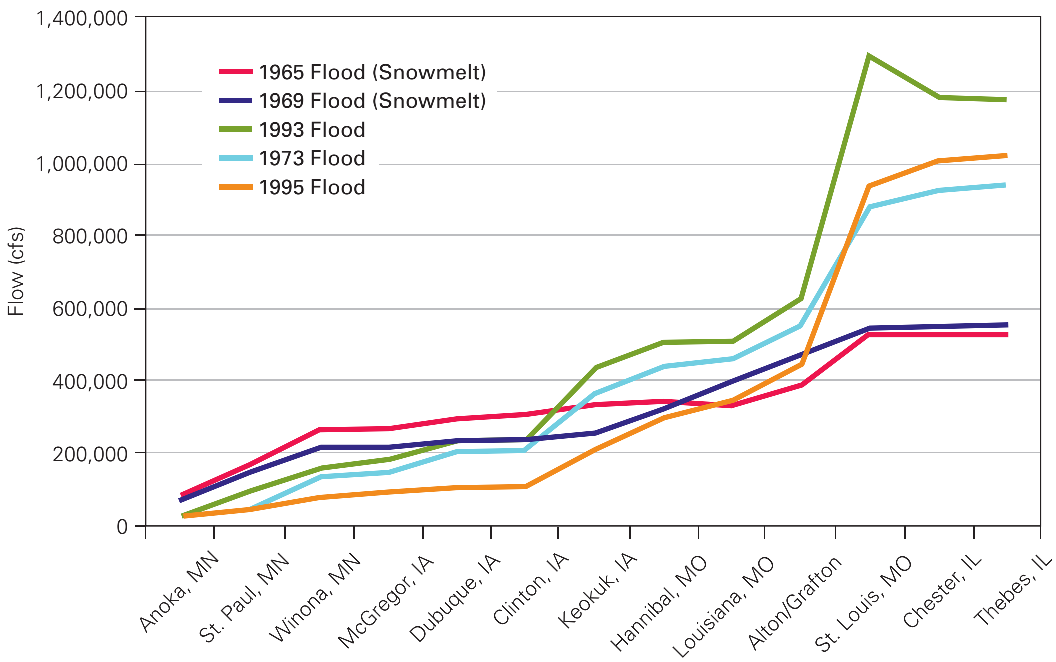
The frequency of days with more than 4 inches (10 centimeters) of precipitation in 24 hours increased by 50 percent over the 20th century.[2] The last three decades have seen the wettest summers and winters in the region.[3]

Figure 7.3: Annual floods for the Mississippi River at St. Louis



Source: Adapted from Olsen et al. (see Appendix A)

Figure 7.4: Peak flow at sites along the Mississippi River for five large flood events



Source: Adapted from Olsen et al. (see Appendix A)

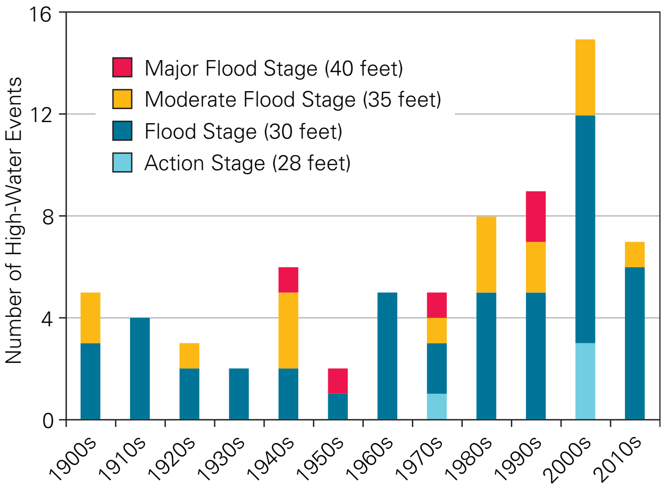
In the future, precipitation is expected to continue to increase, especially in winter and spring.[4] Summertime precipitation may stay the same or decrease.[5] More intense storms in the region are very likely over the coming decades.[6]

Impacts

Increased precipitation could increase streamflow by 51 percent, due to more rain falling on near-saturated soils.[7] The risk of floods has already increased over the past few decades along the Mississippi River near St. Louis due to increased flows (see Figure 7.3).[8] Because of its location at the confluence of the Missouri and Mississippi rivers, peak flows at St. Louis tend to be higher than at points north and south of the city (see Figure 7.4). Floods along the Mississippi River tend to last for a month or longer.[9]

The number of high Mississippi River crests has generally increased since 1900. For the current decade, which at the writing of this report includes only one year—2010—the

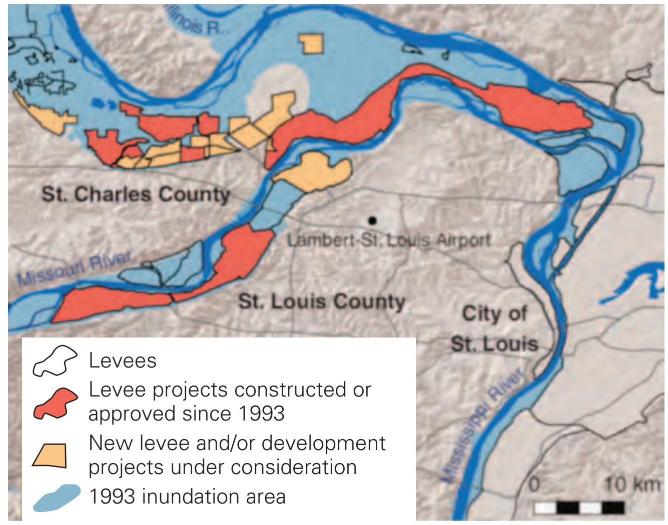
Figure 7.5: Distribution of Mississippi River crest levels per decade



Note: Information to date includes only the year 2010.

Source: NRDC/Data from NOAA (see Appendix A)

Figure 7.6: Floodplain development in the St. Louis region



Source: Pinter (see Appendix A)

number of events approaching flood stage already surpasses the total number of events for each of the first eight complete decades of the 20th century (see Figure 7.5).

Indeed, the worst flood to hit the Upper Mississippi River and Missouri River basins occurred in the summer of 1993 after heavy rains fell on already saturated soils.[10] On August 1 of that year, the Mississippi crested at 49.6 feet at St. Louis, just 2 feet short of the St. Louis floodwall. If cresting had been at 52 feet, the St. Louis floodwall would have been overtopped, causing major damage to downtown St. Louis; at 54 feet the Metro East St. Louis and Fish Lake levees would have been overtopped, threatening 71,000 acres of land.[11] As it stood, more than 1,000 levees in the region, most of them agricultural, were topped or breached during the flood.[12] Fortunately, the levees protecting downtown St. Louis and some other metropolitan areas, designed to withstand a 500-year flood, did not fail.[13]

Record rainfall in the Mississippi River watershed in April and May 2011, combined with springtime snowmelt, created deadly flooding throughout the Midwest. In St. Louis, the National Weather Service and Army Corps of Engineers predicted that levees protecting the city would hold, but further rain could break agricultural levees.

Since the 1993 flood, St. Louis has fortified its levee system. With these new and improved levees in place, people generally seem to have become less concerned about a recurrence of the devastation and have increased development in the floodplains behind the levees—at least $2.2 billion worth in the St. Louis area alone (see Figure 7.6). Such development appears tied to floodplain laws in Missouri that have been criticized as some of the weakest in the nation, and it runs contrary to formal reviews of flood control policy that concluded that the best strategy for reducing flood losses is to limit or reduce infrastructure on floodplains.[14] Further, critical infrastructure, such as drinking water treatment facilities, is located along St. Louis's riverbanks; contamination of these facilities is possible during heavy flooding.

Record rainfall in the Mississippi River watershed in April and May 2011, combined with springtime snowmelt, created deadly flooding throughout the Midwest. In St. Louis, the National Weather Service and Army Corps of Engineers predicted that levees protecting the city would hold, but further rain could break agricultural levees.[15] Because of heavy flow continuing to come down the river as of June 2011, the river is projected to be near flood stage all summer—the "new normal," in the words of a National Weather Service spokesman.[16]

INCREASED TEMPERATURE

Occurrence

Temperatures are expected to be warmer throughout the year in the Upper Mississippi River Basin.[17] Climate models predict a 36 percent increase in heat waves for St. Louis, from 1.4 to 1.9 per year.[18]

Impacts

Although winter temperatures are expected to rise, most winter precipitation is still expected to fall as snow. However, warmer late-winter and spring temperatures means that snowmelt will occur earlier in the year, contributing to early runoff into streams.[19]

Predictions for summer precipitation are less certain, but if summer rainfall decreases while temperatures increase, increased evapotranspiration rates and longer periods between rainfalls could contribute to drought and declining water levels in rivers, streams, and wetlands. Lower water levels could impede river traffic, which occurred during a drought in 1988 that stranded 4,000 barges on the Mississippi River. According to a report by the U.S. Climate Change Science Program, "Reduced summer water levels are also likely to reduce the recharge of groundwater, cause small streams to dry up (reducing native fish populations), and reduce the area of wetlands in the Midwest."[20]

ACTION: MITIGATING AND PREPARING FOR CLIMATE CHANGE

In terms of climate change mitigation and adaptation, the city of St. Louis and the state of Missouri generally lag behind the other cities and states featured in this report. A lack of city-specific information on climate change vulnerability should prompt St. Louis to examine its situation more closely, particularly with regard to potential flooding and water supply issues. Meanwhile, the city is in the plan development stage as it works on its greenhouse gas (GHG) emissions inventory and sustainability plan, and such efforts should be supported by city officials. However, given that many cities have already gone beyond mitigation to focus on adaptive strategies to build resilience to the impacts of climate change, St. Louis would be well served to include considerations for adaptation in its sustainability planning efforts.

STATE, REGIONAL, AND CITY PLANS AND GREENHOUSE GAS REDUCTION MEASURES

A number of reports recommending GHG emissions reduction measures have been made to or by the state, but so far Missouri has not adopted a GHG emissions reduction plan.[21] In recent years, bills to set limits on statewide emissions have been repeatedly introduced in the General Assembly but have made little progress.

St. Louis is currently conducting a GHG emissions inventory for local government as well as a larger, community-wide inventory. The city plans to complete both of these assessments by the end of the summer of 2011. St. Louis is also working on a comprehensive sustainability plan to be completed by the end of 2011. This plan will include a GHG emissions reduction target as well as strategies for meeting it.[22]

NOTABLE LOCAL ADAPTATION EFFORTS

In recent years, St. Louis has made considerable progress in mandating green building practices for municipal construction by adopting two ordinances that address environmental sustainability and energy consumption.[23, 24] These ordinances focus largely on climate change mitigation versus adaptation, but mitigation efforts will impact the level of adaptation needed over the long term.

Further, although climate change may not have been a motivating factor, the city recently initiated a pilot study on the use of permeable pavements as a stormwater best management practice.[25] Pervious surfaces allow precipitation to percolate and infiltrate the ground underneath, diminishing the volume of water that typically runs off.

© NASA

The confluence of the Missouri and Mississippi Rivers near St. Louis, before the 1993 flood (left) and after (right).

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CHAPTER 8

Seattle, Washington

Sea level rise is poised to impact the Port of Seattle and road and rail transport networks critical to the distribution of goods entering and leaving the port. Water supply management strategies will need to adapt to decreasing snowpack, giving rise to changes in the timing of peak streamflows into Seattle's reservoirs. Chronically higher average temperatures will steadily warm streams, threatening valuable salmon species, while sea level rise and acidification threaten commercial shellfish aquaculture. The area is on the forefront of climate research, however, having completed sophisticated analyses examining the vulnerability of all aspects of Washington State to climate change.

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Sea level rise threatens Seattle's infrastructure, including its port, roads, and railways.

Figure 8.1: Seattle and surrounding area

Source: Map Resources/NRDC

AREA OVERVIEW

Seattle, with a population of more than 630,000, is the largest city in the Pacific Northwest. Located in the lush green lap of the Cascade and Olympic mountain ranges, Seattle is known for its striking scenery and natural resources. Bound on the west by Puget Sound and by Lake Washington on the east, Seattle benefits both commercially and recreationally from water-based entities, including the Port of Seattle, and rich commercial fisheries of Pacific salmon, steelhead trout, and shellfish (see Figure 8.1).

Seattle's water and sewage are managed by Seattle Public Utilities (SPU), an agency of the city. SPU owns and manages two major water supplies for Seattle, both located in the Cascade Mountains within the Puget Sound watershed. The Cedar River watershed gathers runoff and snowmelt into two reservoirs—Chester Morse and the Masonry Pool, created by the Masonry Dam—supplying 70 percent of the drinking water for 1.4 million people in Seattle and surrounding suburbs. The South Fork Tolt River watershed supplies the other 30 percent, gathering runoff and snowmelt into the South Fork Tolt Reservoir (see Figure 8.4). SPU manages these reservoirs not only for water supply purposes but also to maintain minimum streamflows to support salmon spawning and rearing, hydroelectricity, and operation of the Lake Washington Ship Channel locks. Various conservation programs have led to a decrease in water demand despite population growth.[1]

Table 8.2: Relative sea level rise projections for Puget Sound

Sea level rise estimate	By the year 2050	By the year 2100
Very Low	3 inches (8 cm)	6 inches (16 cm)
Medium	6 inches (15 cm)	13 inches (34 cm)
Very High	22 inches (56 cm)	50 inches (127 cm)

Source: Adapted from Huppert et al. (see Appendix A)

Table 8.1: Summary of water-related climate changes and impacts in Seattle throughout the 21st century

	Rising sea levels
	Increased flooding
	Increased impacts to fisheries
	Water supply challenges due to early snowmelt
	Increased annual precipitation
	More frequent and intense storm events
	Increased erosion

Highly likely · Likely · Possible

Source: NRDC

POTENTIAL CLIMATE CHANGES AND THEIR IMPACTS

The following sections describe projected water-related climate changes and impacts to Seattle throughout the 21st century. For a general explanation of how increased greenhouse gases affect our climate and seas, and typical resulting impacts of climate changes, see the Background and Methodology section.

SEA LEVEL RISE, COASTAL FLOODING, AND SALTWATER INTRUSION

Occurrence

Projected sea level rise in Puget Sound ranges from 3 to 22 inches (8 to 56 centimeters) by 2050 and 6 to 50 inches (15 to 127 centimeters) by the end of the century (see Table 8.2).[2]

Impacts

The Seattle region has a lot of coastal development that is at risk from sea level rise; in addition to its ports and marina, approximately 90 percent of Puget Sound's shoreline has single-family residences or is available for residential development. This coastal development is increasingly vulnerable as sea level rise shifts shorelines and tides closer to homes and infrastructure. Sea level rise will also increase coastal flooding and erosion of the region's beaches and bluffs.[3]

The Port of Seattle, which sits just slightly above sea level, is one of the largest in the country. Much of the infrastructure in the immediate vicinity of the port was built on landfill within a few feet of the extreme high-water mark, so it is very vulnerable to the higher range of sea level rise projections. The port also relies heavily on the area's road and rail networks to distribute the cargo it receives; the Burlington Northern–Santa Fe railway line, which runs close to the shore of Puget Sound north of the port, is particularly susceptible to flooding from rising seas. To adapt, the port has plans in place to raise critical infrastructure such as docks, piers, and terminals.[4]

Elliot Bay, Puget Sound, and points north are popular with Seattle's private boaters; the Shilshole Marina, 20 minutes from downtown, is described as the "sailing center of the Northwest."[5] The marina and surrounding land would be flooded if sea levels were to rise a few feet. The area will likely require adaptation as sea levels rise.[6]

The Ports of Seattle and Tacoma handle most of the Puget Sound shellfish harvest, which is valued at almost $100 million annually.[7] The region is the foremost U.S. producer of commercially farmed bivalve shellfish including oysters, mussels, small clams, and geoduck clams. Climate change can impact this industry in at least two ways: (1) Inundation of the intertidal substrate where the aquaculture beds are located makes them more difficult to access for planting, tending, and harvesting; and (2) acidification of Puget Sound waters due to absorption of atmospheric carbon dioxide affects the growth and strength of calcium carbonate shells. Even a 6-inch rise in sea level could have a measurable impact on shellfish aquaculture. Property disputes over where intertidal aquacultural boundaries lie could arise as high-water marks advance.[8]

The Seattle region has a lot of coastal development that is at risk from sea level rise; in addition to its ports and marina, approximately 90 percent of Puget Sound's shoreline has single-family residences or is available for residential development. This coastal development is increasingly vulnerable as sea level rise shifts shorelines and tides closer to homes and infrastructure.

Because Seattle's water supply is predominantly from Cascade Mountain reservoirs, saltwater intrusion into groundwater will not be as significant in the city as in other areas along Puget Sound, particularly the islands; on Whidbey Island, at the northern edge of the sound, 72 percent of residents rely on groundwater.[9]

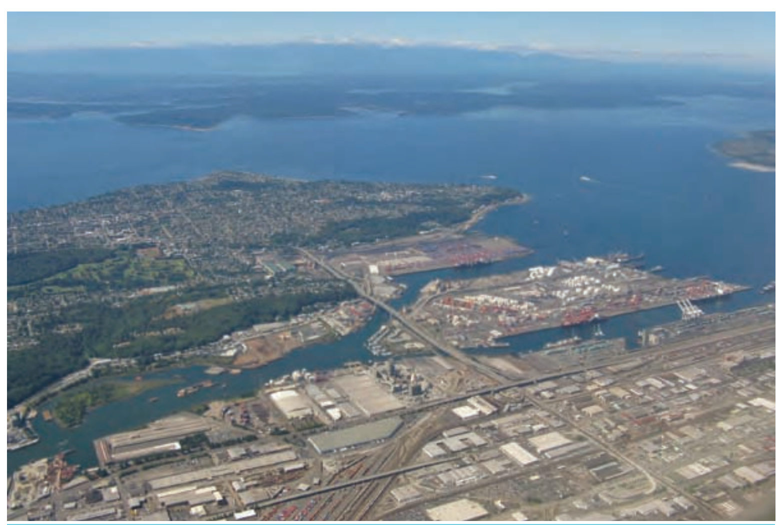
STORM EVENTS AND COASTAL AND INLAND FLOODING

Occurrence

Overall, annual precipitation in the Puget Sound area is projected to increase throughout the 21st century, but these changes are not evenly distributed throughout all seasons.[10] In fact, estimates of precipitation increases in the cool season (October through March) range from 2.3 to 3.3 percent in the 2020s to 6.4 to 9.6 percent in the 2080s, while precipitation in the warm season (April through September) is projected to *decrease* 0.9 percent in the 2020s to 4.7 percent in the 2080s (see Table 8.3).[11] The largest temperature

© Flickr user Lance and Erin

Burlington Northern–Santa Fe railway line runs along Puget Sound.



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Port of Seattle with rail and road transport in the foreground.

Table 8.3: Changes in Puget Sound watershed annual precipitation

Percent Change In	2020s (2010–2039) A1B: Medium GHG emissions scenario	2020s (2010–2039) B1: Low GHG emissions scenario	2040s (2030–2059) A1B	2040s (2030–2059) B1	2080s (2070–2099) A1B	2080s (2070–2099) B1
Annual Precipitation	0.20%	1.90%	2.10%	2.20%	4.90%	3.40%
Cool Season* Precipitation	2.30%	3.30%	5.40%	3.90%	9.60%	6.40%
Warm Season* Precipitation	-4.20%	-0.90%	-5.00%	-1.30%	-4.70%	-2.20%

*Cool season defined as October through March; warm season is defined as April through September.

Source: Adapted from Vano et al. (see Appendix A)

increases over the 21st century are projected to occur in the summer months; the greater the temperature increase, the greater the level of projected summer drying.[12] As with many climate change projections, estimates of precipitation changes for the late 21st century are less certain than those for the early part of the century.[13]

Fall-season precipitation increases for the 2040s are projected to be greater in and around Seattle compared with much of the rest of Washington. The green areas around the city in Figure 8.2, particularly in the watershed areas of the Cascade Mountains east of the city, show a greater increase than the rest of the state.[14]

An increase in extreme precipitation events was already under way in Seattle by the late 20th century. What was considered a once-in-50-year storm based on precipitation in a 24-hour period at SeaTac Airport between 1956 and 1980 became a once-in-8.4-year storm between 1981 and 2005.[15] An increase in extreme precipitation events is likely to continue in the Puget Sound area over the next half-century.[16]

Impacts

Urban stormwater systems like Seattle's are designed to handle the rainfall occurring in a 24-hour period from a once-in-25-year storm (a "design storm"). The results of two different climate change models suggest that the intensity of such storms will increase in the mid-21st century relative to late-20th-century levels, although the magnitude of the projected increase varies (see Figure 8.3).[17] This suggests that Seattle's urban drainage system may be subject to levels of rainfall during the 21st century that are greater than its designed capacity.[18]

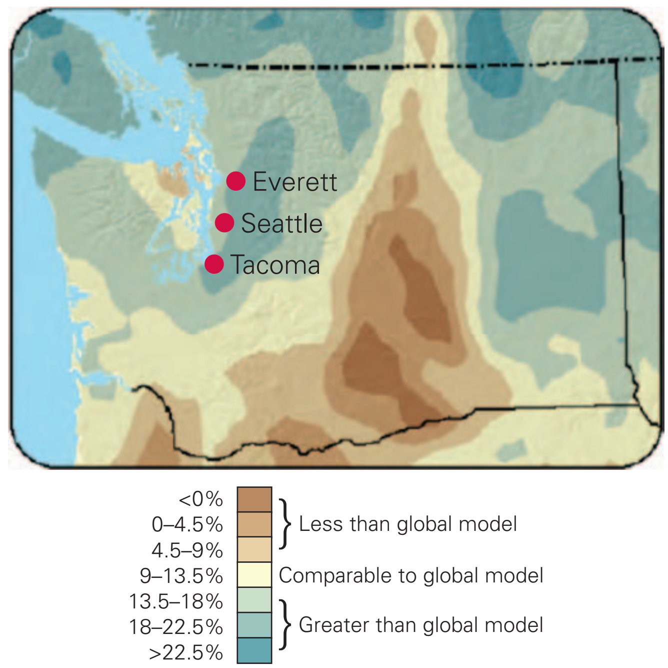
Bluffs are a common natural feature of shoreline areas in Puget Sound, including Seattle. Bluff erosion and landslides are most likely to occur from wave action during extreme storm events at high tide. Sea level rise and surface drainage failures from development atop the bluffs can exacerbate those conditions.[19]

INCREASED TEMPERATURE AND WATER RESOURCES

Occurrence

Compared with the last third of the 20th century, annual average temperatures in Washington are expected to increase about 2.0°F (1.1°C) by the 2020s, 3.2°F (1.8°C) by the 2040s, and 5.3°F (2.9°C) by the 2080s.[20] In the Puget Sound area,

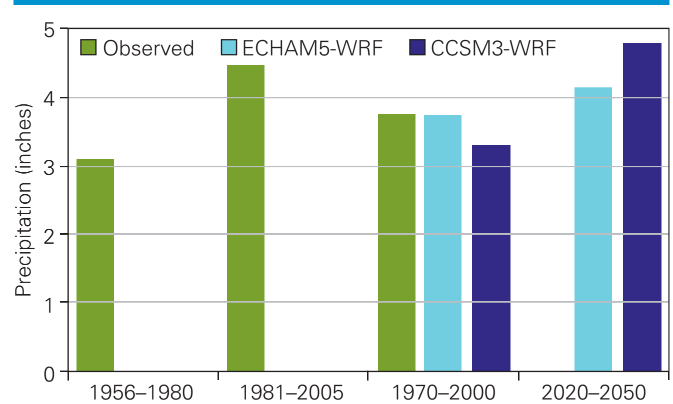
Figure 8.2: Change in fall precipitation for the 2040s



Differences between a regional climate model and a global climate model for projected changes in fall precipitation (September to November).

Source: Adapted from Littell et al. (see Appendix A)

Figure 8.3: Comparison of 25-year, 24-hour design storms based on observed and modeled (regional climate model) data at SeaTac airport



Source: Adapted from Littell et al. (see Appendix A)

Houses on bluffs above a railway line.

Eroded bluffs on Whidbey Island about 30 miles north of Seattle.

temperatures could rise as much as 10.8°F (6°C) by 2100; water temperatures would similarly increase.[21]

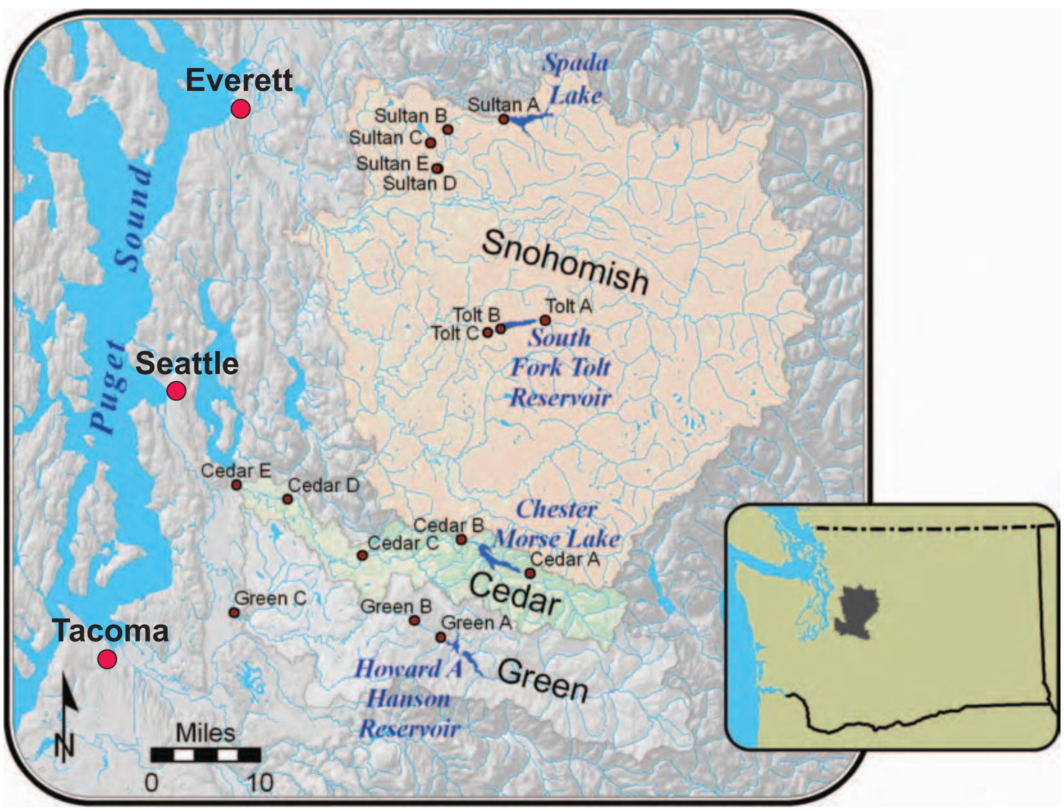
Winter temperature increases for the 2040s are projected to be greater in the north and central Cascades—home to Seattle's water-supply watershed—than in much of the rest of Washington.[22]

Impacts

Management of Seattle's water supply from the Cascade Mountains is particularly sensitive to climate change because that management has been largely based on the timing of precipitation and snowmelt in the Cedar River and South Fork Tolt River watersheds (see Figure 8.4). Currently, most of the precipitation in the area falls in late autumn and winter. Increasing average winter temperatures may significantly alter the timing of snowmelt and thus the management of the water system.

During the 20th century, peak flows into the Chester Morse Reservoir occurred at two distinct times during the year. The first would occur around early December, shortly after the late-autumn rainy season began, and the second, larger peak flow occurred in mid-May, when the winter snows would begin to melt. Warming average winter temperatures are projected to steadily decrease the amount of precipitation falling as snow over the course of the 21st century, thereby reducing snowpack and condensing peak flows into the reservoirs into a single peak occurring in December.[23]

Figure 8.4: Seattle area watersheds



The Snohomish, Cedar, and Green River basins supply water to Seattle, Everett, and Tacoma. (Lettered dots represent reservoir inflows for water resources models.)

Source: Adapted from Vano et al. (see Appendix A)

This change poses a challenge to water supply managers who need to meet the needs of a thirsty human population (whose demand for drinking and landscape irrigation water is greatest during the dry summer months) and to ensure that the region's hydroelectric facilities, shipping locks, and valuable wildlife habitats, particularly salmon streams, are adequately supplied. With the existing double peak of inflow into the reservoirs, managers would often allow reservoir levels to decrease prior to the December peak to reduce the potential for flooding and scouring of downstream areas by heavy late-autumn and winter precipitation. They could usually count on the spring snowmelt peak to replenish reservoirs in time for the high summer demand.[24]

But climate change models project a steady decline and eventual disappearance by the end of the century of the springtime snowmelt in these watersheds, making management of the reservoirs more challenging.[25] Reductions of the snow water equivalent (SWE)—the water content of the snowpack if it were melted—are projected for the Cedar and Tolt watersheds over the course of the century compared with the mean historical April 1 SWE from 1916 to 2006 (see Table 8.4). According to the Washington Climate Change Impacts Assessment, "SWE on April 1 is an important metric for evaluating snowpack changes because in the [Pacific Northwest], the water stored in the snowpack on April 1 is strongly correlated with summer water supply."[26] For the Cedar and Tolt watersheds and for both low- and medium-emissions scenarios, SWE is projected to decline by at least 57 percent. Correspondingly, by the 2080s, the point on the calendar when half the water for the year has flowed into the Cedar and Tolt reservoirs is projected to arrive 5 to 8 weeks earlier than in the past.[27]

The water supply system for Seattle will be impacted by these projected changes in SWE, although if demand is kept steady at levels of the 2000s, impacts could be kept to a minimum. Projections were run for different measures of the system's ability to meet demand (see Tables 8.5 and 8.6). Under both low- and medium-emissions scenarios, Seattle's reliability (defined as the "percentage of years within the model of which there were no municipal and industrial delivery shortfalls") was at least 99 percent. Looking at another metric—minimum reservoir storage, which provides a measure of system stress—another picture emerged. Under the medium-emissions scenarios, the likelihood that Seattle's reservoirs would fall below 50 percent of capacity are projected to increase from a historic level of 34 percent to 58 percent in the 2020s, 67 percent in the 2040s, and 71 percent in the 2080s (see Table 8.5).[28]

If future water demand increases, reliability becomes less robust. For instance, by mid-century, increases of 10, 25, and

Table 8.4: Projected changes in snow water equivalent (SWE) to watersheds supplying Seattle's water

Projected changes in SWE as compared with mean historical SWE 1916–2006	Cedar Watershed		Tolt Watershed	
	A1B: Medium GHG emissions scenario	B1: Low GHG emissions scenario	A1B	B1
2020s	-66%	-64%	-59%	-57%
2040s	-83%	-76%	-79%	-70%
2080s	-97%	-90%	-95%	-87%

Source: Adapted from Elsner et al. (see Appendix A)

Table 8.5: Seattle municipal and industrial water supply system reliability and storage

	Year	Seattle System Reliability	Likelihood active capacity in October will drop below*		
			50% full 55.9 mcm (45,328 af)	25% full 28.0 mcm (22,664 af)	10% full 11.2 mcm (9,067af)
	Historical simulation	100%	34%	1%	0.00%
A1B: Medium GHG emissions scenario	2020	100%	58%	8%	0.20%
	2040	99%	67%	11%	0.30%
	2080	99%	71%	18%	1.60%
B1: Low GHG emissions scenario	2020	100%	49%	4%	0.00%
	2040	100%	57%	7%	0.20%
	2080	99%	65%	12%	0.40%

*mcm: million cubic meters; af: acre-feet

Source: Adapted from Vano et al. (see Appendix A)

Table 8.6: Seattle reservoir system reliability with variations in demand

Scenario	Percent of Current Demand	Reliability			
		Historic	2020s	2040s	2080s
A1B: Medium emissions scenario	50%	100%	100%	100%	100%
	75%	100%	100%	100%	100%
	90%	100%	100%	100%	100%
	100%	100%	100%	99%	99%
	110%	99%	97%	98%	94%
	125%	96%	88%	81%	73%
	150%	74%	57%	49%	38%
B1: Low emissions scenario	50%	100%	100%	100%	100%
	75%	100%	100%	100%	100%
	90%	100%	100%	100%	100%
	100%	100%	100%	100%	99%
	110%	99%	98%	98%	98%
	125%	96%	93%	88%	82%
	150%	74%	68%	59%	46%

Source: Adapted from Vano et al. (see Appendix A)

50 percent might lead to system reliability dropping to 98, 81, and 49 percent, respectively, under a medium emissions scenario (see Table 8.6). In its 2007 Water System Plan, Seattle Public Utilities estimates a new water supply source may be needed after 2060.[29]

Finally, a warmer climate can impact aquatic life. Local salmon populations may be at risk from rising stream temperatures. The duration of time that salmon could be exposed to stressful thermal levels is expected to at least double, and perhaps quadruple, by the 2080s, particularly for adult summer sockeye and chinook in the Lake Washington Ship Canal in Seattle.[30] Warmer waters could also increase the frequency and duration of harmful algal blooms (HABs), which can cause fish kills and produce potent natural toxins that contaminate shellfish and sicken anyone who eats them. Inhalation or skin contact with the toxins can also cause illness in humans. In fact, HABs have been on the rise for the past few decades.[31]

Local salmon populations may be at risk from rising stream temperatures. The duration of time that salmon could be exposed to stressful thermal levels is expected to at least double, and perhaps quadruple, by the 2080s.

ACTION: MITIGATION AND PREPARING FOR CLIMATE CHANGE

Seattle benefits by being home to the University of Washington Climate Impacts Group, an interdisciplinary research group studying the impacts of climate change, particularly in the Pacific Northwest. In 2009 the group released the Washington Climate Change Impacts Assessment, an impressive analysis of climate change impacts on Washington State, including the Puget Sound region where Seattle is located. Such a detailed look at how Seattle is likely to be impacted by climate change helps the city understand the actions it needs to take to become more resilient. Indeed, Seattle is taking many steps to prepare for climate change and its impacts; our discussion of these efforts to become more resilient is not meant to be exhaustive.

STATE, REGIONAL, AND CITY PLANS AND GREENHOUSE GAS REDUCTION MEASURES

In 2010 the state of Washington released an updated plan to reduce its greenhouse gas emissions to 1990 levels by 2020, 25 percent below 1990 levels by 2035, and 50 percent below 1990 levels by 2050.[32]

King County, in which Seattle is located, released a Climate Plan in 2007.[33] Annual reports on implementation of the plan may be found on the county's Web site.[34]

The city of Seattle released its own Climate Action Plan, "Seattle, a Climate of Change: Meeting the Kyoto Challenge," in 2006.[35] The plan sets forth a strategy to reduce greenhouse gas emissions within the city, and periodic progress reports are posted on the city's Web site.[36] In 2007 the Seattle City Council set a goal of reducing greenhouse gas emissions by 30 percent below 1990 levels by 2024 and 80 percent below 1990 levels by 2050. It also set a goal to have all new city buildings be carbon neutral by 2030.[37]

NOTABLE LOCAL ADAPTATION EFFORTS

Seattle is now developing a decision-support tool for new capital facilities. The tool will allow users to input variables about a proposed project, such as the nature of the project, where it will be built, and when it will be built, and learn how projected temperature, precipitation, and sea level rise could impact the effort. The user could then integrate design or location changes based on the results. As of March 2011, the tool was in the testing phase.[38] Ideally, it would be required for all new development and redevelopment and would be part of a larger policy on building in areas at risk for sea level rise.

Seattle will be updating its Climate Action Plan with a new adaptation component, beginning in the fall of 2011.[39]

Seattle Public Utilities (SPU) worked closely with the Climate Impacts Group at the University of Washington between 2002 and 2007 on climate change studies. SPU commissioned or conducted a series of sophisticated analyses to examine the vulnerability of its water supply infrastructure and operations to climate change.[40] On the basis of this analysis, SPU identified a series of intra-system modifications and new supply options and grouped them into tiers. Tier 1 modifications are low-cost, no-regrets options with multiple benefits. Where these modifications did not fully restore supply, subsequent tier options could be implemented. The projected climate impacts are viewed as significant but not imminent; SPU plans on conducting new studies to update its assessment as new information or research becomes available.[41]

SPU also views water conservation as a critical part of the city's response. Toward this end, SPU plans to reduce water usage by 15 million gallons a day by 2030. The utility is further building its capacity to respond to climate change impacts by fostering new skill sets among its employees and collaborating with researchers and other utilities.[42] For instance, SPU is part of the 10-member Water Utility Climate Alliance, which has prepared white papers on how water utilities can incorporate climate change into their planning.[43] SPU also participates in a regional collaborative planning effort.[44]

Impacts to stormwater and drainage are also of concern to Seattle, although more research is needed to better model specific impacts to its drainage system. Currently, it is unclear how much flexibility there is in the drainage system to accommodate departures from historical precipitation patterns. SPU has developed a RainWatch tool that will allow greater refinement in weather forecasts for the city and allow the utility to better anticipate operational needs.[45]

Seattle is studying the effects of reduced snowpack on water supply.

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CHAPTER 9

San Francisco, California

Climate change is expected to cause sea level rise in San Francisco. This, in turn, will cause flooding, erosion, inundation, and, with a change in the timing of snowmelt in the Sierra Nevada mountains, increased saltwater intrusion into freshwater supplies. It is also likely that conditions will be drier and less water will be available. In the Bay Area, many organizations and government entities are working on strategies and policies to adapt to future climate change impacts.

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Rising seas can cause flooding, erosion, and damage to coastal structures and real estate in San Francisco.

Figure 9.1: San Francisco and surrounding area

Source: Map Resources/NRDC

AREA OVERVIEW

San Francisco is located on the central coast of California and has about 800,000 residents. Like much of the California coast, San Francisco has a Mediterranean climate, with wet winters and dry summers. San Francisco has cool summertime temperatures because it is surrounded on three sides by water and its climate is influenced by cool Pacific Ocean currents (see Figure 9.1). The annual average high temperature is 65°F (18°C), the annual average low temperature is 51°F (11°C), and average annual rainfall is 22 inches.

Figure 9.2: San Francisco Bay Area counties

Source: NRDC

Table 9.1: Summary of water-related climate changes and impacts in San Francisco throughout the 21st century

Highly likely	Rising sea levels
Highly likely	Increased erosion
Highly likely	Increased saltwater intrusion
Highly likely	Water supply challenges due to early snowmelt
Highly likely	Increased flooding
Likely	Decreased annual precipitation
Likely	Increased impacts to fisheries
Possible	Water supply challenges due to increased droughts
Possible	More frequent and intense storm events

Highly likely · Likely · Possible

Source: NRDC

The San Francisco Bay Area (comprising San Francisco, San Mateo, Santa Clara, Alameda, Contra Costa, Solano, Napa, Sonoma, and Marin counties) is home to approximately 7 million people (see Figure 9.2). Over the past 150 years, the productive use of the bay's sheltered harbors and shoreline has become the cornerstone of the region's prosperity. The bay's resources help sustain the economy of the western United States, provide opportunities for recreation, and support fish and other wildlife. Its tidal wetlands provide flood protection and improve water quality, in addition to being home to a diverse ecosystem and providing an important resting and feeding place for migratory birds. The Bay Area's municipal water supply is imported mostly from the Sierra Nevada range through the State Water Project, the Hetch Hetchy Aqueduct, the Mokelumne Aqueduct, and the Central Valley Project (see Figure 9.3).

POTENTIAL CLIMATE CHANGES AND THEIR IMPACTS

The following sections describe projected water-related climate changes and impacts to San Francisco and the Bay Area throughout the 21st century. For a general explanation of how increased greenhouse gases affect our climate and seas, and typical resulting impacts of climate changes, see the Background and Methodology section.

SEA LEVEL RISE, COASTAL FLOODING, AND SALTWATER INTRUSION

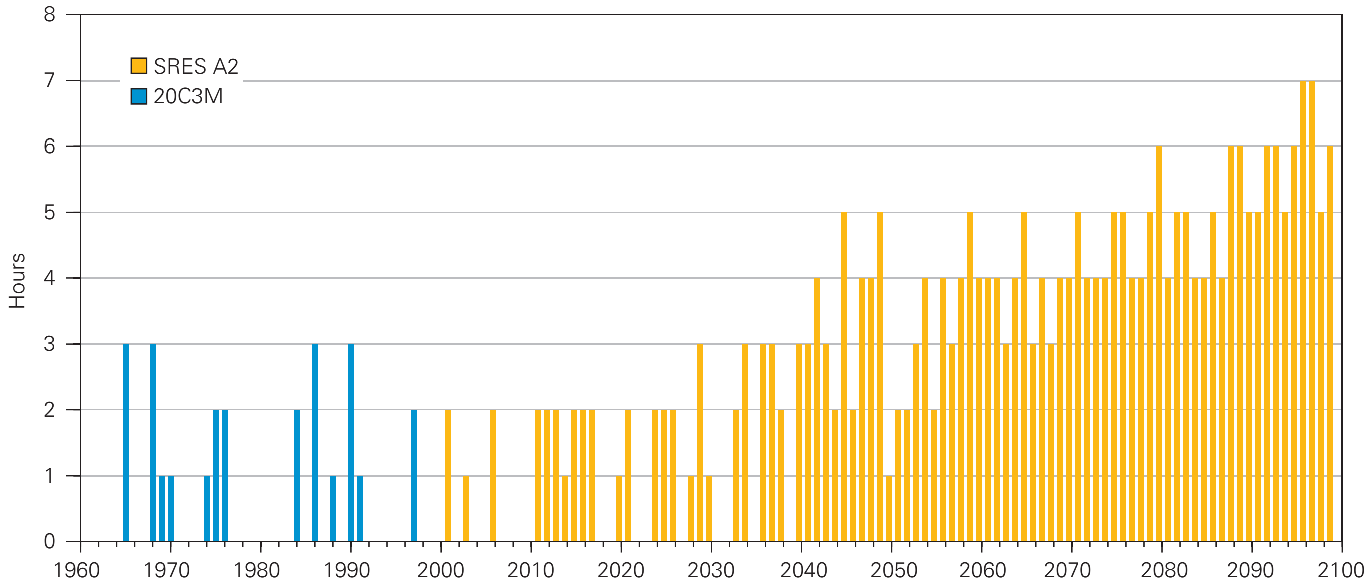
Occurrence

Over the past several decades, sea level along California's coastline has risen at a rate of about 0.67 to 0.79 inch (1.7 to 2 centimeters) per decade, consistent with global sea level rise.[1] Coastal observations and global climate projections indicate that California's coast will experience rising sea levels during the 21st century as well. Sea level rise—

Figure 9.3: California water supply system

Source: Adapted from California Department of Water Resources

Figure 9.4: High-sea-level events



Maximum duration (in hours) that San Francisco sea level exceeds the 99.99th percentile level (1.4 meters above mean sea level), based on historical data (blue), and modeled data (yellow).

Source: Adapted from Cayan et al. (see Appendix A)

projected using output from recent global climate modeling—increases in proportion to the amount of global warming. By 2050, projected sea level rise relative to the 2000 level ranges from approximately 12 to 18 inches (30 to 46 centimeters), depending on the magnitude of climate warming.[2] By the end of the 21st century, sea level is expected to be 20 to 55 inches (50 to 140 centimeters) higher than it was in 2000.[3]

Table 9.2: Projected high-sea-level events in San Francisco throughout the 21st century

Projected time frame	High-sea-level events per year with 11.8-inch (30 cm) sea level rise	High-sea-level events per year with 23.6-inch (60 cm) sea level rise
2005–2034	1.3	4.6
2035–2064	7	41
2070–2099	17	235

Source: Adapted from Cayan et al. (see Appendix A)

There has already been an observable increase in high-sea-level events along the California coastline in the past several decades. (High-sea-level events are defined as events that are higher than the 99.99th percentile of sea level heights for the period 1960-1978.) In San Francisco, this translates to an event in which sea level is 55 inches (1.4 meters) higher than the mean sea level.[4] These events increased in frequency from about one every six years during the period 1915 to 1951, to about one per year for 1960 to 1978.[5] Given projected sea level rise, the number of high-sea-level events is also expected to increase throughout the 21st century (see Table 9.2 and Figure 9.4).[6]

Impacts

A major concern associated with sea level rise in the San Francisco Bay Area are the high-sea-level events that will occur with increasing frequency when the average sea level rises. These high-sea-level events will cause flooding, erosion, damage to coastal structures and real estate, and salinity intrusion. The impacts of sea level rise and attendant inundations will be most severe on low-lying land bordering San Francisco Bay and the Sacramento–San Joaquin River Delta. Along San Francisco Bay, the area that will be vulnerable to inundation with a 16-inch (40-centimeter) sea level rise at mid-century corresponds to today's 100-year floodplain, which covers 281 square miles. (The 100-year floodplain is defined as the area that would be inundated by a flood that has a 1 percent chance of occurring in any given year.) Shoreline development located in the current 100-year floodplain is subject to a 100 percent chance of flooding by mid-century.[7]

A report from the Pacific Institute examined many impacts of a 55-inch (1.4-meter) rise in sea level, the mean sea level rise expected under a medium-high emissions scenario by 2100.[8] Along the Pacific Ocean and the San Francisco Bay coastline of the Bay Area counties, 150,000 people are currently at risk from a 100-year flood. If there is a 55-inch rise in sea level and no increase in development in vulnerable areas, that number jumps to more than 280,000 people. The vast majority of the area vulnerable to flooding is along San Francisco Bay, and in that area, a disproportionate number of low-income people are affected.[9]

The Pacific Institute report also details facilities and property at risk from a 100-year flood with a 55-inch sea level rise. In

2000 dollars, the current replacement value of buildings and contents vulnerable to a 100-year flood in counties in the San Francisco Bay Area is $31 billion; with a 55-inch rise in sea level that figure more than doubles, to $64 billion.[10]

Inundation by sea level rise could have severe impacts to critical infrastructure. Currently, 94 facilities containing hazardous materials—including Superfund sites, hazardous waste generators, major dischargers of air pollutants, and brownfield properties—are at risk of a 100-year-flood in the San Francisco Bay Area. A 55-inch rise in sea level would increase the number of hazardous facilities at risk to 235.[11] Wastewater treatment plants at risk in the Bay Area discharge an average of 350 million gallons per day, and flooding could lead to discharges of untreated sewage. Sea level rise could also impact energy production critical to residents and businesses. Twelve power plants with a combined generating capacity of more than 1,900 megawatts are also at risk of a 100-year coastal flood in the San Francisco Bay Area after a 55-inch rise in sea level.[12]

The risk to transportation infrastructure increases with a 55-inch rise in sea level. Some 890 miles of roads and highways in the San Francisco Bay Area are currently at risk from a 100-year coastal flood; if sea level were to rise 55 inches, the number of miles at risk becomes 1,900. Similarly, there are 68 miles of railway currently at risk; 170 miles would be at risk with a 55-inch rise in sea level.[13] Two major airports in the San Francisco Bay Area—San Francisco International Airport and Oakland International Airport—are vulnerable to flooding with a 55-inch rise in sea level, with potentially significant effects on the state and regional economy.[14] The Oakland airport's 2,600 acres have a maximum elevation of 9 feet above mean sea level, and a portion of them already experience flooding during high tides and winter storms.[15] Significant flooding due to anticipated sea level rise is also possible at the Port of Oakland in San Francisco Bay, with potentially huge economic implications (see Figure 9.5).[16]

Two major airports in the San Francisco Bay Area—San Francisco International Airport and Oakland International Airport—are vulnerable to flooding with a 55-inch rise in sea level, with potentially significant effects on the state and regional economy.

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Pier 14 in San Francisco on February 17, 2011, during a high-tide event

Figure 9.5: Areas of Oakland at risk from 100-year coastal flood

Port of Oakland in center of map.

Source: Google/Pacific Institute (see Appendix A)

In the Bay Area counties, a total of more than 640 miles of new levees, raised levees, or seawalls, at a cost of almost $5.3 billion (in 2000 dollars), would be needed to protect against flooding in the event of a 55-inch rise in sea level. While armoring the coastline would save lives and property, it disrupts natural processes that are also of value.

In the Bay Area counties, a total of more than 640 miles of new levees, raised levees, or seawalls, at a cost of almost $5.3 billion (in 2000 dollars), would be needed to protect against flooding in the event of a 55-inch rise in sea level. Maintaining these additional structures would require annual expenses on the order of a tenth of the capital cost.[17] While armoring the coastline would save lives and property, it disrupts natural processes that are also of value.

Sea level rise will have ecosystem impacts as well. For instance, salinity, which is already a problem in the Sacramento–San Joaquin River Delta, will increase as a result of sea level rise, degrading the quality and reliability of the fresh water supply pumped from the southern edge of the delta.[18]

Further, wetlands will need to have dramatically high accretion rates of sediment deposition to keep up with sea level rise. Because wetlands are a highly tide-sensitive habitat, sea level rise jeopardizes a very high percentage of existing wetlands in the Bay Area. This percentage is not easy to quantify, but one way to assess the impact is to consider how many square miles the wetlands would need to migrate into if the same area of wetland is to exist after the rise in sea level. There are 420 square miles of coastal wetland in the San Francisco Bay Area; 97 square miles of land currently adjacent to wetlands would be needed to accommodate a 55-inch rise in sea level. Of those 97 square miles, 35 square miles are covered by roads, buildings, and pavement and are not viable for wetland migration. Of the remaining 62 square miles needed for wetland migration, some are currently being farmed or used as parks, and those uses would be lost upon conversion to wetland.[19]

Sea level rise also contributes to coastal erosion, although erosion of coastal lands is a function not only of sea level rise but also of changes in deepwater wave direction and energy that are expected to occur as a result of climate change, shifts in deepwater storm patterns and intensities, and changes in the amount of sediment carried by rivers to the sea.[20] Some researchers found that for all wind speeds and directions, wave heights in San Francisco Bay increase with rising sea levels. Increased wave heights are likely to augment erosion of valuable mud flats and unprotected shorelines and might pose a hazard to recreational boating.[21] Bay Area counties are projected to lose 11 square miles due to erosion by processes associated with sea level rise if sea level rises by 55 inches. Assuming no change in current density patterns, 5,000 people reside within this 11-square-mile area, and 81 miles of roads and highways would be vulnerable.[22]

STORM EVENTS AND COASTAL AND INLAND FLOODING[23]

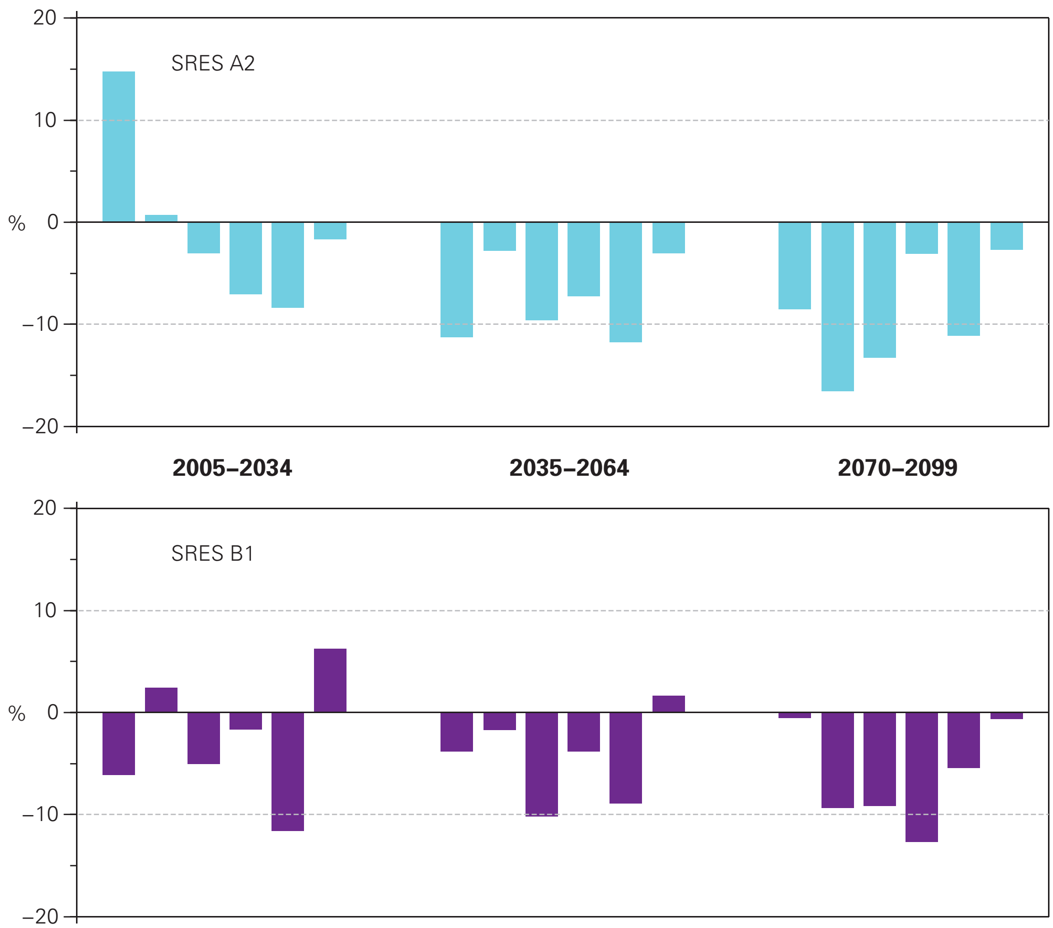
Occurrence

Research about how climate change would impact the intensity and frequency of storms in San Francisco is somewhat varied. Increased storm intensity is forecast by some climate models, whether or not the frequency of storms also increases.[24] Other models generally project slightly fewer storms in the San Francisco region and no change in the pattern of high-precipitation events per year with climate change.[25] With climate change, some research projects that El Niño conditions that bring high levels of rainfall to California may occur more frequently,[26] while other research projects these conditions to occur much as they have historically.[27]

Impacts

If storms become more frequent or severe as a result of climate change, the frequency of high-sea-level events may increase. Cayan et al. explain that "the combination of severe winter storms with sea level rise and high tides would result in extreme sea levels that could expose the coast to severe flooding and erosion, damage to coastal structures and real estate, and salinity intrusion into delta areas and coastal aquifers."[28] For instance, during the 1997–1998 water year, in which there were El Niño conditions, very high seas and storm surge caused hundreds of millions of dollars in storm and flood damage in the San Francisco Bay Area. Highways were flooded as 6-foot waves splashed over waterfront bulkheads, and valuable coastal real estate was destroyed.[29]

Figure 9.6: Projected mean annual precipitation for the Sacramento region



Differences in 30-year mean annual precipitation of early, middle, and late 21st century relative to the 1961 to 1990 time period for the Sacramento region, from six global climate models, for a medium-high emissions scenario (top, blue), and low emissions scenario (above, purple).

Source: Adapted from Cayan et al. (see Appendix A)

Even small increases in temperature with no change in precipitation will affect the timing of flow patterns for rivers in California substantially, with more water flowing in the rivers during the winter and less during the dry season, when agricultural and urban demand is highest.

INCREASED TEMPERATURE, CHANGES IN ANNUAL PRECIPITATION, AND WATER SUPPLY

Occurrence

In each of 12 climate model simulations, temperatures in California warm significantly during the 21st century. There is quite a strong inclination for greater warming in summer than in winter and more warming inland than along the coast. Overall, the models' warming projections for mid-century range from about 1.8°F to 5.4°F (1°C to 3°C), rising by the end of the 21st century about 3.6°F to 9°F (2°C to 5°C).[30]

San Francisco enjoys a Mediterranean climate. Most of the annual precipitation falls in the cooler part of the year, between November and March, and this pattern is not expected to shift due to climate change during the 21st century.[31] In California there is also a great deal of variability in precipitation from year to year and decade to decade, and this variability is expected to continue. Nearly all of the simulations evaluated by Cayan et al. (2009) project a tendency for drier conditions to develop during the mid and late 21st century in Sacramento, near the San Francisco Bay Area (see Figure 9.6). For mid-century, 6 of the 12 simulations have a 30-year mean precipitation in Sacramento that is more than 5 percent drier than its historical average, and by the late 21st century, 8 of the 12 simulations have 30-year averages that decline to more than 5 percent below the historical average in Sacramento. The drying projected in these simulations rivals or exceeds the largest observed long-term dry periods since the late 1800s. For the mid and late 21st century, only 2 of the 12 simulations project 30-year mean precipitation that is higher (slightly) than the historical annual average.[32]

Precipitation in California is strongly affected by El Niño/Southern Oscillation phenomena, and the state's water supply will be affected by variations in the frequency of El Niño conditions. One researcher projects that there will be

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Shifting streamflows, drought, and water diversions threaten fisheries in the Bay Area.

more frequent El Niño conditions, as well as more intense La Niña events, resulting in larger year-to-year variations in precipitation.[33]

Impacts

A report prepared for the California Energy Commission explained that "higher temperatures will have several major effects: they will increase the ratio of rain to snow, delay the onset of the snow season, accelerate the rate of spring snowmelt, and shorten the overall snowfall season, leading to more rapid and earlier seasonal runoff."[34] Seasonal shifts in runoff patterns from spring to winter may already be occurring in California because of climate change.[35] These shifts have important implications for water management and aquatic ecosystems for the San Francisco region and have been the subject of study since the late 1980s.[36]

In the worst-case climate change scenario for water supplies (hot and dry), streamflows may decrease statewide by 27 percent by 2085.[37] Even small increases in temperature with no change in precipitation will affect the timing of flow patterns for rivers in California substantially, with more water flowing in the rivers during the winter and less during the dry season, when agricultural and urban demand is highest.[38] The departure from current typical flow patterns increases with rising temperature and increasing precipitation.[39] Other research and modeling studies are in agreement that under many different climate projections, climate change will result in an increase in winter streamflow and a decrease in late-spring and summer flow for rivers in California.[40] Evaporation losses from reservoirs will increase, but the magnitude of evaporation loss will be dwarfed by the projected change in streamflows caused by higher temperatures and reduced precipitation.[41]

Shifting streamflows may also have implications for the San Francisco region's fisheries, although more research is needed to better understand the impacts. The occurrence of peak flows in California's rivers much earlier in the season due to climate change could result in a washout of the early stages of autumn-spawning salmonids.[42] A wind-driven upwelling north of Point Conception from spring to fall brings cold, nutrient-rich water to the surface, and this in turn supports a diverse fishery. Increased carbon dioxide is expected to increase the land-ocean temperature gradient and result in increased upwelling north of Point Conception. The impact on marine life is unclear, as the beneficial effects of increased nutrients brought up from the bottom could be counteracted by a lower overall concentration of nutrients due to increased mixing and increased seaward transport of surface waters.[43]

ACTION: MITIGATING AND PREPARING FOR CLIMATE CHANGE

San Francisco at the local level and California at the state level have been national pioneers on greenhouse gas mitigation and climate change adaptation action. In the Bay Area, many organizations and government entities are working on strategies and policies to adapt to future climate change impacts. Our discussion below is a brief overview of only a few of the many adaptation activities that are taking place in the San Francisco Bay Area.

STATE, REGIONAL, AND CITY PLANS AND GREENHOUSE GAS REDUCTION MEASURES

In September 2006, Governor Arnold Schwarzenegger signed Assembly Bill 32, the Global Warming Solutions Act of 2006. AB 32 requires California to reduce greenhouse gas emissions to 1990 levels by 2020.[44] The state also released the 2009 California Climate Adaptation Strategy, a detailed, 200-page report covering impacts, risks, and strategies for seven major sectors, including ocean and coastal resources and water management.[45]

In 2002 the San Francisco Board of Supervisors passed the Greenhouse Gas Emissions Reduction Resolution, committing the city to a greenhouse gas emissions goal of 20 percent below 1990 levels by 2012.[46] The city's Climate Action Plan for San Francisco, released in 2004, identified actions necessary to meet this goal.[47] In 2008 the Board of Supervisors passed an ordinance mandating additional incremental greenhouse gas emissions limits: 25 percent below 1990 levels by 2017, 40 percent below 1990 levels by 2025, and 80 percent below 1990 levels by 2050.[48]

NOTABLE LOCAL ADAPTATION EFFORTS

In November 2010 San Francisco took steps to form an interagency task force on sea level rise adaptation. The task force will be responsible for developing policies that utilize both engineered and nonengineered strategies for addressing potential future flood risks associated with sea level rise.[49] One possibility would be developing a uniform set of permitting standards for future sea level rise for new development and redevelopment projects. When redeveloping Treasure Island, an artificial island in San Francisco Bay between San Francisco and Oakland, the city accounted for sea level rise (although developers spent considerable time and resources determining the appropriate amount of sea level rise to accommodate).[50] Levees or flood walls will provide shoreline protection for a 16-inch (40-centimeter) rise in sea level over the mid-term (2050). In addition, building pads and vital infrastructure will be constructed 36 inches (91 centimeters) above the current 100-year-flood level, and a 300-foot (91-meter) setback for development will be implemented.[51]

The San Francisco Public Utilities Commission (SFPUC) is a member of the Water Utility Climate Alliance, a consortium of water utilities nationwide focused on climate change and water resource issues. SFPUC is working with the NOAA Regional Integrated Sciences and Assessments program to conduct a robust evaluation of how climate change will impact the SFPUC system. This collaboration, Piloting Utility Modeling Applications for Climate Change, seeks to identify state-of-the-art climate modeling tools, understand uncertainties in the models, and use climate projection data from these tools in hydrologic models that can be utilized to inform water supply planning models.[52] In the interim, SFPUC is employing a "no regrets" approach to plan for potential water supply shortages by developing local water supplies, integrating water management with other nearby utilities, and pursuing regulatory reforms to support the use of gray water, stormwater, rainwater, and recycled water. SFPUC is diversifying water supplies by increasing recycled water and groundwater use, improving water conservation, and promoting stormwater management techniques that enhance filtration and groundwater recharge and decrease demand for potable supplies. These strategies will help the city to meet the Water Conservation Act of 2009's requirement that urban water providers in California reduce per capita consumption 20 percent by 2020. SFPUC is collaborating with other utilities on the Bay Area Regional Desalination Project, a proposed project to provide up to 71 million gallons per day to the five largest water utilities in the Bay Area.[53] To help mitigate the risk that sea level rise poses to the city's combined sewer system, SFPUC is installing backflow prevention devices that will keep saltwater from entering the combined sewer system and disrupting vital biological treatment processes.[54]

Another agency active in climate change adaptation planning is the San Francisco Bay Conservation and Development Commission (BCDC), the state agency responsible for regulating development in San Francisco Bay. In September 2010, commission staff issued a report about proposed amendments to the San Francisco Bay Plan that would require, among other things:

- the incorporation of sea level rise scenarios in the permitting process;
- the development of a long-term strategy to address sea level rise, storm activity, and other impacts of climate change in a way that protects the shoreline and the bay and allows for appropriate, well-planned development that responds to the impacts of climate change and future sea level rise;
- the provision of recommendations and requirements to guide planning and permitting of development in areas vulnerable to sea level rise; and
- the inclusion of policies that promote wetland protection, creation, enhancement, and migration.[55]

BCDC is involved in numerous other adaptation initiatives as well:

- In 2008 the commission conducted a vulnerability assessment that evaluated the potential impacts and socioeconomic costs of sea level rise and coastal flooding to the natural and built environment.
- BCDC is currently working on a regional climate change impacts assessment and regional climate action plan.
- The commission was instrumental in the creation of an adaptation assistance program for local governments, which provides information and resources that build capacity within local governments to assess relevant climate change impacts and to adapt to these impacts.[56]
- BCDC has partnered with the NOAA Coastal Services Center on the Adapting to Rising Tides Project, a community-based pilot study in Alameda County that matches adaptive strategies with specific climate change vulnerabilities.
- BCDC is working on drafting state legislation that would direct the commission to develop a sea level rise adaptation strategy for San Francisco Bay and Suisun Marsh.[57]

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CHAPTER 10
Los Angeles, California

Los Angeles's water resources are projected to be particularly affected by climate change. Rising seas cause saltwater intrusion into aquifers, and increasing temperatures affect the timing of water availability. There is also a likelihood that conditions will be drier and that less water will be available. To prepare for the possibility of less available water, Los Angeles is working to reduce the daily water use of its residents and increase local supplies, such as reclaimed wastewater and stormwater.


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Loss of spring snowpack causes water supply challenges for Los Angeles.

Figure 10.1: Los Angeles and surrounding area

Source: Map Resources/NRDC

AREA OVERVIEW

Los Angeles enjoys a Mediterranean climate. Most of the annual precipitation (an average of 15 inches, or 38 centimeters) falls in the cooler part of the year, between November and March. Measured downtown, the annual average high temperature is 75°F (29°C) and the average low is 57°F (14°C). Despite its large population, Los Angeles has very little freshwater. Its water needs are met by transporting water that originated in the Sierra Nevada mountain range in central and northern California via the State Water Project and the Los Angeles Aqueduct. To a lesser extent, water is also brought in from the Colorado River, on the border between Arizona and California, and from local groundwater supplies (see Figure 10.5).

POTENTIAL CLIMATE CHANGES AND THEIR IMPACTS

The following sections describe projected water-related climate changes and impacts to Los Angeles throughout the 21st century. For a general explanation of how increased greenhouse gases affect our climate and seas, and typical resulting impacts of climate changes, see the Background and Methodology section.

SEA LEVEL RISE, COASTAL FLOODING, AND SALTWATER INTRUSION

Occurrence

Over the last several decades, the sea level along California's coastline has risen at a rate of about 0.67 to 0.79 inch (1.7 to 2 centimeters) per decade, consistent with global sea level rise.[1] Coastal observations and global climate projections indicate that California's coast will experience rising sea levels during the 21st century as well. Sea level rise, projected using output from recent global climate modeling, increases in proportion to the amount of global warming. By 2050, projected sea level rise relative to the 2000 level ranges from approximately 12 to 18 inches (30 to 46 centimeters), depending on the magnitude of climate warming.[2] By the end of the 21st century, sea level is expected to be 20 to 55 inches (50 to 140 centimeters) higher than it was in 2000.[3]

With sea level rise comes an increase in extreme high-sea-level events (events that are higher than the 99.99th historical percentile of sea level heights). Models also predict an increasing tendency for high-sea-level events to persist for more hours as the 21st century progresses.[4]

Impacts

A report released by the Pacific Institute examined statewide impacts from a 55-inch (1.4-meter) rise in sea level, the mean sea level rise under a medium-high emissions scenario by 2100.[5] In Los Angeles, a rise in sea level of 55 inches is not expected to result in much *permanent* inundation (see Figure 10.2).[6]

Nevertheless, in Los Angeles County, 3,700 people are currently at risk from a 100-year flood along the coast. A 100-year flood is a flood that has a 1 percent chance of

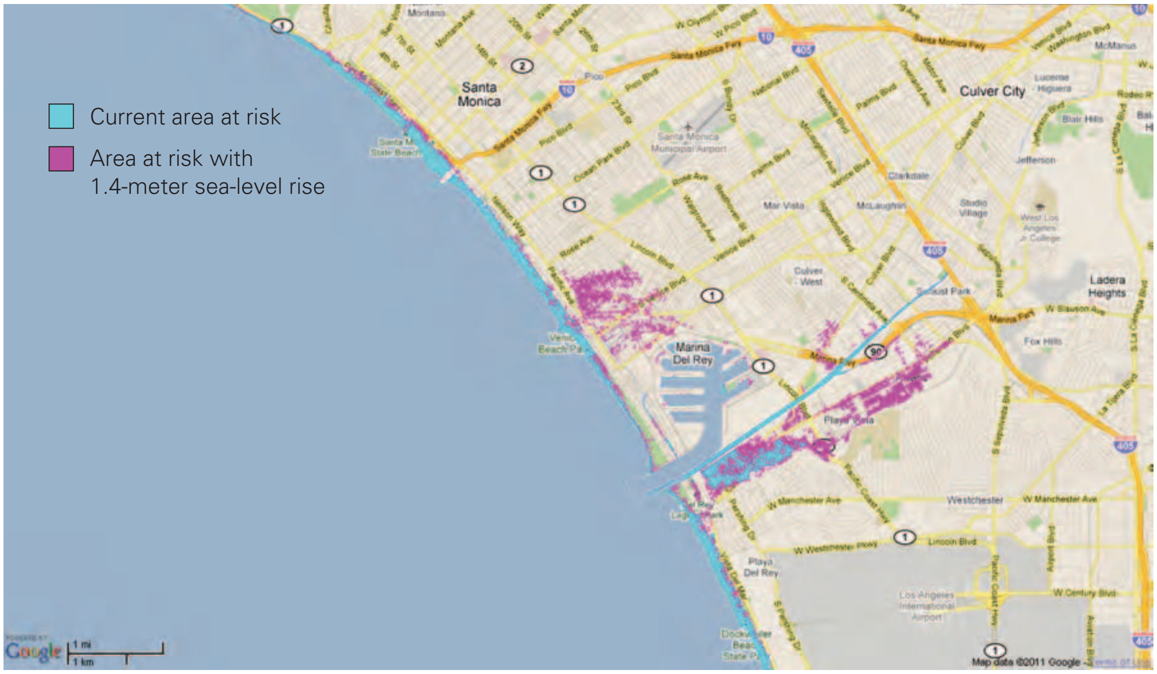
Table 10.1: Summary of water-related climate changes and impacts in Los Angeles throughout the 21st century

(Highly likely)	Rising sea levels
(Highly likely)	Increased flooding
(Highly likely)	Water supply challenges due to early snowmelt
(Highly likely)	Increased saltwater intrusion
(Likely)	Decreased annual precipitation
(Possible)	Water supply challenges due to increased droughts
(Possible)	Increased erosion
(Possible)	More frequent and intense storm events

Highly likely · Likely · Possible

Source: NRDC

Figure 10.2: Areas of the Los Angeles coast at risk from a 100-year flood event



Areas at risk with 55-inch sea level rise include Venice and Marina Del Rey.

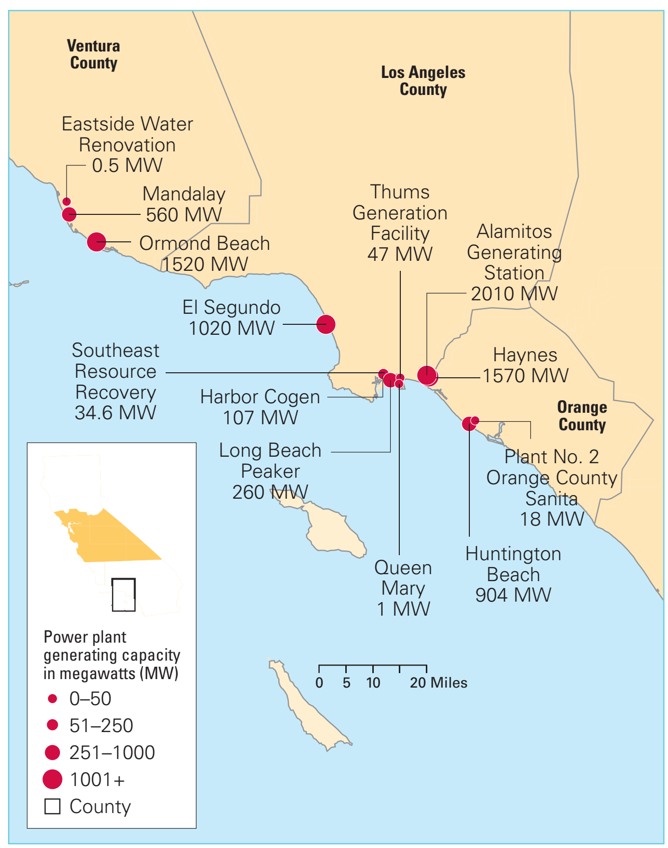
Source: Google/Pacific Institute (see Appendix A)

occurring in any given year, but sea level rise increases their likelihood. If there is a 55-inch rise in sea level and no increase in development in vulnerable areas, the number of at-risk residents jumps to 14,000 people. (Orange County, just south of Los Angeles, is by far the most vulnerable county in the state, with 110,000 people at risk from a 100-year flood after a 55-inch sea level rise.)[7]

The Pacific Institute report also details facilities and property at risk from a 100-year flood with a 55-inch sea level rise. In 2000 dollars, the replacement value of these at-risk buildings and their contents along the coast of Los Angeles County is $3.8 billion (compared with $1.4 billion without sea level rise).[8] A 55-inch sea level rise would double the number of hazardous facilities in Los Angeles County at risk from a 100-year flood, such as Superfund sites, hazardous waste generators, wastewater treatment plants, major dischargers of air pollutants, and brownfield properties.[9] Eight power plants with a combined generating capacity of 5,050 megawatts would be at risk of a 100-year coastal flood in Los Angeles County after a 55-inch rise in sea level (see Figure 10.3). Flooding could damage power-generating equipment, water intakes, or other peripheral structures.[10]

Transportation infrastructure would also be at higher risk with climate change. If the sea level were to rise 55 inches, 171 miles of roads and highways in Los Angeles County would be at risk from a 100-year coastal flood. Flooded roads and highways prevent people from getting to work and impact the movement of goods and services. Similarly, 14 miles of railway would be at risk.[11] Significant flooding due to anticipated sea level rise is also possible at the Port of Los Angeles and the Port of Long Beach in Los Angeles County (see

Figure 10.3: Southern California power plants vulnerable to a 100-year coastal flood with a 55-inch sea level rise



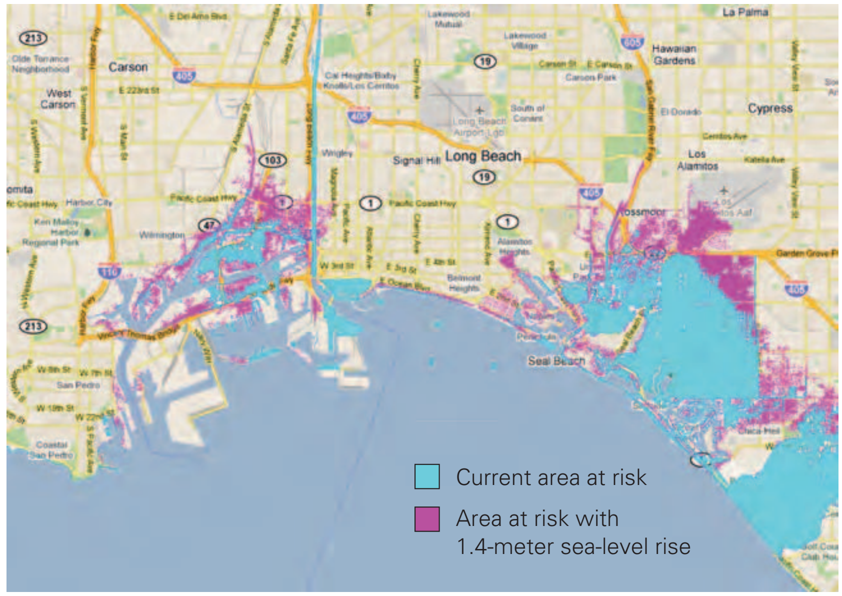
Source: Adapted from Heberger et al. (see Appendix A)

Figure 10.4).[12] These ports are central not just to the economies of the state but to the economies of the nation and the world; the ports handle about half of all the container freight shipped to the United States.[13]

In Los Angeles County, almost 100 miles of raised levees and new levees and seawalls would have to be built, at a cost of $2.6 billion, to protect against flooding in the event of a 55-inch rise in sea level. Maintaining these additional structures would require annual expenses on the order of a tenth of the capital cost.[14] While armoring the coastline would save lives and property, it disrupts natural processes that are also of value.

Seawater intrusion into groundwater aquifers and other sources of drinking water for Los Angeles is another impact of sea level rise. Seawater intrusion into aquifers is already a problem along the coast of Los Angeles County, where water has been withdrawn from aquifers at a rate higher than their recharge rate. Sea level rise will increase saltwater intrusion into these coastal aquifers. It will also degrade the quality and reliability of the freshwater supply pumped from the southern edge of the Sacramento–San Joaquin River Delta by increasing its salinity.[15] Salinity is already a problem in the delta, with pumping restricted during the summer and early fall to counteract increased salinity at those times. The Los Angeles area obtains a significant amount of its municipal water supply from the delta via the State Water Project (see Figure 10.5).

Figure 10.4: Risk from 100-year flood event in Long Beach and Seal Beach



Ports of Long Beach and Los Angeles and Seal Beach Naval Weapons Station at risk of flooding.

Source: Google/Pacific Institute (see Appendix A)

Sea level rise also contributes to coastal erosion, although erosion of coastal lands is a function not only of sea level rise but also of changes in deepwater wave direction and energy that are expected to occur as a result of climate change, shifts in deepwater storm patterns and intensities, and changes in the amount of sediment carried by rivers to the sea.[16] However, studies are not in agreement about the extent of the impact in the Los Angeles area. One study determined that erosion losses attributable to a 55-inch rise in sea level alone are not expected to be substantial in Southern California.[17] But other research indicates that a 55-inch rise in sea level along with shifts in deepwater wave fields that could occur as a result of climate change could cause substantial erosion of cliffs at Torrey Pines (south of Los Angeles), driving the edge of the cliffs 164 feet (50 meters) landward.[18]

STORM EVENTS AND COASTAL AND INLAND FLOODING[19]

Occurrence

Research about how climate change would impact the intensity and frequency of storms in Los Angeles is somewhat varied. Increased storm intensity is forecast by some climate models, whether or not the frequency of storms also increases.[20] Other studies show a decrease in the frequency of significant storms by the end of the 21st century, with less deviation from historical patterns in the southern part of the state.[21] With climate change, some research projects that El Niño conditions that bring high levels of rainfall to California may occur more frequently,[22] while other research projects these conditions to occur much as they have historically.[23]

Impacts

The frequency of high-sea-level events may increase if storms become more frequent or severe, because storms cause heavy surf from wind-driven waves as well as river flooding. As discussed earlier, Los Angeles is at risk from high-sea-level events, the impacts of which could be exacerbated by more severe winter storms.[24]

INCREASED TEMPERATURE, CHANGES IN ANNUAL PRECIPITATION, AND WATER SUPPLY

Occurrence

Temperatures in California are likely to warm significantly during the 21st century. There is a strong inclination for more warming in summer than in winter and greater warming inland than along the coast. Overall, models' warming projections for mid-century range from about 1.8°F to 5.4°F (1°C to 3°C), rising by the end of the 21st century to a range of about 3.6°F to 9°F (2°C to 5°C).[25]

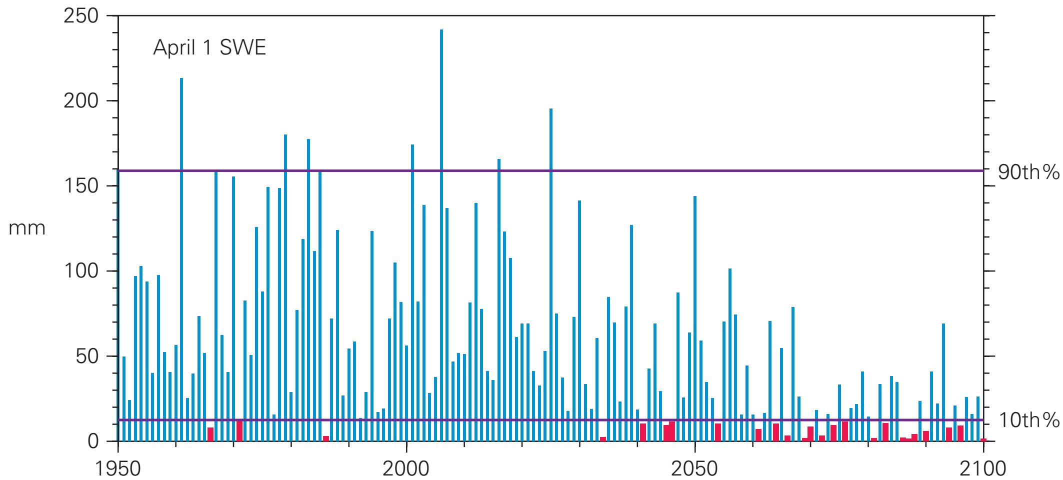
Los Angeles's Mediterranean climate pattern is not expected to change during the 21st century.[26] In California there is a great deal of variability in precipitation from year to year and decade to decade, and this variability, with attendant vulnerability to drought, is expected to continue. Nearly all of the simulations evaluated by Cayan et al. (2009) project a tendency for drier conditions to develop during the mid and late 21st century in Southern California and in central California, where most of Southern California's water supply originates (see Figure 10.5).

For the mid 21st century, 6 of 12 simulations for Sacramento (representing central California) have a 30-year mean precipitation that is more than 5 percent drier than the historical average. For the late 21st century, 8 of the 12 simulations have 30-year averages more than 5 percent below the historical average. Most simulations project a stronger drying trend for Los Angeles than for Sacramento: For the mid 21st century, 6 of the 12 simulations have a 30-year mean precipitation that is more than 10 percent drier than the historical average, and for the late 21st century, 8 of the 12 simulations

Figure 10.5: Water conveyance system in California

Source: Adapted from California Department of Water Resources

Figure 10.6: Projected snow water equivalent in the northern Sierra Nevada



April 1 snow accumulation (snow water equivalent, or SWE), from the A2 (medium-high emissions) scenario. Years with less SWE than the historical 10th percentile (1961–1990) are shown in red. The horizontal lines show the 90th-percentile and 10th-percentile SWE levels.

Source: Adapted from Cayan (see Appendix A)

have 30-year averages that decline by more than 10 percent from the historical average. The drying that is projected in these simulations rivals or exceeds the largest observed long-term dry periods since the late 1800s. For the mid and late 21st century, only 2 of the 12 simulations project 30-year mean precipitation that is higher (slightly) than the historical annual average.[27]

Precipitation in California is strongly affected by El Niño/ Southern Oscillation phenomena, and the state's water supply will be affected by whether El Niño conditions occur more frequently. One researcher projects more frequent El Niño conditions, as well as more intense La Niña events, resulting in larger year-to-year variations in precipitation.[28]

Impacts

According to a report to the California Energy Commission, "Higher temperatures will have several major effects: they will increase the ratio of rain to snow, delay the onset of the snow season, accelerate the rate of spring snowmelt, and shorten the overall snowfall season, leading to more rapid and earlier seasonal runoff."[29] Seasonal shifts in runoff patterns from spring to winter are already occurring in California.[30] Indeed, according to the California Department of Water Resources, "[t]he average early spring snowpack in the Sierra Nevada decreased by about 10 percent during the last century, a loss of 1.5 million acre-feet of snowpack storage."[31] These shifts have important implications for water management for the Los Angeles region and have been the subject of study since the late 1980s.[32]

Loss of spring snowpack in the Sierra Nevada is very likely (see Figure 10.6).[33] In the worst-case climate change scenario for water supplies (hot and dry), streamflows may decrease statewide by 27 percent by 2085. For Southern California, streamflows are projected to decrease by 41 percent in this scenario. Other research and modeling studies are in agreement that under many different climate projections, climate change will result in an increase in winter streamflow and a decrease in late-spring and summer flow for rivers in California.[34] Evaporation losses from reservoirs will increase, but the magnitude of these losses will be dwarfed by the projected change in streamflows caused by higher temperatures and reduced precipitation.[35]

Evaporation losses from reservoirs will increase, but the magnitude of these losses will be dwarfed by the projected change in streamflows caused by higher temperatures and reduced precipitation.

One study shows that even small increases in temperature with no change in precipitation changes the timing of flow patterns for rivers in California substantially, with more water flowing in the rivers during the winter and less during the dry season when demand, both agricultural and urban, is highest. The departure from current typical flow patterns increases with increasing temperature and increasing precipitation.[36]

Earlier snowmelt in the spring will also allow more time for summer saltwater intrusion into the Sacramento–San Joaquin River Delta in addition to the saltwater intrusion caused by sea level rise. Salinity already poses a problem in the delta. There are often pumping restrictions in late summer and early fall, when the availability of water in the reservoirs is at its lowest. With increased salinity due to sea level rise, pumping will have to be further reduced unless more water can be released from reservoirs to combat encroaching salinity.[37] Because water from the delta supplies Los Angeles's residents, these impacts to the delta have repercussions for the city's water supply.

Climate change and attendant disruptions in precipitation patterns could cause an increase in drought periods. Climate change may also cause drought to occur in areas outside of California that affect the flow of the Colorado River, which is a source of some of Los Angeles's municipal water.[38] During a recent California drought, low precipitation resulted in water restrictions for urban customers around the state and cuts in irrigation for agriculture. For instance, customers of the Los Angeles Department of Water and Power (LADWP) are subject to drought responses such as mandatory conservation, rate increases, and restrictions on outdoor watering. During a drought, more water may be withdrawn from groundwater supplies, which may cause land subsidence. Drought may also lead to an increase in the concentration of contaminants in drinking water supplies.[39]

ACTION: MITIGATING AND PREPARING FOR CLIMATE CHANGE

Among the states, California leads the way on addressing climate change, in terms of both mitigation and adaptation. Los Angeles has made some progress toward climate change planning, but those efforts require updating. When compared with other large cities, Los Angeles lags a bit in terms of local vulnerability assessments, but the city and county are working with regional stakeholders to correct that shortcoming.

STATE, REGIONAL, AND CITY PLANS AND GREENHOUSE GAS REDUCTION MEASURES

In September 2006, Governor Arnold Schwarzenegger signed Assembly Bill 32, the Global Warming Solutions Act. AB 32 requires California to reduce greenhouse gas emissions to 1990 levels by 2020.[40] The state also released the 2009 California Climate Adaptation Strategy, a detailed, 200-page report covering impacts, risks, and strategies for seven major sectors, including ocean and coastal resources and water management.[41]

In May 2007, the city of Los Angeles released "GreenLA: An Action Plan to Lead the Nation in Fighting Global Warming." The plan identifies more than 50 action items for reducing the city's greenhouse gas emissions to 35 percent below 1990 levels by 2030.[42] The city's ClimateLA plan, a living document, provides a program to implement the action items in GreenLA.[43]

NOTABLE LOCAL ADAPTATION EFFORTS

Los Angeles's water-related goals are set forth in ClimateLA: "(1) Meet all additional water demand resulting from population growth through water conservation and recycling; (2) Reduce per capita water consumption by 20 percent; and (3) Implement the city's innovative water and wastewater integrated resources plan that will promote increased water conservation and maximize the use of recycled water, including capture and reuse of stormwater."[44] Updates on the city's implementation of these goals are provided in ClimateLA.[45]

Because climate change could cause an increase in drought conditions for Los Angeles, these actions would help the city become more resilient. Unfortunately, in 2010 the city extended by 10 years the original 2019 deadline on its previous goal of creating 50,000 new acre-feet of recycled water. Thus, as with all cities, only time will tell whether Los Angeles meets the goals it created in its climate plan.

The city is currently updating the plan, which has not been updated since 2009, and its Web site.[46] We urge the city to complete these critical tasks; good communication about the impacts and risks of climate change and the city's efforts to mitigate and adapt is a critical component of a robust climate change strategy.

Currently LARC is working on an inventory of greenhouse gas emissions and specialized modeling efforts to determine how Los Angeles would look under various emissions-reduction scenarios for the years 2030 and 2060. The information gleaned from those efforts will be used to develop a climate action plan.

The city also is taking part in a regional effort, the Los Angeles Regional Collaborative for Climate Action and Sustainability (LARC).[47] LARC's membership includes cities, counties, agencies, academics, and nonprofit organizations. Members sign a charter that endeavors to build a regional action plan to: "(1) establish baselines of current greenhouse gas emission levels, (2) identify greenhouse gas emission reduction targets and mandates, (3) develop a mechanism for tracking progress in reducing those emissions, (4) identify a full range of measures for reducing greenhouse gas emissions and adapting to climate change, and (5) provide strategies to help meet those goals."[48] Currently the group is working on an inventory of greenhouse gas emissions and specialized modeling efforts to determine how Los Angeles would look under various emissions-reduction scenarios for the years 2030 and 2060. The information gleaned from those efforts will be used to develop a climate action plan.[49]

Finally, the LADWP and numerous experts are analyzing the impacts of climate change on water supplies from the eastern Sierra Nevada, which provides freshwater to the city via the Los Angeles Aqueduct.[50] This effort is designed to allow LADWP to better evaluate adaptation strategies for an important water source that is dependent upon snowpack and snowmelt.

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CHAPTER 11

Phoenix, Arizona

Climate change and a growing population are very likely to negatively affect the availability of freshwater to homes, businesses, farms, and institutions in Phoenix over the course of this century. Projected higher temperatures and drier conditions will likely decrease rainfall within the urban boundaries as well as in the city's remote watersheds and will increase evaporation of water from soils and reservoirs. In response, Phoenix has developed strategies to address potential deficit conditions between water supply and demand. The city also recognizes the potential for mandatory water use restrictions.

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Increasing temperatures and drier conditions in Phoenix will cause water supply challenges.

Figure 11.1: Phoenix and surrounding area

Source: Map Resources/NRDC

AREA OVERVIEW

Phoenix is the sixth most populous city in the United States, with a population of 1.45 million as of 2010. The city's population has been steadily rising for at least the past 50 years; its current population is about three times what it was in 1960.[1] The greater Phoenix area includes the cities of Mesa, Scottsdale, and Tempe, among others, and has a current population of about 4 million (see Figure 11.1). This population is expected to approximately double by 2040.[2]

Phoenix experiences very hot summers and warm winters, with average high temperatures of 103°F (39°C) in June, July, and August. This Sonoran Desert city on a flat alluvial basin at the confluence of the Salt and Gila rivers receives just under 8 inches (20 centimeters) of rain per year, on average.

Phoenix relies primarily on four sources of water: the nearby Salt River and Verde River watersheds, the Colorado River Basin via a 336-mile canal (the Central Arizona Project), and vast sedimentary aquifers (see Figure 11.2). Phoenix shares the waters of the Colorado River with six other states: California, Colorado, Nevada, New Mexico, Utah, and Wyoming. The city also uses reclaimed waste-water for farm irrigation, public turf maintenance, and cooling water at the Palo Verde Nuclear Generating Station.[3]

Table 11.1: Summary of water-related climate changes and impacts in Phoenix throughout the 21st century

Likelihood	Impact
Highly likely	Water supply challenges due to increased droughts
Likely	Decreased annual precipitation

Highly likely · Likely · Possible

Source: NRDC

POTENTIAL CLIMATE CHANGES AND THEIR IMPACTS

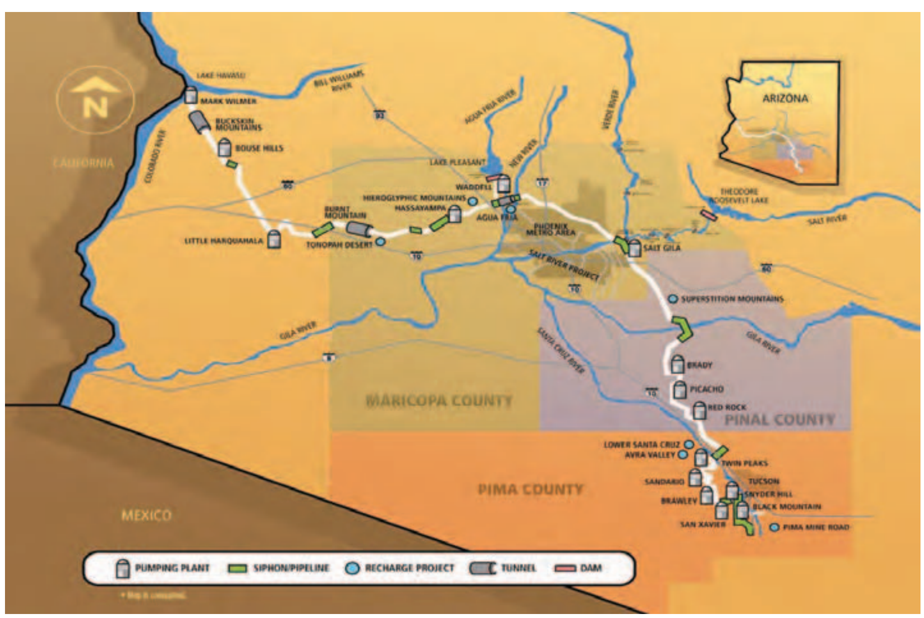
The following section describes projected water-related climate changes and impacts to Phoenix throughout the 21st century. For a general explanation of how increased greenhouse gases affect our climate and seas, and typical resulting impacts of climate changes, see the Background and Methodology section.

INCREASED TEMPERATURE AND MORE FREQUENT DROUGHTS

Occurrence

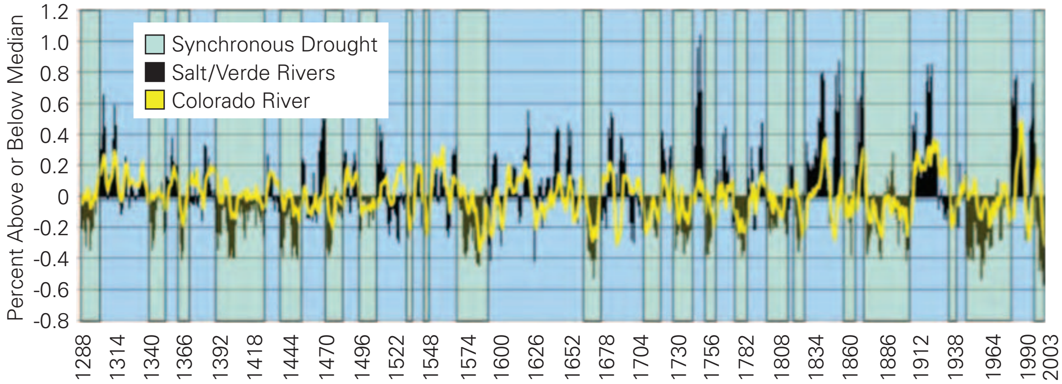
Average temperatures are already on the rise in Phoenix. Over the past few decades, temperatures have risen 0.05°F (0.03°C) per year due to climate change and the urban heat island effect.[4] According to the Southwest Climate Change Network, "The Southwest is projected to warm faster than the world as a whole in coming decades, with summer temperatures rising even faster than winter ones. Average

Figure 11.2: Central Arizona Project water system map



Source: Central Arizona Project

Figure 11.3: Reconstructed Colorado River and Salt River watershed streamflows, indicating long-lasting droughts



Source: Adapted from City of Phoenix/Data from University of Arizona Tree Ring Lab

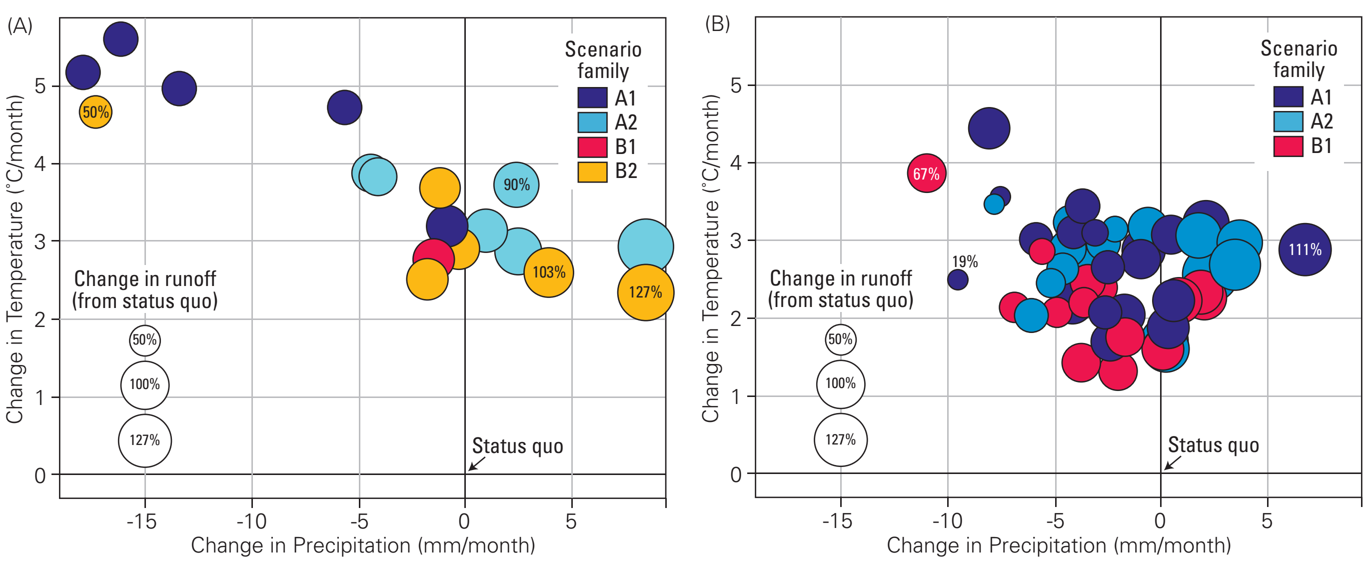
annual temperatures in many parts of the region could be 5 to 8 degrees F [2.8° to 4.4°C] higher than they were even during the hot quarter-century that began in the 1970s."[5]

Although precipitation changes are more difficult to predict than temperature changes, precipitation is projected to decline in southern Arizona by 5 to 10 percent by 2100.[6] Winter snowfalls are crucial to the management of the city's water supply because springtime meltwater in the mountainous Verde River and Salt River watersheds gradually recharges groundwater aquifers and dammed reservoirs. These snowfalls may be decreasing; as of December 2009, the area had had only two adequate spring runoff seasons in the previous dozen years.[7] Although summer monsoons can bring significant rainfall, high temperatures cause much of that moisture to immediately evaporate. These factors indicate increased droughts for the region.[8] Historical data show that major droughts have already occurred in the Phoenix area, wreaking havoc on human and natural systems.[9] Droughts spanning several decades are not unheard of in the region (see Figure 11.3). The current drought began in the mid-1990s, and could continue for another 20 to 30 years.[10]

Impacts

Higher temperatures and decreased precipitation are expected to reduce water supplies.[11] If temperatures are high enough to cause winter precipitation to fall as rain instead of snow, spring and summer runoff from melting snows would disappear just when demand is peaking.[12] Projected precipitation decreases and temperature increases could reduce runoff in the Salt and Verde watersheds to as little as 19 percent of historical flows in one climate scenario, or to 50 percent of historical flows in another (see Figure 11.4).

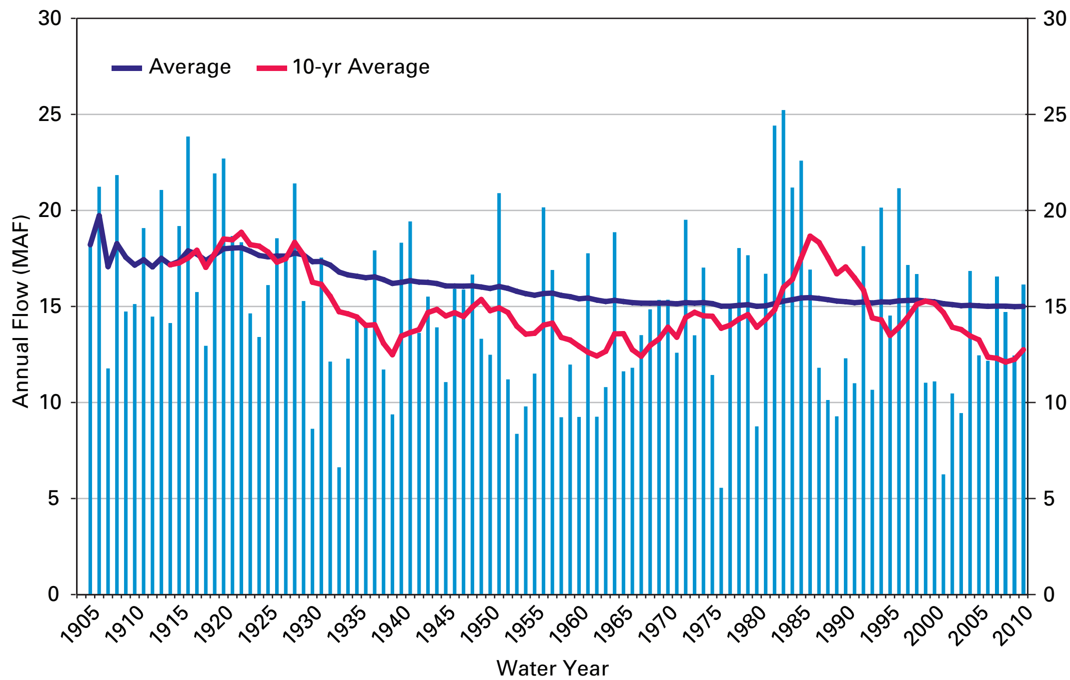
Figure 11.4: Potential impacts on runoff in Salt and Verde watersheds



Impacts on runoff in the Salt and Verde watersheds with varying combinations of temperature increases and rainfall changes, based on the IPCC Third Assessment Report (left, A) and the IPCC Fourth Assessment Report (right, B). The sizes of the circles depict runoff as a percentage of the historical mean from 1961 to 1990.

Source: Gober et al. (see Appendix A)

Figure 11.5: Flow of the already over-allocated Colorado River, showing a general decreasing trend over the past 100 years



Source: Data from U.S. Bureau of Reclamation

Based on the average of climate scenarios, runoff into the Salt and Verde watersheds could decrease by 23 percent.[13] During prolonged droughts, there could be intermittent rainfall events with precipitation above normal levels, but even so, runoff is usually below normal levels when temperatures are above normal (see Figure 11.4).[14]

Water imported from the Colorado River system through the Central Arizona Project (CAP) helps to alleviate the impact of droughts, but it, too, has been significantly below capacity due to drought conditions and over-allocation (see Figure 11.5). Phoenix is at the bottom of the totem pole for Colorado River water allocations;[15] during prolonged or severe drought conditions, the city may not be able to count on water from the CAP. For example, even with a 20 percent increase in runoff into the Colorado River, Phoenix would receive only 97 percent of its full allotment if temperatures also increase. In scenarios in which runoff into the Colorado River decreases, the frequency of times that the CAP would receive its full allotment of Colorado River water would decrease; under one scenario, only the minimum allotment would be delivered.[16]

Reduced surface water supplies necessitate groundwater withdrawals to meet demand. Table 11.2 shows the percent of groundwater that would be needed by the Phoenix Active Management Area (AMA) to meet water demand under various conditions in 2025, compared with the 1995 baseline (the Phoenix AMA covers the larger metropolitan area, about three times the size of the city of Phoenix). In 1995, groundwater supplied 20 percent of the Phoenix AMA's annual average requirements. By 2025, groundwater is expected to

Table 11.2: Percent overdraft of renewable supplies that would need to be met from non-renewable sources

Drought duration	1995 baseline	2025		2025 drought				
		baseline	drought	w/o CAP	+ 1995 agric	+ 1995 agric w/o CAP	w/o agric	w/o agric w/o CAP
1 year	20	24	68	nc	68	nc	43	nc
5 year	20	24	47	67	47	68	6	64
10 year	20	24	39	59	38	59	-8*	27

Percent overdraft of renewable supplies that would have to be met from non-renewable (groundwater) sources in 1-, 5-, and 10-year drought scenarios, including limiting agricultural demand to a 1995 baseline, eliminating agricultural demand, and eliminating Central Arizona Project (CAP) water.

Source: Adapted from Morehouse et al. (see Appendix A)

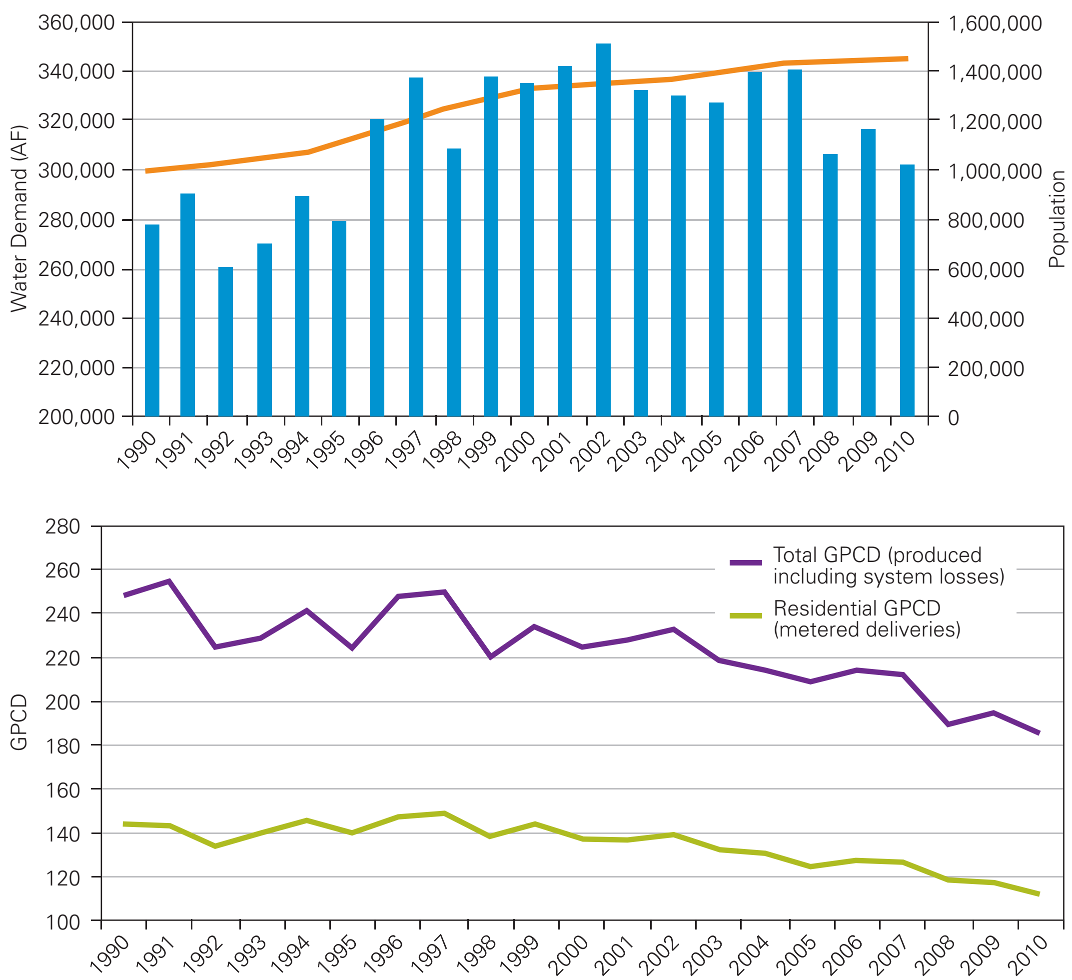
nc = not calculated; *surplus, not overdraft provide 24 percent. During a one-year drought, groundwater would have to supply 68 percent of demand. If agricultural demand were taken out of the equation, groundwater needs would fall to 43 percent because surface waters formerly used for agriculture would be freed up for other uses. Longer droughts of 5 to 10 years are assumed to have intermittent years of normal rainfall, so water deficits are spread out over a longer time frame. For that reason, less groundwater is needed to meet demand in any given year.[17]

However, groundwater aquifers that might otherwise temper the loss of surface waters during times of drought have themselves been overused for decades. Although the Arizona Groundwater Management Act of 1980 set a goal of "safe yields" from groundwater aquifers (i.e., aquifer withdrawals that do not exceed water recharge rates) by 2025, critics believe that goal is unlikely to be met.[18] Further, overuse of groundwater can cause land subsidence and reduced water quality.[19]

Another factor affecting future water availability in Phoenix is population growth. Through water demand management, the city has been able to decrease per capita water consumption despite recent population growth (see Figure 11.6). However, expanding population could result in demand exceeding supply by 2030.[20] Climate change would add a further strain: A temperature rise of 1.8°F (1°C) increases household water use by 1,217 gallons per year.[21] Higher temperatures combined with drought conditions would increase annual household water use even further because of increased evapotranspiration (the combination of evaporation from surface waters and soils and the loss of soil moisture as plant roots pull moisture from soils and release it as vapor through their leaves).[22]

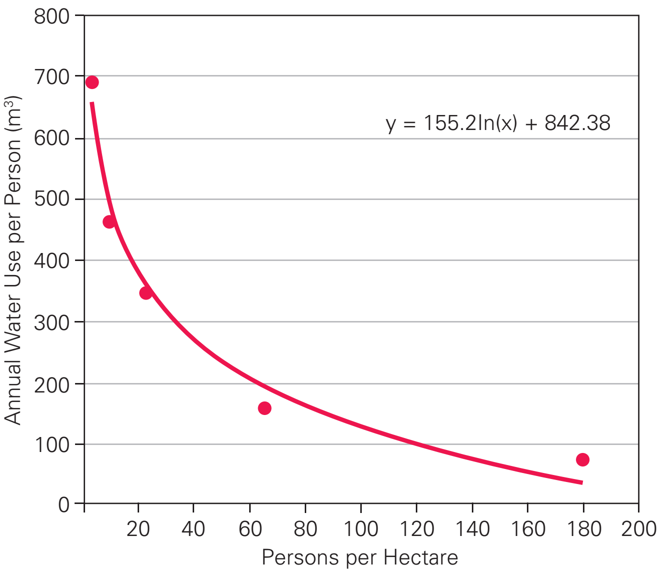
Managing water demands caused by population growth and climate change through urban development rather than suburban sprawl could reduce projected per capita water demand. Nearly three-quarters of residential water use is for landscape and other outdoor purposes. Thus, where urban density is 37 to 74 housing units per hectare (about 2.5 acres), per capita water demand is about 19,813 gallons (75 cubic meters) annually. By contrast, large suburban lots, with just 2.5 units per hectare, use 10 times as much water per year (see Figure 11.7).[23]

Figure 11.6: City of Phoenix water demand and population growth (top) and per capita water consumption (bottom).



Source: Adapted from City of Phoenix

Figure 11.7: Per capita water demand based on residential density



Source: Adapted from Gober and Kirkwood (see Appendix A)

ACTION: MITIGATING AND PREPARING FOR CLIMATE CHANGE

Phoenix's efforts to adapt to climate change are centered on water resource management. Given its arid location, the city had already developed strategies to address potential deficit conditions between water supply and demand before climate change became a dominant factor. Though current climate research has not yet yielded data sufficient to be directly incorporated into the decision process, the city is planning for a variety of future water supply shortage scenarios.

STATE, REGIONAL, AND CITY PLANS AND GREENHOUSE GAS REDUCTION MEASURES

The state of Arizona has adopted the goal of reducing greenhouse gas emissions statewide to 2000 levels by 2020 and to 50 percent below 2000 levels by 2040.[24] Recommendations to achieve these goals were outlined in the Arizona Climate Change Advisory Group's Climate Change Action Plan.[25]

The city of Phoenix has committed to reducing greenhouse gas emissions from city operations to 5 percent below 2005 levels by 2015. The city's Climate Action Plan for Government Operations outlines measures regarding energy efficiency, renewable energy, transportation, and solid waste that can be implemented to achieve this emissions reduction goal.[26]

NOTABLE LOCAL ADAPTATION EFFORTS

Due to its location in the arid southwestern United States, Phoenix by necessity has a long history of active water resource management. The city's heavy reliance on surface water supplies makes it vulnerable to fluctuations in annual river runoff due to climatic variability. In response, Phoenix has developed strategies to address potential deficit conditions between water supply and demand that may occur as a result of future population growth and/or climate change. The city's Water Resources Plan is typically updated every 5 years to ensure that adequate water supplies exist to meet current demand as well as projected changes over the next 50 years. The city's 2010 plan update was expected to be finalized by June 30, 2011.[27]

To better understand the impacts of climate change on the city's surface water supplies, Phoenix has supported research at the University of Arizona and Arizona State University. These efforts have included the modeling of climate change impacts on the river basins (Colorado, Salt, and Verde) that supply the city. Unfortunately, the current research has not yet yielded data that are reliable enough or specific enough to be directly incorporated into decision planning.[28] To address these shortcomings, the city has incorporated long-term precipitation reductions (i.e., surface water supply shortages) into future planning scenarios. The last plan update, in 2005, concluded that the city should have sufficient water supplies in most cases to meet demand through 2015. Nevertheless, efforts to develop additional water supplies and to employ strategies that decrease demand are under way.[29]

The 2005 update identifies several avenues the city can explore to address potential future water supply and demand imbalances. Under every future scenario over the next 50 years, the city anticipates having to develop new supplies to meet demand. Phoenix currently stores excess surface water supplies in underground aquifers through the Granite Reef Underground Storage Project. It also accrues credits through in-lieu recharge by providing surface water to the Salt River Project and reclaimed water to nearby irrigation districts.

Phoenix has also explored acquiring additional surface water supplies by leasing CAP supply rights from other entities (the Arizona State Land Department, Native American communities, etc.) and entering into land-fallowing agreements with irrigation districts that retain agricultural priority CAP water. The city has investigated increasing existing groundwater supplies by expanding groundwater well capacity and by using groundwater supplies from farmland owned by the city in the McMullen Valley, west of Phoenix.[30] Currently more than 90 percent of the water treated by the city's three wastewater treatment facilities is utilized for crop irrigation, golf course watering, habitat restoration, and industrial cooling.[31] Further expansion of reclaimed water use would decrease potable water demands and could be utilized to augment potable supplies through underground storage and later recovery or blending with surface water supplies prior to treatment.[32]

Water demand management through additional conservation and/or curtailments would also aid in providing adequate water supplies by decreasing demand. Since 1980, water use in gallons per capita per day in Phoenix

Continued water conservation and management of Phoenix's water supply, including the Salt River, will help the city become more resilient to climate change.

has decreased more than 20 percent as a result of water conservation measures (e.g., limitations on water applied to large turf facilities, public awareness campaigns, adoption of a new plumbing code).[33] The city believes that an additional 8 to 10 percent reduction in per capita water use can be achieved through enhancement of traditional water conservation measures and that an 8 percent reduction can be achieved through implementation of water use curtailments as part of Phoenix's four-stage drought management response procedure.[34,35] Nonetheless, given its population, arid location, and susceptibility to drought, the city anticipates having to implement mandatory water use restrictions within the next 50 years under all future scenarios of severe drought and also under a moderate-drought and high-density-growth scenario.

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CHAPTER 12
Homer, Alaska

Unlike many coastal cities, Homer, Alaska, does not appear to be highly vulnerable to sea level rise. Coastal uplift of the local landmass will likely counterbalance sea level rise; however, increased precipitation could cause increased bluff erosion. Further, warmer temperatures are likely to cause significant alterations in the area's marine ecosystem, with important implications for fisheries, upon which the local economy depends. Fortunately, the small town of Homer is making large efforts to reduce its contribution to greenhouse gas emissions.

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Increasing temperatures pose a threat to Homer's fisheries and marine ecosystem.

Figure 12.1: Homer and surrounding area

Source: Map Resources/NRDC

Table 12.1: Summary of water-related climate changes and impacts in Homer throughout the 21st century

Highly likely	Increased annual precipitation
Likely	Increased impacts to fisheries
Possible	Increased erosion
Possible	Water supply challenges due to drier conditions

Highly likely · Likely · Possible

Source: NRDC

AREA OVERVIEW

Homer is located on the Kenai Peninsula in south-central Alaska, on the shores of Kachemak Bay to the east and Cook Inlet to the west (see Figure 12.1). Incorporated in 1964, Homer has a population of about 5,500 and a total land area of 15 square miles. Homer is in a transitional climate zone (see Figure 12.2);[1] its average annual temperature is 37°F (–3°C) and average annual precipitation is about 25 inches (64 centimeters). The average annual snowfall is 58 inches (143 centimeters).[2] Unlike much of Alaska, Homer is not impacted by permafrost.[3]

Homer Spit, a long, narrow slice of land jutting into Kachemak Bay, houses the harbor and charter and commercial fishing operations. As in most of Alaska, commercial fishing is a mainstay of the Homer economy.[4] Since the 1960s Homer's drinking water source has been the Bridge Creek Reservoir, which lies at an elevation of 865 feet (264 meters) in the mountains about two miles north of the town center.[5]

POTENTIAL CLIMATE CHANGES AND THEIR IMPACTS

The following sections describe projected water-related climate changes and impacts to Homer throughout the 21st century. For a general explanation of how increased greenhouse gases affect our climate and seas, and typical resulting impacts of climate changes, see the Background and Methodology section.

While there is a fair amount of climate change information for Alaska's larger urban areas and its geographic regions, there is not much specific information for small towns such as Homer. Therefore, this chapter draws on regional information from south-central Alaska.

SEA LEVEL RISE

Occurrence

Sea level rise predictions for other sites in the Cook Inlet area, including the Kenai Peninsula, suggest that at least parts of the region are not particularly vulnerable to the effects of sea level rise over the course of the 21st century. Coastal uplift of the local landmass, predicted to be about 2.3 to 3.6 feet (0.7 to 1.1 meters), will counterbalance much of the effect of rising seas, predicted to be 1.3 to 6.6 feet (0.4 to 2 meters). Therefore, overall sea level change is estimated to be –2.3 to +4.3 feet (–0.7 to +1.3 meters) by 2100. Even if sea level change occurs at the higher end of the estimated range, marshlands will likely keep up with sea levels as they capture sediment and grow vertically.[6]

STORM EVENTS AND EROSION

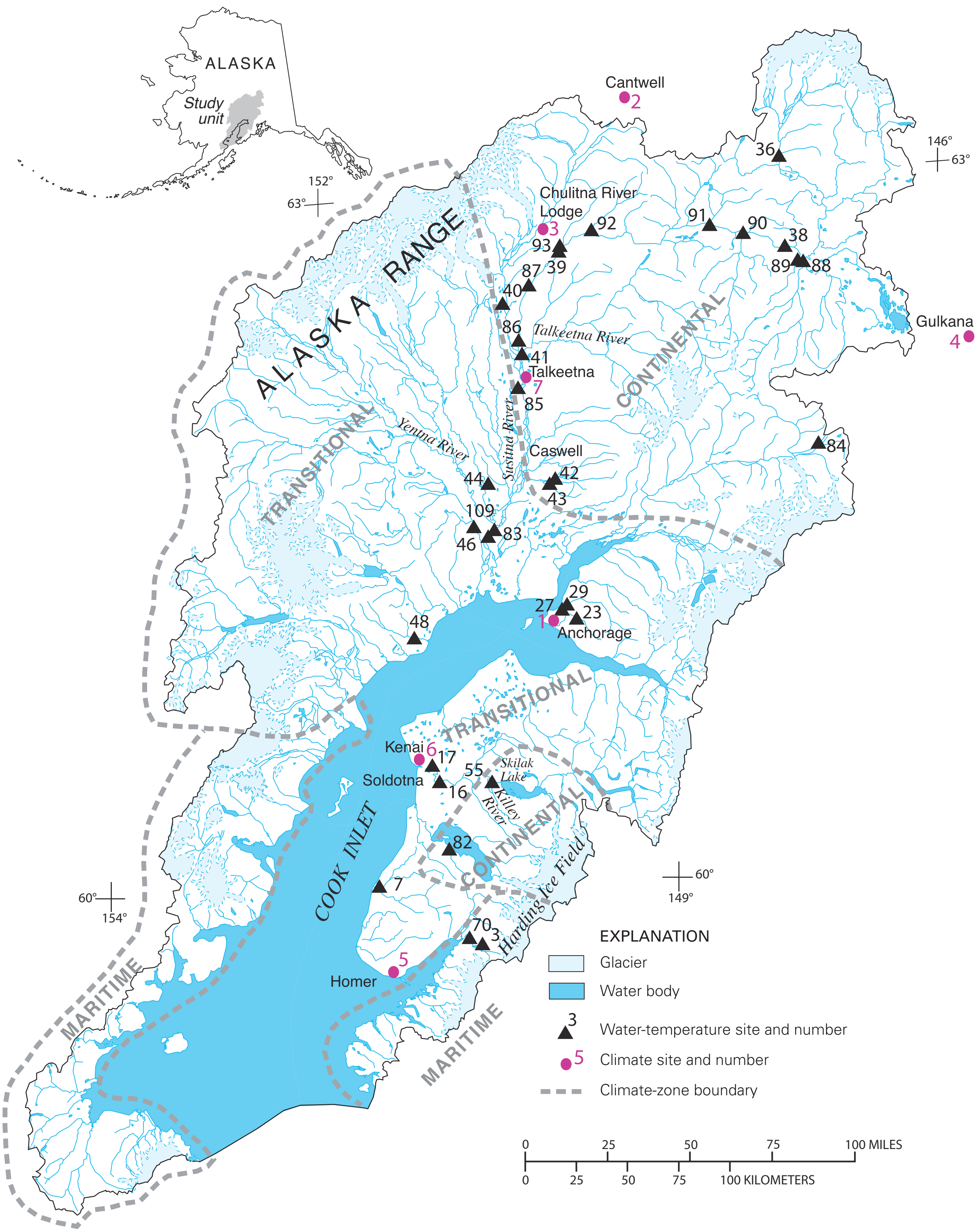
Occurrence

Alaska has witnessed an increase in extreme precipitation events since the late 1950s (see Figure 12.3). Storm severity may increase over the course of the 21st century,[7] and correspondingly, these extreme precipitation events may increase. Overall annual precipitation is also projected to increase by 20 to 25 percent throughout the 21st century.[8]

Impacts

The glacially deposited bluffs common along the Cook Inlet and Kachemak Bay coastlines are susceptible to erosion, particularly during high-tide storms when heavy rains saturate and liquefy unstable soil and clay layers.[9] For instance, in October and November of 2002, heavy rains caused slope failures and debris slides in various parts of Homer, and the storm surge flooded Homer Spit.[10] Freezing brackish water

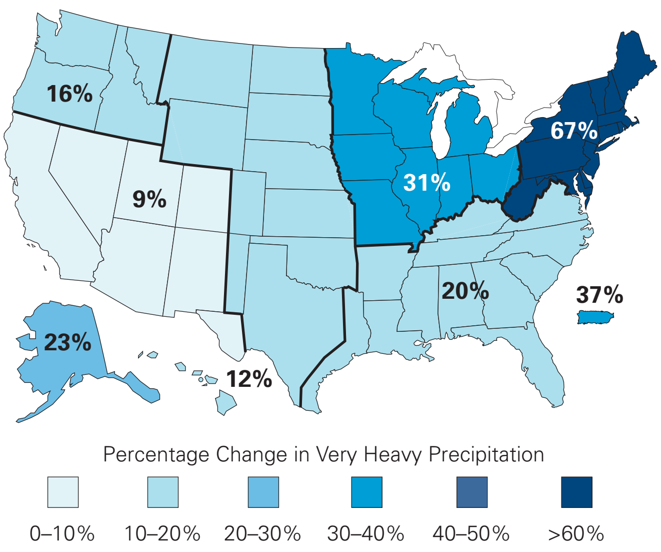
Figure 12.2: The Cook Inlet watershed



Homer (red dot number 5) falls within a transitional climate zone.

Source: U.S. Geological Survey (see Appendix A).

Figure 12.3: Percentage change in very heavy precipitation



Increases in the heaviest 1 percent of all daily precipitation events from 1958 to 2007. Alaska has already seen a 23 percent increase in these events.

Source: U.S. Global Change Research Program (see Appendix A)

on broad tidal flats can create large blocks of "beach ice" that contain coarse sediments. High tides can carry them into open waters, where they become hazards to ships. More intense storms and sea level rise may exacerbate hazards such as erosion and beach ice.[11]

INCREASED TEMPERATURE

Occurrence

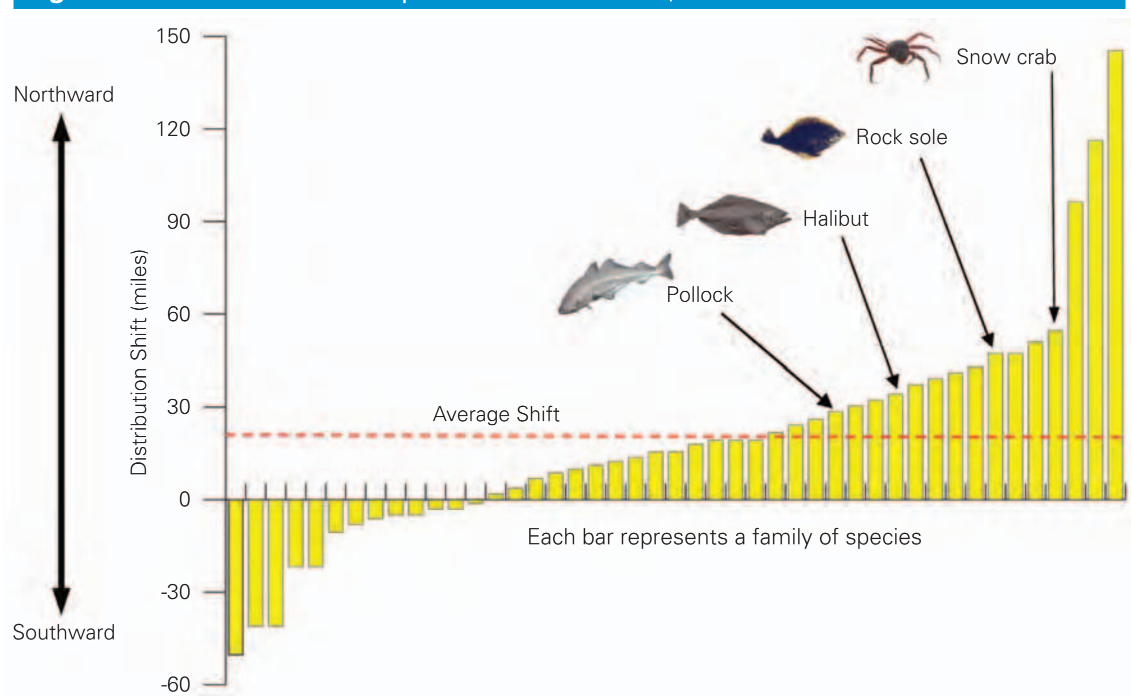
Unlike much of the continental United States, where temperature increases have been, and are expected to continue to be, more dramatic in summer, Alaska is experiencing the greatest increases in average temperatures during winter. Over the past 50 years, average temperatures in Alaska have increased 3.4°F (1.9°C), but winter temperatures have risen by 6.3°F (3.5°C). In fact, since the mid-20th century, Alaska has warmed at nearly twice the rate of the rest of the country.[12] The temperature increase could be as much as 15.3°F (8.5°C) for the Kenai Peninsula by 2100.[13]

Impacts

Increased temperatures pose a threat to the region's fisheries and other marine species, which are important both to the economy and as a food supply, especially to Native populations. Warmer air and water temperatures have already resulted in a shift northward of species important to the region, with implications for the ecosystem and local communities (see Figure 12.4).[14] Water temperatures in streams on the Kenai Peninsula that support salmon populations have been consistently above the levels the state has determined are necessary to protect spawning and migrating fish.[15] Higher temperatures can also increase the incidence of disease in fish.[16]

Warmer temperatures also cause faster and earlier snowmelt, which, along with increased precipitation, can cause higher and earlier peak flows. Such increases in peak flow can disturb fish habitats by killing incubating eggs.[17] Ocean acidification caused by increased carbon dioxide concentrations poses yet another threat to the area's coldwater marine ecosystems.[18]

Figure 12.4: Alaska's marine species shift northward, 1982 to 2006



As air and water temperatures rise, Alaska's marine species shift northward. On average, by 2006 the center of each range had moved 19 miles north of its 1982 location.

Source: U.S. Global Change Research Program (see Appendix A)

Higher temperatures could also increase glacial melting and cause more prolonged high, sediment-laden streamflows that can scour supports for bridges, piers, and abutments.[19]

During the growing season, plants pull water from soil through their roots and release some of it as water vapor through their leaves in a process called transpiration. The combination of direct evaporation of water from soils and transpiration of water from soils through plants is called evapotranspiration. Warmer temperatures over the course of the 21st century will expand the growing season and thus expand the time frame in which moisture is extracted from local soils. In the second half of the 21st century, summertime precipitation in the Homer area is not expected to keep up with evapotranspiration rates, thus leaving soils drier than historic values.[20]

It is also possible that reduced snowpack and increased evaporation could lead to freshwater shortages.[21]

ACTION: MITIGATING AND PREPARING FOR CLIMATE CHANGE

In spite of its relatively small population, Homer has made substantive efforts to mitigate and adapt to climate change. The ongoing work by the city to incorporate climate change into its decision-making should serve as an inspiration to cities and states large and small.

Homer's climate mitigation and adaptation strategies help protect Homer's economy.

STATE, REGIONAL, AND CITY PLANS AND GREENHOUSE GAS REDUCTION MEASURES

In 2009 the Alaska Climate Change Strategy—Mitigation Advisory Group recommended that Alaska adopt a statewide greenhouse gas emissions reduction goal of 20 percent below 1990 levels by 2020 and an 80 percent reduction by 2050; however, the state has not yet adopted these targets.[22]

In December 2007 Homer committed to a 12 percent reduction in municipal greenhouse gas emissions from a 2000 baseline by 2012 and a 20 percent reduction by 2020.[23] The initial measures proposed to accomplish this reduction were outlined in Homer's Climate Action Plan (CAP).[24] In December 2009 the city released a more thorough implementation report that details additional measures to reduce greenhouse gas emissions.[25]

NOTABLE LOCAL ADAPTATION EFFORTS

The city's CAP recommends several adaptation measures to address water-related climate change impacts, such as the protection of existing at-risk structures, emergency preparedness, and wise policies for future development. In support of these efforts, Homer has constructed a seawall to protect private homes against near-term coastal erosion; however, city staff believes planning to address sea level rise over the long term is complicated due to the lack of information regarding what structures could be at risk and at what time scale.[26] The city is working with researchers at the Kachemak Bay National Estuarine Research Reserve to better understand the implications of factors affecting sea level rise—such as nearby ice-field melt and upward movement of the earth's crust—for coastal erosion, infrastructure, planning, zoning, public safety, and biological diversity in estuarine ecosystems.[27]

Climate change could also affect freshwater availability for Homer. In 2009 the city installed a new water treatment plant that has a higher capacity and better efficiency than the previous treatment facility.[28] The city is seeking funding for an alternative water source to augment the existing Bridge Creek Reservoir.[29] Homer states that it also encourages water conservation as a way of increasing freshwater availability.[30] Homer has taken steps in long-range planning by including climate change considerations in the City of Homer Comprehensive Plan and Comprehensive Economic Development Strategy. Both of these long-term plans advocate for smart growth policies that take in account greenhouse gas emissions and environmental sustainability. A notable example of the implementation of these practices is the recent adoption of Ordinance 10–56, which provides for development standards (e.g., setback requirements) on steep slopes and coastal bluffs.[31] Similar measures are expected to be implemented over the long term.[32]

Finally, a critical but often overlooked component of mitigation and adaptation strategy implementation is funding. Homer has created a Sustainability Fund and a Revolving Energy Fund to support implementation of its action plan. The Sustainability Fund can be used broadly to implement any action items in the plan, whereas the Revolving Energy Fund can be used only for municipal energy efficiency improvements.[33,34] It is hoped that the city will commit sufficient resources to ensure the viability of both funds.

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Recommendations

Many cities, on their own and in partnership with regions and states, are taking action to address their vulnerability to the impacts of climate change, as discussed in the individual chapters in this report. Mitigating climate change is crucial, through efforts like reducing carbon emissions and investing in energy efficiency and clean sources of energy. But since the level of carbon dioxide in the atmosphere has reached the point where at least some impacts are inevitable and irreversible,[1] all cities can and should take steps to prepare for the effects of climate change.

All United States cities need to fully assess their own water-related vulnerabilities to climate change. A number of cities in this report are on the forefront of examining threats to their water resources posed by a changing climate. However, some cities appear to have neither adequately considered their vulnerabilities to climate change nor taken action to prepare for and address these vulnerabilities. No doubt many other cities fall into this latter category; they must do more to ensure that they understand potential impacts and what they can and should do to prepare.

Undertake vulnerability assessments that include a complete evaluation of water-related risks, including future water availability, precipitation, drought, runoff patterns, sea level rise, and flooding risks. By examining the full suite of potential impacts, cities can better assess their vulnerabilities as well as prepare for a changing climate.

Pursue impact assessment using local data and downscaled or decision-scaled modeling.[2] It is critical to understand the potential impacts of climate change at a local level. The more localized the data, the more relevant and useful they can be. While some level of uncertainty may be inherent in climate predictions, downscaling available data or, better yet, collecting and analyzing local data is critical to making the most accurate local assessments.

Consider both moderate and worst-case scenarios. By considering a range of risks, local efforts will provide better opportunity for effective long-term adjustment and management. More informed political and financial decisions can be made with access to more diverse information about risks and probabilities.

Create an inventory of critical infrastructure at risk due to flooding or sea level rise. Prioritize in the short term the identification of critical facilities at risk (such as roads, hospitals, drinking water supplies and conveyance systems, sewage treatment and conveyance infrastructure) so as to inform longer-term planning, construction, funding, and other resiliency goals. Identifying this critical infrastructure should be based on available information and refined as improved data become available.

Protect critical infrastructure and require utilities to conduct vulnerability assessments of their systems. Ensuring climate-ready utilities is a key aspect of preparing any community for climate change. Local plans should be strengthened by encouraging and, where possible, requiring water and energy utility operators to prepare and update their own site- and system-specific vulnerability assessments, which should include addressing utility vulnerability to flooding or sea level rise.

Identify and protect critical habitat. Protecting critical habitat provides multiple benefits by providing natural buffers for human infrastructure and important refuge for plants and animals that may be at risk from climate change.

Many more cities—and not just those in the arid West—must prepare for changes in available water resources. With changes in rainfall patterns, storm intensity, snowmelt, and evapotranspiration due to climate change, water availability will become an even more important consideration for cities. Cities must plan now for potential drought or fluctuating supply to ensure future availability for people and ecosystems.

Utilize green infrastructure to capture runoff, both to augment water supply and to reduce downstream flooding. The use of green infrastructure and low-impact development in watershed planning offers many benefits and should be encouraged in local planning. Low-impact development is a simple and cost-effective green development strategy that can help cities, states, and even individuals meet the water supply challenge, clean up our existing water resources, and, in many places, curb global warming pollution by reducing the amount of electricity used to supply water (this is particularly true in Southern California).[3] Moreover, large volumes of urban stormwater runoff, discharged through municipal sewer systems, can exacerbate storm surge–related flooding. Green infrastructure can help reduce this effect, by substantially lessening flow volume and velocity and allowing water to naturally infiltrate for use at a later date. In areas where the groundwater table is too high for infiltration, practices that evaporate or evapotranspire water, like rain gardens, or capture-and-use systems such as rain barrels and cisterns can be successfully used.

Employ water conservation and improved water efficiency measures to protect against potential future water shortages. Maximizing conservation and water-use efficiency is one of the most cost-effective measures communities can quickly implement to protect water supplies while also reducing energy use and global warming pollution.[4] Water-use efficiency and water recycling, along with groundwater recharge and stormwater management options, can provide significant opportunities for water managers to simultaneously improve water supply reliability, cut costs, save energy, and reduce greenhouse gas emissions.

Pursue nonstructural solutions and exploit natural protective features to address problems such as sea level rise and flooding. Nonstructural solutions[5] such as the strategic acquisition of land, buffer zones, wetlands, and open space preservation all create multiple benefits that local governments should encourage as options to address concerns about flooding and sea level rise.

Explore creative legal options to address problems such as sea level rise and flooding. State and local governments should explore the adoption or enhancement of legal mechanisms to aid in adaptation to sea level rise, including seawall waivers and rolling easements.[6] Such mechanisms are under consideration in California and Washington as part of their adaptation planning documents[7] as well as in Lee County, Florida, and Worcester County, Maryland.[8] Examples of oft-cited managed retreat initiatives include the Pacifica State Beach managed realignment project and the Surfers Point project at Ventura Beach,[9,10] both in California.

Prioritize the development of clean and efficient energy. Increasing energy efficiency reduces current and future demand for energy, decreases water consumption related to energy production, and reduces greenhouse gas emissions. Cities should take steps to implement comprehensive and ambitious energy efficiency programs that promote clean and water-efficient forms of energy such as wind, solar, and geothermal.

Think about climate change vulnerability and adaptation in terms of emergency preparedness or risk management planning. This type of approach helps provide a framework with which many city officials and planners are readily familiar and can reduce uncertainty about how to tackle the problem of climate change. For example, conservation planners in Oregon think in terms of preparing for a "slow-moving tsunami"—one that takes years to come ashore but lasts longer and covers a bigger area—when addressing sea level rise.[11]

Pursue regional partnerships for climate change research and planning. Working together is a smart strategy. Neighboring communities can pool resources to develop better data, coordinate on policy development, and share information through events like regional summits. Regional partnerships can in turn provide resources to other, smaller communities to plan for climate change.

Even small cities and cities with limited resources can prepare for climate change. Homer, Alaska, is a good example of a small city with limited resources that has begun the process of assessing and preparing for the potential impacts of climate change. Even places like New York State have been creative in using volunteers to help formulate adaptation strategies, as it did for its recent sea level rise report. Resource-strapped cities can and should pursue similar strategies.

Provide ample opportunity for participation by local stakeholders. Local input is key to any vulnerability assessment and adaptation strategy. Proper planning should include not only city personnel but representatives from local water and energy utilities, emergency response personnel, natural resource managers, homeowners, businesses, and environmental groups.

Take advantage of resources that are designed to help. Environmental organizations like NRDC produce reports designed to educate and assist policymakers and the general public. Recent reports including *In Hot Water: Water Management Strategies to Weather the Effects of Global Warming, Hotter and Drier: The West's Changed Climate,* and *A Clear Blue Future: How Greening California Cities Can Address Water Resources and Climate Challenges in the 21st Century* provide information on the connection between climate change and water resources and solutions for better water management.[12]

A lot of resources exist to specifically aid cities in their assessment and planning efforts. Some resources that might prove particularly useful at a local level include:

- **International Council for Local Environmental Initiatives (ICLEI),** available at *www.icleiusa.org/programs/climate/Climate_Adaptation/about-iclei/members/member-list*;
- **Climate Knowledge Adaptation Exchange,** available at *www.cakex.org*; and
- **EPA's Climate Ready Water Utilities Toolbox,** available at *www.epa.gov/safewater/watersecurity/climate/toolbox.html.*

Legal Options

As highlighted by Caldwell and Segall,[1] numerous legal options exist to protect communities from sea level rise. For example:

- A Maine statute provides that no project may be permitted "if, within 100 years, the property may reasonably be expected to be eroded" and provides that "no new seawall may be constructed."[2]
- Massachusetts regulations stipulate that development on coastal dunes may not interfere with "the landward or lateral movement of the dune" and that development on unconsolidated banks will not be allowed to use seawalls to prevent erosion, except for bank structures existing at the time of the law's passage (1978).[3]
- Rhode Island bars essentially all erosion-control structures along the oceanfront portion of its coast.[4]
- A North Carolina statute provides that no "permanent erosion control structure" may be erected "in an ocean shoreline."[5]
- In Oregon, regulations bar all permits for shoreline armoring for all development built after 1977, and permitted structures must avoid or minimize impact to resource values, including habitat quality.[6]

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APPENDIX A
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