NRDC DOCUMENT

APRIL 2012 D:12-03-D

Ready or Not: An Evaluation of State Climate and Water Preparedness Planning

AUTHOR
Ben Chou
Natural Resources Defense Council

PROJECT DESIGN AND DEVELOPMENT
Steve Fleischli
Natural Resources Defense Council

CONTRIBUTING AUTHOR
Jenna Schroeder

Across the United States, climate change is affecting water resources in many ways, including putting water supplies at risk, increasing flooding and erosion, and threatening fish and aquatic species. As global warming pollution continues to affect our environment, these risks to water resources will only increase, posing grave challenges to our nation's cities, towns, and neighborhoods. Some states are leading the way in preparing for water-related impacts with integrated and comprehensive preparedness plans that address all relevant water sectors and state agencies. Unfortunately, other states are lagging when it comes to consideration of potential climate change impacts-or have yet to formally address climate change preparedness at all.

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Acknowledgments

NRDC would like to acknowledge the generous support of the TOSA Foundation and the Pisces Foundation.
The authors would like to thank Esther Conrad, PhD candidate at the University of California at Berkeley; Fay Augustyn, Katherine Baer, Liz Garland, Brett Swift, Michael Garrity, Sean Foltz, and Michael Fiebig at American Rivers; and Jessica Troell and Jim McElfish at the Environmental Law Institute (ELI) for their guidance and expertise in reviewing the report.

The authors would like to thank Sheryl Carter, Ed Chen, Meleah Geertsma, Becky Hammer, Antonia Herzog, Matt Howes, Karen Hobbs, Alex Kennaugh, Larry Levine, Luis Martinez, Barry Nelson, Monty Schmitt, Tom Singer, Theo Spencer, and Tina Swanson at NRDC for their input and guidance in the development of this report.

The authors would like to thank the following individuals for their contributions to this report: Amanda Stevens, New York State Energy Research and Development Authority; Amber Mace, California Ocean Protection Council; Ames Colt, Rhode Island Office of the Governor/Department of Environmental Management; Andy Holdsworth, Minnesota Department of Natural Resources; Angela Bordegaray, New Mexico Interstate Stream Commission/Office of the State Engineer; Beth Polak, Virginia Coastal Zone Management Program; Bill Caldwell, Kentucky Division of Water; Braxton Davis, South Carolina Department of Health and Environmental Control; Brian Atkins, Alabama Office of Water Resources; Carolyn Rumery Betz, Wisconsin Initiative on Climate Change Impacts; Cheri Vogel, New Mexico Office of the State Engineer; Christine Schell, New Jersey Department of Environmental Protection; Dan Evans, Florida Department of Economic Opportunity; Dan Hardin, Texas Water Development Board; Danny Clayton, Florida Coastal Management Program; David Carter, Delaware Department of Natural Resources and Environmental Control; David Liebl, Wisconsin Initiative on Climate Change Impacts; Dennis McMurray, Illinois Environmental Protection Agency; Dennis Todey, South Dakota State University; Doug McVay, Rhode Island Department of Environmental Management; Ed Swain, Arkansas Natural Resources Commission; Ellen Weiss, The Nature Conservancy Eastern New York Chapter; Glade Sowards, Utah Division of Air Quality; Gwen Dunnington, Vermont Department of Environmental Conservation; Hamilton Davis, Coastal Conservation League; Hedia Adelsman, Washington Department of Ecology; Helen Harrington, Idaho Department of Water Resources; Janine Nicholson, North Carolina Department of Environmental and Natural Resources; Jeff Weber, Oregon Coastal Management Program; Jeffrey Hoffman, New Jersey Department of Environmental Protection; Jen Pagach, Connecticut Department of Environmental Protection; Jennifer Kline, Georgia Department of Natural Resources; Jesse Souki, Hawaii State Office of Planning; Jill Alban, Clark Fork Coalition; John Andrew, California Department of Water Resources; John Jacob, Texas Sea Grant; Jon Wade, Wyoming Water Development Office; Joseph Sherrick, Pennsylvania Department of Environmental Protection; Julia Levin, California Natural Resources Agency; Kathie Dello, Oregon Climate Service; Kathleen Baskin, Massachusetts Executive Office of Energy and Environmental Affairs; Kevin Reidy, Colorado Water Conservation Board; Kurt Hollman, Missouri Department of Natural Resources; Laurna Kaatz, Denver Water; Logan Respess, Texas Sea Grant; Malcolm Burson, Maine Department of Environmental Protection; Kathleen Neill, Florida Department of Transportation; Malcolm J. Wilson, Nevada Division of Water Resources; Margaret Schneemann, Illinois-Indiana Sea Grant; Marjorie Kaplan, New Jersey Department of Environmental Protection; Mark Lowery, New York State Department of Environmental Conservation; Marnie Stein, Iowa Department of Natural Resources; Melissa Iwamoto, University of Hawaii at Manoa; Michael Beaulac, Michigan Department of Environmental Quality; Nancy Hess, Rhode Island Division of Planning; Nap Caldwell, Georgia Department of Natural Resources; Nathan Sanderson, South Dakota Office of the Governor; Patrick Fridgen, North Dakota State Water Commission; Paul Driscoll, Montana Department of Environmental Quality; Ray Alvarado, Colorado Water Conservation Board; Sally Russell Cox, Alaska Division of Community and Regional Affairs; Sarah Pillsbury, New Hampshire Department of Environmental Services; Scott Kudlas, Virginia Department of Environmental Quality; Sherry Godlewski, New Hampshire Department of Environmental Services; Skip Stiles, Wetlands Watch; Spencer Reeder, Cascadia Consulting Group; Steve Sempier, Mississippi-Alabama Sea Grant Consortium; Sue Richards, Idaho Department of Environmental Quality; Susan France, Nebraska Department of Natural Resources; Tancred Miller, North Carolina Division of Coastal Management; Taryn Hutchins-Cabibi, Colorado Water Conservation Board; Terry Johnson, Alaska Sea Grant; Tim Asplund, Wisconsin Department of Natural Resources; Tim Loftus, Chicago Metropolitan Agency for Planning; Tom Buschatzke, Arizona Department of Water Resources; Tracy Streeter, Kansas Water Office; Wilfred Nagamine, Hawaii Department of Health; and Zoe Johnson, Maryland Department of Natural Resources.

This report and its recommendations are solely attributable to NRDC and do not necessarily represent the views of these individuals.

NRDC Director of Communications: Phil Gutis
NRDC Deputy Director of Communications: Lisa Goffredi
NRDC Publications Director: Alex Kennaugh
Design and Production: Sue Rossi

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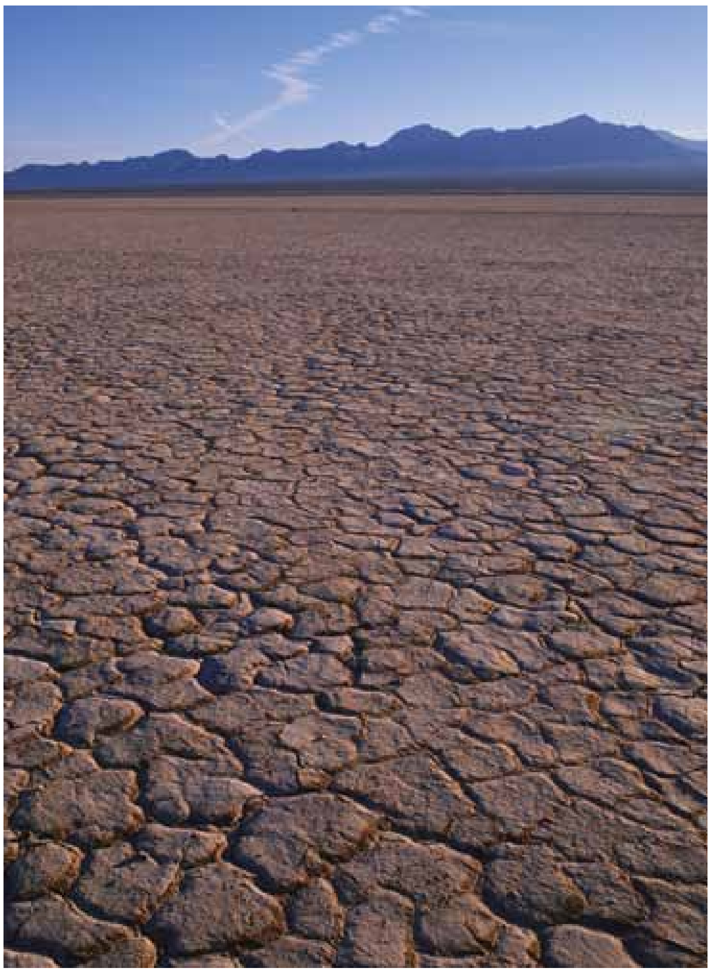
EXECUTIVE SUMMARY

Every region of the United States is potentially vulnerable to adverse water-related impacts from climate change. Some states are taking action by reducing the greenhouse gas pollution that contributes to climate change and by planning for projected climate change-related impacts. However, many states are not. Nonetheless, the effects of climate change on the nation's water resources already are being observed. According to the U.S. Global Change Research Program (USGCRP), warmer temperatures are causing changes to the water cycle that include:



- Changes in precipitation patterns and intensity
- Increases in evaporation
- Changes in runoff and soil moisture
- Changes in the occurrence of drought
- Widespread melting of snow and ice
- Loss of lake and river ice
- Rising water temperatures[1]

These changes and their effects on water resources will have wide-ranging impacts on our nation's cities, towns, and neighborhoods, as well as on our natural resources, and will only intensify as atmospheric greenhouse gas levels grow and temperatures rise further (see Figure ES-1). For a more detailed summary of potential water-related impacts of climate change for each state, see Table ES-1.

To address climate change threats, many states have developed greenhouse gas pollution reduction plans and/or adopted greenhouse gas pollution reduction targets. In fact, 36 states have developed climate action plans that identify measures to reduce greenhouse gas pollution. Meanwhile, 22 states have formally adopted or established greenhouse gas pollution reduction targets or goals. A summary of state actions on climate change pollution reduction and preparedness can be found in Table ES-2.

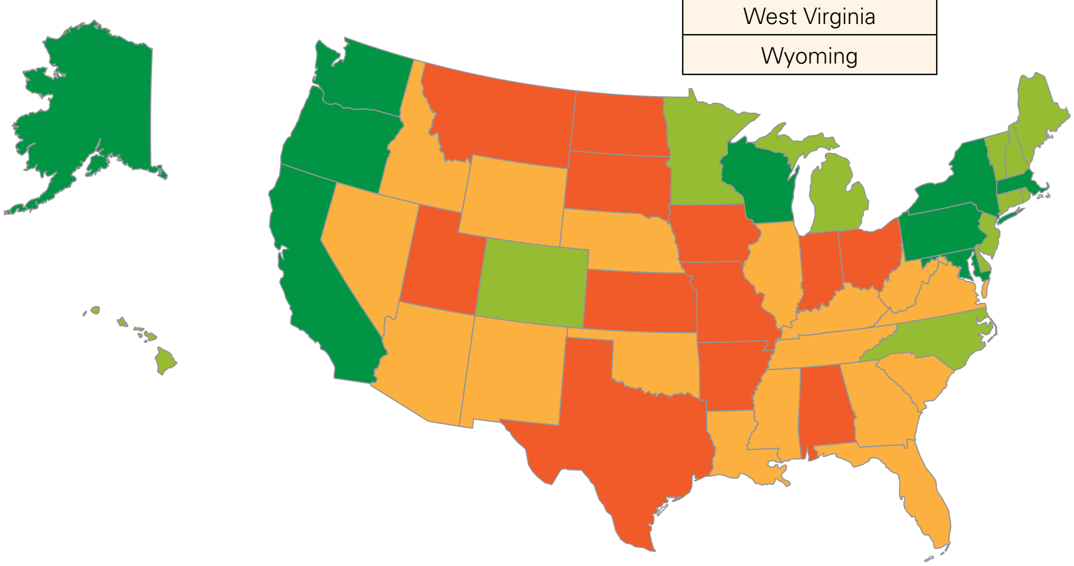
Figure ES-1: Water-related impacts of climate change

CHANGES IN CLIMATE AND RELATED FACTORS	IMPACTS ON WATER RESOURCES
Changes in precipitation, streamflow, and groundwater recharge	Implications for water supply
Shifts in streamflow timing	Implications for water availability and hydropower production
Drought conditions	Threat to all users that rely on water including municipalities, agriculture, and industries
Warmer air temperatures	Compound water availability issues by increasing water demand for irrigation and power plant cooling[2]
Earlier snowmelt and more precipitation falling as rain than snow	Increases in wintertime flooding risks and changes to water availability
More intense rainfall events	Increased flooding risks to property and overwhelmed infrastructure like wastewater treatment plants, leading to increased discharges of untreated sewage
Rising sea levels	Coastal flooding and erosion, saltwater intrusion into coastal freshwater aquifers, threats to aquatic and marine ecosystems[3]
Warmer water temperatures	Reduced dissolved oxygen and less thermally-suitable habitat for aquatic species[4]
Increasing atmospheric concentrations of carbon dioxide	Declining pH of the oceans, which affects the ability of marine organisms to maintain and build calcium carbonate shells and skeletons[5]

The full analysis for this brief provides a state-by-state assessment that specifically focuses on how state governments are planning and preparing for the water-related impacts of climate change. Based on the preparedness actions of state government entities, all 50 states have been categorized into one of four categories, developed to differentiate the best prepared and most engaged states on climate change preparedness issues (i.e., Category 1 and 2) from those that are largely unprepared and lagging behind (i.e., Category 3 and 4). Although many states have yet to formally address climate change preparedness within state government (and therefore fall within Category 4), a number of these states have existing water policies or programs, such as water conservation or efficiency policies, that if recognized within the context of climate change, could prove beneficial.

Figure ES-2: Ranking of states according to climate preparedness planning

Category 1	Category 2	Category 3	Category 4
Alaska*	Colorado	Arizona	Alabama
California	Connecticut	Georgia	Arkansas
Maryland	Delaware	Florida	Indiana**
Massachusetts	Hawaii	Idaho	Iowa
New York	Maine	Illinois	Kansas**
Oregon*	Michigan	Kentucky	Missouri
Pennsylvania*	Minnesota	Louisiana	Montana
Washington	New Hampshire	Mississippi	North Dakota
Wisconsin*	New Jersey	Nebraska	Ohio
	North Carolina	Nevada	South Dakota
	Rhode Island	New Mexico	Texas**
	Vermont	Oklahoma	Utah**
		South Carolina	
		Tennessee	
		Virginia	
		West Virginia	
		Wyoming	



*Denotes a state where climate preparedness activities at the state government level, although once more robust, appear to have slowed or stalled in some planning areas.
**Denotes a state that has some existing water programs and policies (e.g., water conservation) that, if recognized as climate change adaptation tools, could prove beneficial for climate preparedness.

Unfortunately, within roughly the last two years, climate action at the federal legislative and state government levels has noticeably diminished as economic conditions have deteriorated and political interests have shifted. This trend has affected some of the states that have seemingly made the most progress on climate change preparedness planning. Many of the state agency personnel that were contacted for this report indicated that without a top-down directive from the executive level, there is unlikely to be sufficient action by all necessary government agencies within a state on climate change issues. There are clear limits to how far climate preparedness planning can proceed based on a strictly voluntary approach and without executive level support or leadership.

Despite these obstacles, states can implement *no regret* and *multiple benefit* strategies, such as green infrastructure, water conservation, and efficiency measures that address existing water quality and quantity challenges, while also building resilience to climate change impacts.

Governors across the United States must do what is in the best interest of their states and local communities and prioritize and support climate change preparedness planning. To prepare for the impacts of climate change, all states can and should:

Set greenhouse gas pollution reduction targets or goals and develop a plan for meeting these reduction levels

Greenhouse gas pollution reduction and climate change preparedness are related. Globally, the level of greenhouse gas emissions plays a role in determining the severity of climate change impacts. States should formally establish greenhouse gas pollution reduction targets and implement measures to reduce emissions.

Develop a stakeholder group to organize and coordinate state-level adaptation planning and implementation

The states that are the most effective at integrating climate change adaptation into state agency operations, planning, and programs have a central coordinating group to organize adaptation efforts among agencies and organizations within the state. Personnel from state agencies with jurisdiction over water quality, water quantity, hazard response, transportation, public health, aquatic species, and coastal management (where relevant) can help form a comprehensive preparedness team.

Foster partnerships to stay current on climate science and sector-specific developments

Because knowledge around climate modeling and adaptation tools is rapidly evolving, states can benefit from fostering partnerships with the research community to bolster their expertise and remain current on these issues.

Conduct a statewide vulnerability assessment to determine potential climate change impacts

These assessments should include an evaluation of water-related impacts, including precipitation changes, water supply availability, drought, flooding, hydrologic changes, water quality, and, where applicable, sea level rise. The evaluation of a comprehensive set of climate change impacts enables states to better understand their vulnerabilities and develop strategies to reduce them.

Develop a comprehensive adaptation plan to address climate risks in all relevant sectors and integrate climate change preparedness into existing planning processes

Actions and strategies to address vulnerabilities and risks identified during the assessment process should be developed. Framing climate change vulnerability and preparedness planning in terms of emergency or risk management can be useful as many state and municipal officials are readily familiar with this type of approach. Moreover, comprehensive planning should include input from a wide variety of stakeholders—including those outside of state government—and prioritize non-structural and *no regrets* strategies like green infrastructure and water conservation and efficiency. States also should use caution when making investments in *hard* or *gray* infrastructure that is costly and inflexible in the face of changing hydrologic conditions, and may inhibit effective adaptation in the long run. Furthermore, climate change factors should be integrated into existing planning frameworks and policies. This process may benefit from regional partnerships or collaborative efforts to pool resources and share information.

Prioritize and support implementation of the adaptation plan

Goals and tracking metrics to measure the progress of plan implementation are vital, and specific tasks and implementation mechanisms needed to achieve these goals should be developed. Minimum staffing and funding levels also must be made available to support effective implementation of the adaptation plan.

Measure progress regularly and update the adaptation plan as needed

Climate change preparedness should be an iterative and informed process. As climatic conditions change and new information is made available, reevaluation of adaptation options is appropriate. States also should measure progress towards achieving established adaptation goals and make modifications as necessary.

Federal action also is critical

In addition to direct state action, there is clearly a role for the federal government in cutting carbon pollution and supporting climate change preparedness activities in the states. While state efforts to cut carbon pollution are important, federal limits are essential. The Environmental Protection Agency (EPA) is developing standards to limit carbon pollution from new and existing power plants, which will save lives, create jobs, and protect our environment.

Power plants are our nation's biggest carbon polluters. The public health threats to our children, seniors and communities from climate change—fueled by rising levels of dangerous carbon pollution and the resulting temperature increases—include more heat deaths; respiratory complications (such as asthma attacks); more infectious diseases; and severe dangers to life, limb, and property during storms, floods, and other extreme weather events. In addition to finding their own ways to lower carbon pollution, states should be supporting the EPA's efforts to set national standards for power plants.

The federal government, via agencies like the White House Council on Environmental Quality (CEQ), National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), U.S. Department of Agriculture (USDA), and Environmental Protection Agency (EPA), can help states by providing technical information on the projected scope and impacts of climate change. Many states and local governments currently lack the capacity and expertise to conduct some of this research on their own.

Despite the numerous benefits that would result from adaptation planning and action, many states will not act until they are prompted to do so by the federal government. These states must do significantly more to prepare for the water-related impacts of climate change. The federal government can lead by example by requiring climate change impacts to be considered as part of federal agencies' analyses under the National Environmental Policy Act (NEPA).

There also are numerous pathways of funding between the federal government and state governments—Coastal Zone Management Administration Awards, Clean Water and Drinking Water State Revolving Funds, disaster mitigation funding—that should be utilized to advance climate change preparedness planning at the state and local level. The federal government has a key opportunity to ensure effective adaptation by requiring states to consider the implications of climate change in their use of federal funds.

Finally, the actions necessary to prepare and respond to climate change impacts ultimately must be implemented at a local level. While many municipalities are outpacing their respective state governments in addressing climate change,[6] various issues concerning water resources cross political and jurisdictional boundaries and require coordination at a much larger scale. Some municipalities also lack sufficient resources and the capacity to comprehensively prepare for climate impacts. By working together, local, state, and federal governments can ensure that all communities across the United States are better prepared for the water resource challenges inherent in a changing climate. To tackle these challenges, some states are leading the way. It is time for the others to follow.

Table ES-1: Summary of potential climate change impacts within each state.[7]

	Increased Annual Precipitation	Decreased Annual Precipitation	Water Supply Challenges	More Frequent and Intense Storm Events	Increased Flooding	Sea Level Rise	Increased Erosion	Saltwater Intrusion	Aquatic/ Marine Species Impacts
Alabama			●	●	●	●	●	●	●
Alaska	●		●	●	●	●	●	●	●
Arizona		●	●		●				●
Arkansas		●	●						
California			●	●	●	●	●	●	●
Colorado			●	●	●				●
Connecticut			●	●	●	●	●	●	●
Delaware	●		●	●	●	●	●	●	●
Florida			●	●	●	●	●	●	●
Georgia			●		●	●	●	●	●
Hawaii				●	●	●	●	●	●
Idaho			●	●	●		●		●
Illinois			●	●	●		●		●
Indiana	●			●	●		●		●
Iowa			●	●	●		●		●
Kansas			●	●					
Kentucky			●	●	●				●
Louisiana				●	●	●	●	●	●
Maine	●		●	●	●	●	●	●	●
Maryland			●	●	●	●	●	●	●
Massachusetts			●	●	●	●	●		●
Michigan	●		●	●	●		●		●
Minnesota	●			●	●		●		●
Mississippi			●	●	●	●	●	●	●
Missouri				●	●				●
Montana	●			●	●		●		●
Nebraska			●	●					
Nevada			●		●		●		●
New Hampshire	●		●	●	●	●	●	●	●
New Jersey	●		●	●	●	●	●	●	●
New Mexico			●	●	●				●
New York	●		●	●	●	●	●	●	●
North Carolina			●	●	●	●	●	●	●
North Dakota				●	●				
Ohio				●	●		●		●
Oklahoma			●	●	●				●
Oregon			●	●	●	●	●		●

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	Increased Annual Precipitation	Decreased Annual Precipitation	Water Supply Challenges	More Frequent and Intense Storm Events	Increased Flooding	Sea Level Rise	Increased Erosion	Saltwater Intrusion	Aquatic/ Marine Species Impacts
Pennsylvania	●			●	●		●	●	●
Rhode Island	●			●	●	●	●		●
South Carolina			●	●	●	●	●	●	●
South Dakota				●	●		●		
Tennessee			●	●	●				●
Texas			●	●	●	●	●	●	●
Utah			●	●					●
Vermont	●			●	●				●
Virginia	●		●		●	●	●	●	●
Washington			●	●	●	●	●	●	●
West Virginia				●	●		●		●
Wisconsin	●			●	●		●		●
Wyoming			●						●

Table ES-2: Summary of climate change actions by each state.

	POLLUTION REDUCTION		ADAPTATION/PREPAREDNESS			
			CATEGORY 1	CATEGORY 2	CATEGORY 3	CATEGORY 4
	GHG Reduction Target/Goal	GHG Pollution Reduction Plan	Comprehensive Adaptation Plan	Fragmented Adaptation Activities	Limited Adaptation Activities	No Adaptation Planning
Alabama						✘
Alaska		✔	✔			
Arizona	✔	✔			✔	
Arkansas		✔				✘
California	✔	✔	✔			
Colorado	✔	✔		✔		
Connecticut	✔	✔		✔		
Delaware		✔		✔		
Florida	✔	✔			✔	
Georgia					✔	
Hawaii	✔	✔		✔		
Idaho					✔	
Illinois	✔	✔			✔	
Indiana						✘
Iowa		✔				✘
Kansas						✘
Kentucky		✔			✔	
Louisiana					✔	
Maine	✔	✔		✔		
Maryland	✔	✔	✔			
Massachusetts	✔	✔	✔			

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	GHG Reduction Target/Goal	GHG Pollution Reduction Plan	Comprehensive Adaptation Plan	Fragmented Adaptation Activities	Limited Adaptation Activities	No Adaptation Planning
Michigan	✔	✔		✔		
Minnesota	✔	✔		✔		
Mississippi					✔	
Missouri		✔				✘
Montana		✔				✘
Nebraska					✔	
Nevada		✔			✔	
New Hampshire	✔	✔		✔		
New Jersey	✔	✔		✔		
New Mexico	✔	✔			✔	
New York	✔	✔	✔			
North Carolina		✔		✔		
North Dakota						✘
Ohio						✘
Oklahoma					✔	
Oregon	✔	✔	✔			
Pennsylvania		✔	✔			
Rhode Island	✔	✔		✔		
South Carolina		✔			✔	
South Dakota						✘
Tennessee		✔			✔	
Texas		✔				✘
Utah	✔	✔				✘
Vermont	✔	✔		✔		
Virginia	✔	✔			✔	
Washington	✔	✔	✔			
West Virginia					✔	
Wisconsin		✔	✔			
Wyoming					✔	

Endnotes

1 U.S. Global Change Research Program, "Water Resources," *Global Climate Change Impacts in the United States* (2009), 41, http://www.globalchange.gov/images/cir/pdf/water.pdf.

2 Ibid., 49.

3 Ibid., 47.

4 Ibid., 46.

5 U.S. Global Change Research Program, "Regional Impacts: Coasts," *Global Climate Change Impacts in the United States* (2009), 151, http://www.globalchange.gov/images/cir/pdf/coasts.pdf.

6 See Mark Dorfman, Michelle Mehta, Ben Chou, Steve Fleischli and Kirsten Sinclair Rosselot, *Thirsty for Answers: Preparing for the Water-related Impacts of Climate Change in American Cities* (August 2011), 9, NRDC, http://www.nrdc.org/water/files/thirstyforanswers.pdf.

7 If a state is not identified as likely to experience a specific climate change-related impact, this does not necessarily mean that the state is not vulnerable to that impact—only that the literature reviewed contained insufficient information to make a determination. Because the underlying methodologies used to determine projected climate change impacts in the studies considered may differ, climate impacts from different studies should not be directly compared.

Background

Extreme weather in the form of drought, flooding, and other events over the past several years has vividly reminded many people of our vulnerability to weather and climate. Climate change is expected to worsen in the future, increasing this trend of greater variability and more extreme weather events. Across the United States the impacts of climate change on the nation's water resources are already being observed. Between 1906 and 2005, global surface temperatures increased approximately 1.3°F (0.74°C) at an average rate of 0.13°F (0.074°C) per decade.[1] In recent decades this rate of warming has accelerated. Over the past 50 years, the warming trend has averaged 0.23°F (0.13°C) per decade—nearly twice the rate of warming over the past century.[2] According to the Intergovernmental Panel on Climate Change (IPCC), future average global temperatures are projected to increase by 2°F to 11.5°F (1.1°C to 6.4°C) by the end of this century, depending on the rate of future greenhouse gas emissions.[3] Increasing temperatures, changing precipitation patterns, and rising sea levels are fundamentally altering our communities and ecosystems. According to the U.S. Global Change Research Program (USGCRP), observed impacts on the water cycle from warmer temperatures include:

- Changes in precipitation patterns and intensity;
- increases in evaporation;
- changes in runoff and soil moisture;
- changes in the occurrence of drought;
- widespread melting of snow and ice;
- loss of lake and river ice; and
- rising water temperatures.[4]

Hydrologic Impacts

As temperatures increase further, the impacts on water resources will only intensify. Warmer temperatures will increase evaporation from land and ocean surfaces, leading to greater moisture in the atmosphere. These atmospheric changes, in turn, will alter the distribution of precipitation by shifting storm tracks and amplifying hydrologic extremes, making wet areas wetter and dry areas drier.[5] Flooding events are also likely to become more prevalent as more precipitation occurs during heavier, more intense events.[6] Drought conditions are also likely to become more common as hotter temperatures reduce soil moisture and dry periods between rainfall events lengthen.[7]

As precipitation patterns and evapotranspiration rates change, runoff will also be affected. Reductions in snowpack, as well as increases in precipitation falling as rain instead of snow due to warmer air temperatures, will impact the timing and quantity of runoff in snowfall-dominated watersheds in the western and northeastern United States.[8] Furthermore, climate models project that eastern areas of the U.S. will experience increased runoff while parts of the western interior and southwestern U.S. face substantial declines.[9] Groundwater recharge rates will likely be reduced in areas where precipitation declines or surface runoff increases.[10] Water quality will also be affected by climate change. Warmer water temperatures that result from increasing air temperatures could impact aquatic habitats by reducing dissolved oxygen availability and limiting the range of species.[11] Increases in heavy rainfall events also could degrade water quality by flushing pollutants into waterways, and reductions in streamflow could serve to increase the concentration of pollutants in streams.[12]

These changes to hydrologic conditions will have wide-ranging impacts on our nation's cities, towns, and neighborhoods. Changes in streamflow and in rates of groundwater recharge will have implications for water supply, and shifts in streamflow timing could impact hydropower production. Wintertime flood risks could increase as snowmelt occurs earlier and more precipitation falls as rain rather than snow. More extreme rainfall events also are likely to increase flooding risks to property and overwhelm infrastructure such as wastewater treatment plants, which could lead to discharges of untreated sewage. Drought conditions could potentially threaten all users of water, including municipalities, agriculture, and industry. And warmer temperatures could compound water availability issues by increasing water demand for irrigation and power plant cooling.[13]

Coastal Impacts

Many coastal areas will be particularly threatened by climate change. Global sea level rise occurs due to the thermal expansion of water as air temperatures climb as well as the melting of land-based polar and glacial ice. Relative sea level rise is the net change in local sea level due to the combined effects of global sea level rise and local land subsidence or emergence. Land subsidence and emergence generally occur due to plate tectonics and/or glacial isostatic adjustment (i.e., the rise or fall of land masses associated with the accumulation and melting of ice sheets). Land subsidence may also result from ground compaction. From 1961 to 2003, the global average sea level rose at an average rate of 0.07 inch (1.8 mm) per year.[14] Like temperatures, the global rate of sea level rise has accelerated within recent decades. Between 1993 and 2003, the rate averaged about 0.12 inch (3.1 mm) per year.[15] In some coastal states, such as Louisiana, Texas, and Virginia, land subsidence is contributing to rates of relative sea level rise of as much as 0.36 inch (9.24 mm) per year.[16] In its most recent assessment report, the IPCC projects that global average sea levels could rise 0.6 to 1.9 feet (18 to 59 cm) by 2100.[17] However, recent studies suggest that dramatically greater sea level rise—on the order of 2.5 to 6.2 feet (75 to 190 cm) by the end of the century—is possible due to the rapid melting of ice,[18] though there is considerable uncertainty regarding the future acceleration of ice sheet mass loss.[19]

The nation's coastal areas are generally heavily populated—an estimated 53 percent of the U.S. population resides in a coastal county.[20] Consequently, significant numbers of people and substantial amounts of property and infrastructure could be at risk from inundation, flooding, and erosion associated with sea level rise. Low-lying areas will be subject to permanent inundation and flooding from normal tidal events and storm surge from coastal storms. In addition, sea level rise is expected to exacerbate saltwater intrusion into coastal freshwater aquifers.[21] When the potentiometric surface, or water elevation, of an adjacent aquifer falls below sea level, saline water further intrudes into the coastal aquifer.[22] Natural habitats will also be affected by rising seas. Coastal wetlands, beaches, and barrier islands will be subject to permanent inundation and erosion. A sea level rise of 3 feet would submerge approximately 65 percent of all coastal marshlands and swamps in the U.S.[23] In many areas, wetlands act as a buffer against storm surge, wave action, and erosion. In coastal areas where saltwater and freshwater mix, salinity changes from a combination of shifts in freshwater inflow and sea level rise could negatively impact vegetation and estuarine species. These ecosystems provide habitat for a wide range of species, including fish, birds, and other wildlife.[24] In addition, commercially important shellfish and finfish species rely on tidal wetlands for habitat.[25] Consequently, changes to coastal habitats could have severe repercussions for a variety of estuarine and marine species.

As air temperatures rise, sea surface temperatures will rise as well. During this century, coastal waters are likely to warm by 4°F to 8°F (2.2°C to 4.4°C).[26] Warmer ocean temperatures would undoubtedly impact the distribution and health of marine species. A northward shift in the distribution of marine species has already been observed as coastal waters have warmed beyond the temperature tolerance of some animals.[27] Surface water warming also can lead to coral bleaching, which occurs when corals become stressed and release their symbiotic algae.[28] If the stress continues, the coral die. Coral reef ecosystems in the Atlantic, Caribbean, and Pacific are rich in biodiversity and provide habitat and food to many marine species, in addition to being a large tourism draw.[29] Additionally, increasing atmospheric concentrations of carbon dioxide are causing a decline in the pH of the oceans. More acidic conditions impact the ability of marine organisms to maintain and build calcium carbonate shells and skeletons.[30] Plankton, shellfish, and coral reefs are particularly vulnerable to acidification, and any reductions in populations of these species would reverberate through the food chain.

State Action

Many of the initial climate-related actions taken by state governments focused on reducing greenhouse gas pollution. In some states, these activities were driven by a belief that federal legislation or other national action on climate change was imminent and that the state should take steps in advance of federal action. In other states, the need to play a leadership role on climate issues in the absence of timely federal legislative action was the motivating factor. The analysis conducted for this report indicates that 36 states have developed or are in the process of developing a climate action plan that identifies measures to reduce greenhouse gas pollution. In addition, 22 states have formally adopted or established greenhouse gas pollution reduction targets or goals through executive orders or state legislation.

Interest in adaptation or preparedness issues, however, has not been nearly as widespread or extensive. Climate change adaptation planning involves developing strategies to combat or cope with the existing or expected impacts of climate change. Within roughly the past two years, many state governments have responded to declining economic conditions by reducing staffing levels and budgetary expenditures, thereby severely hampering climate-related operations. Despite these setbacks, some state and municipal governments are moving forward aggressively to address climate change vulnerabilities and to build resilience (i.e., the capacity to withstand the impacts of climate change) at the local and regional levels. In fact, many municipalities are outpacing their respective state governments in addressing climate change.[31] However, many issues concerning water resources cross political and jurisdictional boundaries and require coordination at a much larger scale. In addition, many municipalities lack sufficient resources and the capacity to comprehensively prepare for climate impacts. In states where state-level action is lagging progress at the regional or local level, state agencies and executive-level offices should actively engage these entities and learn from their experiences. Ultimately, state-level action is needed to ensure that all communities across the U.S. are better prepared to weather the impacts of a warmer world.

Methodology

This assessment specifically focuses upon the water-related impacts of climate change (precipitation decreases, heavy rainfall events, sea level rise, etc.) and how state governments are planning and preparing for these impacts. Information on the projected climate change impacts for each state was gathered from a variety of sources, including peer-reviewed scientific journals, federal and state government studies and publications, and reports from research institutions and non-governmental organizations. Where state-specific studies or reports were not available, data from the regional climate impacts section of the U.S. Global Change Research Program's 2009 National Climate Assessment, in addition to any other available regional reports or studies, were utilized. Because the underlying methodologies used to determine projected climate change impacts in these studies may differ, climate impacts from different studies should not be directly compared. If a particular state is not identified as likely to experience a specific climate change impact, this does not necessarily mean that the state is invulnerable to that impact—only that the reviewed literature contained insufficient information to make a determination. Information on each state's planning actions on climate change pollution reduction and adaptation, as well as general water resources planning, was obtained from federal and state government websites and publications, publications by non-governmental organizations and research institutions, and correspondence with state government officials and agency personnel. The information included in this assessment is as accurate and up-to-date as possible; however, due to the dynamic and fluid nature of many of these activities, some of the information included may no longer be current.

For the purposes of this report, only those actions undertaken by state government entities, such as executive-level offices (i.e., governor), legislative bodies, or state agencies, were considered "state actions." Publicly funded research institutions, including Sea Grant College programs—although included in relevant state chapters in this report—were not considered state government entities for our purposes of classification. On the basis of the information gathered regarding a state's actions on climate change preparedness and general water resources planning and implementation, each state was placed into one of four categories. These categories were developed to differentiate what are believed by the authors to be the best-prepared and most engaged states on climate change preparedness issues from those that are largely unprepared and lagging behind. A sincere attempt to accurately categorize each state in accordance with the criteria outlined below was made, and special conditions or developments not captured by the criteria but considered noteworthy are mentioned where relevant. Although the authors attempted to make the evaluation process as impartial and as consistent as possible, the qualitative nature of these criteria remains somewhat subjective.

Category	Description
1	The state has developed an integrated and comprehensive adaptation plan that addresses all relevant water sectors and state agencies, and the state is working on implementation.
2	Activities to adapt to water-related climate change impacts are under way in select state agencies, but they are fragmented, not fully coordinated, or not guided by an overarching strategy or plan.
3	The state's consideration of potential climate change impacts on water resources in existing programs and policies is limited. For example, such consideration may take place within the context of a completed state wildlife action plan or as a small component of coastal restoration and management activities.
4	The state has yet to formally address climate change adaptation.

The state chapters in this report are organized alphabetically. Each state is classified, from Category 1 (for the states that are the most engaged in adaptation planning) to Category 4 (for those that have yet to formally address adaptation). However, there are a number of Category 4 states that have existing policies or programs that could prove beneficial within the context of climate change if recognized and implemented as adaptation measures. These policies or programs are included in the relevant state chapters. Conversely, there are four Category 1 states where progress on climate preparedness at the state level has slowed or stalled in some planning areas.

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8 USGCRP 2009a at 45.
9 USGCRP, note 8.
10 USGCRP 2009a at 47.
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28 USGCRP, note 23.
29 USGCRP, note 23.
30 USGCRP, note 26.
31 Mark Dorfman, Michelle Mehta, Ben Chou, Steve Fleischli, and Kirsten Sinclair Rosselot, "Thirsty for Answers: Preparing for the Water-related Impacts of Climate Change in American Cities" (August 2011), 9, NRDC, nrdc.org/water/files/thirstyforanswers.pdf.

Recommendations for State Governments

Many of the state agency personnel contacted for this report indicated that without a top-down directive from the executive level, there is unlikely to be sufficient action by all necessary government agencies within a state on climate change adaptation. There are clear limits to how far adaptation planning can proceed on a strictly voluntary basis and without executive-level support or leadership. Governors across the U.S. must do what is in the best interest of their states and constituents to prioritize and support adaptation planning. All states can and should undertake the following actions to prepare for the impacts of climate change. The states that do so are likely to be better positioned to tackle the inevitable challenges that climate change will present—and, as a result, more competitive economically.

1. Set greenhouse gas pollution reduction targets or goals and develop a plan for meeting these targets.

Greenhouse gas reduction and climate change preparedness are related. Globally, the level of greenhouse gas emissions released determines the severity of climate change impacts. As states address climate preparedness, they should formally establish greenhouse gas emissions caps or targets and reduce emissions by, among other things, improving energy efficiency and pursuing clean energy technologies that do not result in—or at least minimize—the release of greenhouse gases. In California, for example, the Air Resources Board developed a cap-and-trade program that covers major sources of greenhouse gas emissions statewide to reduce emissions to 1990 levels by 2020, as required by Assembly Bill 32.

2. Develop a stakeholder group to organize and coordinate state-level adaptation planning and implementation.

The states that are the most effective at integrating climate change adaptation into state agency operations, plans, and programs have a central coordinating group to organize adaptation efforts among agencies and organizations within the state. This type of group can also assist with the identification and development of responses to water-related impacts across sectors and prevent inconsistency and overlap. At a minimum, group membership should include personnel from all relevant state agencies, such as those with jurisdiction over water quality, water quantity, hazard response, transportation, public health, aquatic species, and coastal management (where relevant). It is also important to consider including individuals from local governments, community organizations, impacted sectors, non-governmental organizations, and others. External stakeholders can provide different perspectives and help to develop strategies that will be supported by the broader community. In California, the Climate Action Team (CAT), which is composed of representatives from various state agencies and boards, coordinates the implementation of the state's greenhouse gas emissions reduction and adaptation programs.

3. Develop partnerships and foster collaboration to stay current on climate science and sector-specific developments.

Because the state of knowledge regarding climate modeling and adaptation tools is rapidly evolving, states can benefit by fostering partnerships and collaboration with the research community to bolster their expertise and remain current on these issues. The Wisconsin Initiative on Climate Change Impacts (WICCI) is governed by a Science Council that contains members from a variety of disciplines from the University of Wisconsin system, other universities and research institutions, and state and federal agencies. In addition, there are federal resources for stakeholders. The Regional Integrated Sciences and Assessments (RISA) program within the National Oceanic and Atmospheric Administration (NOAA) supports research to provide useful climate information to decision-makers. There are currently nine RISA teams operating in the Pacific, western, south-central, and southeastern U.S., and one team each in the Great Lakes region and the urban Northeast.

4. Conduct a statewide vulnerability assessment to determine potential climate change impacts.

Vulnerability assessments should include, at a minimum, an evaluation of water-related impacts, including precipitation changes, changes in water quality and availability, drought, flooding, hydrologic changes, and, where applicable, sea level rise. The evaluation of a comprehensive set of climate change impacts enables states to better understand their vulnerabilities and develop strategies to reduce them. States also should consider non-climate stressors (e.g., population growth and land use changes) and a wide-range of scenarios to enable the selection of flexible adaptation strategies that are effective under a range of conditions. Critical infrastructure networks that are vulnerable to climate impacts—including power-generation facilities, water and wastewater treatment systems, hospitals, and transportation—should be identified for prioritization in the selection and implementation of adaptation strategies.

5. Develop a comprehensive adaptation plan to address climate risks in all relevant sectors, and integrate climate change preparedness into existing planning processes.

On the basis of the vulnerabilities, capacities, and risks identified during the assessment process, states should develop strategies and actions to address water-related climate vulnerabilities and risks. Framing climate change vulnerability and adaptation in terms of emergency or risk management can be useful, as many state and municipal officials are readily familiar with this framework. Moreover, comprehensive planning should include input from a wide variety of stakeholders, especially those outside of state government, such as water and energy utilities, emergency response personnel, natural resource managers, the general public, businesses, and environmental groups. In Washington State, advisory groups composed of local, state, and federal agency personnel, members of the business and nonprofit communities, and other relevant stakeholders are assisting with the development of a state climate change response strategy.

States should use caution when investing in “hard” or “gray” infrastructure (e.g., dams, reservoirs, pipelines, impervious pavements, seawalls, etc.) that is capital-intensive and difficult to modify once built. These structures are inflexible and can be substantially more costly to adapt to climate change impacts over the long term.

- *Nonstructural strategies* such as land use regulations, land acquisition, and habitat restoration should be prioritized whenever possible, as these strategies are relatively low in cost (when compared with traditional structural approaches) and are likely to be the most flexible given the uncertainties surrounding future climatic conditions. In Maryland, the Living Shorelines Protection Act of 2008 requires that only nonstructural stabilization techniques be utilized to preserve the natural environment (except in areas that the state has deemed appropriate for structural stabilization measures). As sea levels rise, living shorelines allow coastal habitats to migrate inland and retain their storm-buffering benefits.

“No regrets” and “multiple benefits” strategies should be an integral part of any adaptation strategy. These strategies address existing stresses and problems, build resilience to climate change, and secure multiple benefits (e.g., water, energy, and cost savings; emissions reductions; and reduced environmental impacts).[1]

- *Green infrastructure* (sometimes referred to as low-impact development) restores or mimics natural hydrologic processes and involves techniques that store rainwater or allow it to infiltrate into the soil. Green infrastructure includes the use of porous pavement, green roofs, rain gardens, roadside plantings, and rain barrels. In addition to being relatively low-cost, green infrastructure can provide multiple benefits by:[2]
    - *Increasing water supplies*. By allowing more water to infiltrate into the ground, green infrastructure increases water supplies through aquifer recharge. Additionally, measures like rain barrels and cisterns capture water for reuse and ease demand on municipal water supplies.

- *Reducing energy consumption.* By lessening municipal water use, green infrastructure can reduce energy consumption associated with the conveyance, treatment, and distribution of water and can contribute to greenhouse gas reduction by sequestering carbon dioxide in plants and trees.

- *Reducing flood risks.* Green infrastructure can diminish the risk of flooding by reducing the volume of stormwater runoff. This can improve water quality by decreasing the occurrence of combined sewer overflows (CSOs).

- *Improving water quality.* Green infrastructure can improve water quality by using vegetation and soils to remove pollutant loads in runoff prior to discharge into receiving water bodies.

- *Adapting to changing conditions.* Green infrastructure is flexible and adaptable—an important characteristic, considering future uncertainty and projections of extreme variability in hydrologic conditions with climate change. Because green infrastructure is a decentralized approach to managing stormwater, it is inherently adaptive and can be easily modified should climatic or hydrologic conditions change.

- *Water conservation and efficiency* are two of the most cost-effective methods to reduce water demand, extend existing water supplies, and reduce the energy use associated with water production. A variety of water conservation and efficiency measures can be implemented, such as water-efficient landscaping, water-conserving plumbing fixtures, irrigation efficiency improvements, and leak detection and repair. These measures also result in benefits for water systems by delaying capital costs for new infrastructure to treat and deliver water and reducing the demand for—and the costs of—wastewater treatment.

Climate change factors also should be integrated into existing planning frameworks and policies. Many states, particularly those in arid climates, have long-term water supply planning processes that seek to ensure that sufficient water is available to meet projected demand over a planning horizon of up to 50 years. In addition, some states have planning processes that govern land use decisions in local communities. By requiring consideration of climate change impacts as a part of these existing planning processes, adaptation can become embedded into routine agency operations and programs, and actions that may inhibit adaptation or increase vulnerability in the long term can be avoided.

Many existing water management issues cross political boundaries. Climate change impacts will occur across these boundaries as well. Furthermore, states located in the same region will likely face similar challenges from climate change. As part of their individual planning processes, states may benefit from regional partnerships or collaborative efforts to pool resources and share information. One recent example is the joint agreement between the Western Governors' Association and NOAA to improve the development, coordination, and dissemination of climate information to support long-range planning and decision-making in western states.[3]

6. Prioritize and support implementation of the adaptation plan.

Goals and tracking metrics to measure the progress of plan implementation are vital. In addition, specific tasks and implementation mechanisms needed to achieve these goals should be developed. Public accountability mechanisms also should be created so that citizens and stakeholders can readily determine whether commitments have been carried out. Specific agencies or entities responsible for task implementation and timelines for execution should also be determined. In recent years, state programs addressing climate change issues have experienced substantial reductions in staffing levels, up to 80 percent in some cases. Without dedicated staff to coordinate implementation, little progress on climate change preparedness is likely to be achieved. Minimum staffing and funding levels also must be made available to support effective implementation of the adaptation plan.

7. Measure progress regularly and update the adaptation plan as needed.

Climate change preparedness should be an iterative and informed process. As climatic conditions change and new information becomes available, it is appropriate to reevaluate implemented adaptation options. States should regularly measure progress toward achieving established adaptation goals by developing performance indicators or metrics. After assessing progress, adaptation strategies should be modified as needed. This can be accomplished by developing an annual progress report for the public and engaging an outside advisory committee.

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2 Noah Garrison, Karen Hobbs, Anna Berzins, Emily Clifton, Larry Levine and Rebecca Hammer, "Rooftops to Rivers II: Green Strategies for Controlling Stormwater and Combined Sewage Overflows" (November 2011), NRDC, nrdc.org/water/pollution/rooftopsii/files/rooftopstoriversII.pdf.

3 "Western Governors, NOAA Agree to Work Together to Improve Climate Services for the West," NOAA, June 30, 2011, noaanews.noaa.gov/stories2011/20110630_westerngovenors.html.

Recommendations for the Federal Government

There is clearly a role for the federal government in cutting carbon pollution across the U.S. While state efforts to cut carbon pollution are important, federal limits are essential. The Environmental Protection Agency (EPA) is developing standards to limit carbon pollution from new and existing power plants. Cleaning up harmful carbon pollution from power plants will save lives, create jobs, and protect our environment. Power plants are our nation's biggest carbon polluters. Every year, power plants dump more than two billion tons of dangerous carbon pollution and other toxic pollutants into the air. The public health threats to our children, seniors and communities from climate change—fueled by rising levels of dangerous carbon pollution and the resulting temperature increases— include more heat deaths; respiratory complications, such as asthma attacks (triggered by associated increases in smog and other pollution); more infectious diseases; and severe dangers to life, limb, and property during storms, floods, and other extreme weather events. In addition to finding their own ways to lower carbon pollution, states should be supporting the EPA's efforts to set national standards for power plants.

There also is a role for the federal government in supporting climate change adaptation in the states. In many cases, state agency personnel have lamented what they perceive as a lack of federal leadership and coordination on adaptation planning. The federal government, via agencies like the White House Council on Environmental Quality (CEQ), NOAA, U.S. Geological Survey (USGS), U.S. Department of Agriculture (USDA), and EPA, can help states by providing technical information on the projected scope and impacts of climate change and examples of best practices for preparedness planning. Many state and local governments currently lack the capacity and expertise to conduct this research on their own. In addition, full implementation of the National Action Plan's Priorities for Managing Freshwater Resources in a Changing Climate must be a priority.[1]

Despite the numerous benefits that would result from adaptation planning and action, the reality is that many states will not act until they are prompted to do so. The federal government should lead by example and has many opportunities to do so. For instance, climate change's effects on water should be considered when evaluating proposed federal actions. Each type of water-related impact has the potential to influence how agencies plan and design a wide variety of measures. Moreover, many federal actions have the potential to exacerbate climate impacts on water. Analyses under the National Environmental Policy Act (NEPA) should consider how federal agencies can design their initiatives to both minimize vulnerability to climate impacts—both now and in the long term—and avoid exacerbating those impacts. If proposed actions are vulnerable to climate impacts or increase the vulnerability of surrounding environments, agencies must consider alternative locations or designs in their NEPA analyses. In February 2010, CEQ released and solicited public comment on a draft guidance document discussing when and how federal agencies must consider greenhouse gas emissions and climate change in their proposed actions.[2] This guidance document should require the consideration of climate impacts on water resources, and it should be finalized as soon as possible.

Meanwhile, the U.S. Army Corps of Engineers, through the Water Resources Development Act (WRDA), has played a large role in altering many of the nation's waterways. The Army Corps' prioritization of "hard" or "gray" infrastructure (e.g., dams, levees, etc.) has resulted in the degradation of natural resources and increases in flood vulnerability. The upcoming revisions to the Principles and Guidelines that determine how federal agencies evaluate proposed water resource development projects should prioritize the use of nonstructural and flexible strategies. Climate change also should play a key role in the siting and design of proposed development and infrastructure projects. All new projects should be assessed in terms of their potential vulnerability to climate change impacts, and also in terms of their effect on the ability of the surrounding environment to manage climate impacts.[3]

Another method of encouraging states to undertake climate preparedness and adaptation actions is to make federal funding contingent upon such actions. There are numerous pathways of funding between the federal government and state governments. The federal government in many cases has a key opportunity to ensure effective adaptation at a state and local level by requiring states to consider the possible impacts of climate change on projects that use federal funds. Below are a few federal funding programs that should require climate change considerations.

- The Coastal Zone Management Administration Awards provide funding to state coastal management programs to implement measures that preserve and enhance the resources within the nation's coastal zone. These programs address issues ranging from water quality and habitat protection to coastal development and public access. NOAA should require states to consider the impacts of sea level rise on coastal areas as a condition of receiving federal coastal zone management funding.

- The Disaster Mitigation Act of 2000 ("DMA2K"), 42 U.S.C. §5121 et seq., requires state and local governments to engage in hazard mitigation planning in order to be eligible to receive disaster assistance funding from the Federal Emergency Management Agency (FEMA). This act amended the mitigation planning section of the Robert T. Stafford Disaster Relief and Emergency Assistance Act. The new section continues the previous version's requirement for a state natural hazard mitigation plan as a condition of receiving nonemergency disaster assistance funding from FEMA. It also creates incentives for increased coordination and integration of mitigation activities at the state level. Using DMA2K funds to encourage state and local governments to consider climate change impacts and preparedness would be very beneficial.

- The Drinking Water and Clean Water State Revolving Funds (SRFs) provide support for drinking water infrastructure improvements and water quality protection projects, such as wastewater treatment and non-point pollution control. While states ultimately have control over how SRF funds are distributed, EPA should ensure that projects receiving SRF funding take climate change into consideration. This should include an evaluation of its potential impacts on energy and water efficiency as well as on the design and siting of proposed projects. These funding criteria can be readily met if the state has conducted climate change vulnerability assessments or adopted planning benchmarks (e.g., a sea level rise of 3 feet by 2100) that project applicants can readily reference. By including climate change as a component of the SRF and other federal funding programs, the federal government can avoid funding projects that do not consider climate change and that may in fact increase vulnerability (i.e., maladaptation).

- The National Flood Insurance Program (NFIP) should be reformed to avoid undermining climate adaptation, as it effectively does by subsidizing and encouraging development in vulnerable areas. To participate in NFIP, which makes available federally backed flood insurance to homes and businesses, communities are required to adopt and enforce floodplain management ordinances. However, the insurance rates offered by NFIP are often considerably lower than those charged by private insurers and may not accurately reflect the true cost of living in a flood-prone area. As of October 2011, NFIP had insurance policies of nearly $1.26 trillion in force.[4] The program also had outstanding debt of nearly $18 billion in June 2011.[5] The best approach is to avoid development in flood-prone areas, thereby reducing the risk of damage from floods and preserving important habitat. Where that is not feasible or where structures already exist, NFIP rates should be revised to accurately reflect the true risk of developing and living in hazardous areas. Furthermore, FEMA should adopt stricter regulations and requirements to ensure that structures insured by NFIP are designed and built to address climate change impacts, such as sea level rise and greater flooding risks.

Finally, there are several bills in Congress that should be enacted without delay. H.R. 2738, the Water Infrastructure Resiliency and Sustainability Act of 2011, would provide needed funding specifically to help address changing hydrologic conditions at the state and local levels. And S. 1881, the Safeguarding America's Future and Environment Act, would help to build the adaptation capacity of the nation's natural resources by requiring federal agencies and encouraging states to develop natural resources adaptation plans.

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2 White House Council on Environmental Quality, Draft Guidance for Greenhouse Gas Emissions and Climate Change Impacts (February 2010), whitehouse.gov/administration/eop/ceq/initiatives/nepa/ghg-guidance.

3 Will Hewes and Andrew Fahlund, "Weathering Change: Policy Reforms That Save Money and Make Communities Safer" (2011), 32−35, American Rivers, americanrivers.org/assets/pdfs/global-warming-docs/weathering-change/weathering-change-full-report.pdf.

4 "Insurance in Force by Month," Federal Emergency Management Agency (FEMA), revised January 9, 2012, fema.gov/business/nfip/statistics/ins.shtm.

5 U.S. Government Accountability Office (GAO), "Flood Insurance: Public Policy Goals Provide a Framework for Reform" (June 2011), gov/new.items/d11670t.pdf.

ALABAMA

In the summer of 2011, dry conditions led Governor Robert Bentley to declare a drought emergency for all of Alabama's 67 counties.[1] Higher temperatures as a result of climate change and subsequent increases in evapotranspiration suggest that future droughts in the state are likely to be more intense, more frequent, and longer lasting. By 2050 Alabama could face a loss of $29 billion in GDP and a loss of 246,000 jobs due to reduced water availability associated with climate change.[2] Alabama's tourism industry and coastal commerce also could be at risk as sea level rise increases flooding and erosion risks. To date, the state has not taken concerted action to address either climate change or long-term water management issues. Considering the enormous challenges the state faces from climate change, in addition to escalating water disputes with neighboring states, **Alabama should act now to reduce statewide greenhouse gas pollution and develop a plan for protecting water resources from these looming threats.**

Water Resources Background

Alabama generally possesses substantial water resources. Average annual precipitation is approximately 55 to 60 inches in northern Alabama, 50 to 55 inches in the central region, and 60 to 65 inches in the southern region.[3] At least one-sixth of the state's surface is covered by water resources in the form of lakes, reservoirs, ponds, wetlands, and rivers.[4] Alabama shares several major rivers with neighboring states, including the Chattahoochee River, shared with Georgia; the Perdido River, shared with Florida; and the Tennessee River, shared with Mississippi.[5] Alabama has been involved in a decades-long dispute with Florida and Georgia over withdrawals by Metropolitan Atlanta from Lake Lanier, which is supplied by the Chattahoochee River.[6] In addition, the state has been involved in a dispute with Georgia over diversions from the Alabama-Coosa-Tallapoosa (ACT) river basin, particularly Lake Allatoona, which also supplies the Atlanta region.[7]

The extreme northern portion of the state drains into the Ohio River via the Tennessee River; the remainder of the state drains directly into the Gulf of Mexico through the Mobile, Alabama, Tombigbee, Chattahoochee, and Coosa rivers.[8] The Tennessee River is the only source of water for some communities, such as Decatur, and supports thermoelectric power and industrial uses.[9] The lower Tombigbee and Alabama rivers, along with their tributaries, provide water to the largest cities in the state—Birmingham, Mobile, Montgomery, and Tuscaloosa.[10] Alabama's rivers are also important for hydropower, commercial navigation, and recreation. Hydropower facilities meet approximately 10 percent of the state's electricity demand, and navigation channels are maintained in the Mobile watershed, Tennessee River, and intracoastal waterway.[11,12] The state's rivers are also filled with biodiversity. Alabama is home to 38 percent of all fish species found in North America, as well as 51 percent of freshwater turtle species and 60 percent of freshwater mussel species found in the U.S.[13] The state also contains large amounts of groundwater, stored in 19 major aquifer systems.[14] Annual groundwater recharge has been generally comparable to groundwater withdrawals; however, recent increases in groundwater pumping and severe drought conditions have led to declining water tables.[15]

In 2005 surface water withdrawals made up 95 percent of total freshwater withdrawals statewide; groundwater made up the remainder.[16] As is the case in many other states, thermoelectric power plants withdrew the largest amount of freshwater—83 percent of the total. The next-largest users were public water systems, industry, irrigation, and aquaculture. About 87 percent of total surface water withdrawals were for thermoelectric power, and 56 percent of groundwater withdrawals were for public supply.[17]

Alabama has 50 miles of coastline along the Gulf of Mexico, more than 27,000 acres of coastal wetlands, and 390,000 acres of estuaries.[18] These resources sustain native plant and wildlife ecosystems. In addition, coastal beaches are the state's largest tourist attraction.[19] The Mobile Bay region, comprising Mobile County and Baldwin County, has a total population of nearly 600,000.[20] In 2009 these two counties attracted more than 7.2 million visitors, who collectively spent in excess of $500 million.[21] The Port of Mobile is also the ninth-largest port in the

U.S., with an estimated annual economic impact of nearly $8 billion.[22] While the state's proximity to the Gulf of Mexico confers many benefits, there are also considerable risks. Since 2000, two tropical storms and five hurricanes have caused parts of Alabama to be declared federal disaster areas.[23]

Climate Change Impacts on Water Resources

Over the past century, average temperatures in Alabama have varied substantially; however, there has been an observed general warming trend since the 1960s.[24] Across the southeastern U.S., average annual temperatures have increased by 2°F since the 1970s.[25] Since the mid-20th century, much of the warming has occurred in the winter.[26] In addition, over the 20th century Alabama experienced a 5 to 15 percent decrease in spring, summer, and winter precipitation and a 30 to 40 percent increase in fall precipitation.[27] There is also evidence of an enhanced hydrologic cycle, seen in a narrower daily temperature range, more atmospheric water vapor, more precipitation, more heavy precipitation events, and stronger extratropical storms.[28]

Climate models project that average annual temperatures across the Southeast will rise by 4.5°F to 9°F by the 2080s.[29] Precipitation models are not as definitive regarding future precipitation trends, but they do suggest that Gulf Coast states will tend to have decreased winter and spring precipitation compared with more northerly states in the region.[30] Higher temperatures lead to increased evapotranspiration rates, indicating likely increases in the frequency, intensity, and duration of drought events.[31]

Changes in precipitation and rates of evapotranspiration will impact surface water and groundwater resources in Alabama. Changes in runoff patterns could impact streamflow regimes, which are important to the state's aquatic ecosystems, hydropower production, and thermoelectric cooling needs. Reductions in surface water resources, especially during the summer, might prompt greater reliance on groundwater resources; however, recently observed groundwater overdraft has demonstrated the susceptibility of underground aquifers to overuse.[32] Future drought events associated with climate change could also result in reduced groundwater recharge and could further strain freshwater availability within the state.[33] In addition, increasing water temperatures could impact aquatic species and biodiversity by reducing dissolved oxygen levels.[34] On the other hand, increases in extreme precipitation events, in addition to causing flooding, could have adverse water quality impacts by overloading sewer treatment systems and causing pollutants to be released into waterways.[35]

The historical rate of sea level rise along the Alabama coast has measured slightly above the global average sea level rise.[36] However, Gulf Coast areas to the west, especially in Louisiana and Texas, are experiencing dramatic rates of relative sea level rise due to local land subsidence.[37] Across the Gulf Coast, sea level rise in conjunction with development, subsidence, and erosion have led to the loss of tens of thousands of acres of wetlands.[38] According to the U.S. Global Change Research Program, average sea levels are likely to rise 2 feet or more over the course of this century.[39] However, this estimate is substantially more conservative than recent studies suggesting that a global sea level rise of approximately 2.5 to 6.2 feet by the end of the century is possible.[40] Rising seas are likely to cause the loss of barrier islands and wetlands that provide storm surge protection, reductions in fisheries as habitats are lost, and saltwater intrusion into freshwater supplies.[41]

For Alabama in particular, rapid land loss on Dauphin Island due to sea level rise is likely, as are more-intense storms and reduced sand supply.[42] Further, higher sea levels and changing freshwater inflows to estuarine ecosystems will likely alter salinity levels and impact species distribution.[43] Coastal infrastructure, such as storm and flood barriers, transportation networks, and water treatment and distribution systems, could also be at risk to flooding, inundation, and erosion associated with sea level rise.[44] Anticipated increases in the intensity of tropical cyclones are likely to further exacerbate coastal vulnerabilities to flooding, erosion, and storm surge.[45]

Greenhouse Gas Pollution Reduction

In 1997 researchers at the University of Alabama developed a report for consideration by state agencies containing policy recommendations for reducing greenhouse gas emissions.[46] The recommendations included strategies for energy efficiency, waste reduction and recycling, methane and natural gas emissions reduction, transportation, and carbon sequestration. Unfortunately, the state has not developed a climate change pollution reduction plan based on this report or adopted greenhouse gas emissions reduction targets. In fact, it has filed suit to overturn the U.S. Environmental Protection Agency's (EPA) regulation of greenhouse gases under the Clean Air Act.[47] On the other hand, Alabama has used more than $55 million in American Recovery and Reinvestment Act funds to improve energy efficiency.[48] **Alabama should adopt a greenhouse gas pollution reduction goal and implement measures to reduce the state's contribution to climate change.**

State Adaptation Planning

The state has not developed an adaptation plan to prepare for climate change impacts; however, the Mississippi-Alabama Sea Grant Consortium (MASGC) is involved in some activities to address issues related to sea level rise. In conjunction with the three other Gulf of Mexico Sea Grant programs (in Texas, Louisiana, and Florida), MASGC is funding a study to quantify the potential impact of sea level rise and hurricane intensification on coastal regions and is developing policy tools for addressing sea level rise in coastal communities.[49] In addition, MASGC in conjunction with the other Gulf of Mexico Sea Grant programs and NOAA have undertaken an initiative, the Climate Community of Practice, to link local decision-makers with extension and outreach professionals to help coastal communities adapt to climate-related impacts.[50] Through this initiative, MASGC is working with the city of Orange Beach and the town of Magnolia Springs to develop a climate adaptation plan. While efforts to support coastal communities in adapting to climate change are vital, all communities across the state need to prepare for climate change impacts. Consequently, **Alabama should develop a coordinated statewide action plan to address climate change impacts.**

In 2008 the Alabama Legislature passed a resolution creating the Alabama Permanent Joint Legislative Committee on Water Policy and Management, which was charged with providing recommendations for developing a comprehensive state water management plan to the legislature by 2009.[51] Despite the amount of time that has passed since this committee was established, Alabama still does not have such a plan.[52] In 2004 the state did develop a drought plan that contains a rather limited and very general discussion of response strategies.[53] In light of recent drought events, disputes with neighboring states over water resources, and the potential impacts of climate change, there is a clear need for water resources planning at the state level. **The state should develop a plan for managing water resources that addresses both short-term and long-term water quantity and quality issues. This plan should consider "no regrets" strategies, such as water conservation and green infrastructure, which provide environmental benefits in the short term, while also building long-term resilience to potential climate change risks including water scarcity and more frequent heavy precipitation events.** Alabama also would benefit from the development and implementation of a more detailed and comprehensive drought management plan.

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ALASKA

The impacts of a warming world can already be seen across Alaska in the form of melting glaciers, earlier snowmelt, loss of sea ice, and thawing permafrost. These impacts and future changes will have wide-ranging implications for the state's human and natural systems. Alaska has done much of the initial groundwork to develop a state climate change strategy that focuses on reducing greenhouse gas emissions, as well as adapting to inevitable climate change impacts, by establishing the Climate Change Sub-Cabinet. However, recent changes in the executive administration have delayed the state's progress on the completion of a unified strategy. **The Climate Change Sub-Cabinet should forge ahead and complete and implement a climate change strategy for Alaska that contains measures to reduce statewide greenhouse gas emissions and prepare for climate impacts.**

Water Resources Background

Alaska is by far the largest state in the U.S., nearly 2.5 times the size of the second-largest state, Texas. The state's large expanse, topography, and proximity to water on three sides create substantially different regional climates. In the maritime zone, which includes southeastern Alaska, the south coast, and southwestern islands, temperatures are moderated by the ocean, whereas in the central and Arctic slope regions of the state, annual temperature ranges are more extreme.[1] The highest rainfall totals also occur in the maritime zone, along the southeastern peninsula and the northern portion of the Gulf of Alaska, which average between 150 and 200 inches a year.[2] In contrast, areas of the Alaskan peninsula and Aleutian Islands receive an average of 60 inches annually, the continental zone receives an average of 12 inches, and the Arctic region receives less than 6 inches.[3] As might be expected, snowfall constitutes a large portion of total annual precipitation.

Alaska has the largest volume of surface water resources of any state in the nation, with approximately 40 percent of all surface water outflows for the U.S. coming from the state.[4] The state's 12 major rivers and 3 major tributaries of the Yukon River drain two-thirds of the state's land.[5] In addition, Alaska also has more than three million lakes.[6] Due to the high latitudes and cold temperatures, many streams and lakes are generally frozen for five to six months out of the year.[7] Temperatures also impact the seasonal hydrology of the state's rivers and streams. Low flows are typical between December and March; peak flows occur between May and June as ice breaks up and glaciers melt; flows are low in July and August; and secondary peak flows are produced by rainfall in the autumn.[8] Additionally, Alaska has substantial groundwater resources in most areas, with the exception of northern zones that contain deep permafrost.[9] Groundwater discharges predominantly into lakes and streams and is recharged in the spring by snowmelt.[10] Underground aquifers are generally more heavily utilized in the south-central and interior regions of the state; surface water use is more prevalent in the Arctic, southeastern, and western regions.[11] Of total freshwater withdrawal in 2005, approximately 55 percent came from groundwater supplies and 45 percent from surface water.[12] The largest use of freshwater in 2005 was for aquaculture, at 82 percent, followed by public and domestic supply (approximately 10 percent), thermoelectric power (nearly 4 percent), and mining (2.5 percent).[13]

Aquaculture in Alaska consists mainly of salmon hatcheries, which require large amounts of freshwater to offset evaporative and infiltration losses.[14] Mining and oil extraction, while not heavy users of water statewide compared with other industries, can have severe local impacts on water supply. Alaska is the second-largest producer of crude oil in the U.S.; along the North Slope, large volumes of water are used for drilling and the construction and maintenance of infrastructure.[15] Despite the state's relatively ample water resources, there are severe disparities between urban and rural communities with regard to access to high-quality water supplies. Major urban areas, such as Anchorage, Fairbanks, and Juneau, typically possess sufficient water supply infrastructure and access to numerous sources to allay availability or quality concerns.[16] In contrast, rural communities often lack basic plumbing and access to freshwater year-round due to the freezing of surface water supplies and the leaching of soil minerals into groundwater as permafrost thaws.[17]

Alaska has approximately 33,000 miles of coastline—50 percent longer than that of the contiguous 48 states combined.[18] More than 80 percent of all economic activity within the state occurs near the coast.[19] This lengthy coastline helps to support one of the largest commercial fisheries in the world. In 2009 the total economic impact of the seafood industry was approximately $4.6 billion.[20] Commercially important seafood species include salmon, crab, walleye pollock, Pacific halibut, Pacific cod, sablefish, herring, shrimp, flatfish, rockfish, lingcod, geoducks, sea urchins, and sea cucumbers.[21] In recent years, tourism has also become a growing component of the state's economy. Between October 2008 and December 2009, an estimated 1.82 million out-of-state visitors traveled to Alaska, with approximately 56 percent arriving by cruise ship.[22] During this period, visitor spending totaled nearly $1.5 billion, which resulted in a total economic impact of approximately $3.4 billion.[23] Offshore and coastal areas also are currently utilized for oil and gas extraction. Absent additional legal restrictions on extraction, such activity will only grow in the future, as the Alaskan Arctic is believed to contain large amounts of the world's undiscovered oil and natural gas reserves.[24] In 2008 the U.S. Minerals Management Service (now known as the Bureau of Energy Management, Regulation and Enforcement) received nearly $2.7 billion from offshore lease sales.[25]

In addition to providing economic benefits, coastal areas also contain a wide variety of habitats: coasts, fjords, mudflats, coastal tundra, eelgrass beds, and river valleys.[26] These coastal areas provide vital habitat to many species of migratory birds, salmon, caribou, and marine mammals.[27]

Climate Change Impacts on Water Resources

Since the middle of the 20th century, Alaska's average annual temperatures have increased by 3.4°F—a rate of warming more than twice the average of the rest of the country. The increase in average winter temperatures over the same period is significantly higher, at 6.3°F.[28] These temperature increases have contributed to earlier spring snowmelt, widespread glacier retreat, permafrost warming, and reductions in sea ice extent.[29] Moreover, the snow-free season increased by about 10 days between 1970 and 2000 as a result of earlier snowmelt in the spring.[30]

The Gulkana Glacier in the interior of Alaska lost about 26 percent of its volume between 1890 and 1999.[31] Recent observations have suggested that the rate of glacial thinning in Alaska has accelerated and could be contributing to global seal level rise at twice the estimated rate of meltwater from the Greenland Ice Sheet.[32] In addition, data from permafrost boreholes in northern Alaska show surface temperature increases of 3.6°F to 7.2°F from the early 20th century to the mid-1980s, and further warming of about 5.4°F since the late 1980s.[33] Since the 1950s, Arctic ice extent has also been decreasing in all seasons.[34] And multi-year analysis of end-of-summer minimum sea ice between the 1979–1989 and 1990–2000 periods indicates substantial reductions (20 to 40 percent) of sea ice off the northern Alaskan coast.[35]

By the middle of this century, average annual temperatures are projected to rise by 3.5°F to 7°F above the 1960s to 1970s baseline.[36] Furthermore, annual temperatures are projected to average 5°F to 13°F higher by the end of the century.[37] Across the Arctic region, warming is projected to be greatest in the fall and winter due to reductions in ice cover and ice thickness.[38] Models also project increases in precipitation, but warmer temperatures are likely to cause greater evaporative losses and lead to drier conditions and increased likelihood of summer drought.[39] Climate change also could have implications for streamflow hydrology. Earlier spring snowmelt will likely occur during periods of lower sunlight, leading to more protracted melting and less intense runoff.[40] The thawing of permafrost will accentuate reductions in spring peak flow and dampen peak responses to rainfall events in the summer as water infiltrates the ground instead of running off.[41]

Over the past 50 years, the surface area of closed-basin lakes has declined across the southern two-thirds of the state as warming has caused greater evaporation and thawing of permafrost.[42] Continued loss of these lakes would have severe implications for the wildlife and indigenous cultures that rely on these wetlands areas for survival.[43] Changes in water quality due to nutrient releases and enhanced geochemical weathering from thawing permafrost are also likely to impact the productivity of freshwater ecosystems.[44] Increasing water temperatures could lead to the loss of aquatic species, such as lake trout, that are not able to tolerate warmer conditions, which would have repercussions for ecosystem food webs.[45]

In addition, the continued thawing of permafrost could lead to land subsidence, which could damage vital infrastructure such as roads, airport runways, and water and sewer systems.[46] It is estimated that the replacement cost of public infrastructure could be as much as 10 to 20 percent greater by 2030 due to the impacts of climate change.[47] Thawing permafrost has also led to an approximately 50 percent reduction in the number of days annually that travel is allowed across the tundra under Alaska Department of Natural Resources standards, inhibiting the ability of the oil and gas industry to explore and extract.[48]

Climate Change Impacts on the Coast and Ocean

As temperatures warm further, reductions in the volume and extent of sea ice are likely to continue expanding opportunities for transport and resource extraction, as well as lead to more coastal erosion and flooding from coastal storms.[49] It is likely that sea ice reductions will result in greater marine access and longer navigation seasons, except during the winter; however, ice conditions may not necessarily be less challenging.[50] On the whole, marine traffic in the Arctic for commerce, scientific exploration, and tourism will likely increase as sea ice decreases.[51]

Unlike many coastal areas in the U.S., sea level rise is not expected to be an issue for southern Alaska. In this region, rates of coastal uplift from the loss of glacial mass are far greater than sea level rise.[52] However, along the Bering Sea and Arctic coastline, sea level rise is exacerbating damage to communities from storm surge flooding, shoreline erosion, and saltwater intrusion.[53] In addition, the loss of sea ice, which acts as a buffer against coastal storms, is leaving coastal areas vulnerable to wind and wave damage. Over the past 50 years, the rate of erosion along the northeastern coastline has doubled.[54] In 2003, the U.S. General Accountability Office (GAO) concluded that 86 percent of the Native villages analyzed (184 of 213) were subject to flooding and erosion.[55] Since then, 31 villages have been identified as imminently threatened, of which 12 have decided to either relocate or explore relocation options at an estimated cost of $80 million to $200 million each.[56]

Warmer sea surface temperatures and reduced ice cover are likely to lead to northward shifts in Pacific storm tracks, and climate models project increased storminess in the region as atmospheric pressures decrease and the longer ice-free season allows for more heat and moisture to be available to Arctic storms.[57] In addition, changes in ice cover and warmer water temperatures would impact the distribution of plankton blooms, which are an essential source of food for fish populations and other marine life.[58] In addition to changes in sea ice, the distribution of marine mammals and seabirds are also likely to be affected by changes in snow cover and rising sea levels.[59]

Greenhouse Gas Pollution Reduction

In September 2007, then-governor Sarah Palin issued an administrative order establishing the Alaska Climate Change Sub-Cabinet to advise the Office of the Governor on the development and implementation of a state climate change strategy.[60] The subcabinet contains two advisory groups: the Mitigation Advisory Group (MAG) and the Adaptation Advisory Group (AAG). In August 2009 the MAG submitted a final report that contained 32 options for reducing greenhouse gas emissions in Alaska.[61] As one of the policy components in the recommendations, the MAG recommended that the state's final climate change mitigation strategy contain a greenhouse gas reduction goal.[62] **Alaska should adopt a greenhouse gas pollution reduction target and develop and implement a plan to reduce the state's contribution to climate change.**

State Adaptation Planning

In January 2010 the AAG submitted a final report that contained strategies to address impacts on public infrastructure, natural systems, health and culture, and economic activities of the state.[63] For public infrastructure, the AAG recommended that a statewide data collection, analysis, and monitoring system be developed; that existing infrastructure be improved using current best practices; and that new and upgraded infrastructure be built to be both resilient and sustainable given future uncertainty.[64] Within these general recommendations, the report also contains more specific supporting actions, such as conducting local vulnerability assessments of infrastructure, prioritizing funding for projects that integrate climate change considerations, and modifying engineering design standards and building codes. Furthermore, to implement these recommendations effectively, the AAG recommended that a coordinating entity similar to the Infrastructure Advisory Work Group (IAWG) be created.

The AAG's broad recommendations for natural systems related to water resources included the integration of climate change into fisheries management and assessment, adaptive management of the state's freshwater resources, reduction of invasive species, and improved capability to adapt harvest regulations to climate change.[65] Elements of these recommendations to support implementation included development of a central repository of information regarding climate change impacts on freshwater and marine fisheries, reestablishment of the Alaska Water Resources Board to improve the coordination of water resource agencies, and development of a monitoring framework for fish and wildlife.

The AAG's water-related recommendations for the health and culture sector included expansion of surveillance and control systems for waterborne diseases, screening of proposed mitigation and adaptation activities for associated health benefits or harm, and assessment of the vulnerability of sanitation infrastructure and practices to climate change impacts such as flooding and thawing permafrost.[66] In addition, the AAG made a few crosscutting recommendations, such as creation of the Alaska Climate Change Knowledge Network to allow for the sharing of information to foster adaptation, and establishment of an entity to coordinate implementation of climate change activities among state agencies.[67] The recommendations in the AAG final report are a solid foundation, albeit largely lacking implementation details, for future adaptation planning in Alaska. These recommendations will be used in conjunction with the recommendations of the MAG, Immediate Action Workgroup, and Research Needs Work Group by the Climate Change Sub-Cabinet to develop the state's climate change strategy. It is not clear if Alaska is moving forward decisively on the completion of this strategy. **The state should prioritize and fully commit to the development and subsequent implementation of the Alaska Climate Change Strategy.**

Recognizing that some Alaskan communities are being disproportionately impacted by climate change, the state has prioritized the implementation of measures to aid these communities. The Immediate Action Workgroup (IAW) submitted recommendations to the subcabinet in March 2009 to address immediate needs for communities under "imminent threat" from climate change, with a particular focus on six villages: Newtok, Shishmaref, Kivalina, Koyukuk, Unalakleet, and Shaktoolik.[68] These communities are predominantly inhabited by Alaskan Natives, are accessible only by air or boat, have largely subsistence-based local economies, and are commonly afflicted by severe erosion, wind-driven ice damage, flooding, and storm surge.[69] Villages like these that already are being harmed by climate change are being assisted by the Alaska Climate Change Impact Mitigation Program (ACCIMP), which is administered by the Alaska Division of Community and Regional Affairs (DCRA).[70] The six communities have received planning grants for projects ranging from the design of emergency shelters to the evaluation of relocation sites.[71] An additional six have received grants to conduct assessments to identify climate change–related hazards from erosion, flooding, storm surge, and thawing permafrost.[72]

Some state agencies also are integrating climate change considerations into planning processes and program operations. In the 2006 state wildlife action plan, the Department of Fish and Game (DFG) identified climate change as a challenge for wildlife and fish conservation.[73] Recommendations to address this challenge included assessing potential impacts on wildlife from climate change, establishing long-term monitoring programs to document changing conditions for species and ecosystems, and building mapping tools to aid fish and wildlife managers. In addition, DFG developed a climate change strategy in 2010 to guide the work of the department over the next four years.[74] Some key components of the strategy include conducting vulnerability assessments of fish and wildlife, integrating climate change considerations into management plans, and adaptively managing fish and wildlife species given their vulnerability.

The Alaska Sea Grant Marine Advisory Program (MAP) also has developed tools, such as a climate change adaptation planning tool and manual, for coastal communities.[75,76] The tool and manual set forth a basic eight-step process by which local communities can develop and implement a plan for adaptation. To complement the tools and help inform coastal communities, MAP has created four fact sheets covering ocean acidification, climate change and subsistence, sea level rise and storm surge, and permafrost.[77] MAP also is considering partnering with a regional environmental organization on a climate risk assessment for the Kenai Peninsula.[78] Much of this work has been supported by the Alaska Center for Climate Assessment and Policy (ACCAP), one of the 11 NOAA-funded Regional Integrated Sciences and Assessments (RISA) teams. ACCAP has been an important entity in assessing the impacts of climate change for Alaska and has provided adaptation assistance to the stakeholder community through web seminars, research, and workshops.[79] However, despite the availability of these resources, there has been limited interest on the part of many communities to utilize these resources to address climate change issues.[80] Consequently, **more coordinated state-level action is necessary to support existing local initiatives on climate adaptation and to encourage other communities to plan for climate impacts.**

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ARIZONA

As one of the driest states in the U.S., Arizona is no stranger to the impacts of drought. Increasing water demand and decreasing water supplies as a result of climate change and population growth are likely to further intensify conflicts over water. While the state has been successful thus far in developing and conserving water supplies to support burgeoning demand, Arizona should be doing more to incorporate potential climate change impacts into planning for limited water resources. Water planning efforts that focus strictly on population growth while failing to consider how climate may change in the future, such as the Blue Ribbon Panel on Water Sustainability, are shortsighted. **The state should develop a comprehensive climate change adaptation plan that identifies a portfolio of strategies that can be implemented to respond to the challenges that both population growth and climate change will pose to Arizona**. Population growth alone will stress Arizona's already limited water resources. The additional stresses from climate change further underscore the need for the state to begin planning now.

Water Resources Background

Precipitation in Arizona, as in many western states, exhibits a strong seasonal pattern and wide geographic variation due to topography. Average annual precipitation ranges from a few inches in the southwest part of the state to more than 36 inches in the White Mountains and in mountain areas of the Mogollon Rim.[1] The summer monsoon season runs from July to mid-September, and the winter season from November to mid-April.[2] Winter precipitation is more beneficial hydrologically because it tends to be more widespread, less intense, longer in duration, and not subject to as much evaporation as precipitation in the summer.[3] The east-central and southeastern parts of the state, however, receive up to 60 percent of total annual precipitation during the summer.[4] Precipitation as snow in the winter, which constitutes more than 75 percent of total winter precipitation in high elevations, is also an important source of water as it melts in the spring and early summer and runs off into streams. Precipitation in Arizona is also subject to high interannual variability due to influences from El Niño-Southern Oscillation events and changes in the Pacific Decadal Oscillation.[5]

Arizona's water supply comes predominantly from surface water and groundwater with a small amount from reclaimed water (i.e., treated wastewater effluent). The state has an annual allotment of 2.8 million acre-feet of water from the Colorado River, which originates mainly as snow in the mountains of Wyoming, Colorado, and Utah.[6] Of this allotment, approximately 1.5 million acre-feet go to the Central Arizona Project (CAP), which supplies much of metropolitan Phoenix and Tucson.[7] Within the state, the Salt, Verde, and Gila rivers are the main surface water sources and derive their supply mainly from snow along the Mogollon Rim and in the high-elevation mountains of east-central Arizona and western New Mexico.[8] The Salt River Project (SRP) delivers approximately one million acre-feet of water each year to users in the Phoenix area from the Salt and Verde rivers and groundwater sources.[9] SRP also operates several dams on these rivers to produce hydroelectricity. Groundwater use is limited in the state's five active management areas (AMAs), where groundwater withdrawal is regulated to prevent depletion; however, outside of these areas, groundwater is often the main source of water. Of the total wastewater processed statewide by treatment facilities that report volume and disposal method (generally the largest facilities), slightly more than half is treated and reused for irrigation, recharge, and industrial cooling. In 2006 this represented nearly 260,000 acre-feet of water.[10]

As in most western states, agriculture is the largest water user in Arizona, accounting for 75 percent of total use. Water for agricultural purposes comes from a mix of imported surface water, in-state surface water, groundwater, and reclaimed effluent.[11] Municipal and industrial demands account for the remaining 25 percent, with municipal supply coming mainly from groundwater sources (except in AMAs, where CAP water, in-state surface water, and groundwater are used).[12]

Climate Change Impacts on Water Resources

Over the past 50 years, temperatures in the western U.S. have increased 1.5°F relative to a 1960–1979 baseline.[13] This temperature increase has led to declines in spring snowpack, earlier peak streamflow, and reduced Colorado River flow.[14] Average annual precipitation has also decreased in most of Arizona since 1958.[15] By the end of the century, temperatures are projected to rise 4°F to 10°F from the historical baseline as a result of climate change.[16] Furthermore, the Southwest is expected to become even drier and more prone to drought in the future, as warmer temperatures cause higher evapotranspiration rates and less precipitation as winter and spring storm tracks move north.[17]

Increasing temperatures could lead to less winter snowfall, more winter rain, and a faster, earlier snowmelt.[18] During the summer, higher temperatures and more evaporation could result in lower reservoir levels, lake levels, and streamflows. In the absence of any changes in precipitation, increasing temperatures alone would result in decreased runoff; in combination with projections for reduced winter precipitation, surface water supplies in Arizona could be at substantial risk. A 2011 SECURE Water Act report by the U.S. Bureau of Reclamation projected an 8.5 percent reduction in runoff of the Colorado River at Lees Ferry, Arizona—the division between the upper and lower basins—by 2050 (relative to a 1990s baseline).[19] Because the CAP has the lowest-priority rights to Colorado River water in Arizona, any curtailments to the state's allocation would directly impact CAP users first.[20]

Decreases in streamflow also could lead to reductions in hydropower generation, water quality issues as pollutant concentrations and salinity increase, and reductions in fish and wildlife habitat.[21] Winter and spring flooding risks could increase as a result of more wintertime precipitation occurring as rain and faster springtime snowmelt.[22] Conversely, decreased late-spring and summer runoff could cause decreased groundwater aquifer recharge and impact areas that rely heavily on groundwater supplies.[23] Any impacts to water availability as a result of climate change would have significant ramifications for the agricultural, urban, industrial, and environmental users that rely on them. A recent study by researchers at Sandia National Laboratories estimated that reduced water availability associated with climate change could cost Arizona close to $70 billion in GDP and more than 480,000 jobs by 2050.[24]

Greenhouse Gas Pollution Reduction

In August 2006 the Arizona Climate Change Advisory Group (CCAG) released a climate change action plan that contained 49 policy recommendations for reducing statewide greenhouse gas emissions. In September 2006, then-governor Janet Napolitano issued Executive Order 2006-13, which followed the recommendations of the CCAG and established a statewide goal to reduce greenhouse gas emissions to 2000 levels by 2020 and 50 percent below 2000 levels by 2040. However, in November 2011, the state formally withdrew from the Western Climate Initiative (WCI), a joint effort by western states and Canadian provinces to implement an emissions trading program to reduce regional greenhouse gas emissions.[25] To reduce the state's contribution to climate change, **Arizona should move forward with the implementation of concrete actions to achieve the state's pollution reduction goals.**

State Adaptation Planning

In its 2006 report, the CCAG recommended that the state develop a comprehensive climate change adaptation strategy for managing the projected impacts of climate change.[26] To date, Arizona has not developed an adaptation plan.

In 2010 the Governor's Blue Ribbon Panel (BRP) on Water Sustainability released its final report outlining strategies for ensuring sufficient water resources in the future to support the demand generated by continued high population growth.[27] The BRP made recommendations to increase water reuse, advance water conservation, reduce the amount of energy involved in recycling water, reduce the volume of water used in energy production, and increase public awareness and acceptance of reclaimed water use. A few specific recommendations from the panel include better coordination among regulatory programs involved in the permitting of reclaimed water use, an

Arizona-specific research study on the water–energy nexus, and the development of incentives to promote the use of alternative water supplies.[28] As noted in the report, Arizona already requires all water providers to submit conservation plans, with providers located in AMAs having more stringent efficiency requirements. **Strategies that increase water efficiency and water reuse are "no regrets" approaches that deliver immediate benefits while also building resilience to climate change impacts. However, effective oversight by state agencies on the implementation of these plans by water providers is crucial in ensuring meaningful reductions in water use.**

Also in 2010, the Arizona State Legislature established the Water Resources Development Commission to assess the state's water demand and available supplies over the next 100 years. In October 2011 the commission released its final report, containing projections of future water demand, future water supply options, and financing mechanisms for new supplies.[29] Climate change and its impact on water supply and demand were factored into these analyses to a limited extent. To account for the impact of climate change and/or drought, baseline in-state surface water supplies were decreased by 5 percent in 2035, 10 percent in 2060, and then held constant through 2110.[30] As acknowledged by the commission, there was "no real attempt to independently evaluate" the effect of climate change on future water supplies and demands.[31] Over the next 100 years, the committee estimates that annual water use in Arizona will increase by more than 40 percent, from 7.1 million acre-feet to over 10 million acre-feet per year. In contrast, currently developed water supplies range from nearly 6.5 million to 6.75 million acre-feet.[32] **By not explicitly assessing the potential impact of climate change on future water supplies and demands, the commission has missed a key opportunity to integrate climate change into long-term water resources planning.** Consequently, the fact that warmer temperatures and decreases in precipitation may drive demand higher and supplies lower is not reflected in the commission's report.

The Arizona Water Banking Authority (AWBA) was created in 1996 to allow the state to fully utilize its allocation of Colorado River water. The AWBA purchases and stores unused CAP water to protect municipal and industrial users against future Colorado River shortages by either storing water in underground aquifers (i.e., direct recharge) or allowing agricultural operations to use the water in lieu of groundwater supplies (i.e., indirect recharge).[33] To date, the AWBA has accumulated approximately 3.7 million acre-feet of storage credits.[34] Apart from the AWBA, individual water providers are also storing water, in facilities like the Granite Reef Underground Storage Project (GRUSP), for later recovery when additional supplies are needed.[35]

While the state's water planning has yet to explicitly include climate change considerations, the Arizona Game and Fish Department (GFD) identified climate change as a major stressor to wildlife and habitats in its 2005–2015 Comprehensive Wildlife Conservation Strategy.[36] A few recommended adaptation strategies for fish species included the protection of instream flow, improved water conservation, and watershed management approaches that maintain hydrologic connectivity.[37] In addition, GFD will be conducting a climate change species vulnerability assessment as part of its plan update process.[38]

Water conservation, reuse, and green infrastructure are a few components that Arizona can utilize to mitigate potential water supply shortages as a result of climate change. However, **the state also should be planning for increased winter flooding risks that may result from more precipitation falling as rain and earlier snowmelt.** To better prepare for these impacts, **the state should develop a comprehensive climate change adaptation plan that identifies a portfolio of strategies that can be implemented to respond to the challenges posed by population growth and climate change.** Population growth alone will stress Arizona's already limited water resources. The additional stresses from climate change further underscore the need for the state to begin planning now.

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ARKANSAS

Unprecedented levels of flooding along the White and Mississippi rivers in the spring of 2011 forced interstate closures and evacuations and damaged homes and businesses in many areas of Arkansas.[1] In addition, more than a million acres of cropland were submerged, resulting in at least $500 million in losses.[2] This flooding was followed by drought conditions across nearly the entire state, with particularly extreme and severe drought in southwestern Arkansas during the summer.[3] Similar flooding risks and increased drought risks are likely in the future due to climate change. **Arkansas should implement the recommendations of the Governor's Commission on Global Warming to reduce greenhouse gas pollution, comprehensively assess the state's vulnerability to climate change impacts, and develop and implement an integrated and inclusive plan for managing these impacts.**

Water Resources Background

The Ozarks and the Ouachita Mountains in the northern and western portions of Arkansas strongly influence precipitation patterns in the state. Average annual precipitation ranges from 40 to 58 inches.[4] Because of their proximity to moisture from the Gulf of Mexico, southern counties generally receive 5 to 6 more inches annually than counties in the north (because of orographic uplift, mountainous areas in the west-central and north are the exception).[5] Winter and spring are generally the wettest seasons, and fall the driest.[6] While most of the state's precipitation falls as rain, snow does occur, mainly at high elevations in the northwestern area of the state.[7] Flooding as the result of locally heavy rainfall is not uncommon, nor are extended dry periods.[8] Furthermore, approximately one-fourth of the entire state is flood-prone.[9]

Arkansas contains five major river basins: the White River, Arkansas River, Red River, Ouachita River, and Delta basins.[10] Cropland is the dominant land type in the Delta Basin, in the eastern part of the state, whereas the other river basins contain primarily forestland.[11] The majority of the state's streamflow is from the Mississippi River, which forms the eastern border of Arkansas; streamflow is highest during the winter and late spring and lowest in the summer and early fall.[12] The state has about 15 million acre-feet of reservoir storage, mainly in reservoirs in the White River Basin, managed by the U.S. Army Corps of Engineers.[13] Reservoirs are utilized for a variety of purposes, ranging from water supply and hydropower to flood control and recreation.[14] Alluvial aquifers in the coastal plain region are the predominant source of groundwater in the state. In 2005, 96 percent of all groundwater withdrawn in the state came from the Mississippi River Alluvial Aquifer.[15] Other important aquifers include the Sparta Sand, Cockfield, Wilcox, and Nacatoch aquifers.[16] To alleviate the stress that agricultural withdrawals have placed on the Sparta and Mississippi River Alluvial Aquifers, the Army Corps is pursuing the Grand Prairie Area Demonstration Project to divert water from the White River for agricultural use.[17] The Army Corps is also working to improve agricultural water supply, waterfowl management, and flood protection through the Bayou Meto Basin Project.[18]

In 2005, approximately two-thirds of total water withdrawn in Arkansas came from groundwater, with the remainder coming from surface water sources.[19] Agriculture, the largest industry in the state, was also the largest water user, accounting for 72 percent of total withdrawals and 92 percent of all groundwater withdrawals.[20] There were nearly 4.73 million acres of irrigated land in 2005, with major irrigated crops including rice, soybeans, corn, cotton, and milo (grain sorghum).[21] Thermoelectric power plants were the second-largest water users, at approximately 17 percent of total withdrawals and 51 percent of surface water withdrawals.[22] Public supply was the third-largest user of water with about 4 percent of total withdrawal, two-thirds of which came from surface water supplies.[23] Duck-hunting clubs, which fill open fields, bayous, or ponds with water to attract migratory waterfowl, were the fourth-largest withdrawer, followed by aquaculture.[24]

Climate Change Impacts on Water Resources

Since 1970, the average annual temperature of the southeastern United States has increased approximately 2°F.[25] This warming has been most prevalent during the winter. Across the region, average fall precipitation has increased by 30 percent since 1901, with Arkansas experiencing a 30 to 35 percent increase.[26] During this same period, average summer precipitation across Arkansas declined by 5 to 25 percent.[27] In addition to changes in the seasonal distribution of precipitation, the intensity of precipitation also has changed, with increases in heavy rainfall events observed across much of the Southeast.[28] Since the mid-1970s, the extent of drought also has increased during the spring, summer, and fall.[29] Temperatures across the Southeast are expected to continue to increase through this century. By the 2080s, average annual temperatures are projected to increase by 4.5°F to 9°F.[30] However, there is not as much confidence in precipitation projections. Current climate models suggest that the state is likely to see a general decrease in precipitation, with the largest reductions in the spring and summer months by the end of the century.[31] Climate models also project that heavy rainfall events also will become more frequent and more intense across the U.S.[32]

Warmer temperatures and precipitation changes are likely to have wide-ranging impacts on Arkansas, especially on the agriculture sector. Higher temperatures lead to greater rates of evapotranspiration, soil moisture loss, and heat stress, which can result in declining crop yields.[33] Consequently, water demand for irrigation, already the state's largest user, are likely to intensify. Most of the water for irrigation currently comes from underground aquifers, and groundwater depletion has been identified as an existing issue of concern in many areas of the coastal plain.[34] In addition, groundwater recharge is likely to be impacted by drought events as less precipitation is available to percolate into underground aquifers.[35] Surface water resources also are likely to be impacted by increasing temperatures and changes in precipitation. The state is party to two interstate water compacts: the Arkansas River Basin Compact of 1970 with Oklahoma, and the Red River Compact with Louisiana, Oklahoma, and Texas.[36] Streamflow in both of these river basins is expected to decline 5 to 10 percent by the middle of the century, potentially putting water deliveries under these compacts at risk.[37]

Greenhouse Gas Pollution Reduction

In 2008 the Governor's Commission on Global Warming (GCGW) released its final report, which contained 54 comprehensive recommendations for reducing greenhouse gas emissions in the state.[38] One key recommendation was that Arkansas adopt a statewide goal of reducing greenhouse gas emissions 20 percent below 2000 levels by 2020, 35 percent below by 2025, and 50 percent below by 2035.[39] The state has yet to formally adopt these or any other greenhouse gas pollution reduction goals. To reduce the state's contribution to climate change, **Arkansas should adopt the goals recommended by the GCGW and implement necessary measures to reduce greenhouse gas pollution.**

State Adaptation Planning

The GCGW also recommended the establishment of the Arkansas Climate Change Center to monitor and assess the impacts of climate change in the state and to help devise solutions.[40] The state has not made any progress on this recommendation either. **Arkansas should assess the potential impacts of climate change and develop a comprehensive plan for addressing these risks.** In the meantime, **Arkansas should implement "no regrets" strategies, such as water conservation and green infrastructure, which provide benefits now while also building resilience to longer-term impacts from climate change.**

Arkansas's state-level water planning document, the Arkansas State Water Plan, has not been updated since 1990. The Arkansas Natural Resources Commission, the state entity charged with water resources planning, recently initiated the process to update the state's water plan. This multiyear process, likely to be completed in 2014, is expected to seek to include strategies to address water excesses and shortages that result from population growth as well as from climate change impacts.[41] To ensure that water resources are managed sustainably in Arkansas, **the state should commit the resources necessary to complete the state water plan update.** In addition, as part of this process, **the state should seek to quantitatively model the potential impact of climate change on water demand and supply and consider the subsequent water deficits (or surpluses) when recommending solutions. The state also should exercise caution when making investments in traditional "gray" or "hard" infrastructure (e.g., dams, reservoirs, and pipelines), which are capital-intensive and inflexible and may inhibit effective adaptation in the long run.**

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CALIFORNIA

With more than 37 million residents, California is the most populous state in the U.S.[1] California's economy, with an annual GDP in 2009 of nearly $2 trillion, would rank as the eighth-largest in the world.[2] A 2008 study found that more than $3.2 trillion of assets are at risk from the impacts of climate change, and that annual damages of $7.3 billion to $46.6 billion could result.[3] Because of the significant risks to the state from increasing temperatures, changes in precipitation, sea level rise, and ocean acidification, California has been one of the leading states in the U.S. on climate change action. While many of these actions have focused on reducing greenhouse gas pollution, the state in recent years has also taken steps to develop and implement strategies that will build resilience and reduce vulnerability to the impacts of climate change. The state has taken significant steps to integrate climate change into a wide range of water resources plans and policies. **To enable effective implementation of adaptation measures, the state should focus on promoting effective coordination across state agencies and on providing adequate guidance and technical support at the local and regional levels.**

Water Resources Background

Water plays a vital role in California's economy, supporting agriculture, industry, urban centers, and the state's diverse ecosystems. Consequently, water has been and continues to be the source of much conflict. Almost three-quarters of California's available water supply originates in the northern third of the state, while 80 percent of water demand is located in the southern two-thirds of the state.[4] Furthermore, California's Mediterranean climate, with wet winters and dry summers, leads to wide seasonal variations in runoff. The majority of precipitation falls between October and March, while the greatest demand for water in urban and agricultural areas occurs during the summer.[5] California relies primarily on the melting of Sierra Nevada snowpack to provide water during the dry summer and fall months and is able to overcome seasonal and geographic disparities in water availability through an extensive network of water storage and conveyance facilities. The state's most complex conveyance systems, the State Water Project and the Central Valley Project, carry one-fourth of California's developed water supply. Of that, a portion is diverted from the Sacramento-San Joaquin Delta. On average, approximately five million acre-feet per year are diverted southward by state and federal water projects through a critical hub of channels located in the Delta; this represents approximately 30 percent of Southern California's water supply. [6,7] Furthermore, the Delta provides a portion of the water used by 25 million people in California and by agricultural areas that yield nearly half of the country's domestically grown fresh produce.[8]

These projects, along with other surface water sources including the Colorado River aqueduct and a wide range of locally developed projects, provide the majority of water for the state's urban and agricultural uses. Groundwater, which varies geographically in its use, is also an important source of water in California, particularly in dry years when it is used to supplement diminished surface water supplies.[9] At least 43 percent of the state's population receives some portion of its drinking water from groundwater sources.[10] In 2005 nearly one-third of total freshwater withdrawals statewide came from groundwater supplies, with the remaining two-thirds from surface water sources.[11] However, in dry years, groundwater provides as much as 40 percent of the state's water supply.[12] Because California has among the western U.S.'s weakest groundwater management laws, groundwater pumping dramatically exceeds natural recharge statewide. In the Tulare Basin alone, approximately 60 million acre-feet of groundwater has been depleted since about 1960.[13]

In 2005 irrigation for agriculture accounted for about 74 percent of total freshwater withdrawals, with public and domestic users withdrawing nearly 23 percent and aquaculture responsible for almost 2 percent of total withdrawals.[14] The pressure on California's water resources can be seen in the degraded status of many of its fisheries and major river systems. Prior to an NRDC-led agreement to restore the San Joaquin River, water diversions literally dried up the Lower Colorado River and San Joaquin River systems. The state's coho salmon fishery was closed in 1993, largely as a result of poor conditions in coastal rivers, and in 1999 coho were listed as endangered under the Endangered Species Act (ESA).[15] In the San Francisco Bay-Delta system, California's largest river system, fish protected under state and federal ESAs include winter-run and spring-run chinook salmon, green sturgeon, steelhead, longfin smelt, and delta smelt; water mismanagement has been identified as a major cause in the dramatic decline of many of these fish in the past decade.[16] The worsening health of fisheries also has repercussions for the economy. In 2008 and 2009, declining fish populations led to the first-ever closure of California's chinook salmon season, resulting in the loss of 2,200 jobs and more than $250 million in economic activity.[17]

In addition to freshwater resources, the ocean and coastal areas are important to the state. The ocean and the 1,100 miles of coastline in California provide mineral resources and support tourism and recreation, marine species habitat, transportation, and commerce. Nearly 85 percent of California's population is located in coastal counties, and the state's ocean-dependent economy is estimated to be worth $46 billion annually.[18] In addition, a study by the National Ocean Economics Program estimated that the total value of economic activity in California's 19 coastal counties in 2000 represented 86 percent of gross state production, or about $1.15 trillion.[19]

Climate Change Impacts: Temperature, Precipitation, and Sea Level Rise

In California, the average annual temperature has been rising since the 1920s. Annual nighttime temperatures increased 0.33°F per decade between 1920 and 2003, and annual daytime temperatures increased 0.1°F per decade over the same period.[20] Depending upon future emissions scenarios, average annual temperatures are expected to increase statewide 1°F to 2.3°F by 2050 and 3°F to 10.5°F by the end of the century.[21]

Most climate models suggest that California will continue to experience a Mediterranean climate of cool, wet winters and dry, hot summers, with most precipitation falling during the winter as a result of North Pacific storms.[22] While changes in precipitation are expected to occur over the next century, the models do not agree as to the location and extent of these changes. Most models do, however, project up to a 10 percent decrease in overall precipitation by midcentury for Northern California, which is a vital region for the state's water supply.[23] Increased temperatures also cause greater evaporation, and drought conditions are likely to become more frequent and persistent during the 21st century.[24]

Sea level along the California coast rose approximately 7 inches over the 20th century.[25] A rise of an additional 1 to 1.5 feet is projected by 2050, with 1.8 to 4.6 feet likely by 2100.[26] These estimates take into account thermal expansion of the ocean and the melting of land-based glaciers as a result of increasing temperatures, but they do not take into account the potential rapid melting of the Greenland and Antarctic ice sheets. More recent studies that do take these factors into consideration suggest that a global sea level rise of approximately 2.5 to 6.2 feet is possible by the end of the century; however, there is considerable uncertainty regarding future acceleration in the loss of ice-sheet mass.[27,28]

Climate Change Impacts: Water Supply, Water Quality, Flooding, and Coastal Areas

Changes in the timing and amount of Sierra Nevada snowpack, effectively the state's largest surface water reservoir, are already occurring and are likely to become more pronounced with increased warming. Since 1950, snowpack has diminished by 10 percent as more precipitation falls as rain instead of snow, and annual spring melt is occurring on average 10 to 30 days earlier.[29] April snowpack in the Sierra Nevada is projected to decrease by 25 to 40 percent by 2050 and 60 to 80 percent by 2100, relative to the mid-20th-century average.[30]

A 2011 SECURE Water Act report by the U.S. Bureau of Reclamation (USBR) modeled the projected impacts of climate change on eight major western river basins, including three in California. The Klamath River, in Northern California, is predominantly used for irrigation and flood control. The USBR found that while there would be small increases in mean annual runoff by 2050, there would be significant reductions in April snowpack and April-to-July runoff, and increases in December-to-March runoff due to warming conditions.[31] The model simulations projected slight increases in mean annual runoff by midcentury for the Sacramento River and a 6 to 9 percent decrease for the

San Joaquin River over the same period.[32] While changes to total annual runoff may not be drastic, the report found reductions in excess of 20 percent in April-to-July runoff for both rivers. The state's other major surface water source, the Colorado River, is projected to experience an 8.5 percent reduction in annual runoff and a 60 percent reduction in mean April 1 snow water equivalent by midcentury.[33]

These changes have serious implications for water resources management in California. The state's reservoir and conveyance systems were built under the assumption that they would be filled in part by rains during the winter months, with additional stored water provided during the summer by melting snow from higher elevations.[34] The Sierra Nevada has historically released an average of 15 million acre-feet annually during the spring and summer months when municipal, industrial, and agricultural demand is greatest.[35] As snowpack decreases due to increasing temperatures, and as urban demand increases as a result of population growth, increased conflicts among urban, agricultural, and environmental demands are likely. The state's agriculture industry, which produces more than $37 billion annually, is particularly vulnerable. Past water shortages, primarily due to droughts, have caused up to $1 billion in annual losses to the Central Valley region.[36]

California's reservoir and conveyance facilities also are utilized for flood control during the wet winter and early spring. As winter runoff volume increases as a result of increased precipitation falling as rain and earlier snowmelt, reservoir managers will need to make difficult choices between storing water supplies for dry months and leaving empty storage space to ensure adequate flood protection during the wet months. Increases in extreme winter rainfall events are likely to lead to increased peak flow events and erosion, which may also have implications for water quality as turbidity and pollutant loads increase.[37] Conversely, decreases in summer runoff and streamflow due to diminished snowpack could also have implications for the water quality of California's streams and rivers. Decreased flows may lead to increased pollutant concentrations, increased water temperatures, and altered flow regimes, all of which could have severe effects on aquatic species and ecosystems. Reductions in flow also would negatively impact hydroelectricity production during the summer months, when electricity demand is greatest. In fact, 12 to 20 percent of electricity produced statewide annually comes from hydroelectric power plants.[38]

Rising sea levels are already having substantial impacts upon the California coast through increased flooding and erosion. Severe winter storms in conjunction with sea level rise and high tides pose serious risks to infrastructure and resources along the coast. A 2009 study by the Pacific Institute estimates that a 100-year flood event following a 4.6-foot rise in sea level would put 480,000 people, $100 billion worth of property, and nearly 4,000 miles of roadways and railway at risk.[39] This study also identified 30 power plants, with a combined capacity of 10,000 megawatts, and 28 wastewater treatment facilities, capable of treating 530 million gallons per day, that would be vulnerable under this same scenario. Floods can damage pumps and other equipment and can interfere with treatment processes, which could lead to untreated wastewater discharges. Higher sea levels also can obstruct effluent flow from outfall pipes, leading to backups at wastewater treatment facilities and in stormwater systems. Major ports in Los Angeles, Oakland, and Long Beach, which are of significant value to the global economy, also would be at risk from sea level rise, as would the San Francisco and Oakland airports.

Flooding and Water Quality Risks in the Sacramento-San Joaquin Delta

The Sacramento-San Joaquin Delta, which is protected by a patchwork of approximately 1,100 miles of levees, is the most vulnerable area in the state to flooding.[40] Approximately $69 billion in assets, including the state's water supply, major freeways, agricultural land, and natural ecosystems, is protected by this levee system.[41] Much of the delta is now below sea level due to soil erosion from farming and land subsidence from soil oxidation and other processes. The aging, piecemeal system of levees is the area's primary defense against flooding and inundation from the river and ocean. Over the past 150 years, more than 200 levee breaches have occurred as a result of external forces, such as high river flows or earthquakes.[42] Increased storm surge, sea level rise, and potentially higher river flows from climate change are likely to increase the risk of levee failures and subsequent flooding.[43] In addition, the state's water conveyance network, which travels through the Delta, would be vulnerable to levee failures and water quality degradation as sea level rise—potentially compounded by lower streamflow during the dry season—causes saltwater intrusion in the Delta. This would result in impacts to critical water supplies, fish and wildlife resources, and Delta agriculture, communities, highways, railroads, and other infrastructure.[44] To address these risks, the California Department of Water Resources' (DWR) public draft of the 2012 Central Valley Flood Protection Plan proposes up to $17 billion in repairs and other investments to reduce flooding vulnerability in the region.[45]

Greenhouse Gas Pollution Reduction

In 2005, then-governor Arnold Schwarzenegger issued Executive Order S-3-05, which established statewide greenhouse gas emissions reduction targets of 2000 levels by 2010, 1990 levels by 2020, and 80 percent below 1990 levels by 2050. In addition, the Global Warming Solutions Act of 2006, commonly known as AB 32, capped statewide emissions at 1990 levels by 2020. This act also directed the California Air Resources Board (ARB) to develop a scoping plan containing measures to achieve this level of emissions reduction.[46] The scoping plan was completed in 2008, and in October 2011 the ARB adopted a final regulation for a cap-and-trade program. The first phase of this program, which addresses all major sources of greenhouse gas emissions, goes into effect in 2013, and a second phase, which covers fuel distributors, begins in 2015.[47] In addition, the Sustainable Communities and Climate Protection Act of 2008 (SB 375) requires ARB to establish greenhouse gas emissions reduction targets for passenger vehicles for 2020 and 2035 for each of the regions covered by the state's 18 metropolitan planning organizations (MPOs). Each MPO is then required to prepare a Sustainable Communities Strategy that proposes a combination of integrated land use, housing, and transportation planning to achieve the region's respective emissions reduction targets.[48] California is also a member of the Western Climate Initiative, a collaboration among four Canadian provinces and the state to reduce regional greenhouse gas emissions.[49]

State Adaptation Planning

In 2008, then-governor Schwarzenegger issued Executive Order S-13-08, which called for the development of a California sea level rise assessment report and a state climate adaptation strategy. This order also directed all state agencies planning construction projects in areas vulnerable to sea level rise to assess potential project vulnerability in 2050 and 2100 and reduce expected risks from sea level rise. The California Natural Resources Agency (CNRA), in cooperation with the state's Climate Action Team, released the other major report component of this executive order, the California Climate Adaptation Strategy (CAS) report, in December 2009. This report assessed potential climate change impacts and risks and recommended adaptation strategies in seven sectors: public health, biodiversity and habitat, ocean and coastal resources, water management, agriculture, forestry, and transportation and energy. A few key water resource recommendations from the strategy report included changing current water management practices as climate change will likely increase competition for limited water supplies, avoiding significant new development in areas that cannot be adequately protected from climate change impacts, requiring state agencies to consider the implications of climate change for their planning and operations, identifying and protecting aquatic habitats that are likely to be impacted by climate change, and supporting local community planning efforts to assess climate change impacts and reduce risks.[50]

Since the strategy was released, the state has made progress in implementing several of these recommendations by integrating climate change into a range of planning processes and by promoting key adaptation strategies. The 2009 California Water Plan developed by the California Department of Water Resources (DWR) included numerous climate change considerations, which formed the basis of the CAS section on water management discussed previously. DWR will continue to incorporate climate change into its Water Plan Update process.[51] A core element of statewide water planning is the Integrated Regional Water Management planning process, which promotes collaborative planning of all aspects of water resources in 48 regions of the state. In 2010 the Integrated Regional Water Management Plans were required to consider climate change mitigation and adaptation.[52] DWR has also been incorporating climate change into projections for the reliability of supplies from the State Water Project and other critical state infrastructure.[53,54] In addition, DWR recently established a Climate Change Technical Advisory Group, which will provide scientific guidance across all of the department's climate change planning efforts.[55] Finally, DWR and the U.S. Environmental Protection Agency Region 9, along with other partners, have developed a climate change handbook for regional water planning, which provides detailed guidance for regional water managers on approaches for considering climate change in planning and operations.[56]

Other state agencies and regional planning bodies also are incorporating climate change into their long-term planning processes. The State Lands Commission is implementing recommendations from a 2009 report on sea level rise preparedness, which included directing staff to include sea level rise effects in environmental determinations and to identify structures vulnerable to sea level rise, among other items.[57] The Ocean Protection Council (OPC) is finalizing a 2012-2017 five-year strategic plan that will address the development and implementation of adaptation strategies to sea level rise and other climate change impacts on ocean and coastal ecosystems.[58] In addition, the Department of Fish and Game is working to include greater inclusion of climate change impacts and adaptation planning in the next California Wildlife Action Plan, due in 2015.[59] Pursuant to state legislation passed in 2009, the Delta Stewardship Council is preparing a Delta Plan to address a range of issues in the Delta, including those resulting from climate change.[60]

DWR, along with local agencies, the Central Valley Flood Protection Board, and the U.S. Army Corps of Engineers, is working to reduce flood risks in the Delta region and is considering climate change as a component in these processes. The draft Central Valley Flood Protection Plan, to be finalized in July 2012, qualitatively considers the impact of climate change on flood hydrology and sea level rise.[61] The plan will help improve system resiliency in the face of climate change by expanding flood conveyance capacities, coordinating reservoir operations, and restoring floodplains. While the draft plan correctly identifies the need to address the impacts of climate change and better manage floodplains to improve public safety and restore wildlife habitat, it falls short by not quantifying these objectives. To plan for increases in the frequency and size of flood events, **the planning effort needs to quantify the changes in hydrology in order to develop environmentally sound and cost-effective measures to mitigate climate impacts.** Similarly, **the planning effort should quantify the floodplain area that must be restored within the flood system to ensure that the plan enables the recovery of listed species whose populations have declined due to habitat loss.**

The Bay Conservation and Development Commission (BCDC), a state agency charged with regulating San Francisco Bay fill and shoreline development, has also been engaged in a multiyear effort to revise the Bay Plan to address climate change impacts. In October 2011 the commission formally approved an amendment to the Bay Plan regarding climate change.[62] The adoption of these amendments is anticipated to be the beginning of a regional adaptation effort involving local communities and regional organizations around the San Francisco Bay shoreline. This regional adaptation effort is currently under consideration by the Joint Policy Committee of the Association of Bay Area Governments, Bay Area Air Quality Management District, Bay Conservation and Development Commission, and Metropolitan Transportation Commission.[63]

California is also acting to ensure that new planning and development activities take potential climate change impacts into account. The California Environmental Quality Act (CEQA) Guidelines, Section 15126.2, were modified in December 2009 to direct lead public agencies to consider not only potentially significant impacts to the environment resulting from development, but also the impacts from locating development in hazardous areas (e.g., coastlines and floodplains) as identified by hazard maps or risk assessments. To support agencies in this effort, CNRA recently developed a climate change risk evaluation tool, CalAdapt, which demonstrates how climate change might impact local communities.[64] CNRA also is working on regional climate vulnerability studies, coordinating with the California Emergency Management Agency on a local climate adaptation policy guide, and coordinating with the National Academy of Sciences (NAS) on a sea level rise study.[65] OPC also adopted a resolution in March 2010 stating that state agencies and private entities implementing projects either funded by the state or on state property must consider potential risks from sea level rise.[66] Similarly, the Strategic Growth Council is requiring that sustainable communities planning grant proposals include consideration of sea level rise.[67] The final NAS sea level rise assessment report , required by Executive Order S-13-08, will not be released until spring 2012, but the Sea-Level Rise Task Force of the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT) has released an interim guidance document for state agencies on sea level rise planning.[68] In this document, CO-CAT recommends that state agencies utilize sea level rise ranges from a 2009 publication by Vermeer and Rahmstorf; consider timeframes, adaptive capacity, and risk tolerance when selecting sea level rise estimates; and coordinate which sea level rise value to use with other state agencies. [69] Furthermore, the State Coastal Conservancy, which funds coastal resources and shoreline access projects, is requiring applicants to consider sea level rise and other climate change impacts to their projects.[70]

California also has implemented measures that are potential adaptation strategies. To improve water efficiency, SB 7X7, enacted in early 2010, calls for a 20 percent per capita reduction in urban water use by 2020 and greater efforts to efficiently use agricultural water.[71] To reduce pressures on existing potable water supplies, the state has increased efforts to measure, support, fund, and coordinate water reuse and recycling. The State Water Board has adopted a policy to increase recycled water and stormwater use and has issued a general permit for landscape use of municipal recycled water to streamline recycled water facility permitting.[72] Pursuant to SB 918, the Department of Public Health is also developing quality criteria for recycled water to support groundwater recharge use and surface water augmentation.[73] In November 2010 California also released its first drought contingency plan, containing strategies and actions that state agencies can implement incrementally to prepare for, respond to, and recover from drought conditions.[74] Some of these responses also could potentially apply in emergency water shortage conditions. To improve stormwater management, the State Water Board is examining how to incorporate low-impact development as a best management practice for stormwater permitting.[75]

The state also recognizes the need for continued research on climate change impacts. While much of the adaptation work on ocean and coastal resources is currently focused on the NAS study, the OPC is also funding a coastal shoreline elevation mapping project that will enable coastal communities to better assess their vulnerability to sea level rise, and is funding research efforts on ocean acidification.[76,77] As mentioned previously, infrastructure in California is also extremely vulnerable to climate change. The California Energy Commission (CEC) is funding several research studies on the impacts of climate change on hydropower generation in California and on other energy infrastructure.[78] The California Department of Transportation is collaborating with the University of California, Davis, on a GIS-based climate change vulnerability assessment of transportation infrastructure, and with the San Francisco Metropolitan Commission and Bay Conservation and Development Commission on a sea level rise vulnerability study for the East San Francisco Bay.[79] In addition, a recent study by CEC and DWR on utilizing forecast information in reservoir management demonstrated that an adaptive approach that incorporates forecasts of climatic and hydrologic data would be more effective in delivering water during low-flow conditions than the existing policy of static decision-making that relies on historical simulations.[80]

From a review of the many reports, studies, and other available resource materials and conversations with state officials, it appears that nearly every California state-level entity (agency, department, commission, board, council, etc.) is evaluating how climate change will impact its relative sector and weighing available options to adapt to these impacts. The state has taken major strides toward formal integration of climate change into state, regional, and local planning processes. However, the process of moving from statewide adaptation planning to local and regional planning and implementation is a formidable challenge. At the local and regional levels, difficult decisions often must be made regarding the protection of current land uses, proposed new development, natural resource impacts, flood protection infrastructure, financing, and other issues. Moving forward, **California should provide sufficient support and guidance for the implementation of these plans at the local and regional levels.** The updates to the

CEQA guidelines that require lead agencies to consider whether proposed development will be affected by climate change impacts is an important step in the right direction. However, these agencies will need strong guidance and technical support from the state in the implementation of these new guidelines. **California also should ensure that adaptation efforts in the state are coordinated across the many agencies involved.** Ultimately, stakeholders at the local, county, regional, and state levels will need to work in tandem to minimize the threat that climate change poses to California. The collaborative adaptation effort that is currently under consideration in the Bay Area by BCDC and the Joint Policy Committee could be a good example of such an effort. Collaborative efforts should be carefully designed to involve key state agencies, local governments, environmental groups, business interests, and other community leaders.

The state also has an important role in minimizing local and regional disparities in adapting to climate change. Currently, DWR only suggests that urban water suppliers take into consideration climate change impacts on water supply and demand in their Urban Water Management Plan (UWMP).[81] **For the next UWMP, due in 2015, California should require all urban water suppliers to consider the impacts of climate change and develop adaptation strategies and responses in consultation with resources such as the DWR Climate Change Handbook for Regional Water Planning. The inclusion of low-impact development practices as standard best management practices for stormwater management also should occur more uniformly throughout the state.** Actions that prevent new development in vulnerable areas also will need to be considered along with strategies on how best to protect existing development in these same areas.

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COLORADO

Containing the headwaters of four major U.S. river systems, Colorado seemingly has plentiful water resources. However, due to interstate compacts and agreements, the state must allow much of this water to leave its borders. As increasing temperatures challenge traditional notions of water management and availability in the West and municipal demand continues to grow as populations swell, conflicts over water resources will intensify. Consequently, the potential economic impacts to the state from climate change are significant. In 2007, winter recreation alone contributed nearly $2 billion to the Colorado economy.[1] Warmer temperatures could lead to less snow and a shortening of the ski season. In fact, a 2006 study projected a loss of 43 to 82 percent in April snowpack for Colorado counties with ski resorts by the end of the 21st century.[2] Dwindling water resources and higher temperatures as a result of climate change could also impair the state's $5.5 billion agricultural industry.[3] To lessen these impacts, **Colorado should continue to fund research on the impacts of climate change on water resources and work to incorporate climate change considerations into all aspects of water resources planning—both statewide and locally.**

Water Resources Background

As in many states in the western U.S., annual precipitation in Colorado varies dramatically across the state—anywhere from 7 inches to more than 50 inches per year, with an annual average of 17 inches.[4] Due to topographical differences, the climate of the eastern plains differs from that of the mountainous regions. In the plains, 70 to 80 percent of annual precipitation falls between April and September, largely during thunderstorms.[5] On the other hand, high peaks and mountain ranges receive the majority of their precipitation in the winter months in the form of snow. As mountain snowpack melts in the late spring and early summer, it flows into surface water supplies and is the major source of water for the state.[6] Approximately 80 percent of the 16 million acre-feet available annually in Colorado's river systems is located on the Western Slope, while only 20 percent is on the Eastern Slope; however, the state's population is heavily concentrated on the Eastern Slope, as are agricultural users.[7]

Because of this geographical disparity in water, transbasin projects are utilized to distribute waters among Colorado's four major river basins: the Colorado, Rio Grande, Arkansas, and Platte.[8] The most significant water project, the Colorado-Big Thompson project, delivers more than 200,000 acre-feet annually to 30 municipalities and 600,000 irrigated acres in northeastern Colorado.[9] The state also has a reservoir capacity in excess of six million acre-feet to manage the significant seasonal and interannual variability in flow.[10]

Colorado is party to nine interstate water compacts due to its being a headwaters state.[11] The most notable of these is the Colorado River Compact. The state is entitled to 51.75 percent, or approximately three million acre-feet, of the water apportioned to Upper Basin states after the Lower Basin states receive their annual 7.5 million acre-feet allotment.[12] Colorado's current consumption is estimated at around 2.4 to 2.6 million acre-feet.[13]

Colorado relies predominantly on surface water supplies, even though it has significant groundwater resources.[14] Nearly 90 percent of freshwater withdrawal is used by agriculture for irrigation, with more than 80 percent of the total coming from surface water sources.[15] Public supply constitutes only 6 percent of total freshwater withdrawal, with 88 percent of the total coming from surface water supplies.[16]

Climate Change Impacts on Water Resources

Over the past 30 years, temperatures in Colorado have increased by about 2°F. No distinguishable trends in precipitation have been observed over the same period.[17] As a result of warming temperatures in the spring, peak streamflow has come earlier, with a shift of about two weeks between 1978 and 2004.[18] Current climate models project that the state will warm 2.5°F by 2025 and 4°F by 2050, relative to the 1950-1999 average.[19] Seasonal projections indicate more warm months and fewer cold months in the winter, and more strings of consecutive warm winters. Summers are projected to warm more than winters, with summer temperatures in 2050 likely to be as warm as or warmer than the hottest 10 percent of summers from 1950 to 1999. There is not a clear consensus from current climate models on any significant changes in total mean annual precipitation; however, the seasonality could change as midwinter precipitation increases and late-spring and summer precipitation decreases in some parts of the state.[20]

As a result of warmer temperatures, snowpack in the lower elevations (below 8,200 feet) is expected to decrease significantly, while smaller declines (10 to 20 percent) are likely in high-elevation snowpack.[21] By 2070, April snowpack is projected to be reduced by nearly 70 percent relative to 1990s snowpack in the Upper Colorado River Basin.[22] Moreover, increased temperatures are expected to lead to more winter precipitation as rain instead of snow, less snowpack accumulation, earlier runoff, and greater evaporation.[23] These changes would affect Colorado's major river basins. A recent SECURE Water Act study by the U.S. Bureau of Reclamation projects an 8.5 percent reduction in mean annual runoff by 2050 at Lees Ferry, Arizona, the dividing point between the Upper and Lower Basin states.[24] In these projections, reductions in mean April-to-July runoff are substantially greater than reductions in December-to-March runoff. While the three other major river basins in the state (Arkansas, Platte, and Rio Grande) have not been examined as closely as the Colorado, studies suggest that 5 to 10 percent reductions in the flow of the Arkansas and Rio Grande rivers are possible by 2050.[25]

Because of Colorado's heavy reliance on surface water supplies, any changes to the timing and quantity of surface runoff would have significant impacts. Earlier snowmelt reduces summer streamflow and disrupts established water-capture systems.[26] A reduction in the flow of the state's rivers could also lead to increased competition over already limited water resources and put Colorado's interstate compacts in jeopardy, particularly the compact for the Colorado River, which is already overallocated.[27] Water demand is likely to grow as warmer temperatures increase irrigation and cooling needs.[28] The frequency, intensity, and duration of drought also are expected to increase as evaporative losses intensify, which could lead to decreased groundwater recharge. Also likely are more intense precipitation events, which would lead to greater flooding risks and potential water quality impacts. Reduced streamflow could also have negative implications for water quality and aquatic species, and climate change could impact aquatic species further by reducing dissolved oxygen levels and decreasing coldwater fish populations like trout.[29,30] Consequently, climate change will further stress water resources that are already under duress from rapid population growth in Colorado and other states in the western U.S.

Greenhouse Gas Pollution Reduction

Colorado released a climate action plan for reducing statewide greenhouse gas emissions in 2007.[31] In 2008, then-governor Bill Ritter issued Executive Order D-004-08, which set statewide greenhouse gas emissions goals of 20 percent below 2005 levels by 2020 and 80 percent below 2005 levels by 2050. **Colorado should implement concrete measures to achieve these pollution reduction goals and lessen the state's contribution to climate change.**

State Adaptation Planning

The preliminary Colorado Climate Action Plan released in 2007 stated that the Departments of Natural Resources and Public Health and Environment would pursue a water adaptation plan composed of scientific investigation, water rights analysis, drought planning, and information exchange and education.[32] As part of the scientific investigation component, the Colorado Water Conservation Board (CWCB) is funding the two-phase Colorado River Water Availability Study (CRWAS). CRWAS Phase I focused on determining the amount of water available to meet future water needs in the Colorado River Basin under three hydrologic scenarios: historical hydrology (i.e., conditions present during the 1950-2005 period), paleohydrology (conditions during the past 1,200 years), and climate-adjusted hydrology (projected climate change conditions). The study's conclusions regarding available water for future consumptive use covered a wide range: zero to 1 million acre-feet by 2040. The upper end of this range is in line with previous studies' estimates of available water; however, the low end suggests that the state has no additional water available from the Colorado River.[33] Phase II of the study, which was originally planned to refine the hydrologic models used in Phase I as well as to develop projections of future water demand, has been put on hold indefinitely.[34] **Colorado should prioritize the completion of Phase II of the CRWAS to inform development of a state water adaptation plan.**

In addition to the CRWAS, the CWCB recently completed an assessment of water needs in Colorado for the next 40 years, the 2010 Statewide Water Supply Initiative (SWSI 2010). The state's population is expected to nearly double to between 8.6 million and 10 million people by 2050; consequently, an additional 600,000 to 1 million acre-feet of water per year will be needed to meet increases in municipal and industrial demand even with passive conservation measures in place.[35] While agriculture is still projected to be the largest user of water, the total number of irrigated acres is expected to decline by 15 to 20 percent. Despite additional available water supplies in the future from planned agricultural water transfers, water reuse, expanded use of existing supplies, and new in-basin and transbasin projects, the report notes that total supplies will not be enough to offset greater water demand in 2050.[36]

Water conservation is an important component in closing the gap between available supplies and demand that will exist in 2050. According to SWSI 2010, widespread adoption of measures such as smart-metering with leak detection, conservation-oriented building codes, and water audits could yield water savings from 160,000 to 460,000 acre-feet per year. While the Water Conservation Act of 2004 requires all water retailers that sell at least 2,000 acre-feet annually to submit a water conservation plan to the CWCB for approval, only slightly more than half of these retailers have done so.[37] This relatively poor compliance rate indicates that many water retailers lack the capacity to develop conservation plans and/or the state is lacking in its enforcement of this provision. Transfers of agricultural water and the development of new supplies, while substantial in cost, are also identified as possible strategies.[38] While climate change impacts on water availability from the Colorado River are included in the analysis, the potential impacts of climate change on future water demand and the availability of water from other major river basins in the state are not considered. These two particular omissions suggest an even greater deficit between water supplies and demand in 2050. As noted in SWSI 2010, **Colorado should make it a priority to include climate change in future water planning efforts for other river basins in the state beyond just the Colorado River Basin**.

The CWCB, along with metropolitan agencies in Colorado's Front Range, are funding the Joint Front Range Climate Change Vulnerability Study. As part of this study, two hydrologic models are being developed to evaluate changes in the timing and volume of runoff in 2040 and 2070 as a result of temperature and precipitation changes. The final report was released in early 2012.[39] In addition, the CWCB is working with NOAA on the development of historic and projected precipitation frequency maps for Colorado, which will allow the state to understand changing flood risks.[40] **The state should incorporate the results of this work into the Colorado Flood Hazard Mitigation Plan, which does not currently include climate change considerations.**[41] The CWCB recently adopted updated floodplain regulations that hold facilities deemed to be critical, such as public safety, air transport, and medical facilities, to a more stringent development standard within the 100-year floodplain. Wastewater treatment plants, however, are specifically exempt from the critical facility designation.[42] **Wastewater facilities should not be excluded from more stringent floodplain development regulations because flooding events that lead to the failure of wastewater infrastructure can have significant water quality and public health impacts**. As flooding risks increase due to more extreme precipitation events and more precipitation as rain in the winter, development outside of an established 100-year floodplain may increasingly be at risk. Consequently, **Colorado should explore the extension of more stringent standards beyond the traditional 100-year floodplain.**

In 2010, Colorado updated its Drought Mitigation and Response Plan to include climate change projections.[43] In addition, the CRWAS discussed previously modeled future drought characteristics due to climate change. These results indicate that future droughts are expected to last longer than average maximum historical droughts. In particular, southern regions of the Colorado River Basin have a greater likelihood of experiencing longer droughts in the future than do northern regions.[44] Currently, local water providers are only encouraged to develop drought plans.

In order to increase the resilience of local communities, the CWCB should require that all water providers develop a drought plan.

With the exception of the Department of Wildlife's climate change update to the State Wildlife Action Plan, due by 2015, most of Colorado's efforts on climate change adaptation thus far appear to heavily skew toward water supply planning. Because warmer temperatures are also likely to change the characteristics of precipitation (intensity, seasonality, etc.) and by consequence runoff and streamflow, **the state also would benefit from examining potential water quality impacts from climate change and implementing strategies, such as green infrastructure, that can ameliorate these effects.**

Denver Water

In 2006, Denver Water set the conservation goal of a 22 percent reduction in overall water use from 2001 levels by 2016. As of 2010, a 19 percent reduction had been achieved as a result of conservation measures like greater public outreach, efficiency rebates for fixtures, and free water-use audits.[45] Denver Water is extending its recycled water distribution system to provide recycled water to a greater number of users. The utility currently provides recycled water to Xcel Energy's Cherokee Generating Station for cooling purposes and to parks, golf courses, and schools for irrigation. In addition to its work on the Joint Front Range Climate Change Vulnerability Study, the city is also a founding member of the Water Utility Climate Alliance (WUCA). Denver Water is currently working on its long-range planning document for the next 40 years, the Integrated Resource Plan (IRP), which will be completed in 2012.[46] The IRP will evaluate the impact of climate change on water supplies and demand and additional water efficiency and conservation measures that can be implemented.

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CONNECTICUT

As one of the most densely populated states in the U.S. and with almost $405 billion worth of insured assets along Long Island Sound,[1] Connecticut is extremely vulnerable to increased flooding risks, more frequent droughts, and sea level rise that may result from a changing climate. The Federal Emergency Management Agency (FEMA) has estimated that the state could incur economic losses of more than $18 billion as a result of a 100-year flood.[2] To address escalating water conflicts, the state has attempted to develop regulations to protect streams from overwithdrawal; however, ongoing disagreements among stakeholders have prevented regulations from being adopted.[3] The state's historical inability to comprehensively manage water resources through regulations and policy do not bode well for a future anticipated to contain greater climate and hydrologic variability. Nonetheless, the state has made efforts to develop climate change adaptation strategies, and local municipalities also have started to prepare. While municipalities in Connecticut ultimately have authority over local planning decisions, **the state should lead the way by incorporating climate change adaptation into all relevant state water resource planning processes.**

Water Resources Background

Water resources in Connecticut are extensive, with about 5,800 miles of rivers and streams; more than 2,300 lakes, ponds, and reservoirs; and groundwater aquifers present throughout the state.[4] Annual average precipitation is 47 inches and relatively evenly distributed throughout the year.[5] Surface waters and groundwaters are substantially connected within the state, as groundwater provides baseflow for streams and surface water occasionally recharges groundwater.[6] Groundwater levels and surface water streamflows vary considerably throughout the year due to changes in evapotranspiration. Between April and September, most precipitation that falls within the state is lost to evapotranspiration or overland runoff to streams; consequently, groundwater levels decline.[7] The discharge of groundwater to streams for baseflow also declines during this period, leading to decreased streamflow.[8] Along urbanized streams in the state, greater water withdrawals during the summer exacerbate these periods of low streamflow.[9] Conversely, more water is generally available in surface water and groundwater supplies during the winter and early spring due to lower evapotranspiration losses.[10]

Surface water reservoirs supply approximately 70 percent of the state's population with water, and the remaining 30 percent are served by groundwater wells.[11] Across Connecticut, thermoelectric power plants are the largest users of water, accounting for more than 80 percent of total statewide withdrawal in 2005.[12] Other large water users in the state include municipal suppliers and industrial users.[13] As a result of increasing demand and the seasonal variability of water supplies, sufficient water supplies are not always available to meet demand. In recent years, municipalities have had to implement mandatory water restrictions, such as bans on outdoor water use, during the summer as a result of heat waves and droughts.[14] The state is also relatively unique in that the public health code explicitly prohibits waters that receive treated wastewater discharges from being used as public water supplies.[15] Consequently, public drinking water supplies are drawn from smaller streams that are likely to have competing uses.[16] Water scarcity issues also have implications for aquatic species and recreational uses.[17]

Connecticut's coast borders Long Island Sound, which is a vital environmental, economic, cultural, and recreational resource for the southern New England region.[18] More than 20 million people live within 50 miles of Long Island Sound.[19] The coastal counties of Connecticut are densely populated and growing at a faster rate than western portions of the state.[20] More than 70 percent of the shoreline is privately owned residential property and not protected from development.[21] The Connecticut coast is also valuable commercially, with more than 30 harbors located along the 130-mile coastal stretch.[22] The state's maritime industry, which includes shipbuilding, commercial fishing, and aquaculture, directly employs more than 20,000 people and generates over $3.6 billion in revenues annually.[23]

Climate Change Impacts on Water Resources

Over the past 100 years, Connecticut has warmed at a rate of 1°F to 3°F per century and has experienced a statistically significant increase in precipitation.[24,25] As a result of temperature increases across the northeastern U.S., less winter precipitation is falling as snow and more as rain, snowpack is reduced, winter ice on lakes and rivers is breaking up earlier, and earlier spring snowmelt is leading to earlier peak streamflows.[26] By 2030 average annual temperatures could increase by 2.5°F; by 2100 they could increase by 4°F to 9°F.[27] The frequency of winter precipitation also is projected to increase by 20 to 30 percent, with more falling as rain than snow, and the frequency of intense precipitation events is expected to increase as well.[28] In response, flooding risks could increase, and in urban areas with combined sewers, more sewer overflows can be expected, resulting in adverse water quality impacts.[29] Increased precipitation would also lead to greater urban runoff, which carries nutrients and pollutants into the state's waterways.[30] As a result of climatic changes, the frequency and intensity of drought events also are projected to increase, altering groundwater recharge and thereby impacting water availability.[31] Shifts in the timing of streamflow could impact the spawning of native fish such as the American shad, alewife, and blueback herring.[32] Furthermore, in many streams, the critical water temperature threshold for coldwater species like trout and burbot is already being exceeded in the summer months.[33] Warmer temperatures in the future would further impair species that require cold water to thrive and would favor the spread of nonnative or invasive species.[34]

Along the Connecticut coast, sea level has risen at a rate between 0.08 and 0.10 inch per year as a result of thermal expansion of the ocean, melting of land-based ice sheets, and local land subsidence.[35] By the 2050s, sea level could rise 0.6 to 1.4 feet above the 1961-1990 mean; by the 2080s it could rise an additional 0.2 to 1.5 feet.[36] The state's east-west orientation makes it susceptible to northward-moving tropical storms, and at least eight hurricanes struck the state during the 20th century.[37] Sea level rise, in conjunction with storm surge from tropical storms and nor'easters, would place significant amounts of private property, transportation infrastructure, and water treatment infrastructure at risk to flooding and erosion.[38] Freshwater quality also would suffer as a result of saline intrusion into coastal aquifers and movement upstream in rivers when flow is reduced.[39,40] In addition, climate change could jeopardize coastal wetlands as the rate of sea level rise exceeds the rate of accretion and deposition.[41] Sea surface temperatures in eastern Long Island Sound have shown an increase of 2.3°F since 1976.[42] Along with this temperature increase, there has been a documented simultaneous decline in the abundance of cold temperate species abundance and an increase in warm temperate species.[43] The American lobster population has been particularly impacted by increasing water temperatures. Since the late 1990s, the lobster population in Long Island Sound has experienced a massive decline, likely as a result of warmer water temperatures that have affected growth and increased the vulnerability of lobsters to disease and predation.[44] Preliminary research has also suggested that ocean acidification, as a result of carbon dioxide uptake, negatively impacts shellfish larvae and juveniles.[45]

Greenhouse Gas Pollution Reduction

The Connecticut Global Warming Solutions Act, passed in 2008, set mandatory greenhouse gas emissions reduction targets of 10 percent below 1990 levels by 2020 and 80 percent below 2001 levels by 2050.[46] The state is required to develop a schedule of recommended regulatory actions and policies beginning in July 2012 and continuing every three years thereafter to achieve these targets. In late 2010, the Connecticut Department of Environmental Protection released an assessment of the greenhouse gas reduction potential of 21 mitigation strategies.[47] **To reduce greenhouse gas pollution and the state's contribution to climate change, Connecticut should prioritize the development and implementation of regulatory actions to achieve the established pollution reduction targets.** The state is also one of nine states participating in the Regional Greenhouse Gas Initiative (RGGI), a collaborative effort among northeastern and mid-Atlantic states to reduce carbon emissions from power plants through a cap-and-trade program.[48]

State Adaptation Planning

In 2008 the Governor's Steering Committee (GSC) on Climate Change established an adaptation subcommittee to determine the impacts of climate change on the infrastructure, natural resources, public health, and agriculture of

Connecticut in accordance with Public Act 08-098. The subcommittee released its report in April 2010 after examining the potential impacts on these sectors from changes in precipitation, temperature, and sea level in 2020, 2050, and 2080.[49] The second phase of this effort, the development of an adaptation strategies report for the state legislature, was originally due in July 2010. However, the report is currently pending approval by the Department of Energy and Environmental Protection (DEEP) commissioner before release. **Given the impacts the state is expected to face from climate change, the DEEP commissioner should expedite approval of the adaptation strategies report.**

Aside from the work of the GSC Adaptation Subcommittee, other agencies in Connecticut have been involved in preparing for climate change. The former Department of Environmental Protection (DEP, now DEEP) developed a series of eight documents entitled "Facing Our Future" on the impacts of climate change on biodiversity and habitat, fisheries, forestry, infrastructure, natural coastal shoreline environment, outdoor recreation, water resources, and wildlife. With respect to flooding and water quality issues, the report noted that low-impact development techniques that reduce impervious cover and policies that protect floodplains and wetlands from development are potential strategies for adapting to more-intense precipitation events and rising sea levels.[50] To address drought and water supply risks, the report recommended greater water conservation efforts and an increased use of reclaimed wastewater for cooling, irrigation, and industrial processes.[51] Overall, the water resources report suggested that the state work to address existing regulatory issues involving water allocation and water quality management.[52] Other strategies recommended to help adapt to climate change include protecting coldwater habitat, locating and designing new infrastructure that is able to meet future needs and protection standards, and utilizing retreat as an option to address sea level rise.[53] The adaptation strategies identified in this set of documents are a promising starting point. **Connecticut should begin to implement these strategies to reduce the state's vulnerability to climate change.** The state also is working with the New England Interstate Water Pollution Control Commission on an adaptation strategies report specifically for water infrastructure.[54]

Climate change also has been recognized in the state's land acquisition and protection planning. The 2007-2012 Green Plan outlines a process to achieve the statutory goal of protecting 21 percent of Connecticut's land area by 2023. The plan recognizes that the preservation of floodplains, coastal waterfront, and adjacent uplands provide opportunities to manage climate change impacts.[55] The forthcoming update to the Conservation and Development Policies Plan for Connecticut also represents a significant opportunity for the state to incorporate climate change adaptation into the actions of state agencies and local municipalities. Under the state's "home rule" system of government, local municipalities regulate land use decisions.[56] Until recently, local conservation and development plans were not required to be consistent with the state plan; however, with the passage of Public Act 05-205, regional planning organizations are now required to develop and adopt plans that are consistent with the state plan.[57] The current 2005-2010 version of the plan, which remains in effect until 2013, contains carbon dioxide emissions reduction provisions. **The state should ensure that climate change impacts, such as increased flooding and drought risks and sea level rise, are considered in the 2013-2018 Conservation and Development Policies Plan update.**

Water resources planning in Connecticut has historically lacked a cohesive long-range vision, largely due to the number of state agencies and myriad rules and regulations involved.[58] Water resources management authorities in the state are distributed among DEEP, the Office of Policy and Management (OPM), the Department of Public Health, and the Department of Public Utility Control.[59] In 2001, in an attempt to better coordinate the state's management of water resources, the General Assembly created the Water Planning Council (WPC), which is composed of representatives from these four state agencies.[60]

In response to issues arising from the historically complex nature of water management in the state, the WPC has focused heavily on water allocation issues through the Water Allocation Policy Planning Model, which provides a framework for allocating water among users at the basin level.[61] However, efforts to resolve longstanding water allocation issues have not been without challenges. Legislative efforts to apply the state's regulatory authority to registered diversions have been unsuccessful.[62] A grandfathering provision contained in the Water Diversion Policy Act, which was passed in 1981 to manage competing uses and improve protection of the state's water resources, has exempted many large water users (as many as 85 percent) from permitting requirements that evaluate the environmental impacts of water diversions.[63] In addition, DEP's attempts to develop streamflow regulations in recent years to ensure that a minimum flow of water exists to protect sensitive stream habitats have faltered.[64] While not explicitly implemented to address climate change, the OPM and WPC are working to improve water conservation statewide by developing best management practices for outdoor water conservation and encouraging conservation rate structures.[65] While water conservation is an important "no regrets" strategy for addressing greater hydrologic variability, **the Water Planning Council should make certain that climate change and its impacts on water are considered explicitly during the water allocation process.**

Climate change and its impacts on sea level, precipitation, storm intensity, flooding, drought, and other natural disasters are described in the 2010 update to the state's Natural Hazards Mitigation Plan.[66] Furthermore, one of the three natural hazard mitigation goals identified by the state for the 2010-2013 period is to promote the implementation of sound floodplain management and other hazard mitigation principles by providing guidance to communities on enhancing floodplain ordinances and investigating climate change adaptation strategies as they affect hazard mitigation and state investment policies.[67] In support of these efforts, DEP has identified as medium-level priorities such activities as modeling floodplain changes as a result of sea level rise and developing policies to reduce risks to new development.[68] **The state should prioritize efforts to identify areas at increased risk of flooding and erosion from sea level rise in order to develop and implement strategies to reduce vulnerabilities in these areas.**

Groton Coastal Climate Adaptation Workshop

In 2010 the U.S. EPA's Climate Ready Estuaries program, ICLEI-Local Governments for Sustainability, and DEP's Long Island Sound Program held a three-part workshop on climate change in the town of Groton. The workshops presented information on the regional impacts of climate change, adaptation strategies, and ways to collaborate among different levels of government to support adaptation.[69] As a result of this effort, the Groton has begun to incorporate adaptation into its Capital Improvement Project Criteria.[70] One example is the consideration of climate change in the reconstruction and update of two bridges in the town.[71] In addition, DEEP and ICLEI are developing an Adaptation Resource Toolbox, a database of adaptation tools and resources to help other communities in Connecticut adapt to climate change.[72]

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DELAWARE

Delaware's coastal infrastructure and resources are extremely vulnerable to sea level rise, due to the state's location bordering Delaware Bay and the Atlantic Ocean. Increasing temperatures and changes in precipitation and subsequent impacts on streamflow hydrology, groundwater resources, and water quality also could have widespread implications for the human and natural systems that rely upon these resources. To reduce future vulnerability to sea level rise, Delaware has undertaken an initiative that includes efforts to build the resilience of local communities and is working to develop a statewide sea level rise adaptation plan. Because the entire state lies in close proximity to the coast, the focus sea level rise is warranted; however, **Delaware also should evaluate the state's vulnerability to other climate change impacts, such as flooding and drought, and develop response strategies to reduce risks associated with these hazards.**

Water Resources Background

Delaware's climate is significantly moderated by the Atlantic Ocean, Delaware Bay, and Chesapeake Bay.[1] Average annual precipitation in the state ranges from about 41 inches in the central region to 46 inches along the southern Atlantic coast.[2] Precipitation is generally evenly distributed throughout the year; however, the summer is usually the wettest season due to rainfall from convective thunderstorms and occasional tropical cyclones.[3] Delaware is also susceptible to climate extremes in the form of floods and droughts. Floods can result from intense precipitation events and from melting snow that causes streams to overflow.[4] Droughts can occur as the result of the Bermuda High shifting to the southeastern or midcontinental U.S. and the subsequent flow of warm, dry air over the state.[5]

Surface water and groundwater resources are both important sources of water in the state. Approximately 80 percent of freshwater withdrawals come from surface water sources, with the remainder coming from underground aquifers.[6] About 80 percent of surface water withdrawals are nonconsumptive and are utilized for cooling in thermoelectric power generation facilities.[7] Freshwater demand is highest in the densely populated and industrialized northern part of the state (New Castle County), where almost all water comes from surface sources and is used for thermoelectric cooling and public supply.[8] In Kent County, the central part of the state, 90 percent of water supplies come from groundwater, and three-quarters of water is used for irrigation and public supply.[9] In Sussex County, in the southern part of Delaware, about 60 percent of water is withdrawn from groundwater supplies and is used for irrigation and public supply; the surface water withdrawn is used mainly for industrial purposes.[10]

Delaware has more than 380 miles of coastline dotted with inland bays, estuaries, wetlands, and beaches.[11] The state is also adjacent to the Delaware River Estuary, which is of significant economic and ecological value. The estuary contains habitat for more than 200 fish species and the largest breeding population of horseshoe crabs in the world.[12] In addition, the estuary contains one of the world's largest freshwater ports, the Delaware River Port Complex, which generates $19 billion annually.[13] It also supports the fifth-most-populated urban center in the U.S., the Philadelphia-Camden-Wilmington metropolitan area, and provides drinking water for more than 15 million people.[14,15] Beaches are also vital to the economy of Delaware. In 2008 almost seven million people visited the state; the tourism industry contributed nearly $2 billion to the state economy and employed almost 40,000 people.[16] Because the entire state is within eight miles of the coast, Delaware is extremely vulnerable to coastal hazards such as tropical storms and nor'easters.[17] These coastal storms cause severe erosion, storm surge, and extensive flooding.[18]

Climate Change Impacts on Water Resources

Over the past century, the average temperature in Dover has risen by 1.7°F, and precipitation has increased by as much as 10 percent in parts of the state.[19] Across the Delaware Estuary watershed, which includes portions of Pennsylvania, New Jersey, and Delaware, temperatures are projected to rise 3.4°F to 6.7°F by the end of the 21st century, with warming expected to be significantly greater during the summer months.[20] Annual mean precipitation also is projected to grow, by 7 to 9 percent by 2100, with greater increases in the winter months and a substantial rise in the frequency of extreme precipitation events.[21]

These climatic changes could impact Delaware's hydrology through diminished streamflows, decreased groundwater recharge, and potential water supply shortages.[22] In particular, warmer temperatures are expected to decrease snowpack and result in earlier melting. Earlier melting, in conjunction with more winter precipitation, could contribute to increased flooding risks and decreased spring runoff, which in turn will impact the timing of freshwater availability.[23] Furthermore, increases in summer evaporation could reduce aquifer recharge, and changes in soil infiltration could affect the rate at which pollutants migrate through aquifers.[24,25]

Since the 1920s, tide gauge records at Breakwater Harbor indicate a relative sea level rise of approximately 1 foot per century.[26] Based on this record and other regional records, average historic relative sea level rise for Delaware is 1.1 feet per century.[27] Rising sea levels are already submerging low-lying land, causing beach erosion, inundating coastal wetlands, increasing coastal flooding, and leading to saline intrusion of coastal aquifers and freshwater resources.[28] The U.S. EPA has estimated that a 1.7-foot rise in sea level could inundate 50 percent of the wetlands in Delaware Bay.[29] Furthermore, the mid-Atlantic states are likely to experience a sea level rise greater than the global average as a result of land subsidence from the melting of ice sheets and groundwater extraction from coastal aquifers.[30] The Sea Level Rise Technical Workgroup projects a rise of 1.6 to 4.9 feet by 2100.[31]

Increases in sea level will exacerbate existing risks associated with erosion, inundation, and flooding and potentially cause damage to coastal infrastructure such as roads, causeways, and bridges.[32,33] The intensity of tropical and extratropical cyclones are projected to increase as well.[34] Higher sea levels, in conjunction with more powerful coastal storms, will intensify hazards associated with storm surge and flooding.[35] Changes in streamflow and increases in sea level also will have impacts on the salinity of the Delaware Estuary. At 70 miles long, the estuary has the largest freshwater tidal region in the world.[36] Greater saline variability will have implications for people who rely on the extended saline gradient for drinking water.[37] Natural communities and aquatic species also could be threatened by these changes. Bivalves (clams, oysters, etc.) are particularly vulnerable to increasing salinity because diseases that lead to high mortality are more pervasive at high salinities.[38] Moreover, freshwater mussels in the esstuary cannot tolerate any salinity at all.[39] Ocean acidification is also a concern: Shellfish larvae are vulnerable to low pH, and adults are susceptible to shell erosion that can lead to acute or chronic stress.[40] Furthermore, warmer ocean temperatures could contribute to the increased duration and intensity of harmful algal blooms that damage shellfish habitats and endanger human health.[41]

Greenhouse Gas Pollution Reduction

In 2000 the Center for Energy and Environmental Policy at the University of Delaware developed the Delaware Climate Change Action Plan for the Delaware Climate Change Consortium. This plan identified strategies necessary to reduce the state's greenhouse gas emissions by 7 percent below 1990 levels by 2010. **Delaware should establish new greenhouse gas pollution reduction goals and update its strategy for meeting them.** The state is also a member of the Regional Greenhouse Gas Initiative (RGGI), a cooperative effort among northeastern and mid-Atlantic states to regulate and reduce carbon dioxide emissions from power plants.[42]

State Adaptation Planning

Nearly all of the climate change adaptation activities at the state level in Delaware have revolved around preparing for sea level rise. The 2007-2017 state wildlife action plan recognizes sea level rise as an issue affecting coastal habitats and ecosystems.[43] Specific actions proposed to address sea level rise impacts include integrating key habitat and conservation into long-range sea level rise planning, incorporating sea level rise scenarios into relevant management plans, and supporting greenhouse gas reduction efforts. In 2009 the Coastal Programs Section of the

Delaware Department of Natural Resources and Environmental Control (DNREC) developed the Sea Level Rise Initiative to promote sea level rise understanding, preparedness, and response among coastal communities.[44]

To accomplish this broad objective, the state is pursuing activities in four main areas: providing scientific and technical support for decision-making, implementing projects in partnership with local communities, providing education and outreach to stakeholders and the public, and improving existing management practices and policies and/or developing new ones where necessary.[45] Sea level rise inundation maps already have been developed, and work has begun to create a marsh vulnerability index that identifies degraded or threatened marshes.[46] The state also is working with the communities of New Castle and Bowers Beach to identify potential vulnerabilities from climate change and to develop an action plan for addressing these vulnerabilities.[47] Furthermore, Delaware Coastal Programs (DCP) is in the process of developing a statewide adaptation plan for sea level rise that will include a vulnerability assessment and recommended adaptation strategies.[48] The three work groups of the Sea Level Rise Advisory Committee (Natural Resources, Public Safety and Infrastructure, and Society and Economy) are in the process of finalizing vulnerability assessments to inform development of the statewide sea level rise adaptation plan.[49] DCP also has made grant funding and technical assistance available for community planning to address sea level rise and coastal hazards.[50] To improve outreach and education on sea level rise issues, DCP developed a sea level rise visualization tool and conducted a survey to assess public knowledge on sea level rise issues to inform the development of a comprehensive outreach strategy.[51]

The DNREC adopted a sea level rise policy in 2010 that requires staff to consider potential coastal inundation in project planning, engineering, design, and review and in land acquisition, management, and restoration activities.[52] The policy also directs programs to assess the vulnerability of DNREC holdings and assets to inundation and to develop plans to increase resilience and adaptability. This vulnerability assessment is nearing completion, and strategies for addressing identified vulnerabilities should be completed by spring 2012.[53] Additionally, DNREC programs are to consider project alternatives that avoid siting buildings and projects in areas vulnerable to inundation; if alternatives are not practical, project design must consider how to address inundation. The policy also sets three scenarios of sea level rise by 2100 for DNREC programs to consider: 0.5 meter (19.7 inches) for low-sensitivity projects, 1.0 meter (39.4 inches) for medium-sensitivity projects, and 1.5 meters (59.1 inches) for high-sensitivity projects. To ensure consistent and effective implementation of this policy, **DNREC should develop detailed implementation guidance for staff that includes, among other things, a discussion of how to determine the sensitivity of projects, the vulnerability of projects to sea level rise, and the adequacy of project design for sea level rise.**

In 2009 the Delaware Sea Grant, with support from the University of Delaware, DNREC, and NOAA, produced the report "Coastal Hazards and Community Resiliency in Delaware." It identifies hazard mitigation opportunities, such as the preservation of undeveloped floodplains and wetlands for use as storm and erosion buffers and flood control, the relocation of critical facilities from hazardous areas, and the use of land use and zoning regulations and incentives to direct development.[54] Elevation and siting are further indicated as important factors in vulnerability and among the most effective methods of coastal hazard mitigation.[55] **In the development of the statewide sea level rise adaptation plan, Delaware should consult existing resources like the coastal hazards report for potential adaptation strategies.** Considering the likelihood of impacts beyond sea level rise in Delaware, **the state also should seek to evaluate and reduce vulnerability to other climate change-related impacts, such as extreme precipitation events, flooding, and drought.**

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FLORIDA

Florida is one of the most vulnerable states in the U.S. to climate change. Water on three sides and a subtropical location make Florida particularly susceptible to sea level rise and tropical cyclones. In addition, 75 percent of the state's population—more than 14 million people—live in coastal counties.[1] A study by the Organisation for Economic Co-operation and Development (OECD) ranks Miami fourth in the world in terms of population and first in terms of exposed assets at risk to a 100-year flood event.[2] By 2070, as a result of climate change and socioeconomic changes, nearly five million people and $3.5 trillion in assets could be flooded by a 100-year event.[3] Furthermore, the state's tourism sector could lose $40 billion annually by 2050 and $167 billion annually by 2100 if no action is taken.[4] Given the enormous risks to the people, economy, and resources of Florida, the state government should be actively developing plans and policies to reduce these vulnerabilities. Instead, the state has moved in the opposite direction by abolishing the Florida Energy and Climate Commission and by potentially increasing, through regulatory changes, the amount of coastal area eligible for development. The few adaptation initiatives in place exclusively focus on sea level rise. While the state is at significant risk from sea level rise, other impacts from climate change, such as drought and more frequent heavy precipitation events, also will pose challenges. **Florida should commit to ensuring that the state is prepared to weather the impacts of climate change by developing and implementing an integrated and comprehensive adaptation plan.** In the absence of state leadership on climate change, regional efforts such as those led by the Southeast Florida Regional Climate Change Compact and the South Florida Water Management District will become increasingly vital.

Water Resources Background

Across the state, annual rainfall averages about 53 inches; however, annual averages range from 40 inches in the Florida Keys to 64 inches in mainland southeast Florida and the panhandle region.[5] There is marked seasonality in precipitation, with 70 percent of annual rainfall occurring between May and October.[6] Extreme interannual variations are also not uncommon, with tropical cyclones and storms causing flooding in some years and low precipitation amounts resulting in drought in other years.[7] The state's five largest rivers are the Apalachicola, Suwannee, Choctawhatchee, Escambia, and St. Johns.[8] With the exception of the St. Johns, all of these rivers are located in northern basins that drain into the Gulf of Mexico.[9] Florida's largest lake, Okeechobee, covers 730 square miles and is the second-largest lake wholly located within the U.S.[10] The state also contains vast underground aquifers that supply municipalities and domestic, industrial, and agricultural wells.[11] The Floridan Aquifer is the principal groundwater source for most of the state and supplies the municipalities of Daytona Beach, Jacksonville, Gainesville, Orlando, St. Petersburg, Tallahassee, and Tampa.[12] The Biscayne Aquifer, located in Broward, Dade, and Palm Beach counties, is an important source of water for south Florida; it is recharged primarily by local rainfall and from canals connected to Lake Okeechobee.[13] In the western part of the panhandle region, sand and gravel aquifers supply wells in Escambia, Santa Rosa, and Okaloosa counties.[14]

In 2005 groundwater accounted for almost 62 percent of all freshwater withdrawn statewide; surface water supplied the remainder.[15] Groundwater withdrawals provided 90 percent of Florida's population with drinking water. Approximately 60 percent of groundwater withdrawals came from the Floridan aquifer, and more than 40 percent of surface water withdrawals came from Lake Okeechobee and associated canals.[16] In addition, reclaimed wastewater and desalinated brackish groundwater are growing sources of water in the state. In 2006 approximately 700 million gallons of reclaimed wastewater were produced each day for irrigation, industrial use, and aquifer recharge.[17,18] Overall, agricultural irrigation withdrawals constituted 40 percent of total freshwater withdrawn in 2005, with public supply close behind at 37 percent.[19] In addition, public supply utilized the majority of total groundwater withdrawals (52 percent), while agriculture used the majority of total surface water withdrawals (56 percent).[20] Nearly one-fourth of total freshwater withdrawals occurred in the months of April and May, and the largest amount of freshwater was withdrawn in the southeast Florida counties of Hendry, Palm Beach, Broward, and Miami-Dade.[21]

Given the state's proximity to saltwater on three sides, saline intrusion into coastal freshwater aquifers when withdrawal rates exceed the rate of recharge is an ongoing concern.[22] Critical water supply issues evidenced by significant declines in groundwater levels have led to substantial parts of the state being deemed water resource caution areas.[23] These areas are projected to have critical water supply issues within the next 20 years and, consequently, are required to utilize reclaimed water from wastewater treatment facilities unless it is not economically, environmentally, or technically feasible.[24]

As a peninsula, the state has extensive coastal and marine resources. The approximately 8,400 miles of tidal shoreline are the most of any state in the U.S other than Alaska.[25] In addition, a large network of estuaries and bays, formed where flowing rivers empty into the ocean, support an ecosystem full of biodiversity.[26] These estuaries, along with coastal wetlands and beaches, also support significant portions of Florida's economy.[27] Tourism is considered by many to be the hallmark of the state's economy. In 2010 more than 82 million people visited the state, spending nearly $63 billion and supporting an industry that employs nearly 975,000 people.[28] Overall, the state's direct ocean economy contributed $25 billion in 2005; the total contribution of coastal counties in 2006 was $562 billion, or 82 percent of total state GDP.[29] Florida's extensive coastline also is home to valuable oceanfront property, which is predominantly residential. In 2006 these properties were collectively valued at more than $180 billion.[30] While economically beneficial, the state's location and proximity to warm tropical waters is also a liability. Nearly 40 percent of all hurricanes that have made landfall in the U.S. have hit Florida, particularly along the panhandle and southern parts of the peninsula.[31] Since 2000, 19 hurricanes or tropical storms have directly hit the state.[32] In addition, more than $450 billion in hurricane damage has occurred in Florida since the early 20th century.[33] Each year, the state has an estimated 20 percent chance of incurring at least $1 billion in hurricane-related damages.[34]

Climate Change Impacts on Water Resources

Over the course of the 20th century, average temperatures across the southeastern U.S. have largely remained unchanged; however, since 1970, annual average temperatures have increased about 2°F.[35] Since the early 1900s, precipitation in southern Florida has declined nearly 10 percent in the spring, summer, and fall, while winter precipitation has increased 5 to 25 percent over the peninsula.[36] There also has been an increase in heavy rainfall events in many parts of the southeastern U.S.[37] By 2100, mean annual temperatures in Florida could increase by 2°F to 10°F, depending on the rate of future greenhouse gas emissions.[38] In addition, future precipitation in southern Florida is expected to occur as more-frequent intense events separated by longer dry periods.[39]

Temperature increases and changes in precipitation patterns are likely to have major implications for the state. Rising air temperatures are expected to increase evapotranspiration rates by an estimated 15 percent in south Florida by the end of the century, potentially leading to increases in irrigation demand and water needs for wetland areas.[40] Increased evapotranspiration is also likely to lead to greater losses from surface water storage systems, which would affect water availability.[41] Reductions in precipitation, in conjunction with higher temperatures, could increase the frequency and intensity of drought events.[42] Droughts also can lead to saline intrusion into aquifers as groundwater recharge rates decrease and water tables decline.[43] Conversely, increases in extreme rainfall events would pose flooding risks to infrastructure and property and could negatively impact water quality through increased pollutant runoff and damage of water treatment systems.[44] Higher water temperatures in rivers and streams are also likely to reduce dissolved oxygen availability and decrease the range of suitable habitat for aquatic species.[45]

Climate Change Impacts on Coastal and Marine Environments

While observed rates of sea level rise vary along the coast, relative sea level rise in Florida can be considered similar to the estimated rate of global sea level rise of 0.07 inch per year between 1936 and 2009.[46,47] Furthermore, global mean sea levels are projected to rise 2.5 to 6.2 feet by 2100 as a result of thermal expansion of the oceans and ice melt.[48] Sea level rise could have potentially devastating impacts on coastal areas. Higher sea levels will exacerbate existing erosion problems and could cause inundation of coastal infrastructure, including bridges and roads.[49] A recent study estimates that a rise in sea level of 2.25 feet would place 9 percent of Florida's current land area—an area with a population of 1.5 million—underwater during high tide.[50] In addition, two-thirds of this area is composed of wetlands, which would be converted to open water.[51] Over the past 100 years, 40 percent of the shoreline along Florida's Atlantic coast have retreated.[52] Furthermore, where shorelines are armored, coastal wetlands will be unable to migrate inland and will be lost to rising seas. The southern tip of Florida is especially at risk, with more than 99 percent of Monroe County and nearly 70 percent of Miami-Dade County likely to be submerged with a 2.25-foot rise in sea level.[53] In Palm Beach County alone, property valued at $1.3 billion to $1.9 billion would be vulnerable to inundation after a 2-foot rise in sea level, and property valued at $3.6 billion to $4.5 billion would be at risk to inundation after a 3-foot rise.[54] Moreover, the intensity of Atlantic hurricanes is expected to increase, leading to higher winds, more intense rainfall, and higher storm surges.[55] More powerful tropical cyclones along with higher sea levels would lead to even greater coastal areas being subject to damage from erosion and flooding. Sea level rise also could exacerbate existing problems with saline intrusion of coastal aquifers and, in concert with changing streamflow patterns, change the salinity of estuarine ecosystems and coastal habitats.[56]

As air temperatures rise, sea surface temperatures are likely to increase as well, jeopardizing many ocean species and the state's coral reefs.[57] In fact, Florida's 300-nautical-mile reef system is the only barrier reef in the entire continental U.S.[58] Corals are sensitive to temperature changes, and the bleaching of corals as ocean temperatures rise would have negative repercussions throughout marine ecosystems, affecting 25 percent of all known marine fish species due to their reliance on corals for habitat and food.[59] Warmer temperatures are also likely to increase the frequency and intensity of harmful algal blooms, which could impact marine food webs and coastal populations.[60] Ocean acidification as a result of uptake of carbon dioxide would also have negative implications for marine ecosystems. Global average ocean surface pH has already decreased by 0.1 unit since preindustrial times.[61] Under a business-as-usual emissions scenario, pH is projected to decline 0.35 unit by the end of the century in the Atlantic Ocean and Caribbean Sea—more than a twofold increase in acidity.[62] Consequently, organisms with calcium carbonate shells or skeletons, such as coral and clams, would have weaker skeletons and slower growth as calcification rates decline.[63]

Greenhouse Gas Pollution Reduction

In 2007, then-governor Charlie Crist issued Executive Order No. 07-127, which established statewide greenhouse gas emissions reduction targets of 2000 levels by 2017, 1990 levels by 2025, and 80 percent below 1990 levels by 2050.[64] In October 2008 the Governor's Action Team on Energy and Climate released its final report, which contained 50 policy recommendations to reduce statewide greenhouse gas emissions; if enacted, these recommendations would surpass the state's emissions reduction targets.[65] However, since the report's release, Florida has made little progress in reducing statewide greenhouse gas pollution and in March 2012, the state legislature passed a bill repealing provisions for a cap-and-trade regulatory program.[66] **Florida should take concrete measures to achieve its pollution reduction targets and reduce its contribution to climate change.**

State Adaptation Planning

The Governor's Action Team on Energy and Climate's final report also included a framework for adaptation. These initial recommendations for adaptation included supporting climate science research for Florida; integrating climate change into local, regional, and state planning; protecting ecosystems and wetlands through land acquisition and nonstructural techniques; minimizing impacts to water quantity and quality; minimizing impacts to infrastructure and property by requiring design to consider climate change impacts; and improving emergency response and preparedness capabilities. Furthermore, in 2008 the Florida Energy and Climate Commission was established to implement the recommendations contained in the Energy and Climate Action Plan.[67] However, recent political changes in state government have shifted momentum away from climate change issues. Consequently, the commission was dissolved in July 2011 with the passage of SB 2156, which transferred the duties of the commission to the Department of Agriculture and Consumer Services.[68] During its brief existence, the commission focused predominantly on energy efficiency projects and very little on responding to the impacts of climate change.[69] **Florida should develop and implement a comprehensive adaptation plan to prepare the state for the impacts of climate change. The state would benefit from the implementation of adaptation strategies outlined in the Energy and Climate Action Plan as well as strategies developed by other groups, such as the Center for Urban and Environmental Solutions.**[70]

While efforts to develop and implement an integrated and comprehensive approach to climate change adaptation may have stalled with elimination of the commission, there are a few initiatives in progress to address sea level rise and climate change impacts on coastal communities, transportation, wildlife, and coral reef ecosystems. In 2006 the Florida Division of Emergency Management received a five-year grant to facilitate the development of local Post-Disaster Redevelopment Plans (PDRPs).[71] As a part of this process, six pilot communities were selected to assist in the development of a guidebook on post-disaster redevelopment planning for communities. This guidebook included a discussion of the potential impact of sea level rise in coastal areas and recommended that coastal communities conduct an analysis of future sea level rise inundation and storm surge.[72] In 2010 the Florida Coastal Management Program (FCMP) added a priority category under the Coastal Partnership Initiative Grant program for projects that help coastal communities prepare for climate change, natural hazards, and disasters.[73] Two projects in this category have been funded: a sea level rise modeling and adaptation strategies study for wetland areas in the Apalachicola Bay system, and an update to the Pinellas County PDRP.[74] FCMP and the Guana Tolomato Matanzas National Estuarine Research Reserve also have proposed a project to assess the impacts of sea level rise on the vulnerability of coastal and estuarine ecosystems. The expected outcome of this project is a habitat restoration planning and guidance document for land use planning.[75]

The Florida Department of Economic Opportunity (DEO), formerly known as the Department of Community Affairs, is launching a five-year project, the Community Resiliency Initiative, to improve coastal community resiliency and address the impact of sea level rise. An expected outcome of this project is an update of the State Hazard Mitigation Plan to include sea level rise and its impact on coastal hazards and guidance for local communities on how they can integrate sea level rise adaptation into local hazard mitigation, economic development, and land use planning.[76] State agencies also have provided funding support for adaptation planning efforts in local communities like Punta Gorda and Satellite Beach.[77] As part of the 2060 Florida Transportation Plan, the Department of Transportation included the long-range objective of reducing the vulnerability and increasing the resilience of critical infrastructure to the impacts of "climate trends and events."[78] To achieve this objective, the department has supported research on the development of a method to assess the impacts of sea level rise on transportation modes and infrastructure and is in the process of developing a GIS-based analysis tool to identify potentially vulnerable infrastructure.[79,80]

In August 2011 the Florida Fish and Wildlife Conservation Commission released a draft update to the state's wildlife action plan, which included a sea level rise vulnerability assessment of six focal species (American crocodile, Atlantic salt marsh snake, Key deer, Florida panther, least tern, and short-tailed hawk) and potential adaptation strategies.[81] The second phase of this revision to the wildlife action plan is scheduled for completion in 2015 and is expected to include a broader assessment of climate change impacts—such as ocean acidification, precipitation changes, and warmer temperatures—on the state's wildlife.[82] In addition, the state's land acquisition program, Florida Forever, has a category for the acquisition of lands that offer opportunities for carbon sequestration, provide habitat, protect coastal lands, and help adapt to sea level rise.[83] However, state budget shortfalls have led to dramatic cutbacks in the program's financial resources.[84]

The state, in partnership with local, national, and international organizations, also is addressing the impact of climate change on the state's coral reef ecosystem through the Florida Reef Resilience Program. In 2010 the program released a five-year climate change action plan to guide reef management for the Florida Reef system. The plan identified several actions to be implemented to increase reef resilience while minimizing impacts upon reef-dependent industries (diving, snorkeling, fishing, etc.). Some of these actions include the development of a marine zoning plan that minimizes non-climate stressors, expansion of disturbance response monitoring, increases in the enforcement of regulations to mitigate negative reef use impacts, and development of models to predict reef system responses to climate change and ocean acidification.[85]

In addition, other programs that work closely with state agencies are addressing climate change impacts. The Florida Sea Grant College Program is in the middle of a four-year strategic plan that includes climate change as a focus.[86] The program is working to educate local policymakers and stakeholders on climate change impacts and is funding research in conjunction with the three other Gulf of Mexico Sea Grant programs on the impacts of sea level rise and hurricane intensification, as well as the implications of "takings law" on the ability of coastal communities to develop adaptation strategies.[87]

Florida possesses several planning and policy frameworks that can be utilized to address climate change impacts. All municipalities and counties are required to have a comprehensive land use plan to guide future development.[88] Comprehensive plans are required to include elements that address future land use, housing, transportation, capital improvements, intergovernmental coordination, potable water, stormwater, and wastewater, among other issues.[89] In 2011 the state legislature passed the Community Planning Act, which made significant revisions to Florida's growth management laws. This act gave local communities the option of designating areas that experience coastal flooding and that are vulnerable to sea level rise as "adaptation action areas."[90] Local governments that designate adaptation action areas can include sea level rise adaptation strategies in the coastal management element of their comprehensive plan. FCMP and DEO have applied for funding to develop a guidance document containing adaptation options for local governments interested in implementing adaptation action areas and policies in their local comprehensive plan.[91] **Florida should require local governments to include adaptation strategies for sea level rise, climate change, and other coastal hazards in their local comprehensive plans.[92]**

The state has a separate water management planning process that is implemented mainly by the five water management districts. Each district is responsible for developing a Regional Water Supply Plan (RWSP) that identifies additional sources of water for areas within its jurisdiction that do not have sufficient water resources to meet projected needs over the next 20 years.[93] Furthermore, districts reassess the need to develop new RWSPs or update existing RWSPs at least once every five years.[94] Some of the initiatives identified by districts include regional water system interconnections, additional reclaimed water projects, and water conservation.[95] The Department of Environmental Protection (DEP) anticipates that climate change will be included in future updates to RWSPs.[96] **The DEP Office of Water Policy should make it a priority to assist the water management districts with integrating climate change into water supply assessments and RWSPs.** Since Florida statutes require municipalities and counties to update their comprehensive plans within 18 months after a RWSP is updated or developed,[97] this also would be an effective means of ensuring that local governments address climate change issues. **The implementation of "no regrets" strategies, such as greater water conservation and efficiency measures and green infrastructure for stormwater management, should be an integral component of these water supply plans.**

While land use ordinances can be a particularly effective way to reduce vulnerabilities to sea level rise, erosion, and flooding, they also can serve to increase vulnerabilities by encouraging development in hazardous areas. In 2006 the state legislature revised the statutory definition of the Coastal High Hazard Area (CHHA) from the category 1 hurricane evacuation zone to the area below the category 1 storm surge line as established by the SLOSH storm surge model (i.e., the land area that would be flooded by storm surge from a category 1 hurricane).[98] Localities are restricted from making public investments in CHHA-designated areas in order to discourage private development in these potentially hazardous areas.[99] However, the change in the CHHA definition actually has served to decrease the amount of land designated as high hazard in many localities. In Palm Beach County, the CHHA-designated area decreased by nearly 90 percent, from 18,000 acres to 2,000 acres, as a result of the new definition.[100] Because the new CHHA definition is topographically based, higher-elevation areas could be excluded despite their proximity to coastal or intracoastal waterways.[101] Furthermore, reliance on the SLOSH model for boundary delineation of the CHHA recognizes risks only from storm surge flooding and not from wind or erosion.[102]

In the absence of clear directives from DEP on climate change, some districts, such as the South Florida Water Management District (SFWMD), have developed their own climate change initiatives. SFWMD is working with the U.S. Army Corps of Engineers and the Department of the Interior to develop saltwater intrusion models and is conducting an assessment of projects that may be impacted by sea level rise.[103] Over the next several years, the district aims to develop flood protection modeling tools and to devise and implement adaptation strategies for structures vulnerable to sea level rise.[104]

Southeast Florida Regional Climate Change Compact

The Southeast Florida Regional Climate Change Compact is a collaborative effort among Broward, Miami-Dade, Palm Beach, and Monroe counties to coordinate their climate change activities.[105] These counties contain a population of 5.6 million people, which represents 30 percent of Florida's total population.[106] The counties have committed to engaging in climate change policy discussions at the state and federal levels and working together to develop a regional climate change action plan that identifies strategies for reducing greenhouse gas emissions as well as adapting to climate change impacts.[107] In support of these efforts, the counties have worked to develop a single set of sea level rise projections for use in the regional climate action plan and in county planning.[108] These unified projections include a sea level rise of 3 to 7 inches by 2030 and 9 to 24 inches by 2060.[109] The Compact is currently seeking funding for the first phase of a regional adaptation pilot project to model climate change impacts on local surface water and groundwater, saltwater intrusion, and drainage and flood-control infrastructure.[110] In January 2012 the counties released a draft regional climate action plan that proposes 100 action items, which include identifying and designating "Adaptation Action Areas" (areas deemed most vulnerable to climate impacts), modifying design standards for transportation infrastructure built in vulnerable areas, and assessing the vulnerability of water infrastructure to climate change.[111]

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GEORGIA

Georgia is no stranger to impacts from extreme climate variability. In the past two decades, the state has experienced the two worst droughts on record, a 100-year flood, and a 500-year flood.[1] In addition, rapid economic expansion and population growth are intensifying pressures on water resources that have long been disputed, such as the Apalachicola-Chattahoochee-Flint (ACF) and Alabama-Coosa-Tallapoosa (ACT) river basins. Warmer temperatures, potential changes to precipitation patterns, and rising sea levels are likely to exacerbate existing vulnerabilities. By 2050 the state could lose more than $100 billion in GDP and approximately 752,000 jobs as a result of reduced water availability driven by climate change.[2] Growing concern over drought and interstate water conflicts has pressed the state to improve water resources management and adopt strict water conservation policies; however, the state has yet to address climate change on a broad scale. **Georgia should seek to better understand the state's vulnerabilities to climate change impacts and develop a coordinated strategy to adapt to these impacts.** In the meantime, **the state should prioritize the widespread adoption of relatively low-cost water supply strategies, such as improved water efficiency and green infrastructure, which remain flexible in the face of greater climatic and hydrologic variability.**

Water Resources Background

While average annual precipitation is approximately 50 inches statewide, it is highly variable across the state.[3] The extreme northwest corner receives about 75 inches annually, the central region about 45 inches, and southern parts of the state an average of 53 to 54 inches.[4] The driest season for the state is normally the fall, and the wettest season varies by region. In the northern third of the state, mid-latitude storms that arrive in late winter and early spring make January or March the wettest month. Most sections of central and southern Georgia have the greatest rainfall during the summer, and coastal areas have the highest rainfall in September as a result of tropical systems.[5] The state has more than 70,000 miles of streams that drain into the Atlantic or the Gulf of Mexico and more than 400,000 acres of lakes.[6,7] The Savannah and the Altamaha are the main rivers that drain into the Atlantic, and the Chattahoochee and Flint are the main rivers in western Georgia that flow to the Gulf of Mexico.[8]

Surface water is the main source of water in northern Georgia; groundwater is predominantly used in the coastal plain, where aquifers are well defined and highly productive.[9] The two most heavily utilized river basins for surface water withdrawal are the Altamaha-Satilla-St. Mary's Basin in southeast Georgia and the Apalachicola Basin, which serves Metro Atlanta.[10] Of total withdrawals statewide, nearly 80 percent was surface water, used mainly for thermoelectric power generation, while groundwater withdrawals were predominantly used for irrigation, industry, and mining.[11] Of overall statewide water withdrawals, the thermoelectric sector utilized nearly half, followed by public supply, irrigation, and industrial and mining uses.[12]

The Chattahoochee River is the main water source for the rapidly expanding Metropolitan Atlanta region; it is also a vital source for downstream users in Alabama and Florida.[13] The Chattahoochee begins in northeast Georgia, about 80 miles from Atlanta.[14] As the river flows southwest, it supplies Lake Lanier, which is formed by the Buford Dam and provides about 70 percent of Metro Atlanta's drinking water supply.[15] After continuing towards the southwest, it joins the Flint River near the Alabama and Florida borders.[16] From there, it becomes the Apalachicola River and flows through the Florida panhandle into the Gulf of Mexico at Apalachicola Bay.[17] Southeastern Alabama relies on the Chattahoochee to supply drinking water, industry, agriculture, and recreation.[18] Apalachicola Bay in Florida is a critical habitat for juvenile aquatic species found in the Gulf of Mexico and supplies more than 10 percent of the oysters consumed in the U.S.[19] The productivity and biodiversity in the bay is due to a unique saltwater-freshwater balance that results from discharge from the Apalachicola-Chattahoochee-Flint river basin.[20]

Legal disputes among Georgia, Alabama, and Florida began in the early 1990s when Alabama and Florida filed suit to prevent Atlanta and the U.S. Army Corps of Engineers from increasing withdrawals from the Chattahoochee.[21] Georgia filed lawsuits against the Army Corps in 2000; power distributors then filed suit against the Army Corps, alleging that the Corps' management of the river had resulted in inflated electricity prices.[22] The states' effort to negotiate a water allocation agreement ended unsuccessfully in 2008.[23] In 2009 a federal judge ruled that the U.S. Congress had to approve withdrawals from Lake Lanier and that current withdrawals from the lake were to remain frozen pending congressional authorization or a negotiated agreement.[24] According to the ruling, if a solution were not negotiated within three years (that is, by July 2012), the Atlanta metro region would not be able to use the reservoir as its main source of water.[25] A subsequent ruling by the 11th U.S. Circuit Court of Appeals in June 2011 overturned the previous decision and set a one-year deadline for the Army Corps to make a final determination on allocation from Lake Lanier.[26]

Georgia's coast contains rich biodiversity. Wetlands, coastal marine waters, barrier islands, and estuaries provide habitat for birds, turtles, marine mammals, shellfish, and fish, including commercially important grouper and snapper.[27] Eight main groups of barrier islands, which provide a buffer for the coast, stretch more than 100 miles from Tybee Island near the South Carolina border to Cumberland Island near the Florida border.[28] The role of coastal commerce is also of growing importance to the state. The Port of Savannah is the fastest-growing container port in the nation, responsible for nearly 20 percent of all East Coast container trade.[29] In addition, the Port of Brunswick is the sixth-largest automobile port in the U.S.[30] In total, the state's deepwater ports provide nearly 300,000 jobs and contribute almost $27 billion annually to Georgia's gross state product (GSP).[31]

Climate Change Impacts on Water Resources

Across the southeastern U.S. since 1970, average annual temperatures have increased about 2°F, with the greatest increases occurring during the winter.[32] Although total annual average precipitation may not have changed significantly, there have been observed changes in seasonal precipitation across Georgia and the Southeast. Regional average precipitation during the fall has increased nearly 30 percent, but in Georgia, spring, summer, and fall precipitation have decreased by about 15 percent.[33] As a result of these temperature and precipitation changes, the extent and intensity of drought has increased throughout the region, and there also has been an increase in heavy rainfall events in some areas.[34] Climate models project an average temperature increase of 4.5°F in the region by the 2080s under a low-emissions scenario and an average warming of 9°F under a higher-emissions scenario.[35] Projections for precipitation are not as determinate, with models indicating possible slight increases in total annual precipitation in Georgia by the end of the 21st century but less precipitation in other parts of the southeastern U.S.[36]

Because higher temperatures increase evapotranspiration, the frequency, intensity, and duration of droughts are likely to increase.[37] Warmer temperatures are also likely to lead to lower streamflows and lake levels, especially during the summer, which could lead to water availability issues that impact power production, navigation, and recreation.[38] Past drought events in Georgia, such as one that occurred in 2007, have intensified existing water conflicts in the ACF Basin and cost the state $1.3 billion in economic damage.[39] Major droughts also have had coastal impacts by increasing coastal salinity and contributing to salt marsh dieback and decreased shrimp and crab landings.[40] Groundwater levels also could drop as recharge rates decrease during dry periods, jeopardizing water users that rely heavily on aquifers. Continued groundwater pumping will only compound these problems by depleting water tables and possibly contributing to saline intrusion into coastal aquifers.[41] Aquatic species also could be impacted as warmer temperatures reduce dissolved oxygen in water bodies, leading to fish kills and loss of aquatic species diversity.[42]

Tide gauge data from Fort Pulaski indicate that between 1935 and 2006, mean relative sea level increased at a rate of nearly 0.12 inch per year, or about 1 foot per century.[43] By the end of the 21st century, sea levels in the region are projected to increase by 2 feet or more.[44] However, more recent studies predict that global sea levels could rise 2.5 to 6.2 feet by the end of the century due to the accelerated melting of land-based ice sheets.[45] Rising sea levels could increase flooding of coastal property and infrastructure, loss of coastal wetlands, erosion of beaches, and saline intrusion into drinking water supplies along the state's 100-mile coastline.[46] A 20-inch rise in sea level by 2100 is projected to result in a 20 percent reduction in salt marsh and a 47 percent increase in estuarine open water.[47] Sea level rise in conjunction with projections of more intense tropical cyclones due to warmer sea surfaces would increase storm surge, erosion, and flooding risks in coastal areas.[48] Warmer ocean temperatures could also contribute to the occurrence of harmful algal blooms, which can damage shellfish nurseries, impact human health, and carry bacteria.[49]

Greenhouse Gas Pollution Reduction

Georgia has not adopted a greenhouse gas pollution reduction goal or developed a strategy for reducing statewide greenhouse gas pollution. Greenhouse gas reduction efforts are crucial because at the global level, they play a role in diminishing the severity of climate change impacts. Consequently, **Georgia should adopt greenhouse gas pollution reduction targets and develop and implement a pollution reduction strategy to decrease the state's contribution to climate change.**

State Adaptation Planning

While the state has not developed an adaptation strategy, there have been some notable efforts to address sea level rise. The Coastal Incentive Grant program, administered by the Coastal Resources Division of the Department of Natural Resources, is funding a three-year study, currently underway, to model sea level rise along the Georgia coast.[50] In October 2011, the Georgia Coastal Management Program embarked on a five-year Post-Disaster Redevelopment Program that will integrate sea level rise considerations into coastal redevelopment following a major natural disaster.[51] The state also is seeking funding to conduct a coastal vulnerability assessment and to develop a coastal climate change adaptation plan.[52] In addition, Georgia is promoting living shorelines through demonstration projects on Sapelo Island, where mesh bags filled with oyster shells are being used to replace bulkheads and rock wall barriers.[53] To ensure that all coastal communities are addressing climate change risks consistently, **the state should look at regulatory approaches that other states along the Atlantic Coast, such as Maryland and South Carolina, are adopting to address coastal erosion and development issues.**

In response to severe drought events and growing concern over water curtailments from Lake Lanier, Georgia in recent years has pushed for improved management of water resources. In 2008 the Georgia Legislature and then-governor Sonny Perdue approved a comprehensive statewide water management plan that laid the framework for the development of regional water planning councils (RWPCs) and regional water development and conservation plans (WDCPs).[54] Each regional water planning council is required to assess the condition of current groundwater and surface water resources, project future demand for water and wastewater at 10-year intervals for the next 40 years, and identify management strategies to address gaps between capabilities and needs.[55] In November 2011, the 10 draft regional WDCPs were officially adopted by the Georgia Environmental Protection Division (EPD).[56] There have been no attempts to include climate change as part of this inaugural regional water planning cycle.[57] **In subsequent five-year reviews of the WDCPs, EPD should require RWPCs to include an assessment of the impact of climate change on water supplies and demands in each water planning region.**

In March 2010, the EPD released a state Water Conservation Implementation Plan to advocate for improved water conservation and more efficient use of water resources in Georgia.[58] The plan addresses water conservation and efficiency goals, benchmarks, and best practices in seven sectors: agricultural irrigation, electric generation, golf courses, industrial and commercial, landscapes, domestic and noncommercial, and state agencies. Examples of recommendations in the plan include the use of irrigation scheduling to determine when and how much to water crops to achieve optimal growth, nontraditional water supplies (i.e., reclaimed water or stormwater) in electricity generation, water budget-based rate structures, retrofit and rebate programs for fixtures and appliances, and more thorough metering and measurement of water usage.[59]

Also in 2010, the state legislature enacted the Georgia Water Stewardship Act.[60] This act requires local governments, public water suppliers, and state agencies to implement policies to improve water conservation and efficiency. Before January 1, 2011, local governments were required to adopt ordinances to restrict outdoor irrigation using publicly supplied water between 10 a.m. and 4 p.m.[61] The act also stipulates that new construction must utilize high-efficiency toilets, urinals, showers, and faucets and that new multi-unit residential construction permitted on or after July 1, 2012, must submeter water and wastewater usage. State agencies are also required to collaborate and identify incentives and programs to encourage water conservation and enhance water supply as well as to report annually on these activities.[62] Furthermore, the act also sets a time frame for public water utilities to conduct water-loss audits.[63] While measures in Georgia to improve water conservation and efficiency were not implemented as a direct result of concerns over climate change, they do better position the state to handle the impacts of a warmer world. Nevertheless, **the state should initiate a comprehensive process to identify climate change vulnerabilities and establish a coordinated strategy to reduce the risks of climate change to Georgia's people, economy, and natural resources.**

In January 2011, Governor Nathan Deal issued an executive order directing the Georgia Environmental Finance Authority (GEFA) to convene a task force to provide guidance on the development of the Governor's Water Supply Program, which aims to assist local governments in developing new sources of water. In its draft report released in November 2011, the Water Supply Task Force made recommendations for funding reservoir and water supply projects.[64] Before investing hundreds of millions of dollars in traditional "hard" or "gray" infrastructure like dams and reservoirs, **Georgia should prioritize the widespread adoption of relatively low-cost and flexible strategies, such as water conservation and green infrastructure, which will remain effective under a wide range of hydrologic and climatic conditions.**

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HAWAII

As the only U.S. state that is completely surrounded by water, Hawaii is particularly vulnerable to a world with higher temperatures, changing rainfall patterns, and rising seas. Due to the state's small land area and proximity to the ocean, freshwater resources are rather limited and saltwater intrusion is an ever-present concern. Recognizing the risks that climate change poses, the state has created a framework process to guide the development of a state adaptation plan. In the absence of a formal adaptation coordinating group, state agencies and other organizations have begun to implement components of the framework. To ensure that Hawaii's communities and natural resources are prepared for climate change, **the state should prioritize the development and implementation of a comprehensive statewide adaptation strategy.**

Water Resources Background

Hawaii is composed of six major islands (Kauai, Oahu, Molokai, Lanai, Maui, and Hawaii) that lie within a narrow, 430-mile zone in the tropical Pacific Ocean.[1] The islands are the peaks of volcanic mountains formed by repeated undersea eruptions. Consequently, the islands are characterized by steep changes in elevation. In total, 50 percent of the state lies above an elevation of 2,000 feet, and 10 percent is higher than 7,000 feet.[2] The islands' topography and proximity to the ocean and trade winds exert a strong influence on climate. Average annual precipitation is approximately 70 inches for the state, but there are large geographic disparities: in some mountainous areas the total can exceed 240 inches, and there are also very dry areas.[3] Incoming moist ocean air largely flows over low mountains and around higher mountains. Consequently, the driest areas in the state are commonly found along the upper slopes of high mountains and along leeward coasts and interior areas, such as Kawaihe Bay on the island of Hawaii, which averages less than 7 inches of rain annually.[4] In general, elevations of less than 2,000 feet and very high, dry mountain areas receive the most rainfall during the winter months. In contrast, average monthly precipitation in extremely wet areas is fairly uniform.[5] There can also be significant interannual variability in precipitation. Drought conditions are not uncommon in dry areas that receive their precipitation mainly from winter storms, but such droughts are generally limited to small areas. In contrast, extreme rainfall events that cause flash flooding are common, due in part to the steep terrain and small drainage basin areas.[6] In addition, the highest mountain areas (Haleakala, Mauna Kea, and Mauna Loa) can experience up to a foot of snow from major storms between October and May.[7]

Most of the state's streams originate in the mountainous interiors of the islands and flow to the coast. Streamflow in Hawaii is highly variable with regard to both time and location.[8] In drier areas of the state, ephemeral streams, or streams that are dry much of the year, are commonly found. Perennial streams, or streams that flow continuously, are commonly found in areas with significant groundwater discharge.[9] Streams supply a majority of the water used for irrigation and in some areas are the sole source of supply for drinking water.[10] Groundwater, however, is the preferred supply due to the decreased treatment requirements and greater reliability.[11] Most underground freshwater resources in the state are found in freshwater-lens or dike-impounded systems. In a freshwater-lens system, freshwater floats above denser saltwater with an intermediary zone of brackish water.[12] In a dike-impounded system, near-vertical dikes confine water in areas of permeable volcanic rock.[13] In Hawaii, the most productive and substantial groundwater aquifers are found in volcanic rocks throughout the state and support a variety of domestic, agricultural, industrial, and commercial uses.[14] However, declining water levels and saltwater intrusion are major factors in groundwater availability.[15]

Overall, nearly 80 percent of total freshwater withdrawals come from groundwater, and groundwater provides more than 95 percent of water used for public and domestic supplies.[16] Of total freshwater withdrawal in 2005, approximately 61 percent was used for public and domestic supplies, followed by irrigation at nearly 22 percent, thermoelectric power generation at 8.5 percent, and industrial use at 6.5 percent.[17] Sugarcane is a large consumer of irrigation water; other commonly cultivated crops include pineapple, other tropical fruits, nuts, coffee, and vegetables.[18]

Given Hawaii's island composition, coastal resources play an integral part in the state's identity, culture, and economy. Approximately 85 percent of the potential reef area of the entire United States (the area where favorable environmental conditions exist to support coral reef ecosystems) is located in Hawaii.[19] Coral reef ecosystems contribute about $360 million annually to the state economy through recreation, tourism, and fisheries while also promoting biodiversity and providing erosion protection.[20] These ecosystems possess an overall asset value estimated at $10 billion.[21] Tourism is the largest industry in the state, with more than seven million people visiting and spending in excess of $11.1 billion in 2010.[22] The state also has a substantial military presence, with several major military installations employing approximately 66,000 active service members and civilian personnel—roughly 10 percent of Hawaii's total employed workforce.[23]

Climate Change Impacts on Water Resources

Over the past 30 years, temperatures in Hawaii have increased at an average rate of 0.3°F per decade, with the greatest warming observed at high elevations.[24] By 2100, average annual temperatures are projected to increase by about 3.5°F to 6°F.[25] In addition, within the past two decades rainfall has declined about 15 percent.[26] The amount of rain falling in extreme events, however, increased approximately 12 percent between 1958 and 2007.[27] In general, climate models project that there will be an increase in the frequency of heavy downpours and an increase in the amount of rainfall during the summer in the Pacific.[28]

Increases in extreme rainfall events and summer rainfall are likely to increase flooding threats and place infrastructure, property, crop yields, and drinking water quality at risk.[29,30] In particular, polluted runoff from agricultural areas or overwhelmed sewage infrastructure driven by flooding or intense rainfall can compromise water quality.[31] In addition, direct cloud and land interactions result in water droplets being deposited directly on vegetation and land, creating a vital source of water for mountain ecosystems.[32] Higher temperatures could potentially diminish cloud zones and reduce the amount of cloud water available to these areas.[33]

Sea level rise is likely to have severe impacts for the Hawaiian Islands. Over the past 100 years, the sea level in Honolulu has risen an average of 0.6 inch per decade.[34] Some studies project a possible global sea level rise of more than 3 feet by the end of the century.[35] Higher sea levels exacerbate coastal flooding, inundation, and erosion. Coastal communities and ecosystems are likely to be threatened by higher seas. The low-lying northwestern Hawaiian Islands are home to a high concentration of endangered and threatened species whose habitats could be at risk due to sea level rise.[36] Increasing salinity of coastal wetlands would also impact estuarine species, and saline intrusion into underground aquifers would imperil valuable freshwater supplies.[37] About 25 percent of beaches on Oahu have been lost due to the construction of seawalls in response to chronic erosion problems.[38] Similar effects have been observed on other islands, such as Maui and Kauai, where average long-term rates of erosion approach 1 foot per year and large percentages of beaches are chronically eroding.[39] Furthermore, stormwater drainage in coastal areas will likely be negatively impacted by increased runoff from heavy rainfall events and sea level rise affecting gravity-fed outfalls.[40] The intensity of tropical cyclones also is projected to increase. In concert with higher sea levels, this would subject coastal areas to greater storm surge and flooding.[41] The most powerful hurricane to hit Hawaii, Hurricane Iniki, caused seven deaths and $2 billion in damage in 1992.[42]

As air temperatures have risen, sea surface temperatures have risen as well at an average rate of 0.22°F per decade.[43] Coral reef ecosystems are particularly susceptible to temperature increases as relatively small amounts of warming can lead to coral bleaching, the phenomenon that occurs when corals lose the symbiotic algae that provide them with food and their vibrant colors.[44,45] Subsequently, diverse coastal ecosystems can be damaged or lost. The uptake of carbon dioxide by the oceans is also leading to acidification. The mean pH of the global ocean surface has declined from 8.2 to 8.1 over the past 250 years, which translates to an increase in acidity of approximately 30 percent.[46]

Moreover, there has been an observed long-term decline in ocean-surface pH near the Hawaiian Islands.[47] Global models project that pH levels could decline an additional 0.3 to 0.4 unit during the 21st century.[48] As oceans become more acidic, the availability of dissolved carbonate decreases, and marine organisms—such as corals, plankton, algae, and shellfish, which contain calcium carbonate in their shells, skeletons, or tissues—can be negatively impacted.[49] The loss of coral ecosystems would also have profound impacts upon tourism and marine species biodiversity, including reductions in commercially important shellfish and finfish populations.[50]

Greenhouse Gas Pollution Reduction

Hawaii developed an initial attempt at a greenhouse gas reduction strategy for the state in 1998.[51] In 2007 the state legislature passed Act 234, Hawaii's Global Warming Solutions Act, which requires the state to reduce greenhouse gas emissions to 1990 levels by 2020.[52] In December 2009 the Greenhouse Gas Emissions Reduction Task Force submitted a work plan to the state legislature.[53] The Department of Health is currently working on an administrative rulemaking to require mandatory reductions for large emitters; this rule will go into effect in 2012.[54] **Hawaii should prioritize the completion and implementation of this administrative rulemaking to reduce the state's greenhouse gas pollution and contribution to climate change.**

State Adaptation Planning

In November 2009 the Ocean Resources Management Plan (ORMP) Working Group, which is tasked by the Hawaii Coastal Zone Management Program to develop the ORMP, released a climate change adaptation framework for the state.[55] The framework lays out a process for developing and implementing a statewide climate change preparedness plan. Framework components identified by the ORMP Working Group include building a climate change adaptation team, developing and adopting a long-term vision, identifying planning areas relevant to climate change, scoping impacts to major sectors, and conducting a vulnerability and risk assessment. To further progress on adaptation, the ORMP Working Group also conducted a preliminary assessment of likely sectors to be involved in adaptation planning and how they might be impacted by climate change.[56] The framework further identified several next steps: prioritizing areas for adaptation planning, setting preparedness goals, prioritizing preparedness actions, implementing a preparedness plan, and monitoring and updating the plan. The Climate Change Task Force, established by Act 20 in 2009 and housed within the Office of Planning in the Department of Business, Economic Development, and Tourism, was tasked with assessing the potential impacts of climate change on the state and making recommendations to the governor and legislature on how to mitigate these impacts.[57] However, the task force expired in June 2011 without ever receiving funding or holding a meeting.[58]

With the dissolution of the Climate Change Task Force, other state agencies and partners are implementing components of the adaptation framework. The ORMP Policy Group is the state's de facto climate adaptation coordinating group. In consultation with other partners, including the Office of Planning, Coastal Zone Management Program, and Office of the Lieutenant Governor, the ORMP Policy Group is developing a long-term vision and statewide climate change policy. The Office of Planning has drafted a climate change adaptation policy that has been submitted as part of the Department of Business, Economic Development and Tourism's package to be included in the governor's legislative package for the 2012 legislative session.[59] The policy would add climate change adaptation priority guidelines under the Hawaii State Planning Act, which is one of two statewide planning documents that guide the activities of all local and state agencies.[60] Because the actions of state agencies and counties must be consistent with the act, the inclusion of adaptation as a priority guideline would influence the implementation of state programs and policies, local land use decisions, and the allocation of public funding.[61] In addition, Hawaii Sea Grant is conducting an assessment of climate change impacts to major sectors in the state, which is expected to be completed in 2012.[62] Several other studies are also in progress, including a vulnerability assessment of transportation assets on Oahu, an analysis of climate change impacts on the Ala Wai Watershed, and a statewide risk and vulnerability assessment of water resources in conjunction with the U.S. Army Corps of Engineers.[63] The results of these projects will help to form the foundation for the next steps in the state's adaptation framework. **Hawaii should make available the resources and support necessary to implement the components of the adaptation framework and develop a cohesive adaptation plan for the state.**

In coordination with the state, other groups such as the Pacific Islands Climate Change Cooperative (PICCC) and the Pacific RISA also are conducting research to support climate change adaptation. Some of the projects funded by PICCC include statistical climate model downscaling of future rainfall, sea level rise mapping, and testing of management methods to reverse coral reef bleaching by locally increasing pH to combat ocean acidification.[64] Pacific RISA is also pursuing research on downscaling climate models for application to the islands and for evaluating the impacts of climate change on freshwater availability and groundwater sustainability.[65,66] In addition, Pacific RISA is funding a five-year research project at the Center for Island Climate Adaptation and Policy (ICAP), a Sea Grant center of excellence, on climate adaptation law and policy that includes an analysis of current laws, development of model legislation or draft revisions for consideration, and incorporation of indigenous knowledge in strategy development.[67] In 2011 ICAP released a report on the implications of climate change adaptation policies, specifically coastal development regulations, on regulatory takings claims in Hawaii.[68] To protect against takings challenges, the report recommended that implemented setbacks allow economically viable land use, hazard planning begin as early as possible in the development process, regulations relating to hazard mitigation be characterized as such, agencies exercise existing legal authority to deny development when possible, and government agencies be made aware of their potential liability for allowing development in hazardous areas.[69]

While Hawaii is in the initial planning stages of developing and implementing a coordinated climate change adaptation plan, the state has existing policies that may prove beneficial in a changing climate. Although the state's ORMP does not address climate change directly, many of the groups that are implementing projects under the plan are considering climate change. One example is the West Maui Watershed Plan, where the potential impact of climate change is being considered early in the development process.[70] Counties in the state also have a variety of shoreline setbacks for new development, which may prove to be beneficial in adapting to sea level rise. The County of Kauai has a setback of the annual average rate of shoreline erosion multiplied by a planning period of 70 years plus an additional buffer of 40 feet. For structures larger than 5,000 square feet, the planning period is extended to 100 years.[71] In Hawaii County, the minimum setback is 40 feet; this is also the case on Oahu, with the exception of new subdivisions at 60 feet and small lots where the setback is as little as 20 feet.[72] Maui's setback is the annual average rate of shoreline erosion multiplied by a planning period of 50 years plus a 25-foot buffer.[73] **Hawaii also should seek to implement "no regrets" strategies, such as improved water conservation and green infrastructure for stormwater management, to build resilience to potential climate change impacts.**

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Warmer temperatures, reductions in snowpack, and shifts in hydrology as a result of climate change could have severe repercussions for agricultural, municipal, and industrial users and wildlife in Idaho. Changes to natural habitats and the range of wildlife species due to warmer temperatures could impact the tourism and recreation industry, which brings in more than $3 billion annually.[1] Population growth in Idaho, in the absence of significant water conservation, will lead to greater water demand from domestic and municipal users and could exacerbate conflicts with existing agricultural users. In recent years the state has begun to include consideration of climate change impacts in water planning. **Idaho should take additional steps to evaluate potential impacts of climate change on water resources beyond water demand and supply and should identify strategies to adapt to these changes. The state also should expand consideration of climate change to all planning and decision-making related to water quality, stormwater, flooding, drought, and aquatic species.**

Water Resources Background

Because of the rain shadow effect imparted by the Cascade Range to the west, Idaho on average receives only 22 inches of precipitation annually—far less than western Washington or Oregon.[2] The geographic and seasonal distribution of annual precipitation varies, however, as a result of topographic and regional influences. Most of the precipitation in the northern and western parts of the state falls in the winter months because of Pacific maritime air masses drawn eastward by mid-latitude cyclonic storms.[3] In contrast, in the northeastern and eastern highland regions of Idaho, more than 50 percent of annual rainfall occurs between April and September as a result of moist air coming from the Gulf of Mexico and Caribbean.[4] Southern portions of the state are generally drier; while average annual precipitation in high elevations can exceed 60 inches, mostly in the form of snow, areas of southern Idaho receive on average less than 10 inches annually.[5]

Precipitation provides nearly 100 million acre-feet of water annually; however, about 50 percent is lost through evapotranspiration.[6] Surface water flowing into the state provides an additional 37 million acre-feet annually, primarily via the Snake, Salmon-Clearwater, Bear, Spokane, Pend Oreille, and Kootenai rivers.[7,8] Streamflow in Idaho is supplied largely by melting snowpack; consequently, natural flow generally demonstrates strong patterns of seasonality, with low flows occurring in the fall and winter months and high flows in the spring and early summer.[9] However, storage reservoirs, with a total capacity exceeding 15 million acre-feet statewide, largely damp the seasonality of flow on managed rivers.[10] Spring snowmelt initiated by warm temperatures is a main contributor to severe flooding events that are common statewide from April to June.[11] Approximately 95 percent of the state drains into the Columbia River Basin, with the remaining 5 percent draining to the Great Basin.[12] Groundwater discharge is also a significant component of flow to all streams, with the ratio of groundwater to surface water generally increasing as total runoff declines.[13] Surface water supplies also play a large role in replenishing groundwater resources. Most of the state's groundwater resources lie in intermountain regions like the Snake River Plain, the Lewiston area, and in the valleys of the panhandle.[14]

Idaho's water resources have been extensively developed for agricultural irrigation, hydropower generation, aquaculture, and municipal and industrial uses. In 2005 Idaho withdrew nearly 22 million acre-feet of freshwater, making it the third-largest water user in the U.S.—behind only California and Texas—and the state with the highest water consumption per capita.[15] Irrigated farmland is found almost exclusively in the Snake River Basin in southern Idaho, which is also one of the driest regions in the state. Consequently, in 2005 irrigation for the state's 3.5 million acres of farmland was by far the largest user of water, at 85 percent, with aquaculture at 13 percent and water for public supply at slightly over 1 percent.[16] Moreover, nearly one-third of irrigated land in the state is irrigated by water-intensive gravity or flooding irrigation.[17] In 2008 there were 115 facilities permitted by the state for aquaculture production, with rainbow trout, catfish, carp, and sturgeon the most common commercial species.[18] Hydropower production in Idaho can fluctuate considerably due to variations in precipitation and snowpack. In recent years, hydropower has provided 51 percent to 67 percent of the electricity consumed in the state.[19] Across all users, nearly 80 percent of withdrawal statewide comes from surface water supplies. For public supply, more than 90 percent of withdrawal is from groundwater resources.[20]

Climate Change Impacts on Water Resources

Over the past century, the average temperature in the Pacific Northwest as a whole has increased by about 1.5°F.[21] There has been no observed trend with respect to average annual precipitation.[22] As a result of increasing temperatures, the western U.S. has experienced a decline in spring snowpack, a reduction in the amount of winter precipitation falling as snow, and earlier snowmelt runoff in the spring.[23] In addition, over the past 50 years, there has been an observed decrease in mean August stream discharge in the Central Rocky Mountains.[24]

By the end of the 21st century, the Columbia River Basin is projected to warm by 6°F to 7°F relative to a 1990s mean, but no significant changes are expected for average annual precipitation.[25] Higher temperatures and subsequent hydrologic changes will have implications for water supply, water quality, flood risks, hydropower, and aquatic species. Warmer temperatures during the cool season (October through March) cause more precipitation to fall as rain instead of snow and contribute to earlier snowmelt, increased runoff, and greater winter flood risks.[26] A 2011 study by the U.S. Bureau of Reclamation estimates a 21 percent increase in mean December-to-March runoff by the 2070s for the Snake River.[27] In the past, heavy precipitation events and rain-on-snow events have led to substantial erosion of steep, intermediate-elevation slopes in the Idaho batholith. The increasing likelihood of these types of events suggests that increases in sediment loads and transport to downstream areas is also very likely.[28] In addition, spring peak runoff is projected to occur 20 to 40 days earlier by the end of this century.[29] Less winter snowpack accumulation, in conjunction with earlier snowmelt, reduces the amount of water available during the warm season (April through September) and increases drought risk.[30] Reduced snowpack volume also could result in decreased groundwater infiltration.[31] Increased evapotranspiration in response to warmer temperatures could drive more intense but less frequent rainstorms as well as increase demand for irrigation water.[32] Decreases in streamflow in the warm season could negatively impact the state’s 3-gigawatt-plus hydropower capacity, with such an impact occurring at the same time that electricity demands are the highest.[33] Because Idaho’s water management infrastructure was built to take advantage of existing climate conditions, any changes to the seasonality of streamflow could have significant repercussions for reservoir operations.[34]

Aquatic species in the Pacific Northwest historically have been threatened as a result of development projects and other human activities on the region’s rivers. Climate change could further threaten these species. Increased temperatures alone—without taking into consideration streamflow changes—are projected to lead to a 40 percent reduction in salmon habitat and an 8 to 33 percent loss in suitable trout habitat in Idaho by 2090.[35] Further, increases in the intensity and frequency of winter flooding can negatively affect overwintering juvenile fish and incubating eggs. Warmer water temperatures in the winter can also accelerate embryo development, leading to the premature emergence of fry and increased mortality rates.[36] Reductions in summer streamflow may also decrease the quality of rearing habitat and increase susceptibility to predation.[37]

Greenhouse Gas Pollution Reduction

In 2007, Governor C. L. “Butch” Otter issued Executive Order 2007-05, which directed the Department of Environmental Quality (DEQ) to develop a greenhouse gas emissions inventory and provide recommendations to the governor on how to reduce greenhouse gas emissions in the state.[38] DEQ formed a Greenhouse Gas Working Group, composed of representatives from state agencies, to reduce greenhouse gas emissions from state agencies; however, DEQ has not provided recommendations to the governor on the reduction of statewide greenhouse gas emissions.[39] Because Idaho is expected to face significant climate change impacts, **the state should decrease its contribution to climate change by prioritizing the development and implementation of a statewide greenhouse gas pollution reduction strategy.**

State Adaptation Planning

Water planning in Idaho at the state level consists of three components: the Idaho State Water Plan, comprehensive basin planning, and comprehensive aquifer planning. The current State Water Plan was released in 1996 and does not include consideration of climate change impacts. The state has been working on an update to this plan since 2007; the update will include a discussion of climate variability and the need for increased flexibility in water management to adapt to climate-induced hydrologic changes.[40,41] Other updates to the plan involve water rights transferability, water supply banking, conjunctive management of surface water and groundwater, aquifer recharge and storage, weather modification, and water use efficiency. In addition, comprehensive basin plans, which focus on assessing regional water resources and existing water supply and quality issues, have been completed for 10 basins statewide and are included in the State Water Plan.[42]

In 2008 the Idaho Legislature passed legislation requiring the Idaho Water Resource Board (IWRB) to conduct a statewide Comprehensive Aquifer Management Planning (CAMP) effort for 10 river basins over 10 years.[43] Compared with comprehensive basin planning, the CAMP program focuses more on addressing future water needs and potential conflicts.[44] Earlier planning efforts, like the Eastern Snake River Plain Aquifer CAMP, completed in 2007, do not include climate change considerations, but more recent CAMPs have integrated some climate change components.[45] The IWRB began work on the CAMP for Treasure Valley, which includes Boise, in 2008 to ensure reliable sources of water over the next 50 years, develop strategies to avoid conflicts over water, prioritize future state water resources investments, and bridge future gaps between supply and demand.[46] The Treasure Valley CAMP is expected to be completed in 2012 and will include an evaluation of climate change impacts and adaptation strategies.[47] In particular, an assessment of how climate change may impact water supply was conducted by downscaling regional data to the basin scale, and similar analyses are anticipated in future CAMPs.[48, 49]

The Rathdrum Prairie CAMP currently is being finalized and is expected to be submitted to the Idaho Legislature for approval in 2012.[50] In the draft Rathdrum Prairie CAMP, climate variability is included as a factor affecting future water demand through increased evapotranspiration and water supply through hydrologic changes.[51] The Rathdrum Prairie CAMP makes recommendations to meet future needs, to prevent and resolve water conflicts, and to protect aquifer quality. In order to meet future demand, the report recommends that water conservation measures be implemented, municipal water rights be established, and future water demand estimates be updated periodically.[52] Because the Spokane Valley Rathdrum Prairie Aquifer is a water resource shared by Idaho and Washington, the report also suggests the development of a framework for discussion and cooperation between the two states as well as a mechanism to resolve local issues.[53] It urges the IWRB to ensure that all projects implemented as part of the CAMP process protect the aquifer from contamination. And it sets an adaptive management approach to implementation of the plan that allows for actions to be revised as new information becomes available or needs change.[54] The CAMP process is an important component of water resources planning in Idaho, and **the state should continue to incorporate climate change considerations as a part of these analyses.**

While water conservation has come a long way in Idaho, there are still significant opportunities to improve conservation and efficiency. Agriculture is by far the largest user of water in the state, and a considerable amount of irrigation is conducted with inefficient methods that are prone to high evaporative losses.[55] Consequently, **the state should increase water conservation efforts in the agricultural sector through greater technical assistance and outreach.** While domestic and municipal water demands currently account for only a small amount of overall water use statewide, population growth will increase water demand in these sectors. **Idaho should require water providers to develop water conservation plans, as is done in many other western states, to ensure that population and economic growth do not intensify existing water conflicts.** In conjunction with water supply augmentation and diversification options, water conservation can build resilience and reduce the state's vulnerability to climate change impacts on water supply.

Idaho's inclusion of climate change in recent water resources planning initiatives is a significant step forward. **The state should work to maintain a discussion of climate change impacts in future planning efforts and expand consideration of climate change to all planning and decision-making related to water quality, stormwater, flooding, drought, and aquatic species.** To date, there has been little research on the implications of climate change for water resources specifically in Idaho. **Greater awareness and understanding of climate change impacts in the state are needed in order to develop effective climate change adaptation strategies and policies.** In 2008 Idaho received a $15 million, five-year grant from the National Science Foundation to build research capacity at the state's three public universities (University of Idaho, Boise State University, and Idaho State University) with respect to water resources and climate change.[56] Research completed under this grant has included an analysis of lake sediment in the Pacific Northwest to determine the influence of the El Nino-Southern Oscillation on drought variability over the past 6,000 years.[57] **The state should take advantage of the significant opportunity that this grant provides to fund research that can be used to help Idaho prepare for a changing climate.**

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ILLINOIS

Warmer temperatures and changing patterns of precipitation are likely to exacerbate current water resource issues in Illinois and present new challenges for water resources management. Widespread flooding in the spring and summer of 2011, a result of melting winter snowpack and heavy rains upstream of the state, forced the U.S. Army Corps of Engineers to breach a levee in Missouri in order to protect the city of Cairo, Illinois.[1] Similar flooding episodes could occur due to more frequent heavy rainfall events from climate change. These rainfall events also could lead to more combined sewer overflows, which can cause beach closures, fish kills, and waterborne disease outbreaks. Illinois has acted to reduce the state's level of greenhouse gas emissions by setting reduction goals and developing pollution reduction strategies and has integrated climate change into regional water supply planning. However, the state has not consistently funded regional water supply planning groups or developed a comprehensive statewide adaptation strategy for addressing potential climate change impacts. **The state should develop and implement a statewide climate change adaptation plan and utilize measures recommended by the regional water supply planning groups, including water conservation, water use efficiency, and green infrastructure.**

Water Resources Background

Warm air from the Gulf of Mexico and cool air from Canada are the dominant factors influencing Illinois's climate. Average annual precipitation is higher in the southern part of the state than in the north, even though average snowfall totals are higher in the north than in the south. Northern Illinois experiences annual precipitation of around 32 inches and annual snowfall of 36 inches, while southern Illinois has annual precipitation of about 48 inches a year but only 10 inches of snowfall.[2] On average, May and June are typically the wettest months, and January and February are the driest.[3] Flooding events in the summer are common in Illinois; in fact, flooding is the single most damaging weather event.[4] Flood losses in the state are the third-highest in the nation and have topped $257 million annually since 1983.[5]

Lake Michigan is an extremely important source of water for a majority of Illinois's population. In 2000, Lake Michigan supplied 64 percent of total statewide water withdrawals.[6] Furthermore, nearly 60 percent of the city of Chicago's diversion from Lake Michigan is for domestic supply, and the lake supplies at least 77 percent of the population in northeastern Illinois with drinking water.[7] With Chicago's population expected to grow 26 percent by 2030, burgeoning water demand could place added strain on the lake.[8] Projections suggest that population growth through 2050 will result in an increase in water demand of 26 to 64 percent.[9] Because Illinois is limited by a U.S. Supreme Court consent decree to withdrawals of 2.1 billion gallons a day from Lake Michigan,[10] withdrawals are projected to meet demand only through 2030.[11] In addition to its contribution as a source of water, the moderating effect of Lake Michigan also has a significant impact on weather and climate in north and northeastern Illinois. While the lake contributes to warmer winters and cooler summers, it also suppresses precipitation in the summer and causes an increase of snowfall in the winter.[12] Illinois also has other substantial surface water resources. The Mississippi, Wabash, and Ohio rivers form portions of the western, southern, and eastern borders of the state, and within Illinois, major rivers include the Des Plaines, Fox, Kankakee, Illinois, Rock, Chicago, Sangamon, Kaskaskia, Little Wabash, and Big Muddy.[13]

Groundwater resources occur primarily in three types of aquifers: sand and gravel, shallow bedrock, and deep bedrock.[14] About 65 percent of the total yield of principal sand and gravel aquifers is found in alluvial areas near major rivers such as the Mississippi and Ohio.[15] Around 68 percent of total bedrock aquifer yields are available from shallow bedrock aquifers; these are located mainly in the northern third of the state, as are most deep bedrock aquifers.[16] Groundwater resources in the state are heavily drafted. A 2008 report by the Illinois State Water Survey found that drawdown was common among northeastern Illinois's deep bedrock aquifers as a result of regional withdrawals' exceeding the rate of recharge.[17,18] Furthermore, by 2050, there is a high potential for drawdown by suburban areas and counties surrounding Chicago to have adverse impacts on groundwater, such as increased salinity, higher pumping costs, and decreased water quality.[19] Inadequate local water supplies could potentially limit future growth and development opportunities in portions of the region.[20]

Water usage in the state is comparable to that of other states in the region. Total water use in Illinois in 2005 was 5.5 trillion gallons (nearly 16.9 million acre-feet).[21] The largest user was the thermoelectric power plant sector, which accounted for 81.5 percent of total withdrawals.[22] The second-largest user was domestic supply, with just under 12 percent of total water use.[23] Although agriculture is a $9 billion annual industry in Illinois, irrigation represented just over 3 percent of total water use in 2005 because most agriculture in the state is rain fed.[24,25] In 2005 groundwater accounted for approximately 8 percent of total use; surface water accounted for the remaining 92 percent.[26]

The Great Lakes Compact

The Great Lakes contain six quadrillion gallons of water (about 18.4 billion acre-feet), comprising more than one-fifth of the world's surface supply of freshwater and more than 95 percent of the surface freshwater supply in the U.S.[27] Although the volume of the Great Lakes is vast, less than 1 percent of its water is renewed annually through precipitation, runoff, and infiltration.[28] The Great Lakes Basin ranks third in terms of total freshwater use out of the 21 major watersheds in the U.S.[29] Water levels are expected to decline over the next century in each of the Great Lakes, from 1 foot on Lake Superior to as much as 3 feet on Lakes Michigan and Huron.[30] Management and use of water in the eight Great Lakes states is governed by the Great Lakes– St. Lawrence River Basin Water Resources Agreement and Compact.[31] In ratifying the Compact, each state agreed to undertake a series of actions, including the establishment of thresholds governing new or increased withdrawals of water; implementation of a permitting process for new withdrawals; development of water conservation and efficiency programs, including the establishment of state-specific goals and objectives to guide individual states' programs; and improved data gathering and sharing across the basin. In addition, the Compact directs states to "[g]ive substantial consideration to climate change or other significant threats to Basin Waters and take into account the current state of scientific knowledge, or uncertainty," and to take appropriate measures, such as adaptive management, to address these threats.[32]

Climate Change Impacts on Water Resources

Over the past century, average annual temperatures in Illinois have increased by 0.4°F, with the greatest warming (1.1°F) occurring in the spring.[33] Models indicate that average annual temperatures in the state could rise between 3.6°F and 5.4°F by midcentury, and between 5.4°F and 9°F by the end of the century.[34] Under both low- and high-emissions scenarios, summers in Illinois by midcentury are projected to feel more like summers in southern states like Louisiana or Arkansas.[35]

Annual average precipitation in Illinois also increased by 3.6 inches over the past century.[36] In addition, heavy downpours across the region are now twice as frequent as they were a century ago.[37] In Chicago, rainfall of more than 2.5 inches per day is the approximate threshold at which the city's combined sewer system overflows into Lake Michigan; however, analyses have shown that overflow events can occur with rainfall of as little as 0.67 inch in a 24-hour period.[38,39] Combined sewer overflows can lead to beach closures, fish kills, and waterborne disease outbreaks. Furthermore, rainfall of this magnitude is expected to occur two to three times as frequently by the end of the century, depending on the emissions scenario.[40] While annual average precipitation may not change significantly, precipitation is expected to increase in both winter and spring in the region and become more intense throughout the year.[41] Winter and spring precipitation increases of 10 percent by midcentury and 20 to 30 percent by the end of the century are likely.[42] Although winter temperatures will probably continue to rise, there is little to no decrease projected in the amount of snowfall because of increased overall winter precipitation.[43] However, projected summer precipitation decreases of up to 15 percent coupled with higher evapotranspiration rates could increase the likelihood of drought events and reduced water levels in rivers, streams, and lakes.[44,45]

Warmer winter temperatures are likely to reduce the number of days when snow is on the ground, with potential losses of up to 30 days by the end of the century under a high-emissions scenario.[46] Increasing temperatures also could increase demand for drinking water, increase evaporation from lake surfaces, and cause thermoelectric power generators to withdraw more water for cooling to meet increased demand for electricity.[47] While evapotranspiration is expected to increase throughout the year as temperatures increase, runoff is also likely to increase. Under a low-emissions scenario, peak flows in rivers such as the Illinois are expected to increase slightly; however, under a higher-emissions scenario, a major increase in peak flows is projected, and this would increase flooding risks.[48] Heavy rainfall events and subsequent flooding can pose significant risks to buildings and infrastructure such as roads, bridges, and rail systems.[49]

Climate change also will impact Lake Michigan and the other Great Lakes. Under a low-emissions scenario, water levels in Lake Michigan are not expected to change dramatically because increased evaporation will be offset by increased precipitation during the winter and spring.[50] However, under a high-emissions scenario, increased precipitation is unlikely to compensate for reductions in lake ice and higher evaporation rates, leading to an average lake level reduction of 1.5 feet by the end of the century.[51] A reduction in lake level could limit access to docks and ports and diminish the cargo capacities of commercial vessels. Large vessels could lose up to 240 tons of capacity for every 1-inch decline in draft—that is, the distance between the water line and the bottom of the ship.[52] Lower water levels also could affect hydropower production and reduce the amount of water available for industrial operations, agricultural irrigation, and municipal supply.[53] Winter ice cover, which acts as a protective buffer against shoreline erosion, is also likely to diminish with higher temperatures. This reduction could allow more shoreline erosion from wave action, especially during strong storms.[54] Warmer temperatures are also likely to change nutrient cycles in the Great Lakes and reduce the phytoplankton crop, which would impact other plankton types and fish that rely on them for food.[55] Furthermore, warmer lake temperatures could impact the distribution of fish species, allowing warmwater species to expand their range while also reducing or eliminating suitable habitat for coldwater species.[56]

Greenhouse Gas Pollution Reduction

Executive Order 2006-11 created the Illinois Climate Change Advisory Group (ICCAG), which was tasked with identifying strategies for the state to reduce greenhouse gas emissions. In 2007, then-governor Rod Blagojevich announced statewide greenhouse gas emissions reduction goals of 1990 levels by 2020 and 60 percent below 1990 levels by 2050.[57] The ICCAG final report, which contained recommendations for reducing greenhouse gas emissions, was published in 2008 and submitted to the governor.[58] **Illinois should focus on implementing pollution reduction strategies to meet the state's greenhouse gas pollution reduction goals.**

State Adaptation Planning

In the final report, ICCAG did not recommend that the state undertake any adaptation planning, and the group was formally dissolved with completion of the report.[59] The report briefly mentions the work of the Chicago Climate Change Task Force on adaptation as potentially applicable to the whole state but made no recommendations for further investigation.[60] Since the release of the ICCAG report, Illinois has not developed a comprehensive state adaptation plan. Because climate change will impact a wide range of sectors in Illinois, **the state should develop and implement a coordinated strategy for adapting to the impacts of climate change.**

Illinois has, however, made initial steps toward integrating climate change into water resources planning. In January 2006, then-governor Blagojevich issued Executive Order 2006-1, which established a comprehensive statewide strategy for water supply planning and management. Among other things, this executive order required the development of strategic regional water supply plans. So far, the state has prioritized planning in three regions: east-central Illinois, northeastern Illinois, and the Kaskaskia region.[61] Climate change has played an integral part in each of the regional planning processes. The report for northeastern Illinois (including the greater Chicago area) linked water demand analysis and water supply planning to climate change by using five different emissions scenarios to examine water withdrawals for Chicago and the adjoining region through 2050.[62] Under a worst-case scenario (warmer and drier), climate change alone could increase total withdrawals in the area by as much as 12 percent by 2050 (not counting additional water demand for power generation).[63] The planning process for east-central Illinois determined that drought conditions brought on by climate change could increase regional water demand by approximately 20 percent over projected normal baseline demand in 2050.[64] The region depends heavily on the Mahomet Aquifer, and models project that confined areas of the aquifer will not be significantly impacted by climate change, whereas unconfined areas could increase or decrease several feet due to climate change.[65] The regional water planning process in the Kaskaskia region of Illinois is currently under way. Thus far, a water demand forecast and a water supply assessment report have been completed. By midcentury, with an estimated temperature increase of 6°F and a reduction in summer precipitation of 3.5 inches, total water demand is estimated to increase 8 percent over a baseline 2050 scenario that does not include climate change.[66] In addition, the water supply assessment contains an estimate of the 90 percent yield available from surface water supplies during a repeat of the "drought of record"—that is, the severest drought ever recorded, which in this region occurred in 1953-1955—and determines if a community would have sufficient supplies during a drought.

In June 2009 the regional water plan for east-central Illinois was released. The committee made several general recommendations regarding regional water management: increase water efficiency, increase the use of alternative sources (recycled water, stormwater, surface water and groundwater in conjunction), design and construct water facilities in a staged or incremental manner in order to provide flexibility in the face of uncertainty, and update water supply plans at least every five years.[67] In March 2010 the Chicago Metropolitan Agency for Planning (CMAP) and the Regional Water Supply Planning Group (RWSPG) released the water supply and demand plan for northeastern Illinois. In this plan, the group recommended the implementation of demand management strategies such as improved water conservation through plumbing retrofits, leak repair, water-waste prohibitions, and public education campaigns.[68] The group also recommended that the state promote graywater use by establishing permitting regulations for graywater and providing incentives for homeowners to install graywater systems, and that it promote wastewater reuse by identifying numeric water quality standards and encouraging reclaimed wastewater use for irrigation.[69] Finally, the group advocated for the development and implementation of drought preparedness plans including mitigation measures and green infrastructure to promote groundwater recharge and protect water quality.[70]

While Illinois has taken initial steps toward the development of a statewide water supply planning process by creating regional water supply plans, the state still lacks a functional and consistently funded water supply program. There has been no movement toward the development of regional water supply plans for the seven remaining regions, and the funding for existing regional water supply planning groups has not been sustained.[71] Climate change undoubtedly will have implications for water supply and demand. **Illinois should prioritize the development of water supply plans for all remaining regions in the state and strongly consider the benefits that water conservation and efficiency and green infrastructure provide in adapting to climate change.**

The Illinois-Indiana Sea Grant (IISG) also is working with communities to address climate change. IISG and other partners have completed a study that evaluates residential rate structures for water and wastewater services in northeastern Illinois in order to determine if conservation rate pricing is a viable demand management strategy to meet future water needs.[72] IISG is interested in utilizing rate structures, especially seasonal rates, as a tool to reduce consumption and raise revenue to implement necessary adaptation strategies.[73] The results of this study have been incorporated into the CMAP/RWSPG plan for northeastern Illinois and have been presented at several conferences throughout the state. IISG and CMAP also are finalizing a white paper on water pricing aimed at policymakers for release in spring 2012.[74] **Water pricing should be included as a potential demand management strategy in future regional water supply plans.** IISG also has developed fact sheets on climate change in order to encourage communities to implement water conservation and green infrastructure measures as effective strategies for reducing water demand and managing stormwater.[75]

Despite the lack of comprehensive climate change preparedness planning at the state level, the recent development of statewide plans should help Illinois respond to some climate impacts. In October 2011 the State Water Plan Task Force (SWPTF) adopted a Drought Preparedness and Response Plan.[76] In this plan the task force recommends that water systems focus on planning for the "drought of record." While the potential impact of climate change on drought frequency and intensity is not integrated into the plan, the SWPTF does note that water systems "may also" give consideration to the potential for climate change to lead to warmer and drier conditions not previously seen in the hydrologic record (i.e., non-stationarity).[77] The plan notes that long-term permanent water conservation measures (water-efficient fixtures, water-use metering, full-cost pricing, etc.), as part of a water demand management plan, are likely to be more effective in reducing drought vulnerability than are temporary measures implemented during drought conditions only.[78] **Illinois should require all water systems to develop and implement water conservation and efficiency plans.** The effective implementation of these plans also would serve to help Illinois meet its requirements under the Great Lakes Compact.

In addition, the Illinois Department of Natural Resources has applied to the National Oceanic and Atmospheric Administration for approval of a state coastal management program.[79] One of the key areas for the proposed coastal program is to address sustainable development by creating strategies to reduce carbon emissions and by supporting projects in northeastern Illinois focused on adapting to climate change impacts.[80]

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INDIANA

Indiana, like other Midwest states, already is experiencing the impacts of climate change in the form of increased temperatures and precipitation and reduced ice cover on lakes. As the result of climate change, temperatures are projected to further increase; precipitation will likely occur more frequently in extreme precipitation events; and aquatic habitats will be threatened by warmer water temperatures, reduced lake levels, and more wave action during the winter. Considering the implications of these impacts on the people, economy, and wildlife of Indiana, **the state should immediately develop and implement a comprehensive strategy for reducing the state's greenhouse gas pollution and preparing for the impacts of climate change.**

Water Resources Background

In Indiana, average annual precipitation ranges from 37 inches in the north to 47 inches in the south.[1] The timing of precipitation is usually uneven, but May is generally the wettest month of the year and mild drought sometimes occurs in the summer.[2] The climate in northern Indiana is strongly affected by Lake Michigan, which causes large amounts of lake-effect snow in the winter. Because of this lake effect, there is a significant increasing gradient in snowfall from north to south, with average annual snowfall in the southwest approximately 14 inches and on the shore of Lake Michigan approximately 76 inches.[3]

The Wabash River watershed drains most of Indiana, with the remainder of the state's waters flowing into either the Great Lakes or Mississippi watersheds.[4] Indiana has strongly marked seasons, though not to the same extent as the state's northern neighbors.[5] Warm air from the Gulf of Mexico and cool air from Canada are the dominant factors impacting Indiana's weather. The collision of these masses makes for an active spring and summer, with severe weather, such as thunderstorms and tornadoes, common during this season.[6] Flooding is also common in the state throughout the year, though it is most prevalent December through April from the early thawing of snowpack.[7]

Water usage in Indiana is typical of the Midwest, with consumption dominated by electrical power generation and industrial uses. Withdrawals from surface and groundwater sources in 2009 totaled approximately 3.0 trillion gallons (about 9.2 million acre-feet).[8,9] Groundwater represented only about 7 percent of total withdrawals in the state in 2009, but these withdrawals are on the rise in virtually all categories, particularly agriculture and public supply.[10,11] Electrical generators are the largest users of surface water, at approximately 65 percent of the total water withdrawn.[12] Industry is the second-largest, representing approximately 25 percent of total water withdrawals.[13]

Indiana has approximately 45 miles of shoreline along Lake Michigan.[14] Compared with other coastal states this stretch of shoreline may seem insignificant, but the coastline plays in important role in the state's economy. According to the 2000 census, approximately 12 percent of the state's population resided in the coastal region of Lake, Porter, and LaPorte counties.[15] Together with the other Great Lakes states and Canadian provinces, the region is an industrial and economic hub, owing to the transportation network in place along the lakes. Major cargo transported from ports in the Great Lakes includes coal, iron ore, steel, fertilizer, grain, and salt.[16] In fact, the Port of Indiana-Burns Harbor on Lake Michigan handles more oceanbound cargo than any other U.S. port in the Great Lakes, including 15 percent of all U.S. steel trade with Europe.[17] Indiana's coastal areas also have substantial natural resources, including sand dunes in Indiana Dunes National Lakeshore and Indiana Dunes State Park.[18] Tourism and recreational fishing are also important facets of the state's coastal areas, with the lakeshore drawing in more than two million visitors annually with an annual economic impact exceeding $50 million.[19]

The Great Lakes Compact

The Great Lakes contain six quadrillion gallons of water (about 18.4 billion acre-feet), comprising more than one-fifth of the world's surface supply of freshwater and more than 95 percent of the surface freshwater supply in the U.S.[20] Although the volume of the Great Lakes is vast, less than 1 percent of its waters are renewed annually through precipitation, runoff, and infiltration.[21] The Great Lakes Basin ranks third in terms of total freshwater use out of the 21 major watersheds in the U.S.[22] Lake levels are expected to decline over the next century in each of the Great Lakes, from 1 foot on Lake Superior to as much as 3 feet on Lakes Michigan and Huron.[23] Management and use of water in the eight Great Lakes states is governed by the Great Lakes– St. Lawrence River Basin Water Resources Agreement and Compact.[24] In ratifying the Compact, each state agreed to undertake a series of actions, including the establishment of thresholds governing new or increased withdrawals of water; implementation of a permitting process for new withdrawals; development of water conservation and efficiency programs, including the establishment of state-specific goals and objectives to guide individual states' programs; and improved data gathering and sharing across the basin. In addition, the Compact directs states to "[g]ive substantial consideration to climate change or other significant threats to Basin Waters and take into account the current state of scientific knowledge, or uncertainty," and to take appropriate measures, such as adaptive management, to address these threats.[25]

Climate Change Impacts on Water Resources

Temperatures in the Indiana Dunes National Lakeshore have been rising over the past century and are now, on average, 1.6°F warmer.[26] As a result of these higher temperatures, lake temperatures have increased and there is less ice cover in the winter.[27] Since the turn of the century, average annual precipitation has increased by 4.4 inches, the largest such increase in the Midwest.[28] In addition, across the Midwest, the amount of rain falling in heavy rainfall events has increased by 31 percent over the past century.[29] Climate models project summer average temperatures to increase by 2.7°F to 9.5°F by midcentury and by 4.9°F to 15.4°F by the end of the century.[30] Total annual precipitation is expected to increase approximately 20 percent in portions of northern Indiana, and the frequency of extreme precipitation events is expected to increase by 40 percent over the whole state by the end of the century.[31] There will also likely be a corresponding shift in the seasonality of this precipitation. Winter and spring precipitation totals are projected to increase by 21 percent and 30 percent, respectively, while summer precipitation will likely decrease by approximately 9 percent by the end of the century.[32] The number of days on which severe thunderstorms occur is also expected to increase by 1 to 3 days per year in the future, largely during the existing extreme weather season, the summer.[33]

The potential effects of warmer temperatures and changes in precipitation patterns on Indiana are substantial. More rainfall in the winter and spring along with more frequent extreme rainfall events are likely to increase flooding risks as streamflows increase.[34] During these seasons, rainfall will combine with melting snow and frozen soils to increase runoff and flood risks.[35] Total annual runoff (direct surface flow and groundwater return flow) is expected to increase by 25 to 38 percent by the end of the century.[36] The largest increase (33 to 59 percent) is projected to occur in the winter as warmer temperatures shift precipitation from snow to rain.[37] Total runoff is expected to increase during the summer as well, mainly due to the increase in spring precipitation, but summer surface runoff is actually expected to decrease by around 8 percent.[38] Higher total runoff also could have water quality impacts as pollutants are flushed into waterways and as sewer systems in urban areas are overwhelmed, discharging raw sewage into rivers and streams.[39]

Indiana's agricultural sector output totaled nearly $10.5 billion in 2010.[40] Although agriculture is not a major economic contributor statewide, there are many farming communities, and climate change impacts on agriculture could be particularly detrimental to these communities. With reductions in summer precipitation, rain will no longer be as abundant during the growing season.[41] The longer duration of dry periods will have important implications for soil moisture and, correspondingly, the frequency of droughts in the state. Increasing rates of evapotranspiration, especially in the summer when temperatures are the hottest, will reduce soil moisture levels and are likely, in conjunction with decreased summer precipitation, to increase the risk of short-term droughts as water levels decline.[42] Dry conditions could pose problems for agriculture as only 3 percent of total cropland is currently irrigated.[43] Increasing temperatures are expected to decrease the number of days with soil frost by 37 to 56 days by the end of the century.[44] In addition, by the end of the century the first snow is projected to arrive two weeks later and leave approximately two weeks earlier.[45] These impacts could significantly lengthen the growing season in Indiana, which could increase the quantity of water used for irrigation.

In the state's coastal areas along Lake Michigan, climate change is likely to have numerous impacts. Water temperatures in Lake Michigan already have increased and are projected to increase by 2°F to 12°F during this century.[46] These increased temperatures are serving to reduce ice cover, which protects shorelines from wave erosion intensified by strong winter storms.[47] Increased wave action in the winter could negatively impact winter-spawning fish species such as whitefish, whose eggs are spread on the lake bottom and could be destroyed by rougher currents.[48] Warmer water temperatures also are likely to impact the distribution of aquatic species. Warmwater species are projected to move northward by as much as 400 miles as water temperatures become more favorable, and coldwater species may be eliminated altogether.[49] Changing ecosystem conditions also favor nonnative species, such as the Asian carp, which are adapted to a wider range of conditions.[50] By the end of the century, the level of Lake Michigan is projected to be 9.8 to 16 inches lower due to greater evaporation from the lake surface as well as increased evapotranspiration in the drainage basin flowing into the lake.[51] Reduced lake levels would have potentially severe economic and environmental impacts as shipping access and aquatic habitats are affected.[52] Heavier precipitation events also can negatively impact water quality in the Indiana Dunes State Park by causing sewer overflows and subsequent beach closings.[53]

Greenhouse Gas Pollution Reduction

Indiana has not adopted greenhouse gas pollution reduction targets or developed a statewide strategy for reducing greenhouse gas emissions. To reduce the state's contribution to climate change, **Indiana should adopt greenhouse gas pollution reduction targets and develop and implement a strategy for achieving these reductions.**

State Adaptation Planning

The state has not developed a comprehensive plan for adapting water resources to the impacts of climate change. Considering the potential implications of warmer temperatures and changing precipitation patterns for the state's people, economy, and natural resources, **Indiana should develop a comprehensive strategy for adapting to climate change.**

Although state agencies have not addressed climate change directly, universities in Indiana are working to address the impacts of climate change. Purdue University recently received a $5 million grant from the U.S. Department of Agriculture to help develop decision-making tools for farmers to adapt to climate change impacts.[54] The Purdue University Climate Change Research Center (PCCRC) released a report in 2008 discussing the impacts of climate change on water resources, agriculture, plants and animals, soils, human health, and heating and cooling demands. While adaptation is not specifically included in this report, the expertise within PCCRC could be utilized in future adaptation planning efforts. The PCCRC's Seed Grant Program is of particular note as it encourages cross-collaboration on projects. Some examples of projects funded under this program during the 2009 to 2010 period include examination of emissions trading policies and climate regulating ecosystems services in the agricultural sector, among others.[55]

The Indiana Department of Natural Resources Water Shortage Plan, while not specifically related to climate change, is an important component in preparing for a future with potentially less water.[56] The purpose of the plan is to provide a systematic process for managing Indiana's water resources in the event of a short-term shortage or a long-term drought. The plan helps to establish priority uses and water conservation measures and gives some consideration to establishing minimum streamflows for ecosystem functions in the midst of a water shortage. Specific water conservation measures included in the plan—such as eliminating water leakages, improving outdoor water efficiency, using volumetric pricing for water and wastewater services, and metering of all uses—should be put into place permanently and not only as a temporary measure when the state is facing a water shortage.[57] **The state also should adopt the water conservation measures directed toward state government, which include requiring conservation for projects that receive grants or loans, adopting a statewide plumbing code, and requiring conservation measures for water development projects as a condition of permit approval.**[58] By doing so, Indiana will be better positioned to weather future climate change impacts.

Indiana also has developed a model ordinance for flood hazard areas. Aspects of this ordinance, such as discouraging the development of critical infrastructure in flood-prone areas and freeboard requirements for new or substantially improved construction, could be beneficial, considering projections of increased flood risks in the state from more precipitation and heavy rainfall events.[59] **Indiana also should be implementing green infrastructure strategies for managing stormwater, such as permeable pavements and green roofs, which increase infiltration, recharge groundwater, and reduce runoff.**

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Iowa lies within two of the largest watersheds in the U.S: the Missouri and the Mississippi. While the state's proximity to these water resources is largely beneficial, it is also not without risks. These risks were displayed during the spring and summer flooding in 2011, which caused $207 million in crop and economic losses, according to estimates by the Iowa Farm Bureau.[1] Like its neighbors in the region, Iowa is experiencing changes in its climate in the form of higher temperatures, shifts in the seasonality of precipitation, and increased extreme weather events. To address the threat of climate change, the Iowa Climate Change Advisory Council developed a report outlining measures to reduce the state's greenhouse gases emissions, and the Iowa Climate Change Impacts Committee released a study on climate change impacts for various sectors. However, both groups were disbanded in 2011, leaving the state without a group focused on developing a climate adaptation strategy for Iowa. Given the significant threats climate change poses to the state, **Iowa should develop and implement a comprehensive adaptation strategy for addressing the risks of climate change.**

Water Resources Background

Iowa's climate is influenced by two large continental air masses. Warm, humid air from the Gulf of Mexico dominates during the summer and is responsible for the annual precipitation maximums typical during this season. In the winter, cool, dry air flows from Canada.[2] Throughout the year, moist air from the Pacific Ocean can also influence the state's climate.[3] Annual precipitation averages 34 inches statewide, with the wetter northwest averaging around 38 inches and the drier southeast averaging about 26 inches.[4] Nearly 75 percent of the state's total precipitation comes between April and September.[5] Seasonal snowfall averages 32 inches across Iowa, though, like rainfall, it decreases from northwest to southeast.[6]

Iowa lies between two of the largest river basins in the world: the Mississippi and the Missouri.[7] Consequently, the state has a vast array of surface water resources, including nearly 72,000 miles of rivers and streams and more than 160,000 acres of lakes, reservoirs, and ponds.[8] The state also has three major aquifer types: alluvial and buried channel aquifers, bedrock aquifers, and glacial drift aquifers.[9] Iowa contains the majority of the Jordan Aquifer, which is part of the larger Cambrian-Ordovician Aquifer system. This large aquifer is available in all but the northwestern corner of the state and provides much of Iowa's industrial and agricultural water.[10] Due to heavy use, water levels in the aquifer have dropped 250 to 300 feet since withdrawals began in the late 1800s.[11,12] In 2009 approximately 25 billion gallons (about 76,700 acre-feet) of water were drawn from the Jordan Aquifer.[13]

In 2005 Iowa's total water use was 1.23 trillion gallons per year (nearly 3.8 million acre-feet).[14] The largest withdrawal of water came from the thermoelectric power plant sector, which accounted for 75 percent of all water withdrawn.[15] The next-largest use was public supply, accounting for roughly 12 percent of water withdrawn, followed by industry at approximately 6 percent and livestock at slightly over 3 percent.[16] While Iowa is a heavily agricultural state, irrigation withdrawals amounted to less than 1 percent. Groundwater withdrawals accounted for over one-fifth of total withdrawals in the state.[17] The public-supply sector and the industrial sector (which includes ethanol producers) are heavily reliant on groundwater, supplying 78 percent and 62 percent, respectively, of their total consumption from groundwater.[18]

Agriculture is an important part of the state's economy, accounting for nearly $24.35 billion in sales in 2009.[19] This ranked the state second in the country in terms of total agricultural output. Iowa is also currently the largest producer of corn and soybeans.[20,21] Consequently, agriculture influences many of the state's water consumption and water quality issues. Between 2000 and 2010, more than half of monthly stream samples in Iowa were ranked as poor or very poor in terms of water quality.[22] Water quality is generally worse during the growing season in spring and summer, due mainly to the runoff of agricultural fertilizers and chemicals from fields into neighboring waterbodies.[23] Iowa is also the largest ethanol-producing state in the country, with 41 plants producing approximately $13 billion in ethanol each year.[24] The process of converting corn and other crops into ethanol is extremely taxing on water resources. While most plants recycle a large percentage of their process water, water is still needed for the cooling tower and boiler systems. An estimated 3 to 4 gallons of water are used for every gallon of ethanol produced.[25,26] In 2009 Iowa's ethanol capacity was approximately 2.1 billion gallons a year, representing about 6 billion to 8 billion gallons a year of water used in ethanol processing.[27]

Climate Change Impacts on Water Resources

The Iowa Climate Change Impacts Committee reported in 2011 that temperatures across the state are increasing.[28] This conclusion is confirmed by data from the Midwest Regional Climate Center, which found that Iowa has warmed 0.9°F in the past century, with much of this warming occurring during spring and winter, when temperatures have increased 1.5°F and 1.4°F, respectively.[29] Iowa is also among the states that are experiencing the largest increase in nighttime minimum temperatures.[30] In fact, in 2010, while none of Iowa's weather stations reported that summer as being among the hottest on record, many reported that their area was experiencing the highest average nighttime temperature ever recorded.[31] This warming has had an impact on winter weather as well, with the state experiencing 8 to 9 more frost-free days per year than it did at the beginning of the 20th century.[32] By the end of this century, seasonal daily average maximum temperatures in the region are projected to rise 5.4°F to 12.6°F in the winter and 7.2°F to 20°F in the summer.[33]

In addition, precipitation in Iowa has increased by 4.2 inches over the past century—the second-largest increase in the entire Midwest.[34] Over the past 136 years, this change represents an approximate 8 percent increase in precipitation.[35] Changes in the seasonality of precipitation also have been particularly dramatic in Iowa, with more rain occurring in the first half of the year and less in the second, leading to wetter springs and drier falls.[36] Across the central U.S., more intense rainfall events have also been occurring during the summer, leading to episodes of higher runoff.[37] Because Iowa lies at the confluence of many different climatic patterns, projected drying patterns to the west and south and projected wetter conditions to the north and east could cause more extreme interannual variability in Iowa's precipitation.[38] Climate model projections indicate that winter and spring precipitation could increase by 30 percent and that summer precipitation could decrease by 10 to 35 percent by the end of the century.[39] Although total precipitation during the summer may decline, this precipitation is likely to come in the form of heavy rainfall events.[40]

Enhanced streamflow and more flooding risks are expected in the future as areas upstream of the state receive more precipitation and more frequent extreme precipitation events.[41] A projected 21 percent increase in precipitation by the 2040s would lead to a 50 percent increase in streamflow in the Upper Mississippi River Basin.[42] Communities along rivers and those unable to manage stormwater runoff from extreme precipitation events could be at risk of landslides, flooding, and property damage.[43] In 2008 weather-related disasters led to more than $1.3 billion in damage to property, nearly $1 billion in agricultural and environmental losses, and more than $600 million in damage to infrastructure.[44] There could be public health risks as well if waters inundate facilities that contain hazardous materials and if overwhelmed wastewater treatment facilities discharge raw sewage.[45] However, reductions in summer precipitation coupled with higher rates of evapotranspiration are likely to lead to reduced streamflows overall, which could reduce groundwater recharge and the size of wetland areas.[46] Increasing temperatures also could serve to increase water demand, particularly during the summer, which could cause localized water shortages and conflicts.[47]

The effects these changes could have on agriculture are especially important for Iowa, but the overall impact on Iowa's agricultural sector is unclear.[48] For instance, while climate change is lengthening the growing season and thus boosting output, other effects, such as an increase in severe weather and corresponding crop damage, could counteract such increases.[49] Furthermore, increased precipitation can increase crop yields, but if too much of this rain falls during the spring, soil can become waterlogged and delay planting.[50] In addition, precipitation increases and more intense rainfall events cause significant topsoil erosion: A 20 percent increase in precipitation can increase erosion rates by an estimated 37 percent.[51] Additionally, while Iowa scientists report that the increased soil moisture present from greater precipitation has helped to keep summer daily high temperatures from rising by suppressing surface heating, a period of severe drought could cause soil moisture levels to decrease significantly and lead to a rise in extreme summer heat.[52]

Climate change could have particularly devastating impacts on the state's aquatic habitats. Warmer water temperatures in lakes, rivers, and streams could eliminate suitable habitat for coldwater fish like trout, and changes in stream hydrology, such as earlier spring runoff and lower summer streamflows, could reduce wetland habitats.[53] In addition, increases in rainfall frequency and intensity could degrade water quality as more pollutants and sediments are flushed from surfaces. These changes in water quality could have negative implications for fish that are sensitive to sedimentation, such as trout and smallmouth bass.[54] In addition, nutrient and chemical runoff from agricultural areas would pose substantial risks to water quality in the state as well as in downstream areas, including the Gulf of Mexico.[55]

Greenhouse Gas Pollution Reduction

In 2007 the Iowa Climate Change Advisory Council (ICCAC) was established to provide policy options for reducing greenhouse gas pollution in the state. The ICCAC published its final report in December 2008 outlining recommendations to meet two statewide greenhouse gas emissions reduction scenarios: a 50 percent reduction below a 2005 baseline by 2050 and a 90 percent reduction below 2005 levels by 2050.[56] However, the state has not adopted a greenhouse gas pollution reduction target, and the ICCAC was formally disbanded in July 2011 as part of a state government reorganization.[57] To reduce the state's contribution to climate change, **Iowa should adopt a greenhouse gas pollution reduction target and implement necessary actions to achieve these reductions.**

State Adaptation Planning

Adaptation was identified as a crosscutting issue in the ICCAC final report, and the ICCAC recommended the development of a statewide climate adaptation plan.[58] However, no progress has been made on this recommendation, and with the disbandment of the ICCAC, the future of adaptation work at the state level is in question. Iowa has, however, completed an assessment of potential climate change impacts on the state. Charged by the state legislature, a group of scientists formed the Iowa Climate Change Impacts Committee (ICCIC) in July 2009 to examine the ways in which climate change could impact different sectors across Iowa. The ICCIC was composed mainly of scientists from Iowa State University and the University of Iowa, though Iowa's state agencies, including the Department of Natural Resources (DNR) and Department of Public Health, and representatives from the state's utility sector also were involved. The areas investigated by the committee included agriculture, flora and fauna, public health, the state economy, and infrastructure. The group published its findings and presented them to the governor and state legislature in January 2011. However, the ICCIC was dissolved in July 2011. **Given the significant threats climate change poses to the state, as detailed in the ICCIC report, Iowa should develop a comprehensive adaptation strategy to prepare for these threats.**

While Iowa's wildlife action plan identifies climate change as a potential stressor to aquatic species, it considers the potential impact of climate change on fish and mussel species to be low.[59] The plan also does not include any conservation actions to address climate change stresses. Although Iowa does not appear to have any climate change planning in progress aside from the DNR's fish and wildlife vulnerability assessment,[60] the DNR's Resource Enhancement and Protection (REAP) program could prove to be beneficial in reducing the impacts of climate change in the state.[61] REAP provides grants for county, city, and private projects that fall under specified funding categories. Twenty percent of these funds are dedicated to projects that enhance soil and water. These include projects that protect groundwater and surface water from nonpoint contamination, reforestation projects, woodland protection projects, protection of highly erodible soils, animal waste management, and other efforts aimed at more general water quality issues.[62] Other REAP funding categories include land conservation, public open space acquisition, and roadside vegetation management.[63] Considering the likelihood of more extreme precipitation events in the future, appropriately targeted REAP-funded projects could help to reduce the water quality and flooding risks associated with these events. **The state should encourage the use of REAP funds for green infrastructure projects to reduce the impacts of flooding and address water quality problems associated with extreme precipitation events.**

Iowa does not currently have a comprehensive state water plan. The last comprehensive state plan dates from 1978. Recognizing that the state needs a plan for managing water resources, the DNR and nonprofit environmental organizations have lobbied for the development of a new comprehensive state water plan covering both surface water and groundwater.[64,65] To provide the foundation for a new state water plan, the Iowa General Assembly in 2007 funded a small portion of the research necessary to develop a plan, with the idea that other portions would be completed each year as funds became available. These funding decisions are guided by a planning document that the DNR produced in 2007.[66] The first report covered water allocation rights and floodplain control.[67] As part of the water plan development process, **Iowa should consider the potential impacts of climate change on the state's water resources.** The state also currently requires all users that withdraw at least 25,000 gallons of water in any 24-hour period during any calendar year to obtain a water use permit.[68] As part of the permitting process, **the state should evaluate water withdrawal impacts with climate change in mind and require permittees to adopt water conservation and water use efficiency measures.**

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KANSAS

Because Kansas relies on the system of prior appropriation for management of its waters, many of the state's surface water and groundwater resources are approaching full allocation. In addition, more than 90 percent of water withdrawn in the state is from historically overused and overappropriated aquifers.[1] The state's existing water resource issues are likely to be only further intensified by climate change. The state's agriculture-dominated economy relies heavily on water resources and is vulnerable to climate extremes, as evidenced by the statewide crop losses in excess of $1.7 billion from the 2011 drought that afflicted much of the south-central United States.[2] Considering the potentially severe implications of warmer temperatures and changing precipitation patterns for the state's people, economy, and wildlife, **Kansas should complete the work of the Kansas Energy and Environmental Planning Advisory Group on the development of a strategy to reduce the state's greenhouse gas pollution. The state also should develop and implement a comprehensive and integrated climate adaptation plan to reduce Kansas's vulnerability to climate change impacts.**

Water Resources Background

The majority of annual precipitation in Kansas occurs during the summer months as warm, moist air from the Gulf of Mexico collides with cold fronts steered by the jet stream, which causes rain and thunderstorms.[3] There is also significant variability within the state as average annual precipitation ranges from 20 inches in the west to 42 inches in the east.[4] In the western parts of the state, Kansas's water resources are dominated by groundwater from the High Plains (Ogallala) Aquifer.[5] In the eastern areas, water supply is dominated by surface water from the state's major rivers: the Arkansas, Missouri, and Republican. Climate also varies across the state. The western portions are generally semi-arid with low precipitation, owing to the fact that they lie within the rain shadow of the Rocky Mountains.[6] As a result, these regions rely more on groundwater than do eastern portions of the state, which receive more precipitation and have access to surface water.[7] Variation is also seen in the streamflows across the state, with the east containing greater streamflows than in the west.[8] The entire state eventually drains to the Gulf of Mexico via the Mississippi River, with the northern half of the state drained by the Missouri and its tributaries and the southern half drained by the Arkansas and its tributaries.[9]

The Ogallala Aquifer is the main source of water for western Kansas and is used largely for irrigation.[10] In Kansas most of this aquifer is closed to additional development because it is threatened by historical overusage and declining water quality in some areas.[11] Other important aquifers in the state include the Dakota, Flint Hills, and Ozarks aquifers.[12] In areas where groundwater usage is high, water tables have declined over the years.[13] This generally portends a decrease in baseflows of hydraulically connected rivers and streams, with a corresponding impact on riparian vegetation and ecosystems.[14] To address concerns over declining water tables as well as climatic variability, Kansas relies on a large number of reservoirs, with more than 6,000 dams currently functioning in the state.[15] Kansas uses nearly 1.4 trillion gallons of water (over 4 million acre-feet) annually, with the vast majority consumed by the agricultural sector in the form of irrigation, which has accounted for 80 to 85 percent of total water withdrawals in recent years.[16] Corn is the most popular irrigated crop, followed by wheat, soybeans, sorghum, and alfalfa.[17] The second-largest withdrawer is municipal supply, accounting for approximately 10.5 percent of total usage.[18] Approximately 90 percent of all water used in the state comes from groundwater.[19]

Climate Change Impacts on Water Resources

Across the Great Plains, average temperatures have increased by 1.5°F relative to a 1960s-to-1970s baseline.[20] Between 1895 and 2009, Kansas experienced an average winter temperature increase of 2°F and an overall average annual temperature increase of 1.2°F. By the end of the century, summer temperatures in the state could rise by 6°F to 10°F, depending on the emissions scenario.[21] While precipitation in Kansas has actually increased by about 7 percent in the past century, the state lies in the boundary area between northern states that are expected to become wetter and southern states that are likely to be drier in the future.[22,23] Therefore, some areas of the state are likely to see a precipitation increase while others may experience a decrease. Under a low-emissions scenario, small portions of southwestern Kansas are projected to see decreases of approximately 5 percent in spring precipitation by 2080, and other areas of the state could see moderate precipitation increases of up to 15 percent.[24] However, even moderate precipitation increases are unlikely to offset decreasing soil moisture due to warmer temperatures.[25] In a high-emissions scenario, much of the western part of the state could see precipitation reductions in spring of up to 20 percent by the end of the century.[26] Additionally, the timing of this precipitation could change, with rain events becoming less seasonal, more infrequent, and more intense.[27] Across the High Plains states, an increase in extreme weather events, such as heavy precipitation and extreme cold, are more likely in the future.[28]

In conjunction with higher temperatures, any reductions in precipitation could prove disastrous for water resources in western and southwestern portions of Kansas, where precipitation is already low and the climate already more arid. Projections of warmer temperatures, higher rates of evaporation, and prolonged droughts brought on by climate change are likely to further stress water resources in these areas,[29] which are already under duress due to Kansas's reliance on overutilized groundwater resources. Climate change also could impact the state's interstate water agreements, such as the Arkansas River Compact with Colorado, the Arkansas River Basin Compact of 1965 with Oklahoma, the Big Blue River Compact with Nebraska, and the Republican River Compact with Colorado and Nebraska.[30] A comprehensive study of these compacts determined that climate change impacts in the region will be, for the most part, severe, and that these agreements will be mostly inadequate to address the water needs of the parties, given the warming these states will experience.[31] In fact, water conflicts have already occurred between Kansas and its neighboring states. As a penalty for withdrawing too much water from the Arkansas River between 1950 and 1999, Colorado was forced to pay the state $34 million.[32]

Agriculture is also likely to be heavily impacted by climate change. The number of freezing days each year is declining, and by 2060, most days will stay above freezing.[33] Furthermore, most states in the region are expected to experience, on average, an approximately 14 percent reduction in snowfall.[34] The decrease in the number of days with freezing or subfreezing temperatures suggests that the growing season will lengthen, but any expected increases in productivity will likely be negated by heat stress on crops from increasing temperatures, as well as a more active summer storm season.[35,36] Decreasing soil moisture will likely lead to increased demand for irrigation water.

The native prairie pothole ecosystem that characterizes much of the Kansas landscape is also at risk from the impacts of climate change. These shallow, ephemeral lakes create a distinct environment that helps support diverse plant and animal species, particularly native birds and migrating waterfowl.[37] These pothole lakes are also the main source of recharge for the High Plains' vast aquifer systems.[38] Extensive cultivation and water withdrawal by agricultural activities have already begun to threaten these unique areas. Climate change is expected to threaten the viability of these ecosystems by increasing water withdrawals, particularly for agricultural irrigation.[39]

Greenhouse Gas Pollution Reduction

In early 2008, then-governor Kathleen Sebelius issued Executive Order No. 08-03, establishing the Kansas Energy and Environmental Planning Advisory Group (KEEP). This group's purpose was to help the state start to address the threat of climate change, become more energy efficient, and spur economic growth.[40] In 2009 the group released an interim report containing an inventory and forecast of the state's greenhouse gas emissions.[41] A final report with recommendations for reducing the state's greenhouse gas emissions was due in January 2010; however, the work of KEEP was suspended prior to completion of the final report.[42] **To reduce the state's contribution to climate change, Kansas should complete the KEEP report, adopt a statewide greenhouse gas pollution reduction goal, and implement strategies to reduce the state's greenhouse gas pollution.**

State Adaptation Planning

In KEEP's 2009 interim report, adaptation and vulnerability were handled by the Cross-Cutting Issues Technical Working Group, which listed adaptation as one of nine recommended priority policy options.[43] Specifically, the working group recommended undertaking a comprehensive, statewide planning effort to assess adaptation opportunities.[44] The state has yet to follow up on this recommendation. **Given the potential impacts of climate change on the state, Kansas should develop a statewide adaptation plan.**

Another potentially important tool in adapting to climate change in Kansas is a $20 million grant recently received by four universities in Kansas to examine climate change issues.[45] The grant, provided by the National Science Foundation, will focus on four large projects, including solar power, agriculture, climate modeling, and the impacts of climate change on Native American lands. This grant connects the climate expertise of academics throughout Kansas's university system. The capacity and information network created by this grant program could be extremely useful in addressing other climate change impacts, such as those in the water resources sector.

The state does have some existing programs and policies that could be useful for climate change adaptation. One example is the 2009 Kansas Water Plan, which lists reducing the vulnerability of communities to floods as a priority of the Kansas Water Office.[46] Actions contained in the plan, particularly the use of nonstructural measures, like floodplain regulations, to mitigate flood damage will reduce the vulnerability of floodplain areas to damage both now and in the future.[47] **In addition, green infrastructure, such as permeable pavement, green roofs, and rain gardens, can provide flood protection benefits by reducing stormwater runoff.**

The state water plan also identifies water conservation measures that will help the state to better adapt to greater climate variability in the future. These include reducing water losses from municipal suppliers, metering water diversion points, adopting conservation rate structures, and requiring conservation plans for water rights holders.[48] Because agriculture is such a large user of water in the state, many potentially effective adaptation strategies could be realized through the agricultural sector.[49] For example, the use of mixed cropping-livestock systems, diverse cropping systems, and increased water efficiency in irrigation technology could help reduce agricultural water demand.[50] **Kansas should implement "no regrets" strategies, such as improved water conservation and efficiency, to address existing water resource issues and to build resilience to future climate impacts.**

In addition, Volume III of the Water Plan, which details river basin management plans, recommends evaluating climate change impacts on water supply and demand for some of the state's basin areas, such as the Ogallala Aquifer in the Cimarron Basin.[51] **Kansas should take into consideration climate change impacts in all water basin management planning efforts.** To move in this direction, the state is pursuing federal grant funding to refine climate model data to the river basin level.[52] Other recommendations in the water plan, such as encouraging water reuse in the Lower Arkansas Basin, also would prove beneficial, considering the potential impacts of climate change on water supply and demand.[53]

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KENTUCKY

Severe storms and the flooding that occurred along the Mississippi and Ohio rivers in the spring of 2011 caused significant damage in Kentucky. Drought events in recent years also have wreaked havoc. These wide variations in precipitation are likely to increase as temperatures continue to rise. In November 2011, Kentucky released a final climate action plan containing strategies to reduce the state's greenhouse gas emissions. Considering that climate change is already occurring and its impacts are projected to intensify, **the state also should actively be working to identify and implement adaptation strategies to reduce vulnerability and build resilience.** "No regrets" strategies, such as water conservation and efficiency measures and green infrastructure for stormwater management, are particularly useful for addressing existing water quality and quantity issues while also increasing the capacity to adapt to future climate impacts.

Water Resources Background

The mid-latitude, inland location of Kentucky and the state's proximity to warm, moist air from the Gulf of Mexico help to shape its climate.[1] A large precipitation gradient in the winter leads to distinct differences in annual average precipitation in the state, which ranges from 42 inches in the north to 52 inches in the south.[2] Snowfall is most common from December to March, with seasonal averages of about 10 inches in the south to more than 20 inches in the north.[3] Thunderstorms during the summer months are common and can deliver considerable amounts of rainfall and even cause localized flooding.[4] The fall tends to be the driest season and spring the wettest.[5] Of all precipitation falling in the state, approximately 61 percent is lost to evapotranspiration; the remainder runs off into streams.[6] Surface water and groundwater resources within the state are inherently connected, as groundwater provides baseflow to the state's rivers and streams and karst landforms allow surface waters to flow into underground aquifers.[7] Most of the state drains into the Ohio River (with the exception of a small part of western Kentucky that drains directly into the Mississippi River) through 13 major river basins, which contain nearly 90,000 miles of streams.[8,9] Major tributaries of the Ohio include the Big Sandy, Kentucky, and Green rivers.[10] These basins also contain more than 2,700 lakes and reservoirs with a storage capacity of nine million acre-feet.[11] The Tennessee Valley Authority manages the Kentucky Reservoir (or Lake) for flood control, navigation, recreation, and hydroelectric power, and the U.S. Army Corps of Engineers manages Lake Cumberland and Lake Barkley, which are utilized for similar purposes in addition to providing wildlife habitat.[12,13] Kentucky also contains hundreds of thousands of acres of lake and river wetlands that support 55 percent of all rare and endangered species within the state.[14]

Of total freshwater withdrawals in 2005, nearly 98 percent were from surface water sources, with the remaining 2 percent from groundwater.[15] The largest withdrawer of freshwater was the thermoelectric power industry at nearly 80 percent, followed by public suppliers and industrial users. While groundwater does not furnish a large portion of total withdrawals, it is a significant source of water for approximately two million Kentuckians who either depend on public water suppliers that use groundwater or obtain their water from private wells.[16] Although approximately half of the land in the state is used for agriculture, water withdrawals for agriculture are not substantial due to the lack of irrigated cropland.[17]

Climate Change Impacts on Water Resources

Between 1901 and 2008, average annual temperature in Kentucky increased by nearly 1°F, with the most prevalent warming occurring during the winter.[18] From 1970 to 2008, this warming trend was even more pronounced, as evidenced by an increase of 1.4°F in average annual temperature. Changes in total annual precipitation for these two periods are not nearly as distinctive—although there have been observed increases in heavy rainfall events.[19] Total annual precipitation increased by almost 6 percent from 1901 to 2008, with increases of 6 to 13 percent in the spring, summer, and fall; however, from 1970 to 2008, total annual precipitation increased by only about 1 percent.[20] By 2050, average annual temperatures are projected to increase 3.6°F to 5.1°F above 2006 averages, depending on the emissions scenario.[21] Furthermore, across the southeastern U.S., temperatures are projected to increase 4.5°F to 9°F by the 2080s.[22] Future projections of precipitation are considerably less consistent, with models showing decreases of 10 percent to increases of 15 percent under a low-emissions scenario and decreases of 10 percent to increases of 30 percent under a high-emissions scenario.[23] Aside from changes in total annual precipitation, the characteristics of precipitation are also projected to change, with increases in extremes—both heavy rainfall events and drought—very likely.[24]

Changes in temperature and precipitation as a result of climate change will have impacts on Kentucky's water resources. Temperature increases result in greater evapotranspirative losses, suggesting that the intensity, frequency, and duration of drought events are likely to grow.[25] Decreases in water availability are likely to afflict many of the state's water users, largely because of heavy reliance within the state on surface water resources. Groundwater recharge is also reduced during drought events.[26] At the same time as water supplies decline, demand may increase as irrigation and power generation needs grow. Moreover, a higher number of heavy rainfall events could increase flood risks to infrastructure and property and could impact water quality as runoff from agricultural, mining, and urban areas carries pollutants into waterways.[27] In addition, subsequent increases in pollutant, nutrient, and sediment loads and changes in hydrology could impact the reproduction and health of aquatic species.[28] Warmer water temperatures would also reduce the amount of suitable habitat for aquatic species, foster waterborne disease persistence, and reduce dissolved oxygen levels, which could potentially favor the spread of nonnative species.[29]

Greenhouse Gas Pollution Reduction

In November 2008, Kentucky released an energy plan that called for a 20 percent reduction from 1990 levels of greenhouse gas emissions statewide by 2025, to be achieved by increasing energy efficiency and renewable energy use through various technologies.[30] In November 2011, the Kentucky Climate Action Planning Council (KCAPC), appointed in December 2009 by the Energy and Environment Cabinet Secretary, released a final climate action plan that builds upon aspects of the earlier energy strategy and outlines actions to reduce the state's greenhouse gas emissions.[31,32] **To decrease the state's contribution to climate change, Kentucky should establish pollution reduction targets and implement strategies identified in the climate action plan to reduce the state's pollution.**

State Adaptation Planning

Kentucky has not developed a comprehensive climate adaptation plan. **The KCAPC should develop a plan for Kentucky that identifies adaptation strategies to minimize the impacts of climate change in the state.**

There are practically no state agencies working to address the impacts of climate change, with the exception of the Kentucky Department of Fish and Wildlife Resources (KDFWR). In 2010 the department developed a climate change chapter for the state wildlife action plan by analyzing the potential impacts of climate change on species and habitats. In order to enhance the resilience of ecosystems to allow them to better adapt to changing environmental conditions, the plan proposed conserving and restoring functioning ecosystems, protecting key habitats, improving wildlife connectivity, monitoring ecological responses to climate change, and evaluating the effectiveness of actions implemented as part of this plan to support adaptive management.[33] While KDFWR is certainly well ahead of other state agencies in addressing climate change impacts, the climate change chapter largely lacks details on how to complete the proposed actions. In addition, considering the likelihood of an increase in the rate of warming,[34] **KDFWR should commit to updating the climate change chapter on a more frequent basis than every 10 years.[35]**

Despite the lack of action on climate change adaptation, Kentucky has existing plans and programs that, while put in place to address other issues, could also build resilience to potential climate change impacts. In 1999 the state released a plan to ensure that all Kentuckians would have access to safe and reliable water supplies by 2020.[36] Recommendations in the plan included maintaining and expanding a comprehensive water resources database;

providing technical, managerial, and financial assistance to small systems; establishing a statewide water loss, leak detection, and repair program; promoting water system regionalization, including incentivizing mergers; encouraging water rates based on cost of service; and improving the water project funding process, among others.[37] Many of these recommendations, such as regionalization (connecting smaller water systems located near each other to take advantage of economies of scale), also would lessen potential impacts to water system users from higher temperatures and changing precipitation patterns. However, **Kentucky should realize the benefits that nonstructural and "no regrets" strategies, such as improved water use efficiency and green infrastructure, provide over traditional "hard" or "gray" infrastructure in the face of changing climatic and hydrologic conditions.** These strategies are relatively low-cost, flexible, and inherently adaptive.

The Kentucky Division of Water requires users that withdraw more than 10,000 gallons per day from any surface water or groundwater source to apply for a withdrawal permit.[38] Although uses that potentially could be very large, such as irrigation, thermoelectric power generation, and hydraulic fracturing, are exempt from permit requirements, **this program could be an effective tool in ensuring efficient and sustainable water use if mandatory conservation measures were included in the permit.** Also, the state released a drought mitigation and response plan in December 2008.[39] In order to reduce vulnerability to drought, the plan proposed seven broad drought mitigation actions: Improve water resources and drought monitoring networks, develop an inventory and projection of available water resources, assess drought vulnerabilities, develop additional water sources in drought-vulnerable areas, improve the effectiveness of the state drought plan through periodic updates, provide leadership on water conservation and efficiency, and enhance public outreach and awareness of drought preparedness.[40] **In particular, improved water conservation and use efficiency should play a central role in the state's drought management plan.** Undoubtedly these actions, if implemented successfully, would enhance Kentucky's ability to manage drought conditions, which are likely to intensify due to climate change.

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LOUISIANA

Louisiana is one of the most vulnerable states in the U.S. to the impacts of climate change. In 2005 Hurricane Katrina critically exposed the state's vulnerability to flooding and destruction from tropical cyclones. Six years later, to avoid unprecedented levels of flooding in Baton Rouge and New Orleans from the Mississippi River, the U.S. Army Corps of Engineers opened the Morganza Floodway for the first time in nearly 40 years.[1] At the same time in 2011, Louisiana faced the second-driest year on record, which pushed much of the state into severe or extreme drought.[2] In coordination with federal and local partners, the state has undertaken several efforts to address coastal risks from hurricanes, flooding, sea level rise, and erosion; however, Louisiana has yet to act to reduce greenhouse gas pollution or develop a coordinated plan for adapting to a broad array of potential climate change impacts. **The state should develop and implement a climate action strategy to reduce greenhouse gas emissions and prepare for the impacts of climate change.** In the absence of action on these issues, Louisiana's people, economy, and natural environments will continue to be at unnecessary risk.

Water Resources Background

As is the case with many states along the Gulf of Mexico, Louisiana has an abundance of water resources. In fact, it is the wettest state in the coterminous U.S.[3] Average annual precipitation ranges from 48 inches in Caddo Parish in the northwest to 75 inches in the southeast.[4] The timing of precipitation also varies geographically within the state. In the summer, rainfall increases from the northwest to the southeast as moist tropical air brings almost daily precipitation in coastal parishes.[5] Contrastingly, in the winter, the greatest amount of precipitation falls in the northeast as cold air dominates the northern parishes.[6] Overall, fall is generally the driest season. The entire state drains into the Gulf of Mexico, primarily through the Red, Atchafalaya, Old, Sabine, and Calcasieu rivers, and one-third of the state lies in the Mississippi Delta.[7] Louisiana also has substantial groundwater resources in 13 major aquifer systems, with the Chicot Aquifer in the southwest and the Mississippi River Alluvial Aquifer in the northeast being the most heavily utilized.[8]

Approximately 85 percent of total freshwater withdrawn in 2005 came from surface water sources; the remainder came from underground aquifers.[9] Thermoelectric power generation was the largest withdrawer at around 50 percent, followed by industry at 30 percent, irrigation at nearly 10 percent, and domestic and public supply at 7 percent.[10] The two largest industrial groups were the chemicals and petroleum-refining industries, which together accounted for more than 90 percent of all industrial withdrawal.[11] By water source, irrigation was the largest consumer of groundwater at more than 40 percent of total withdrawals, followed by domestic and public supply at 25 percent, industry at 17 percent, and aquaculture at 13 percent.[12] In addition, rice represented the largest use of irrigation water at nearly 80 percent.[13] Of total surface water withdrawals (fresh and saline), thermoelectric power plants withdrew nearly 60 percent; industrial facilities were in second place at more than 30 percent.[14]

The Mississippi River system, while also used directly for water supply, is perhaps best known for its role in commerce. It is among the busiest waterways in the world, with more than 6,000 vessels traveling through New Orleans each year.[15] The ports of Baton Rouge, South Louisiana, and New Orleans allow cargo to be transported to 33 states in the Mississippi River system and are ranked in the top 15 ports nationally in terms of total cargo volume.[16,17] In fact, the Port of South Louisiana is the second-largest port by cargo volume in the entire Western Hemisphere.[18] Major import and export commodities passing through these ports include petroleum products, chemicals, steel and other metals, grain, coffee, and vegetables.[19] The five largest ports in Louisiana handled nearly $75 billion worth of cargo in 2005.[20]

The state's coastal areas are also of substantial economic, ecological, and cultural importance. More than two million people, or nearly half of the total state population, lived in coastal parishes in 2009.[21] The wetlands of Louisiana make up the seventh-largest river delta in the world and support the second-largest commercial fishery in the U.S., after Alaska.[22] The state contains about 40 percent of all total wetlands in the lower 48 states; these wetlands serve as habitat for fish, migratory birds, and other wildlife in addition to supporting local cultures like the Acadians, who settled in coastal Louisiana after being exiled from present-day Nova Scotia and New Brunswick.[23] The Acadians and their descendants, now known as the Cajuns, have lived off the alligators, oysters, and shrimp found in the coastal wetlands for over 200 years.[24] In 2006 commercial marine fisheries produced nearly $265 million in landings and had a total economic impact in excess of $2.3 billion.[25] The state's coastal areas are also of significant recreational value, with saltwater fishing producing an economic impact of more than $750 million in 2006.[26]

However, Louisiana's coastal resources face persistent threats. Since 1932 approximately 1,883 square miles of coastal area have been converted to open water.[27] From 1985 to 2010, the rate of wetland loss was roughly 16.5 square miles per year, equivalent to the loss of a football field–size area every hour.[28] This loss of wetlands can be attributed to tropical cyclones, land subsidence, sea level rise, saltwater intrusion, and changes in sediment deposition as a result of river diversions.[29] Immediately after Hurricanes Katrina and Rita in 2005, there was an approximate increase of 217 square miles in open-water area.[30] In the 2000s a total of six hurricanes and six tropical storms struck the Louisiana coast.[31] The most infamous of these, Hurricane Katrina, led to the deaths of more than 1,500 people in Louisiana and caused an estimated $81 billion worth of property damage in the U.S.—making it the costliest natural disaster in the nation's history.[32]

Climate Change Impacts on Water Resources

Across the southeastern U.S., average annual temperatures have risen about 2°F since 1970, with the greatest warming observed during the winter months.[33] In Louisiana temperatures have risen approximately 1°F since the late 1960s.[34] Furthermore, average fall precipitation has increased by as much as 30 percent in the state since 1901, and there has been an increase in heavy precipitation events in many areas. However, spring and summer precipitation has declined by 5 to 10 percent.[35] The extent of areas experiencing moderate to severe drought also has expanded over the past 30 years.[36] Climate models project that all seasons will experience warming, with average annual temperatures projected to rise by 4.5°F to 9°F by the 2080s.[37] Models generally project that Gulf Coast states like Louisiana will have less precipitation in the winter and spring compared with more northerly states in the region; however, climate model projections are not consistent with respect to trends in total annual precipitation across the southeastern U.S.[38]

The frequency, length, and intensity of drought events are likely to increase as higher temperatures cause greater evapotranspiration.[39] These factors are likely to result in growing water demand for irrigation as rates of groundwater recharge are impacted by drought conditions.[40] Furthermore, changes in precipitation and patterns of runoff will impact surface water resources and the users and ecosystems that rely upon them. More heavy precipitation events are also likely to have negative implications for property and infrastructure located in vulnerable floodplains by escalating flooding risks, and on aquatic species by deteriorating water quality. Extreme runoff events also could lead to the overload of sewage treatment systems and result in the discharge of untreated sewage into waterways.[41] In particular, increasing runoff of the nutrient-laden Mississippi River into the Gulf of Mexico could increase the size and frequency of low-oxygen (hypoxic) conditions, which would impact coastal fisheries.[42] Moreover, increasing water temperatures in response to rising air temperatures could reduce dissolved oxygen in other water bodies and lead to fish kills and a loss of biodiversity.[43]

The rate of relative sea level rise along Louisiana's coast is among the highest anywhere in the world. Over the past several centuries, about 25 percent of delta wetlands have been permanently inundated as a result of subsidence and sea level rise.[44] In just the past 100 years, water levels have risen as much as 40 inches along the coast.[45] Conservative estimates suggest a relative sea level rise of 1.6 to 4.6 feet by 2100.[46] At this rate, an estimated 4,000 to 5,200 square miles of delta plain could be submerged by the end of the century.[47] However, recent projections of global sea level rise on the order of 2.5 to 6 feet by 2100 would translate to a relative sea level rise of as much as 5 to 9 feet along the most heavily subsiding areas of the Louisiana coast, such as Grand Isle on the Lafourche Delta.[48]

Rising sea levels could lead to the permanent inundation and erosion of wetlands, the flooding of low-lying communities and infrastructure, and changes in salinity in coastal environments.[49] In addition, higher sea levels in combination with changes in river runoff and aquifer recharge are likely to lead to saltwater intrusion into freshwater supplies.[50] The loss of wetlands that provide buffering capacity against storm surge will only exacerbate existing vulnerabilities to tropical cyclones, which are projected to grow more intense under climate change.[51] Increasing ocean temperatures are also likely to have impacts on coastal ecosystems. In addition to affecting the range of aquatic species, changes in water temperature and salinity influence the prevalence and persistence of many pathogens.[52]

Greenhouse Gas Pollution Reduction

The State of Louisiana has not adopted a greenhouse gas pollution reduction goal or developed a plan for reducing pollution. In addition, the Climate Change Policy Commission, established in 2009 to develop a state strategy for climate change, was recently dissolved, having never been fully appointed or ever holding a meeting.[53] **Because climate change impacts are projected to be particularly detrimental to the state, Louisiana should adopt greenhouse gas pollution reduction goals and implement measures to reduce the state's contribution to climate change.**

State Adaptation Planning

Louisiana has not developed a comprehensive statewide plan for adapting to climate change. There are efforts under way to address some climate change impacts in the state; however, these initiatives focus exclusively on coastal hazards. **While the state is clearly vulnerable to coastal hazards associated with climate change, Louisiana also should be assessing vulnerabilities and developing response strategies to other climate impacts (drought, flooding, stresss on aquatic species, etc.) throughout the state. In particular, "no regrets" strategies, such as water conservation and efficiency and green infrastructure, address existing water resource issues while also building resilience to future climate impacts.**

The federal government has worked with the state to fund and implement coastal wetlands restoration projects as a result of the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA), enacted in 1990.[54] Although CWPPRA was effective at implementing local projects quickly, it largely lacked the tools and resources necessary to address large-scale wetlands degradation.[55] Consequently, federal, state, and local stakeholders worked together in the late 1990s to develop an integrated plan, Coast 2050, to maintain and restore natural processes to protect the coast.[56] Following up on the strategies outlined in this plan, the Louisiana Department of Natural Resources and the U.S. Army Corps of Engineers partnered on the Louisiana Coastal Area Ecosystem Restoration Study (LCA) in 1999 to establish priorities, identify projects for implementation in the near term (within five to ten years), and to develop a strategy for addressing long-term coastal restoration needs, among other goals.[57] However, prior to congressional action on the study's recommendations, Hurricanes Katrina and Rita struck Louisiana in 2005. The Water Resources Development Act of 2007 eventually authorized federal funds for six LCA projects, including river diversions to restore wetlands and combat saltwater intrusion and the restoration of shoreline on barrier islands.[58]

In the aftermath of the catastrophic 2005 hurricane season, the Louisiana Legislature established the Coastal Protection and Restoration Authority (CPRA) to coordinate local, state, and federal coastal restoration and flood control efforts.[59] In 2007 CPRA developed a master plan to guide hurricane protection and coastal restoration projects.[60] Perhaps most distinctive when compared with earlier coastal restoration plans, CPRA advocated for a multiple lines of defense strategy (MLODS) that utilizes structural, nonstructural, and ecological components to reduce risks from coastal hazards. MLODS measures include river diversions, restoration of barrier islands, marsh creation, elevation of structures, construction of levees and floodgates, and evacuation.[61,62] While these measures are primarily meant to provide protection against hurricanes and other coastal hazards, they also will provide benefits in the face of sea level rise. As a supplement to this master plan, the U.S. Army Corps developed a technical report containing a range of flood control, hurricane protection, and coastal restoration measures for coastal Louisiana.[63]

A 2012 update to the coastal master plan builds on previous initiatives to meet five main objectives: (1) reduce economic losses from storm surge to residential, public, industrial, and commercial infrastructure; (2) promote sustainable coastal ecosystems through natural processes; (3) provide habitats suitable for commercial and recreational uses; (4) sustain the unique cultural heritage of coastal Louisiana by preserving historic structures and traditional living cultures; and (5) promote a viable working coast that supports the regional and national economy.[64] In March 2012, the CPRA approved submission of the 2012 Coastal Master Plan to the Louisiana Legislature.[65] As part of the analysis to determine which projects to include in the plan, two environmental scenarios were developed. These scenarios included factors such as sea level rise, subsidence, storm intensity, and storm frequency, among many others.[66] The moderate scenario utilized an increase of 0.81 feet in sea level while the "less optimistic" scenario used an increase of 1.4 feet in sea level over the next 50 years. The plan also notes that since the state's original sea level rise analysis took place, more extreme projections of sea level rise have been developed, and these new rates will be incorporated into future project planning and design.[67] The plan proposes $50 billion worth of coastal protection and restoration projects, including marsh creation, structural and nonstructural measures, and sediment diversions.[68] Although over $10 billion of nonstructural projects are proposed, the plan only considers nonstructural measures such as the elevation of residential structures, commercial and residential floodproofing, and voluntary acquisition of structures.[69] As acknowledged but not evaluated by the plan, nonstructural programmatic measures, such as zoning ordinances and building codes, also are necessary to protect communities from flooding.[70] During implementation of this plan, **Louisiana should thoroughly examine hazard mitigation techniques that involve changes to conventional land use, construction, and regulatory practices (as identified in reports like the Louisiana Coastal Hazard Mitigation Guidebook) and also should ensure that strategies selected for implementation remain robust and effective in the face of climate change.**

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MAINE

Tourism, the largest economic sector in Maine, generated more than $6 billion in revenue, brought in more than $500 million in tax proceeds, and employed nearly 180,000 people in 2004.[1] As a result of rising sea levels, coastal resources that are valued for their natural and economic benefits are at risk from flooding and erosion. Current projections of more precipitation and extreme precipitation events could result in increased flooding risks and the degradation of surface water quality as greater storm runoff carries pollutants into valuable freshwater resources. Shifts in streamflow hydrology could impact the replenishment of underground aquifers, which are the source of water for almost half of Maine's population. In recent years, the state has developed a broad report containing adaptation options to inform future planning efforts and has been proactive in implementing regulations to mitigate erosion risks from sea level rise. However, recent political changes in the state's government have impeded any additional progress on climate change activities. To prepare the state for climate change, **Maine should develop a comprehensive adaptation plan that integrates and builds upon existing efforts and that also features specific actions for implementation by state agencies and local governments.**

Water Resources Background

Maine is commonly thought to have abundant water resources. Across the state's three climate divisions, an average of 40 to 46 inches of precipitation falls each year.[2] This precipitation is generally evenly distributed throughout the year; however, the coast is wettest in the winter whereas the north is wettest in the summer.[3] Approximately 30 to 40 percent of precipitation is lost through evapotranspiration and 10 to 20 percent infiltrates into the ground.[4] The rest runs off into Maine's thousands of lakes, rivers, and streams.

The timing of snowmelt and the ratio of rain to snow in the late winter has a significant influence on streamflows in the spring and summer months.[5] Peak streamflows generally occur in the early spring as a result of rain falling on melting snow or running off from saturated soils.[6] In addition, spring streamflow and precipitation are particularly important to groundwater recharge in the Northeast U.S., where groundwater resources consist of bedrock aquifers and relatively thin sand and gravel aquifers with little storage capacity.[7] Groundwater resources are also vital to maintaining summer streamflow during low-flow periods.[8]

Both surface water and groundwater resources are heavily utilized in the state. While more public water systems in the state rely on groundwater than on surface water, surface water supplies more than 70 percent of the total volume of water withdrawn for domestic public supply.[9] In addition, nearly 40 percent of Maine's population relies on private groundwater wells.[10] In 2007 paper mills accounted for nearly two-thirds of all freshwater withdrawal reported to the state, followed by municipal water suppliers at almost one-third.[11] However, the state-reported statistics do not provide an accurate assessment of water withdrawal in Maine because many commercial and industrial users are exempt from annual reporting requirements, either because they receive water from public water suppliers or because their daily withdrawals are below the minimum level set by the state.[12] According to the USGS, in 2005 industrial users were the largest withdrawers of freshwater at nearly 35 percent, followed by public and domestic users at 28 percent, thermoelectric power plants at 21 percent, and aquaculture at 11 percent.[13]

Maine's coastal resources are a core component of the state's identity and economy. The majority of the state's population lives along the more than 3,500 miles of shoreline.[14] The coast is also a big driver of Maine's tourism economy as well as a supporter of commercial fisheries, marinas, shipyards, ports of commerce, and recreation.[15] In 2004 the state's direct ocean economy contributed nearly $2 billion, or 4.5 percent, of Maine's total GDP.[16] Of this total, recreation and tourism provided nearly $1 billion.[17] The value of lobster landings alone exceeded $260 million in 2007.[18] The coast also has substantial indirect benefits to Maine: Shoreline counties generated nearly $30 billion, or 60 percent, of the state's GDP in 2007.[19]

Climate Change Impacts on Water Resources

Since 1970 the temperature in the northeastern U.S. has increased by an average of 0.45°F per decade, and the surface temperature of Maine's coastal waters has increased nearly 2°F.[20] Within the past 150 years, earlier snowmelt runoff in the late winter and early spring, decreasing duration of ice on rivers and lakes, a decreasing ratio of snowfall to total precipitation, and thinner late-winter snowpack have been observed in the northeastern U.S.[21] Moreover, from 1950 to 2007, all three of Maine's climate divisions have trended toward wetter conditions.[22] Several stream gauges in Maine have shown a shift in peak flows to earlier in the spring and lower flows in the late spring, and lake ice-out dates (the date of ice cover loss in the spring) in New England have advanced by up to two weeks since the 1800s, resulting in shorter seasons for ice-fishing, skating, skiing, and snowmobiling.[23]

Over the next century, Maine's average annual temperature is projected to increase by 3°F to 10°F, the growing season is expected to lengthen, and the characteristics of precipitation are expected to change substantially.[24] Projected increases in temperature and precipitation tend to be greatest in the north and smallest in the coastal regions.[25] These projections of warming and increased precipitation indicate a potential shift in hydrology in the northern and southern interior climate divisions from a snow-dominated to more of a rain-dominated watershed, and consequently an increase in winter flooding risks.[26] In addition to wetter future conditions, some projections also forecast heavier precipitation intensity.[27]

These changes in climate could cause earlier spring runoff, decreased snow depth, greater fluctuations in lake levels, and saline intrusion into coastal aquifers.[28] Higher water temperatures and increased pollution from stormwater runoff could result in degradation of water bodies through eutrophication and high turbidity events.[29] These impacts upon sources of drinking water could decrease freshwater availability at the same time as population growth increases demand.[30] Lower summer flows also could impact the state's hydropower generating capacity, currently at almost 770 megawatts, and cause reductions in vernal and coldwater holding pools, which would have implications for aquatic species.[31,32]

Since 1912, the sea level along Maine's coast has risen at a rate of 0.07 inch per year—the highest rate in the past 5,000 years.[33] This rise in sea level is the result of thermal expansion of the water in the ocean, increased meltwater from glaciers and land-based ice sheets, and coastal subsidence.[34] Regional sea surface temperatures in the Gulf of Maine are projected to increase an additional 6°F to 8°F, contributing to a sea level rise of 2 feet by the end of the 21st century.[35] However, more recent projections that take into account rapid ice melt indicate that a global sea level rise of 2.5 to 6.2 feet by the end of the century is possible.[36] These changes in the ocean would impact Maine's coastal infrastructure and ecosystems. While the majority of the state's coast is steep, rocky, and resistant to rising sea levels, at least 40 percent of the coast is composed of bluffs that are vulnerable to erosion from higher sea levels.[37] Moreover, unstable bluffs cover 17 percent of the coastline.[38] The Gulf of Maine is also susceptible to tropical storms, with two to five storms per year impacting the region.[39] Increased intensities of tropical storms during the summer and fall and increases in extratropical storms during the fall and winter, further exacerbated by sea level rise, would result in stronger and more destructive storm surges along the coast.[40] A study of nine towns in York County estimated that 265 businesses with annual wages of $41 million would be at risk from coastal flooding associated with sea level rise and higher storm surges.[41] More intense rainfall events could also overwhelm sewer systems, leading to poor water quality and beach closures.[42] Coastal wetlands, which are valuable for wildlife habitat, water quality enhancement, and shoreline protection, could also be vulnerable to sea level rise and wave action erosion.[43]

The productivity of the state's coastal waters is largely determined by whether cold, relatively fresher water from the Labrador Sea or warmer, saltier water from the south flow into the Gulf of Maine.[44] Salinity and temperature changes in coastal waters as a result of climate change could affect these ocean circulation patterns and, consequently, impact the distribution of marine species. Ocean acidification as a result of the absorption of carbon dioxide could have potentially severe implications for the growth and survival of aquatic species that use carbonate (coral, clams, mussels, lobsters, etc.) to build shells.[45] Warmer water temperatures could also allow for the spread of invasive species like the Asian shore crab—which have been limited thus far by water temperatures that are too cold to allow eggs and larvae to grow—and increasing occurrences of harmful algal toxin blooms.[46]

Greenhouse Gas Pollution Reduction

In 2001 Maine signed on to the Climate Change Action Plan developed by the New England governors and the eastern Canadian premiers. This plan contributed to the development of the Regional Greenhouse Gas Initiative (RGGI), a collaborative effort among nine states to reduce greenhouse gas emissions through a cap-and-trade system.[47] In 2003 then-governor John Baldacci signed into law the Act to Provide Leadership in Addressing the Threat of Climate Change, which established statewide greenhouse gas emissions reduction targets of 1990 levels by 2010, 10 percent below 1990 levels by 2020, and 75 to 80 percent below 2003 levels in the long term. In 2004 the Department of Environmental Protection (DEP) submitted a climate action plan to the state legislature containing strategies for achieving these levels of greenhouse gas reductions.[48] **To reduce the state's greenhouse gas pollution and contribution to climate change, Maine should commit to implementing strategies from this action plan.**

State Adaptation Planning

In 2009 the Maine Legislature directed the DEP to develop a report of climate change adaptation options for the state. This report, "People and Nature Adapting to a Changing Climate: Charting Maine's Course," was released in February 2010 after input from 13 executive-branch agencies, stakeholders in the private sector, and public interest groups.[49] The report's recommendations focus on several key areas: enhanced monitoring, data collection, and modeling; improved dissemination of climate change information to boost awareness; increased planning and coordination of adaptation, especially at the local and regional levels; development of adaptive capacity in the private sector; and integration of adaptation into Maine's existing mitigation plan. More specific water-related recommendations include assessing the vulnerability of infrastructure (wastewater treatment systems, storm sewers, roads, etc.) to climate change impacts; revising design standards for critical infrastructure; encouraging property insurers to incorporate climate change into underwriting requirements; and developing new standards to control nonpoint source pollution.[50] Because the coast is particularly important to the state, the report makes a few specific recommendations regarding coastal areas, such as including sea level rise benchmarks, siting criteria, and risk reduction guidelines in coastal facility planning; restoring natural processes through protective zoning, conservation, and land acquisition to protect against erosion and flooding; and updating current setback requirements for beaches and bluffs.

Overall, the report lays out a broad framework for Maine on adaptation, with the keystone recommendation being that the state develop a complete adaptation plan that contains more specific and actionable recommendations for implementation. This initial effort is commendable and contains several adaptation options that are necessary to address climate change impacts. In 2009 the Maine Department of Transportation also outlined a strategy for protecting and preparing the state's infrastructure against climate change.[51] Short-term approaches include assessing the ability of existing infrastructure to handle anticipated climate impacts, using cost/benefit analyses to prioritize the most vulnerable infrastructure for retrofitting, and incorporating climate change considerations into decision-making and planning. Long-term approaches include designing and building infrastructure to withstand projected climate change impacts and restoring habitat connectivity for wildlife migration. However, the 2010 election of Governor Paul LePage, who has openly questioned the science behind climate change,[52] has resulted in many state agencies' placing adaptation activities on hold. **The executive and legislative leadership in Maine should realize the significant risks that climate change poses to the state and should make it a priority to develop a more comprehensive and formal adaptation plan for implementation by state agencies and local governments.**

Due to the importance of the coast to Maine's identity and economy, the state historically has at least been relatively proactive in addressing sea level rise. The Maine Geological Survey, in conjunction with several partners, has developed a coastal sea level rise adaptation tool, COAST, that simulates flooding associated with sea level rise and analyzes the economic impacts of flooding and the costs of different adaptation strategies.[53] The state has also assisted local and regional adaptation planning efforts. One example is the formation of the Sea Level Adaptation Working Group in the Saco Bay area. With funding assistance from the state, the group has conducted a sea level rise vulnerability assessment and will develop strategies for adapting to a two-foot rise in sea level by 2100.[54]

Within recent years, the state also has adopted policies to protect its beaches from erosion caused by sea level rise, storms, and development. While sandy beaches make up about 1 percent of the state's shoreline, nearly half of all visitors to the state spend time at a beach.[55] In addition to their recreational and economic value, Maine's beaches provide habitat for wildlife and shield adjacent development from storms and flooding.[56] In 2006 the state adopted the revised Coastal Sand Dune Rules (CDSR), which redefined an Erosion Hazard Area (EHA) as any portion of the coastal sand dune system that can be reasonably expected to become part of a coastal wetland within the next 100 years due to shoreline changes from historical long-term erosion, short term erosion from a 100-year storm, or flooding from a 100-year storm after a two-foot rise in sea level.[57] Within an EHA, building sizes are restricted unless they are sufficiently elevated to remain stable after taking into account a 2-foot sea level rise over 100 years.[58] Furthermore, the CDSR prohibits the permitting of projects that may be subject to erosion after a two-foot sea level rise over 100 years. In 2006 the state also adopted revised setback rules for new development on coastal bluffs that require municipal setback ordinances to be based not on the shoreline but on the top edge of the bluff.[59] While the current political climate might not be ideal for Maine's future adaptation efforts, these prior regulatory efforts addressing sea level rise provide important examples of proactive coastal policies that other states can and should follow.

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MARYLAND

In 2003 Hurricane Isabel flooded Maryland with 4 to 12 inches of rain and storm surges 6 to 8 feet high, causing more than $460 million in damage.[1] This type of extreme precipitation event is likely to become more intense due to climate change. In addition, Maryland is likely to experience winter precipitation increases, drier summers, and higher sea levels. Rising seas and tides would threaten ports, infrastructure, private property, and ecosystems along the coast. Fortunately, the state has recognized the risks that climate change poses to Maryland and is acting to reduce its vulnerability. The state has developed a two-phase adaptation strategy that addresses risks across six major sectors and has worked to build the adaptive capacity of local communities by providing financial and technical support. Maryland also has sought to reduce existing environmental stressors by requiring Environmental Site Design or low-impact development techniques to manage stormwater runoff. Furthermore, an executive order requires an annual report on the implementation of the state's Climate Action Plan to be provided to the governor and General Assembly; this is a vital tool in ensuring that planning translates into action. Ultimately, the effective implementation of adaptation strategies requires continued support and coordination by state agencies, but it is unclear whether the necessary coordination among state agencies is occurring. **Maryland should work to ensure that the resources necessary to fully implement its adaptation strategy are sustained and that all state agencies are engaging in adaptation planning.**

Water Resources Background

Average annual precipitation in Maryland ranges from 48 inches in the Eastern Shore area and the Allegheny Plateau in the west to as little as 37 inches in portions of Allegany County, near Cumberland. Annual precipitation in the Chesapeake Bay area averages about 44 inches.[2,3] Precipitation is fairly evenly distributed throughout the year, with monthly precipitation totals ranging from 3 to 5 inches.[4] Eastern portions of the state tend to have the most precipitation in July and August, while western parts have the highest monthly precipitation totals between May and August.[5] Although the heaviest precipitation occurs during the summer, severe droughts are also most common during this season as the result of precipitation variability and high rates of evapotranspiration.[6] Snow is also common in winter months, with average annual snowfall ranging from 8 inches in coastal areas to more than 100 inches in Garrett County in far western Maryland.[7]

Nearly all of the state lies in the Atlantic drainage basin, with the exception of a portion of Garrett County that drains into the Ohio Basin.[8] The Potomac River, which drains into Chesapeake Bay, is the state's largest river and forms the majority of its southern border.[9] Stream discharges vary seasonally as a function of climate and storm activity. The highest streamflow amounts generally occur in the spring, when precipitation and snowmelt combine and run off into streams, which can increase flooding risks.[10] In the central and western portions of the state, surface water is the primary source of supply due to high variability in groundwater resources.[11] However, in the eastern and southern regions of the state, groundwater is a significant source of supply. In the 12 counties located in the coastal plain, groundwater makes up nearly 90 percent of total water use.[12] Statewide, more than 80 percent of total freshwater withdrawals come from surface water supplies, much of which is used to meet the high demand from thermoelectric power plants and from the population centers of Baltimore and Washington, D.C.[13] Baltimore City, which supplies Baltimore County and parts of Anne Arundel, Howard, Harford, and Carroll counties, has three major reservoirs with total storage capacity in excess of 266,000 acre-feet, in addition to a pipeline that can withdraw water from the Susquehanna River during periods of extreme drought.[14] The Washington metropolitan area obtains roughly 75 percent of its water from the Potomac River; it also has about 52,000 acre-feet of connected reservoir storage and an additional 55,000 acre-feet of storage capacity in nearby, unconnected suburban reservoirs.[15] The industrial, irrigation, and commercial sectors are also significant users of water.[16]

Maryland's 3,000-plus miles of coastline are vital to the state's human and natural systems.[17] The 16 counties within the coastal zone contain nearly 70 percent of the state's total population and generate more than 60 percent of its total GDP.[18,19] In addition, more than 60 percent of the $11.72 billion in spending by visitors to the state in 2007 took place in coastal counties.[20] There are also considerable commercial and industrial assets along the coast. The Port of Baltimore produces nearly $2 billion annually in economic benefits and provides 127,000 maritime-related jobs.[21] Furthermore, Maryland's commercial fishing and crabbing industry generates more than $207 million annually.[22] The Chesapeake Bay, the largest estuary in the U.S. at approximately 200 miles long, supports 3,600 species of plant and animal life including more than 300 fish species.[23] The estimated economic value of the bay is greater than $1 trillion, and the estimated annual economic benefits to the states of Virginia and Maryland from the bay exceed $60 billion.[24]

Climate Change Impacts on Water Resources

Between 1977 and 1999, the average annual temperature across Maryland increased by 2°F, but there was no discernible trend in precipitation for this same period.[25] Mean climate model projections suggest that an additional warming of 2°F by 2025, between 2°F and 4°F by 2050, and between 4°F and 9°F by 2100 are likely, depending on the emissions scenario.[26] Temperature increases are projected to be greater during the summer and higher in western Maryland than along the Eastern Shore because of the moderating influence of the ocean.[27] Precipitation model projections show a likely increase of 6.6 to 6.8 percent by 2050 and 10.4 to 12.6 percent by 2090 in winter precipitation, with no significant changes in summer precipitation.[28] In addition, the amount of winter snow volume is expected to decrease by 25 percent by 2025 and 50 percent by 2050 as a result of warmer temperatures.[29] This reduction in snow is likely to be substantial enough to reduce spring stream discharges that are normally augmented by snowmelt.[30] Due to climate change, the characteristics of precipitation are also expected to change, with the percentage of total rainfall occurring in extreme events projected to increase.[31]

Higher temperatures are expected to lead to lower soil moisture as evapotranspiration rates increase. Similarly, summer-to-fall droughts of modest duration are likely to increase, and models suggest that monthlong droughts, which currently occur every 40 years, may occur as often as every 8 years by 2100 under a high-emissions scenario.[32] Furthermore, water demands are expected to increase over the next 30 years as a result of increased development, population growth, and greater irrigation needs associated with warmer summers.[33] Projected increases in winter precipitation will increase the likelihood that reservoirs will be full heading into drier summer periods.[34] Consequently, areas that have significant reservoir storage capacity, like Baltimore, should have sufficient water supplies in the future given climate change; however, the Washington metropolitan area may have to develop additional supplies or restrict demand due to heavy reliance on the Potomac River, whose flows are largely unregulated.[35] Shallow groundwater supplies, located largely in rural areas, are also susceptible to short-term variations in climate and land-use changes.[36] Confined aquifers in Maryland's coastal plains, however, are not sensitive to short-term climatic variation but are already rapidly declining due to development and excessive withdrawal.[37] Continued groundwater overdraft in conjunction with sea level rise may lead to saline intrusion into coastal aquifers and contribute to land subsidence, further exacerbating local sea level rise.[38]

As a result of increases in extreme precipitation events, flooding risks are likely to increase.[39] Hydrologic changes associated with climate change, such as increased runoff and greater streamflow variations, are likely to have water quality impacts. In particular, pollutants may increasingly be flushed into waterways and flow into the already polluted Chesapeake Bay.[40] These pollutants, in addition to warmer stream temperatures and changes in streamflow, would stress aquatic species. A projected 12°F increase in stream temperatures could occur by the late 21st century in the Washington, D.C., area under a moderate-emissions scenario that also considers the temperature impact of urbanization, stressing as many as 29 aquatic species and reducing the growth and reproduction of recreationally important species by 40 to 90 percent.[41]

Climate Change Impacts on Coastal Areas

Along Maryland's coast, sea level has risen approximately 1 foot in the past 100 years.[42] Rates of sea level rise in the region are greater than the global average due to land subsidence caused by retreating glaciers and groundwater extraction.[43,44] The effects of rising seas have already impacted the Maryland coast in the form of erosion, flooding, and inundation. Approximately 31 percent of the state's shoreline is currently experiencing erosion, and approximately 580 acres of coastal land are lost annually.[45] Over the past century, 13 islands in the Chesapeake Bay have disappeared due to sea level rise.[46] Relative sea level in Maryland is projected to increase 0.6 to 1.3 feet by mid- and 2.7 to 3.4 feet by 2100, depending on the emissions scenario and the melting rate of land-based ice sheets.[47] Recent studies that have taken into account accelerated melting of these ice sheets suggest that global sea level rise on the order of 2.5 to 6.2 feet is possible by the end of the century.[48]

Continued sea level rise will intensify existing stresses on coastal resources and infrastructure. Coastal wetlands, which provide habitat for commercially important fisheries and wildlife and act as a buffer against coastal storms, are unlikely to be able to keep pace with sea level rise over the 21st century and will need to migrate inland in order to survive.[49] With a relative sea level rise of just 1.5 feet, 264 miles of roads, 226 miles of railway, and 31 percent of port facilities in Maryland would be subject to inundation.[50] As a result of warmer air and sea surface temperatures, the intensity of tropical cyclones and the frequency and intensity of nontropical storms are expected to increase.[51] Higher storm surges, more intense rainfall, and stronger winds would increase the potential for flood and erosion damage to coastal areas. Climate change also will have implications for the Chesapeake Bay and the Coastal Bays ecosystems in Maryland. Warmer water temperatures and changes in streamflow and nutrient cycling could impact the occurrence of harmful algal blooms in the Chesapeake Bay and limit the range of suitable habitat for fish species.[52] Cool-temperature species, such as soft shell clams and sturgeon, have already experienced a decline in the Chesapeake Bay; however, warmer temperatures may expand the range of species like the Atlantic croaker and shrimp populations, providing new commercial opportunities.[53] Ocean acidification, which is occurring due to the uptake of carbon dioxide by the ocean, is also a considerable threat to marine environments. Mussel and oyster calcification rates are projected to decline 20 to 25 percent by the end of the century, and the ability of oyster larvae to form thin shells will likely be impacted by the decreasing pH of the ocean.[54]

Greenhouse Gas Pollution Reduction

In 2008 the Maryland Commission on Climate Change released a final report containing options to reduce the state's greenhouse gas pollution.[55] With passage of the Greenhouse Gas Emissions Reduction Act of 2009, the state committed to a 25 percent reduction in greenhouse gas emissions below a 2006 baseline by 2020.[56] The act also requires the state to develop by 2012 a final plan to achieve this reduction.[57] However, the Maryland Department of the Environment (MDE) failed to submit a draft plan to the governor and legislature by the 2011 deadline.[58] Instead, the draft plan was released in March 2012.[59] **Maryland should prioritize the finalization of this draft plan so that the state can begin implementation.** Maryland also is a member of the Regional Greenhouse Gas Initiative, a cooperative effort among nine northeastern and mid-Atlantic states to reduce carbon emissions from power plants through a cap-and-trade program.[60]

State Adaptation Planning

In 2008 the Adaptation and Response Working Group (ARWG) of the Maryland Commission on Climate Change released its Phase I adaptation strategy for reducing risks associated with sea level rise and coastal storms. In this report, the ARWG made several notable recommendations for responding to sea level rise impacts. These included integrating adaptation strategies into local planning, codes, and ordinances; developing and implementing adaptation strategies for vulnerable public and private infrastructure; strengthening building codes and construction techniques for new structures in vulnerable areas; and protecting and restoring natural resources that provide protection against coastal floods, heavy winds, and strong waves.[61] Unlike many state-level plans that lack details regarding implementation, the Phase I strategy report contained specific implementation actions for state agencies to achieve these recommendations. For example, to ensure that structures in floodplains are less vulnerable to floodwaters, the

ARWG noted that MDE would take the lead role in developing the necessary legislation and regulatory amendments to the Flood Hazard Management Act to require all counties to adopt standards requiring at least two feet of freeboard in tidally influenced floodplains.[62]

Following up on the Phase I report, the ARWG released its Phase II strategy in early 2011 and made 18 key recommendations to reduce the impacts of climate change on human health, agriculture, forest and terrestrial ecosystems, bay and aquatic environments, water resources, and population growth and infrastructure.[63] To protect bay and aquatic environments, the ARWG recommended that at-risk species and habitats be better targeted for protection and that existing stressors, such as water pollution and barriers to habitat connectivity, be reduced.[64] A few of the recommendations concerning water resources included working with local communities to promote water conservation, protecting high-quality water recharge areas, revising Clean Water Revolving Fund criteria to require low-impact development techniques for stormwater and combined sewer projects, and incorporating climate change projections into the Water Resources Element in local comprehensive plans.[65] The ARWG also recommended that the state adopt and fund the recommendations of a 2008 report on water resources management known as the Wolman Committee Report.[66] In order to ensure sustainable long-term use and protection of Maryland's water resources, the Wolman Committee recommended that the state improve hydrologic monitoring, develop a comprehensive statewide water supply plan, adequately fund and staff the MDE Water Supply Program, and consider alternative water rate structures to promote conservation, among many other items.[67] The ARWG also suggested that the state undertake a comprehensive vulnerability assessment of infrastructure, accelerate use of improved stormwater management practices (e.g., green infrastructure), strengthen building and infrastructure design standards, and work to integrate climate change adaptation into existing state and local policies and programs.[68] State lead agencies are currently working to develop detailed implementation plans for the six sectors in the Phase II strategy.[69]

In recent years, Maryland has developed new regulations and modified existing ones to address climate change impacts. The Living Shorelines Protection Act of 2008 requires that only nonstructural stabilization techniques be utilized to preserve the natural environment, except in areas that the state has mapped as appropriate for structural stabilization measures.[70] As sea levels rise, living shorelines allow coastal habitats to migrate inland and retain their storm-buffering benefits. The Chesapeake and Atlantic Coastal Bays Critical Area Protection Program Act, also passed in 2008, requires the map of critical areas to be updated at least every 12 years to reflect changes in tidal wetlands due to sea level rise, an increase in the vegetated buffer requirement for new development, and inclusion of coastal flood hazards in the review process for additional growth and development in critical areas.[71,72] The state also has passed regulations that, while aimed at addressing existing problems, also will build the resilience of local communities to climate change impacts. The Stormwater Act of 2007 requires new development and redevelopment to incorporate Environmental Site Design or low-impact development (LID) techniques wherever possible to promote natural recharge and reduce the volume of runoff and water pollution.[73] While not specifically adopted to address climate change issues, LID techniques nonetheless will help to address water quality and stormwater runoff issues associated with increases in extreme precipitation events.

In addition, the Water Resources Element (WRE) Law requires that the adequacy of water resources (water supply, wastewater treatment capacity, etc.) for existing and future development be evaluated as part of local comprehensive plans.[74] The WRE currently does not require climate change to be considered; however, the state is working to develop tools to guide the integration of climate science and adaptation strategies into the WRE through collaborations with NOAA Climate Services and the University of Maryland.[75,76] Climate change also will play a fundamental role in the state's upcoming sustainable growth and development plan, PlanMaryland. As part of the plan, five special area designation categories will be available for local governments to utilize to identify areas to protect and preserve, and one of these categories includes areas subject to climate change impacts such as sea level rise or extreme weather events.[77] In these designated areas, infrastructure capacity improvements that increase exposure to natural disasters and financial risks associated with development and redevelopment in vulnerable coastal areas will be avoided. In addition, public investments within the sea level rise inundation zone (i.e., lands within four feet of mean sea level) will consider the potential impacts of sea level rise.[78] **The integration of climate change into the WRE and PlanMaryland is an essential step toward ensuring that local communities begin preparing for climate change impacts.**

The Maryland Department of Natural Resources (DNR) is taking the lead on many of the state's adaptation activities. In October 2010, DNR adopted a policy that seeks to ensure that departmental practices and procedures consider both contributions to climate change and possible impacts from climate change.[79] The policy applies to new land investment decisions, the siting and design of facilities and infrastructure, habitat restoration, government operations, research, resource planning, and advocacy. DNR has also begun several initiatives to improve the capacity of local governments to address sea level rise risks in their communities. Through the CoastSmart Communities Initiative grant program, DNR has provided technical and financial assistance to the counties of Worcester, Somerset, Dorchester, Kent, Prince George's, Baltimore, Anne Arundel, and Caroline, the towns of Queenstown and Crisfield, and the city of Annapolis.[80,81,82] These projects have included sea level rise vulnerability assessments and recommendations to mitigate risks through changes in planning, regulations, and public investment.[83] In addition, the Coastal Atlas, a mapping and planning tool developed by DNR and others, enables local decision-makers to visualize ocean, shoreline, and estuary data.[84] The Shorelines component of the tool specifically allows users to view shoreline erosion, coastal inundation from storms, and areas at risk to sea level rise. In addition, for 2012, DNR is prioritizing preparedness planning with respect to water resources, sea level rise and coastal storms, and human health.[85]

The Maryland Department of Transportation (MDOT) also has worked to institutionalize climate change into departmental operations. All MDOT modal administrations (State Highway Administration, Maryland Transportation Administration, Maryland Port Administration, Maryland Aviation Administration, and Maryland Transit Administration) have formally incorporated sea level rise and storm surge projections into planning frameworks to ensure that the vulnerability of future projects will be assessed.[86] MDOT agencies have also largely completed vulnerability assessments of infrastructure to sea level rise, and where possible will develop plans to move sensitive infrastructure to higher elevations.[87] **Other state agencies, if not already doing so, should follow the lead of MDOT and DNR to integrate climate change into all applicable aspects of agency operations.**

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MASSACHUSETTS

As a result of climate change, Massachusetts is projected to face increases in winter precipitation, more extreme precipitation events, declining streamflows in the summer, and rising sea levels. A sea level rise of a little more than two feet by mid-century would place $460 billion worth of assets at risk in the Boston area alone.[1] Massachusetts is taking concrete steps to reduce greenhouse gas pollution and adapt to climate change. In September 2011, the Adaptation Advisory Committee released a report containing adaptation strategies for implementation across a broad array of sectors. **Massachusetts should seek to build upon the momentum generated by this report and direct state agencies to begin implementation of these strategies. The state also should take advantage of opportunities to build resilience and address climate change impacts through existing water resources and coastal planning programs.**

Water Resources Background

Annual average precipitation in Massachusetts is around 44 inches per year, with mountainous areas in the western part of the state experiencing somewhat more.[2] The lowest streamflow generally occurs in July through September as a result of high evapotranspiration rates, and peak discharges usually occur in March or April as snowmelt is supplemented by rainfall.[3] The state's surface waters are divided into 27 basin planning regions, with the lower parts of the Connecticut and Merrimack having the highest volume of flow.[4] Groundwater resources are commonly found in stratified-drift and bedrock aquifers throughout the state.[5]

Of total water withdrawals in 2005, more than 90 percent came from surface water sources.[6] Cooling water for thermoelectric power generation was the largest user at 68 percent, followed by public water supply at 22 percent, and agricultural and industrial users at approximately 3 percent each.[7] Surface water is the main source of supply for thermoelectric, public supply, and industry in all major urban areas.[8] Groundwater resources are used for about 25 percent of public water supply and for industrial users especially in the west-central and western part of Massachusetts.[9] The largest reservoir in the state, the Quabbin Reservoir, covers an area of nearly 40 square miles and contains nearly 1.3 million acre-feet of water at full capacity.[10] The Quabbin and the nearby Wachusett Reservoir are the primary public water supplyies for the metropolitan Boston area.[11] The state also has more than 250 megawatts of hydropower capacity, which provides nearly 2 percent of the state's total energy use.[12] Although Massachusetts can be considered relatively water rich when compared with many other states, the state has a history of water availability issues. As a result of water quality issues and diminishing groundwater resources, the state regulates water transfers between river basins in the state and requires users that withdraw more than 100,000 gallons per day to obtain a permit from the Massachusetts Department of Environmental Protection (MassDEP).[13]

The coast plays a vital role in the Massachusetts economy. The counties along the state's 192-mile coastline are home to 75 percent of Massachusetts's population and produce more than 85 percent of the state's $350 billion GDP.[14,15] Of the industries that rely directly on the ocean, coastal tourism, commercial seafood, and marine-related construction and infrastructure are the largest.[16] In 2009 the commercial seafood industry had an overall economic impact in excess of $2.6 billion, with the highest revenue coming from sea scallops, American lobsters, and cod and haddock.[17]

Climate Change Impacts on Water Resources

Since 1970 the mean annual temperature in Massachusetts has risen by approximately 1.6°F, with greater winter temperature increases likely due to decreasing snow cover and subsequent increases in solar energy retention.[18] Over the 20th century as a whole, precipitation across the northeastern U.S. generally increased, although with significant interannual variability.[19] As a result of climate change, spring is now arriving earlier, summer temperatures are higher, and winters are warmer with less snow.[20] Over the next several decades, temperatures are projected to increase 2.5°F to 4°F in the winter and 1.5°F to 3.5°F in the summer.[21] Furthermore, by the end of the century, average annual temperatures are projected to rise 5.2°F to 9.5°F.[22] The northeastern U.S. also is expected to have a 20 to 30 percent increase in winter precipitation.[23] As a result of warmer temperatures, less winter precipitation is expected to fall as snow and more as rain, the number of snow-covered days is expected to decline, and the frequency of short-term droughts is projected to increase as a result of greater evapotranspiration combined with no change in summer precipitation.[24] Short-term droughts could exacerbate existing summer low-flow conditions that are common to some rivers, like the Ipswich in the northeastern part of the state, which, as a result of excessive municipal withdrawals and pumping of groundwater nearby, runs dry periodically.[25,26] These low-flow conditions place stress on aquatic ecosystems and on water users that depend on these rivers for supply. The frequency and intensity of extreme precipitation events is also expected to increase, which could have widespread implications for flooding risks and water quality due to greater stormwater runoff volume.[27,28] Many of the state's existing combined sewer systems already discharge untreated wastewater during large rainfall events.[29] Without structural improvements or the use of green infrastructure to reduce stormwater runoff volume, more intense rainfall events would lead to increases in combined sewer overflows.

Over the past century, relative sea level in the Boston area has risen approximately 11.8 inches.[30] This rate is greater than global sea level rise due to land subsidence. Communities along the coast are accustomed to occasional flooding events and erosion that occur as a result of nor'easters and hurricanes.[31] By 2100, relative sea levels are projected to rise 2 to 3.3 feet; these estimates, however, do not take into account the recently observed melting of land-based ice sheets or the potential for accelerated melting.[32] More recent studies that take these factors into consideration suggest that global sea level rise of 2.5 to 6.2 feet is possible by the end of the century.[33] Sea level rise, in conjunction with projected increases in the intensity of storms, would lead to more severe and frequent flooding events and greater damage to coastal structures.[34] In the Boston area alone, a sea level rise of slightly more than two feet by mid-century would place over $460 billion worth of assets at risk from a 100-year coastal flood.[35] Sea level rise and the accompanying erosion would also threaten coastal wetlands and estuaries, which provide critical habitat for wildlife.[36] Between 1970 and 2002, sea surface temperatures in Great Harbor in Falmouth increased at a rate of 0.07°F per year.[37] Warmer ocean temperatures, particularly south of Cape Cod, could limit the range of lobster and cod, which are both important to the state's commercial fishing industry.[38]

Greenhouse Gas Pollution Reduction

In 2008 Governor Deval Patrick signed the Global Warming Solutions Act, which required the state to achieve greenhouse gas emissions reduction goals of 10 to 25 percent below a 1990 baseline by 2020 and 80 percent below the baseline by 2050.[39] In December 2010, the Executive Office of Energy and Environmental Affairs (EEA) released a plan for achieving a reduction of 25 percent below 1990 levels by 2020.[40] **The state should commit to implementing strategies in the Clean Energy and Climate Plan for 2020 to reduce statewide pollution.** Massachusetts is also a member of the Regional Greenhouse Gas Initiative (RGGI), which is using a market-based regional cap-and-trade program to reduce carbon emissions from power plants.[41] The state has received more than $140 million from the first 13 RGGI auctions, which has resulted in the creation of nearly 3,800 jobs and almost $500 million in economic activity.[42]

State Adaptation Planning

The Global Warming Solutions Act also required the state to form a committee to develop strategies and recommendations for adapting to climate change. The Adaptation Advisory Committee was established in May 2009.[43] In September 2011 the committee released its report addressing adaptation in five areas: natural resources and habitat, key infrastructure, human health and welfare, local economy and government, and coastal zone and oceans. Strategies to enable aquatic and coastal ecosystems to adapt to climate change included land protection of headwaters, wetlands, and buffer areas through acquisition and conservation restrictions; development of streamflow criteria and regulations to encourage reestablishment of natural flow regimes; removal of in-stream barriers to reconnect habitats; restoration of floodplains and coastal wetlands; and expanded use of ecological and natural solutions to address sea level rise.[44]

To prepare infrastructure for climate change impacts, the committee recommended conducting mapping and surveys to identify and prioritize at-risk facilities; implementing no-regrets strategies such as water conservation and efficiency and improving stormwater management; exploring amendments to land use planning and zoning regulations and building permitting that account for climate impacts; and enhancing natural systems through wetlands restoration to provide flood protection.[45] Specifically with regard to water resources infrastructure, the committee recommended the use of low-impact development (LID) to maintain stormwater on-site and improve groundwater recharge and the expansion of water conservation and reuse measures.[46] In addition, the committee recommended that new construction and major renovation projects be required to include provisions to address climate impacts, such as the protection of basement and ground-floor levels against flooding, the use of green roofs to absorb precipitation and decrease cooling needs, and the use of green infrastructure to control surface water runoff.[47]

To reduce climate change risks to water quality and subsequent impacts on human health and welfare, the committee identified potential strategies that included continued monitoring of research studies on the impact of flooding on waterborne disease, public education regarding nonpoint source pollution, improved stormwater management to reduce runoff and flooding, relocation of pollutant sources away from floodplains, and reevaluation of standards for the design and maintenance of septic systems.[48] Regarding the local economy sector, the report included potential strategies such as assessing the vulnerability of fish species to climate change, exploring opportunities to coordinate water treatment and electricity generation through the use of reclaimed wastewater for cooling needs, and encouraging businesses to integrate climate change into risk management strategies.[49] The committee also recommended that governments enhance emergency response and preparedness processes, improve planning and land use by ensuring that state investments in infrastructure and development projects consider future climate risks, use regulations to ensure that new buildings are sited and built in a way that reduces climate change vulnerabilities, create flood storage whenever possible by providing incentives for the adoption of LID strategies, and consider floodplain expansion in land use planning as a means of directing development away from vulnerable areas.[50]

In regard to coastal zones and the ocean sector, in addition to a few strategies that are common with other sectors, the committee recommended that all new and redevelopment projects in coastal flood zones meant for human occupancy consider sea level rise over the project design life, that repetitive losses be reduced through the purchase of vulnerable properties or conservation restrictions, that the state consider the adoption of a statewide rolling easements policy for existing development, and that soft engineering approaches to manage risks to existing development be utilized.[51] Overall, this report contains a wide variety of potential adaptation strategies for Massachusetts to consider. **Massachusetts agencies should immediately work to identify and implement strategies from this report to reduce the state's vulnerability to climate change impacts. In particular, the state should prioritize the implementation of "no regrets" strategies, including water conservation and efficiency measures and green infrastructure, because of their numerous co-benefits, relative low cost, and flexibility in the face of changing hydrologic and climatic conditions.**

Some state agencies are already working to integrate climate change into decision-making processes. In early 2008 the Division of Fisheries and Wildlife (MassWildlife), The Nature Conservancy, and others worked together to improve climate criteria in the State Wildlife Action Plan.[52] MassWildlife and the Manoment Center for Conservation Sciences also developed a report outlining strategies for managing a variety of habitats in the face of changing climatic conditions, such as utilizing regulations to protect wetlands and their hydrology.[53] In addition to the adaptation plan by the Adaptation Advisory Committee, the state has some existing programs in place that will be beneficial in light of a changing climate. Due to the high population density and significant interannual variability in precipitation, Massachusetts historically has had a strong regulatory framework for water resources management. In the mid-1980s, the state adopted the Interbasin Transfer Act and the Water Management Act. The Interbasin

Transfer Act requires that all proposed water and wastewater transfers between the state's basins be submitted for approval. Prior to review by the Department of Conservation and Recreation, projects must meet other requirements including completion of the environmental review requirements of the Massachusetts Environmental Policy Act and implementation of all practicable water conservation measures.[54] The Water Management Act requires users that withdraw an average of 100,000 gallons per day (on an annual basis or in any three-month period) from surface or groundwater sources to apply for a permit.[55] As a condition of the permit, permittees in stressed basins are required to adhere to specific values for water use per capita and water loss as well as to implement landscape water use restrictions.[56] The state also released standards in 2006 to improve water conservation and efficiency. As part of these standards, water suppliers are required to conduct water audits annually, ensure 100 percent metering of all uses, and implement a comprehensive residential water conservation program.[57]

In 2007 the Coastal Hazards Commission, established to develop recommendations to improve the state's management of coastal hazards, released its final report containing 29 recommendations.[58] These included developing risk and vulnerability assessment maps for coastal communities, improving outreach on insurance coverage types to coastal homeowners, and updating building code requirements for coastal construction, among many others. Many of the report's recommendations fall under the jurisdiction of the Massachusetts Office of Coastal Zone Management (CZM), which is responsible for ensuring that development activities along the coast are balanced with the protection of coastal and marine resources. In order to prevent or minimize the threat to human and natural resources from flooding, erosion, storms, and sea level rise, CZM promotes the use of nonstructural methods of shoreline protection, limits or prohibits public expenditures in high-hazard areas, and prioritizes public expenditures for the acquisition and relocation of structures out of hazardous coastal areas.[59] Recently updated CZM policies state that rates of erosion and relative sea level rise should be taken into account during the review of proposed new, substantially reconstructed, or substantially improved building projects.[60] Moreover, CZM policies require proposed major energy projects in coastal areas to evaluate the feasibility of alternative locations.[61] CZM also has joined the StormSmart Coasts program to help coastal communities address impacts from storms, floods, and sea level rise.[62] The program suggests that communities mitigate flood and erosion risks through the use of zoning ordinances that prohibit new residential construction in hazardous areas or that require higher freeboard, implementation of nonstructural shoreline protection measures, and adoption of more stringent criteria for the siting of critical facilities.

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MICHIGAN

While Michigan's proximity to the Great Lakes seemingly provides the state with an abundant supply of water, climate change will have broad implications for the state's water resources. The impacts of warmer temperatures and changing precipitation patterns on water resources will exacerbate existing challenges and present new ones for Michigan and other Great Lakes states. Recognizing the threat that climate change poses, the state has established greenhouse gas pollution reduction goals and a strategy for reducing greenhouse gas pollution. In addition, many state agencies are beginning to explore ways to adapt to inevitable climate change impacts and are working to coordinate these projects through the Michigan Climate Coalition. **To ensure that the adaptation activities currently under way by state agencies and other organizations are unified, comprehensive, and well coordinated, the state should develop and implement an overarching state adaptation plan.**

Water Resources Background

Michigan, like other midwestern states, exhibits a continental climate characterized by extremes in temperature and precipitation. However, the so-called lake effect present throughout Michigan does moderate these extremes. The lake effect results from the ability of the vast quantities of water in the Great Lakes to regulate temperature and humidity in the region by being slow to warm and to cool. This creates a climate in Michigan that is unusual for the state's mid-latitude location and more similar to states farther south.[1] Michigan averages approximately 31 inches of precipitation a year, with 55 to 60 percent of rain falling during the growing season.[2] Precipitation in the summer comes mainly in the form of thunderstorms, which are numerous statewide.[3] Despite these storms, flooding is infrequent relative to other midwestern states and normally occurs during the spring snowmelt or during rapid winter warming episodes.[4] Additionally, the lake effect moderates the drought conditions seen in other midwestern and High Plains neighbors by creating relatively high levels of humidity and evenly timed precipitation.[5] Snowfall can reach as high as 180 inches a year in parts of the Upper Peninsula.[6]

Michigan has fairly abundant surface water that is replenished by precipitation.[7] The Great Lakes are the most prominent aspect of the state's water resources. Michigan borders on all of the Great Lakes except Lake Ontario. The state has more than 3,000 miles of shoreline along the Great Lakes, making Michigan the state with the longest freshwater coastline in the U.S.[8] The state relies significantly on the Lakes' continued health for industry, agriculture, public supply, tourism, and many other uses. In addition to the Great Lakes, there are 11,000 smaller lakes and more than 36,000 miles of streams scattered throughout the state.[9] Because of high humidity from the lake effect, evapotranspiration is low, which is another reason drought is uncommon in the state.[10] Industry and agriculture place fairly heavy demands on surface water and groundwater resources in Michigan. In addition to supplying water for a variety of uses and providing transportation opportunities, the state's water resources also support a wealth of wildlife. The Great Lakes are home to commercially valuable salmon, lake trout, whitefish, chubs, and perch, and the state's other lakes and rivers support populations of pike, bluegill, brown trout, bass, and walleye.[11]

The Great Lakes Compact

The Great Lakes contain six quadrillion gallons of water (about 18.4 billion acre-feet), more than one-fifth of the world's surface supply of freshwater and over 95 percent of the surface freshwater supply in the U.S.[12] Although the volume of the Great Lakes is vast, less than 1 percent of its waters are renewed annually through precipitation, runoff, and infiltration.[13] The Great Lakes Basin ranks third in terms of total freshwater use out of the 21 major watersheds in the U.S.[14] Lake levels are expected to decline over the next century in each of the Great Lakes, from 1 foot on Lake Superior to as much as 3 feet on Lakes Michigan and Huron.[15] Management and use of water in the eight Great Lakes states is governed by the Great Lakes–St. Lawrence River Basin Water Resources Agreement and Compact.[16] In ratifying the Compact, each state agreed to undertake a series of actions, including the establishment of thresholds governing new or increased withdrawals of water; implementation of a permitting process for new withdrawals; development of water conservation and efficiency programs, including the establishment of state-specific goals and objectives to guide individual states' programs; and improved data gathering and sharing across the basin. In addition, the Compact directs states to "[g]ive substantial consideration to climate change or other significant threats to Basin Waters and take into account the current state of scientific knowledge, or uncertainty,"[17] and to take appropriate measures, such as adaptive management, to address these threats.

The largest user of water in the state in terms of withdrawals is, as in many other states, the power generation sector. In 2004 this use accounted for more than 81 percent of the state's total withdrawals.[18] Water for public supply accounted for a little over 10 percent of withdrawals. This was followed by industry and agriculture, which withdrew approximately 6 percent and 3 percent, respectively. Approximately 89 percent of all water used in the state is withdrawn from Great Lakes sources; thermoelectric power plants are the largest users of this source, with 95 percent of their water coming from the Great Lakes.[19] In contrast, 64 percent of irrigation water comes from groundwater.[20] Agriculture is the state's second-largest industry, generating more than $71 billion annually for the state economy.[21] Common crops include tart cherries, cucumbers, squash, apples, beans, and carrots.[22] Michigan is also a leading state for floriculture products such as geraniums and petunias.[23]

Climate Change Impacts on Water Resources

Although Michigan's "State of the Environment 2008" report stated that there was no statistical evidence that the state's climate had changed significantly from 1949 to 2007, other reports suggest that it had changed.[24] The U.S. Global Change Research Program (USGCRP) reports that the region is warming considerably, with the largest increase detected during the winter months, which has extended the length of the frost-free or growing season.[25] Furthermore, the climate of Michigan is expected to be more like the climate of Indiana by mid-century, and by the end of the century its climate will be more like that of Arkansas or Missouri.[26] Temperatures are expected to increase by 6°F to 10°F in the winter and 7°F to 13°F in the summer by the end of the century.[27] Precipitation also is increasing across the region. The past three decades have been the wettest of the 20th century in the region.[28] Heavy downpours are also twice as frequent as they were a century ago.[29] High- and low-emission climate models project that precipitation levels for the region will be 10 to 20 percent greater than the historic average by the end of the century.[30] The seasonality of precipitation is likely to change as well, with increases in winter and spring but reductions of up to 50 percent possible during the summer.[31] The frequency of heavy rainstorms is projected to continue to increase, with a doubling of these events possible by the end of the century.[32]

However, the region is expected to be much more arid overall, as increases in precipitation and snowfall are unlikely to offset increased rates of evapotranspiration.[33] This could have implications for soil moisture, with levels expected to drop 30 percent in the summer by the end of this century.[34] Declining soil moisture would increase the need for irrigation; accordingly, irrigation water demands could increase. Additionally, increased evaporation also could negatively affect groundwater and surface water bodies by impacting recharge rates.[35] These impacts could cumulatively serve to increase pressure to withdraw greater amounts from the Great Lakes,[36] potentially violating the Great Lakes Compact. Increased rates of evapotranspiration also will impact wetlands, with less recharge contributing to reductions in total wetland area.[37] In contrast, increases in the frequency of extreme precipitation events are likely to lead to a decrease in water quality, as polluted runoff from agricultural and urban areas is deposited into receiving water bodies.[38] More heavy rainfall events and earlier spring thaws also could increase flooding risks and threaten property and infrastructure, especially in urban areas that are not able to manage the resulting stormwater runoff.[39]

The Great Lakes themselves are also at significant risk to climate change. Increased evaporation from lakes due to warmer temperatures suggests the continuing trend of less ice cover in the future.[40] Studies indicate that there has been a decrease in the maximum ice cover on the Great Lakes over the past 30 years, with the largest loss on Lake Erie, at 17.2 percent, and the smallest loss on Lake Huron, at 10 percent.[41] Increased evaporation could also have an effect on lake levels, which are expected to drop over the next century anywhere from 1 foot on Lake Superior to more than 3 feet on Lakes Michigan and Huron.[42] In addition, the date of freeze-up (the date on which a lake freezes) has been occurring 1.5 days later per decade, while the ice-out date (the date of ice cover loss in the spring) has been occurring 2 days earlier per decade.[43] In Michigan, this trend has been most prevalent in inland lakes.[44] Potential changes in lake levels and ice cover on lakes have enormous consequences for shipping and power generation in the region. The Great Lakes Carrier Association estimates that a 1-inch drop in lake levels means a 1000-foot ship traveling across the Great Lakes loses the ability to carry between 240 and 270 tons of cargo.[45, 46] In addition, a conservative estimate suggests that decreased water levels in the Great Lakes could decrease hydropower generation 15 percent by 2050.[47] Finally, less ice cover will also allow more wave action, which could lead to increased erosion of shoreline areas as well as corresponding decreases in water quality due to sediment loading.[48]

Fish species also will be impacted by warmer temperatures and hydrologic changes. Coldwater species, such as trout, whitefish, and walleye, are extremely sensitive to changes in water temperature.[49] Populations of coldwater fish species are expected to decline in southern portions of the state as lakes, rivers, and streams become too warm to support them.[50] Conversely, warmwater species like bass are expected to increase in northern lakes as those water temperatures become more favorable.[51] Because of warmer temperatures, lakes would also remain thermally-stratified longer in the summer, leading to the formation of more deep-water anoxic regions (dead zones), which would have an impact on aquatic organisms.[52] Dead zones in deeper waters have been seen every summer in Lake Erie for almost a decade.[53] Lower water levels due to warming will also increase the concentrations of certain bioaccumulants in water bodies, like mercury, which would also have negative implications for aquatic life.[54]

Greenhouse Gas Pollution Reduction

The Michigan Climate Action Council (MCAC) was established by then-governor Jennifer Granholm as part of Executive Order 2007-42.[55] MCAC's mandate was to inventory the state's greenhouse gas emissions as well as consider actions to reduce these emissions and actions to adapt to climate change in the future. MCAC was asked to conduct its work in two phases: a first phase containing policy recommendations on reducing greenhouse gas emissions, and a second phase assessing likely climate change impacts in the state and potential adaptive measures. The Michigan Climate Action Plan was published in March 2009 and contained a suite of recommendations on reducing the state's greenhouse gas emissions.[56] In addition, Governor Granholm issued an executive directive in July 2009 establishing a greenhouse gas emissions reduction goal for the state of 20 percent below 2005 levels by 2020 and an 80 percent reduction by 2050.[57] **Michigan should implement strategies identified in the state's climate action plan to reduce greenhouse gas pollution.**

State Adaptation Planning

No funds have been provided to the Michigan Department of Environmental Quality (MDEQ) to develop a state adaptation plan in accordance with the executive order and MCAC's recommendations in the climate action plan.[58] However, state agencies are involved in the Michigan Climate Coalition (MCC), which was founded in November 2010 to gather stakeholders from across Michigan to help tackle climate change impacts.[59] The MCC is sponsored by Michigan State University with in-kind support from MDEQ to facilitate climate adaptation in the state by tracking climate-related projects, translating technical reports into more user-accessible information, and identifying research gaps to further target.[60] The MCC includes members from the private, public, and nonprofit sectors in Michigan, including the Departments of Natural Resources, Environmental Quality, Agriculture, and Transportation; universities such as the University of Michigan and Michigan State University; and nonprofits like The Nature Conservancy.[61] The MCC is modeled after the Wisconsin Initiative on Climate Change Impacts (WICCI), which released a state adaptation plan in early 2011. In addition, the Michigan and Wisconsin Departments of Natural Resources have agreed to exchange information and collaborate on projects to reduce greenhouse gas emissions and adapt to climate change.[62]

The MCC provides an overview of the adaptation activities in Michigan, including projects under way in state agencies. MDEQ currently is working to ensure that the lakewide management plans for the Great Lakes address climate adaptation and is helping the International Joint Commission, a bi-national organization tasked with managing transboundary water issues between the U.S. and Canada, conduct a study on climate change impacts on the Great Lakes.[63] The Department of Natural Resources is developing a climate change adaptation framework for the state's wildlife action plan and is working with the University of Wisconsin to research potential lake level changes from climate change and implications for wildlife.[64,65] In addition, the Michigan Department of Community Health developed the Michigan Health and Adaptation Plan, a planning document to help integrate climate change adaptation into public health decision-making in the state.[66] This plan identified events likely to occur as a result of climate change in the coming decades, such as an increase in heat waves, declining air and water quality, and rising cases of infectious diseases.[67] The plan then identified response methods and strategies to address these impacts, such as better public education, specific training for public health workers, and identifying areas particularly at risk from climate change impacts.[68] While adaptation activities appear to be under way in many state agencies, **Michigan would be well served to develop an overarching adaptation strategy for the state to ensure that all sectors are being addressed and adaptation efforts are complementary and well coordinated.** As part of this strategy, **the state should prioritize the implementation of "no regrets" strategies, such as green infrastructure for stormwater management and water conservation and efficiency measures, which address existing water quality and supply issues and also build resilience to climate impacts.**

Michigan's universities also have been active in climate change adaptation efforts. Michigan State University has several research projects under way: the Pileus Project, an effort to provide climate information to tourism and agricultural stakeholders; the Michigan Natural Features Inventory, a climate change vulnerability assessment of non-game species and natural communities in coastal areas; a project to model how climate change might impact corn and soybean crops in 12 states in the Midwest; and a modeling project on land use and climate change impacts on the hydrologic cycle.[69,70,71] The Great Lakes Integrated Sciences and Assessments (GLISA), a collaboration between Michigan State and the University of Michigan supported by the National Oceanic and Atmospheric Administration, is also funding research projects on adaptation and water resources. For 2011, GLISA funded one-year studies on the impacts of climate variability and change on evaporation from the Great Lakes, the implications of climate change on the state tourism industry, climate change impacts on agriculture and water resources in the Maumee River watershed in southeastern Michigan, and development of a decision support tool for lake whitefish harvest management.[72] Michigan Sea Grant is currently studying how climate change will impact Michigan's lakeshore communities as well as how these communities can adapt to these impacts. For educators and nonprofits, Sea Grant has developed an online Climate Ready Great Lakes training program that includes training modules on climate change impacts, adaptation planning, and available adaptation resources.[73]

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MINNESOTA

Although Minnesota contains the greatest amount of freshwater resources of all 48 contiguous states, climate change is expected to present substantial challenges. While lack of water may not necessarily be an issue, water quality and flooding risks will be made worse by climate change. In addition, less winter ice cover on Lake Superior due to warmer temperatures could lead to increased erosion in shoreline areas. In recognition of the threat climate change poses, many state agencies are undertaking adaptation planning efforts. While Minnesota has formed an interagency team to coordinate the state's adaptation activities, the team has not yet developed an integrated and detailed plan to guide state adaptation planning. Recent political and economic changes also have placed much of the team's work on hold. **Minnesota should prioritize and focus on consolidating the existing fragmented adaptation approach into a single state-level planning effort that connects all relevant parties and agencies. This statewide initiative should develop specific, goal-driven actions for state agencies and local governments to implement.**

Water Resources Background

Minnesota's climate is heavily influenced by its geography. Because of its location, it is impacted by the confluence of many different weather system types. The state has warm, humid summers and cold, dry winters. This natural variability has a strong effect on precipitation and, consequently, on water resources within the state. Minnesota receives 99 percent of its water from rain or snow.[1] Annual average precipitation ranges from approximately 34 inches in the south to over 19 inches in the north. Most of this precipitation occurs between May and September.[2] Average annual snowfall ranges from more than 70 inches in the north to approximately 35 inches in the south and occurs mainly between November and March.[3,4]

Although Minnesota is known as the Land of 10,000 Lakes, it actually contains nearly 12,000 lakes, 63,000 miles of streams, 13.5 million acres of wetlands, and a substantial amount of groundwater.[5] As such, it has more freshwater than any of the other 48 contiguous states.[6] The state is home to the headwaters of three major continental river basins: the Red River of the North, the Mississippi River, and Lake Superior, which flows into the St. Lawrence River.[7] In total, eight major river basins and six major groundwater provinces cover the state.[8] Although Minnesota has sufficient quantities of water, it is not evenly distributed throughout the state or throughout the year.

While power generation is the largest withdrawer of water in Minnesota, the majority of the water used is returned to the environment. The mining sector is the largest consumptive user of water, accounting for approximately 26 percent of the state's total consumptive water use.[9] Public supply is the next-largest consumer of water, accounting for 22 percent of total consumptive use, followed by agriculture.[10] Of the approximately 7,000 active water permits in the state, nearly 73 percent are for irrigation and livestock watering, which together account for 19 percent of the state's total consumptive use.[11] Public water suppliers and irrigation users are the largest users of groundwater and are distributed fairly evenly across the state.[12] On the other hand, ethanol producers use a much smaller amount of water but are concentrated in only a few locations, making their regional impact more pronounced.

Minnesota's main aquifer, the Prairie du Chien–Jordan Aquifer, is predicted to experience drawdown of more than 5 feet in many areas and more than 40 feet in some places by 2030.[13] In addition, the population of the state is expected to grow 22 percent by 2035, increasing the demand for water.[14] But this is not the most pressing issue for the state's water resources. Both the recently released "Minnesota Water Sustainability Framework" and a poll of Minnesota residents identified water quality issues, specifically excess nutrient pollution, as the most pressing water issue for the state.[15]

The Great Lakes Compact

The Great Lakes contain six quadrillion gallons of water (about 18.4 billion acre-feet), more than one-fifth of the world's surface supply of freshwater and over 95 percent of the surface freshwater supply in the U.S.[16] Although the volume of the Great Lakes is vast, less than 1 percent of its waters are renewed annually through precipitation, runoff, and infiltration.[17] The Great Lakes Basin ranks third in terms of total freshwater use out of the 21 major watersheds in the U.S.[18] Lake levels are expected to decline over the next century in each of the Great Lakes, from 1 foot on Lake Superior to as much as 3 feet on Lakes Michigan and Huron.[19] Management and use of water in the eight Great Lakes states is governed by the Great Lakes–St. Lawrence River Basin Water Resources Agreement and Compact.[20] In ratifying the Compact, each state agreed to undertake a series of actions, including the establishment of thresholds governing new or increased withdrawals of water; implementation of a permitting process for new withdrawals; development of water conservation and efficiency programs, including the establishment of state-specific goals and objectives to guide individual states' programs; and improved data gathering and sharing across the basin. In addition, the Compact directs states to "[g]ive substantial consideration to climate change or other significant threats to Basin Waters and take into account the current state of scientific knowledge, or uncertainty,"[21] and to take appropriate measures, such as adaptive management, to address these threats.

Climate Change Impacts on Water Resources

Temperatures in Minnesota and across the Midwest have increased noticeably in recent decades. The state has experienced a warming of more than 1°F during the summer in the southern portions of the state and more than 2°F in the north, with nearly all of this temperature increase occurring in the past three decades.[22] The largest seasonal increase in temperature in Minnesota has been observed during the winter months, where the temperature has risen approximately 3°F in the past century, causing an increase in the number of days that are frost-free. The frost-free period is now a week longer than in the early part of the last century.[23] Minnesota's climate is trending toward even warmer temperatures. Climate change models for the region now project that upper Midwest average annual temperatures will increase by 5.8°F by 2069.[24]

The characteristics of precipitation statewide also have changed. Heavy precipitation events are now twice as frequent as they were a century ago. Furthermore, rain in summer and winter months has been above average for the past three decades, making this the wettest period in Minnesota in the past century.[25] Precipitation records for the fall and spring indicate that these seasons have become notably wetter over the past 100 years.[26] Variation in the timing and delivery of precipitation is also an issue. Climate change models project that precipitation for the region will be 6 to 8 percent higher by 2069.[27] However, this precipitation will likely come less frequently and in greater intensity, especially during the summer months. This could be a particular problem for stormwater management infrastructure. If it is unable to handle the accompanying runoff from these intense rainfall events, more overflow events and flooding could occur. Greater precipitation variability also could increase the length of dry periods.[28] More extreme precipitation events also could increase flash flooding risks, and warmer temperatures could lead to earlier spring snowmelt and more spring flooding events.[29]

Lake temperature is another important climate variable for many midwestern states as the Great Lakes influence the region's climate. Lake Superior has warmed as much as 4°F in the past 25 years. This is due to the warmer summers as well as reduced ice cover during the winter.[30] Less winter ice cover could also allow more wave action, leading to increased erosion of shoreline areas and corresponding decreases in water quality due to sediment loading.[31] A related indicator of climate change is the date of "ice-out" on lakes in the state. While the definition varies across the state, it can be the first day navigation is possible across a lake or the day when 90 percent of the ice is gone. Records are kept for each lake in the state, and data have shown that the ice-out date now comes as much as five days earlier than it did a century ago, which is consistent with the overall warming trend observed.[32]

Commercial fishing and sportfishing, which generate $4.7 billion annually, are also likely to be impacted by climate change.[33] The continued warming within the state will impact habitats, such as rivers and streams, that support trout and other coldwater fisheries. Many of these aquatic species are particularly sensitive to water temperature changes. Conversely, a warming climate could help to lengthen the growing season for some important species of commercial fish, such as walleye.[34] Yet their main source of food requires cooler temperatures. In short, the potentially cascading ecosystem effects of climate change on fisheries in Minnesota are not yet fully understood.

Nonpoint source pollution, which was identified as the most pressing water quality issue in the state by the recently released "Minnesota Water Sustainability Framework," is likely to be exacerbated by climate change. More-frequent large rainfall events could potentially lead to greater amounts of runoff from agricultural areas into receiving water bodies, degrading water quality through increases in the amount of fertilizers, pesticides, and other nutrient and chemical pollutants. Stormwater runoff is also a significant cause of beach closures.[35] Conversely, extended dry periods from climate change could serve to concentrate pollutants in lakes and streams as water levels decline.

Greenhouse Gas Pollution Reduction

In 2007 then-governor Tim Pawlenty signed into law the Next Generation Energy Act of 2007, which established a statewide greenhouse gas emissions reduction goal of 15 percent below 2005 levels by 2015, at least 30 percent by 2025, and at least 80 percent by 2050.[36] In 2008 the Minnesota Climate Change Advisory Group released a final report containing recommendations for reducing greenhouse gases in the state.[37] In addition, the Department of Commerce and the Pollution Control Agency are statutorily obligated to submit an annual report to the legislature outlining policies necessary to achieve the emissions reduction goals.[38] **To reduce pollution and the state's contribution to climate change, Minnesota should implement concrete and mandatory measures to reduce statewide greenhouse gas pollution.**

State Adaptation Planning

In July 2009, a state-level Interagency Climate Adaptation Team (ICAT) was created to explore the potential impacts of climate change on the state and to develop an adaptation plan. The team was composed of representatives from the Departments of Agriculture, Commerce, Health, Natural Resources, and Public Safety and Transportation, as well as the Pollution Control Agency. ICAT released its preliminary report in August 2010 as a first step toward creating an adaptation plan for the state. The report mainly provides an overview of the adaptation actions currently under way or planned by state agencies, as well as additional research needs and next steps for the team. In the report, water resources are generally addressed peripherally, depending on each agency's jurisdiction over water resources. While this was a good start for the state's adaptation efforts, the report lacks an overarching and cohesive strategy to guide state agencies, and **a more robust, specific, and goal-driven plan for adaptation in Minnesota needs to be developed.** Since the release of the report in 2010, cross-agency collaboration on adaptation issues through ICAT has slowed substantially as a result of political and economic changes. In the meantime, many state agencies, such as the Department of Natural Resources, are focusing their adaptation efforts internally.

The Minnesota Department of Natural Resources (DNR), a member of ICAT, established climate change mitigation and adaptation as one of eight agency strategic priorities in its 2009 Strategic Conservation Agenda.[39] DNR also has organized a staff-level climate change adaptation scoping discussion to begin to identify approaches and organizational needs for reviewing and developing adaptation strategies.[40] In addition, DNR is conducting vulnerability assessments to identify which aquatic species might be most vulnerable to the habitat changes caused by climate change; it is also implementing the federal National Fish and Wildlife Adaptation Strategy in the state.[41] Finally, DNR's Sustaining Lakes in a Changing Environment project is studying how climate change will affect the chemical and biological integrity of a core group of sentinel lakes, which are representative of the state's most common aquatic environments.[42]

The Minnesota Pollution Control Agency (PCA), also a member of ICAT, is undertaking watershed-based monitoring of specific climate stressors to help track changes at an appropriate resolution. PCA also is integrating chemical, biological, and physical monitoring to develop relationships between environmental factors such as climate change and aquatic life. Finally, PCA is pursuing low-impact development strategies to reduce stormwater runoff.[43] Although this work is not being done specifically within the context of climate change preparedness, it will serve to decrease the state's vulnerability to extreme precipitation events. In addition, the Minnesota Department of Health (MDH) is currently studying the effects of climate change on the state's water resources, their implications for public health within the state, and strategies for addressing negative health impacts. In 2010 the MDH released a draft five-year strategic plan for adapting to climate change.[44] These efforts are part of the MDH's broader efforts to address climate change and public health, which is funded by a 2010 grant from the Centers for Disease Control and Prevention.

Water resources planners also are beginning to consider climate change impacts. The Minnesota Water Sustainability Framework, released in January 2011, is a broad, high-level attempt to identify water resources management and planning issues within the state. The report was funded by the Clean Water, Land, and Legacy Amendment. This amendment to the state constitution, passed in 2008, raised the state sales tax for the next 25 years to fund the Clean Water Fund to protect and enhance the state's water resources. The state legislature commissioned the report from the University of Minnesota Water Resources Center with the intention of identifying actions necessary to achieve a sustainable water future for the state considering the strain that population growth is expected to place on the state's water resources.[45] Areas addressed in the framework included potable water, stormwater, water use, surface water and groundwater interactions, and infrastructure needs.[46] Furthermore, all of these issues were considered within the context of projected changes in climate. Some of the strategies identified in the framework that would be beneficial in the face of climate change include requiring conservation water pricing, planning for water reuse, and greater consideration of green infrastructure and low-impact development practices for stormwater management.[47] **Minnesota should move strongly toward the implementation of these "no regrets" strategies, which address existing water quantity and quality issues as well as build resilience to future temperature and precipitation changes associated with climate change.**

Last, the Minnesota Sea Grant, which is part of the national Sea Grant consortium funded by the National Oceanic and Atmospheric Administration, is currently studying how climate change will impact Minnesota's lakeshore communities and how these communities can adapt to these changes. In particular, Sea Grant is researching how coastal communities along Lake Superior can adapt, how shipping on the Great Lakes may be impacted, how recreation will be affected, and how Lake's Superior's fisheries will be impacted by climate change.[48] In a parallel effort to the ICAT preliminary report, the University of Minnesota Water Resources Center established the Climate Change Adaptation Working Group. This team is connecting Minnesota's scientific and academic communities in an effort to aid research, education, and communication around the theme of adaptation to climate change, particularly in the water sector.

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MISSISSIPPI

Mississippi is no stranger to water-related disasters. Since 1993, all of the state's 82 counties have suffered at least one flooding disaster declaration.[1] Hurricane Katrina caused an estimated $80 billion in damage in 2005, and in May 2011, historic flooding along the Mississippi River resulted in the inundation of about 600,000 acres of farmland in the Delta region.[2,3] In addition, at the same time as unprecedented levels of flooding were occurring along the Mississippi River, the state's Gulf Coast counties were facing an extreme drought.[4] As a result of climate change, the state is likely to face more extreme precipitation, drought conditions driven by higher temperatures, and rising sea levels. In the aftermath of Hurricane Katrina, the state and the U.S. Army Corps of Engineers have been working to protect the coast from future storms and coastal hazards; however, other regions of the state are not receiving nearly as much attention. **To ensure that all Mississippians are equally protected, the state should develop and implement a plan to reduce greenhouse gas pollution and to adapt to the potential impacts of climate change.**

Water Resources Background

Mississippi averages approximately 56 inches of precipitation annually, with local averages ranging from 50 inches near the northern border to 65 inches along the Gulf Coast.[5] The peak rainfall season varies geographically: Maximum precipitation during the winter is centered on the northern and western areas of the state, whereas during the summer, maximum precipitation occurs along the coast.[6] The fall is generally the driest season of the year.[7] The entire state drains directly into the Gulf of Mexico via the Tombigbee, Pascagoula, and Pearl rivers in the northeast and south, and into the Mississippi River through the Tellahatchie, Yalobusha, Yazoo, and Big Black rivers in the west.[8] While the state has substantial surface water resources, more than 90 percent of Mississippi's drinking water supply comes from groundwater resources.[9] The state has 14 major aquifer systems, with the Mississippi River alluvial aquifer in northwestern Mississippi the most heavily utilized.[10,11] The alluvial aquifer underlies portions of seven states and is the third-most used aquifer in the U.S.[12] In Mississippi the aquifer lies under the Mississippi River alluvial plain—an area, commonly known as the Delta, that covers 7,000 square miles in 19 counties.[13] This region is the agricultural center of Mississippi and produces 99 percent of the rice, 96 percent of the catfish, 79 percent of the soybeans, and 72 percent of the cotton grown in the state.[14] Approximately 98 percent of water withdrawn from the alluvial aquifer is used for agriculture—mainly for water-intensive catfish and rice production.[15] However, there is growing concern that the rate of water use from the aquifer may ultimately not be sustainable, as evidenced by declines in water levels.[16, 17] In 2005 irrigation was the largest use of freshwater withdrawals statewide at nearly 55 percent, followed by public and domestic supply at almost 15 percent, thermoelectric power generation at 12.5 percent, and aquaculture at about 10 percent.[18] In addition, groundwater made up almost 80 percent of total freshwater withdrawals statewide.[19]

Mississippi has nearly 360 miles of coastline spread over three counties: Hancock, Harrison, and Jackson.[20,21] The state's coastal wetlands provide flood control, water storage, and water quality benefits while also serving as habitat for shellfish, finfish, and other wildlife.[22] In 2007 more than $20 million in menhaden and $16 million in shrimp were caught along the Mississippi coast.[23] The Port of Gulfport is also commercially valuable with more than two million tons of cargo handled in 2009, making it the third-busiest container port in the Gulf of Mexico.[24] The coast is also a large tourism draw, especially for the casino gaming industry. In 2010 total gross gaming revenue in the coastal region reached almost $1.1 billion.[25] While the state's proximity to the Gulf of Mexico is economically beneficial, Mississippi is also highly vulnerable to tropical cyclones. Since 2000 the state has been struck by 12 tropical storms or hurricanes.[26] The most notable of these, Hurricane Katrina, brought storm surges of 24 to 28 feet and caused 238 deaths and massive destruction along the Mississippi coast.[27] As a result of the storm, 90 percent, 68 percent, and 64 percent of housing units in Hancock, Harrison, and Jackson counties, respectively, were destroyed.[28]

Climate Change Impacts on Water Resources

Since the late 1960s, average annual temperatures in Mississippi have increased about 1°F.[29] In addition, while total annual precipitation has changed only minimally, summers have become drier and winters slightly wetter.[30] Extreme rainfall events also have become more common.[31] These changes in precipitation patterns have resulted in observed increases in annual median and minimum flows in the Lower Mississippi Valley.[32] Over the course of the 21st century, winter temperature lows are projected to increase 3°F to 10°F and summer highs are projected to increase 3°F to 7°F.[33] Projections for precipitation are not as clear, with models suggesting that immediate coastal areas may be drier in the winter and spring.[34] Areas of northern Mississippi have divergent precipitation projections as a result of differing locations of storm tracks in various models.[35] More extreme rainfall events could overload sewage treatment systems and result in the discharge of untreated wastewater into waterways and coastal areas.[36] Declines in summer soil moisture along the Gulf Coast are likely as higher temperatures lead to greater evaporative losses from soil and vegetation, which would likely increase drought intensity.[37,38] In turn, drought events could lead to reductions in groundwater recharge,[39] which could have particularly severe impacts on the state due to the heavy reliance on groundwater. Simultaneously, higher temperatures could result in increased demand for irrigation to maintain current crop production levels, placing competing demands on freshwater resources.[40] As a result of higher evapotranspiration rates, historical summer low flows could be more extreme and negatively impact water quality through reduced dissolved oxygen, potentially increasing the occurrence of fish kills and harmful algal blooms.[41] Increased water temperatures also would impact aquatic ecosystems by changing the distribution of species.[42]

Over the past 100 years, sea levels along Mississippi's coast have risen as much as 8 inches.[43] As a result of rising sea levels and wave action, the erosion of coastal wetlands occurred at a rate of more than 40 inches per year between 1850 and 2001, resulting in average land loss of 7.8 acres per year in southwestern coastal Mississippi.[44] By the end of the 21st century, an increase of 2 feet or more in sea level and increases in hurricane intensity and resulting storm surge are likely across the region.[45] This sea level rise estimate is substantially lower than recent studies suggesting that global sea level rise of approximately 2.5 to 6.2 feet by the end of the century is possible.[46] Sea level rise will increase the rate of coastal erosion, and where wetlands are unable to migrate inland, they may face inundation.[47] Sea level rise also could lead to saline intrusion into coastal groundwater resources, and changes in streamflow patterns along with higher sea levels could impact the salinity of estuarine ecosystems, an important habitat for shellfish and fish species. [48] Coastal infrastructure, such as property, roads, bridges, and port facilities, also could be at risk to erosion and inundation from rising seas and higher storm surge from more intense tropical cyclones.[49,50]

Greenhouse Gas Pollution Reduction

Mississippi does not have any greenhouse gas reduction targets in place and has not developed a plan for reducing statewide greenhouse gas pollution. **Because climate change is expected to present a wide range of risks to Mississippi, the state should adopt greenhouse gas pollution reduction goals and implement concrete measures to reduce the state's contribution to climate change.**

State Adaptation Planning

Mississippi has not developed a state-level climate change adaptation plan. Many state agencies have not addressed climate change either, but there are some efforts under way by the Department of Marine Resources (DMR) and the Mississippi–Alabama Sea Grant Consortium (MASGC) to address climate change. In conjunction with the three other Gulf of Mexico Sea Grant programs (in Texas, Louisiana, and Florida), MASGC is funding a study to quantify the impact of sea level rise and hurricane intensification on hurricane-induced economic damage and population dynamics and is developing policy tools for addressing sea level rise in coastal communities.[51] In addition, a contractor for the DMR recently conducted an assessment of hazards to coastal areas in the state due to sea level rise.[52] This report also contained a discussion of the relative merits of armoring, retreat, and adaptation strategies.[53]

Some of the recommendations included establishment of a climate change commission or task force to consider and plan for the potential effects of sea level rise and other climate change impacts; improvements to statewide research and monitoring efforts; development of detailed vulnerability assessments; and development of sector-specific adaptation strategies.[54] To reduce the risk that climate change poses to coastal areas, **Mississippi should consider the recommendations in the sea level rise assessment report and develop and implement an adaptation action plan.**

The state has worked with the U.S. Army Corps of Engineers on the development of the $1.2 billion Mississippi Coastal Improvements Project (MsCIP), which aims to reduce hurricane and storm damage risks, saltwater intrusion, and shoreline erosion and to protect fish and wildlife through a multiple lines of defense approach. The MsCIP includes barrier islands restoration, shoreline damage reduction, wetlands restoration, and floodplain evacuation.[55] Perhaps most noteworthy, the project also proposes the acquisition and demolition of approximately 2,000 coastal tracts that are at highest risk of storm surge damage.[56] Other notable elements of the project include ecosystem restoration, modifications to existing levees, and construction of a low-level sand dune system in the Gulf Islands National Seashore.[57] In 2009 Congress appropriated $439 million in funds for the barrier islands restoration component and other restoration projects.[58] The other plan elements are on hold pending congressional authorization and funding appropriation.[59] In addition, while the plan was under development, 15 interim projects were authorized and funded in 2006.[60] These projects included the repair of marsh drainage outfalls, repair of seawalls, and dredging of drainage canals.[61]

Mississippi does have some planning frameworks in existence that can be utilized to address climate change impacts. In 2010 the Mississippi Emergency Management Agency (MEMA) updated the state's hazard mitigation plan. Local governments utilize information in the state hazard mitigation plan to inform the development of local and multi-jurisdictional hazard mitigation plans. Similarly, the state hazard mitigation plan incorporates information from local plans.[62] The 2010 update contained an assessment of potential risks from floods, hurricanes, wildfires, tornadoes, earthquakes, extreme winter weather events, droughts, and dam and levee failures; however, no mention of climate change and its impact on these hazards was included in the plan. **Because climate change is likely to increase the risks associated with these hazards, the state should incorporate climate change into future updates of the hazard mitigation plan.**

Mississippi's statewide water planning approach has historically focused on "bottom-up" planning with regard to water quality issues.[63] While most groundwater and surface water users are required to obtain a withdrawal permit, the state does not have a comprehensive plan for managing issues concerning water quantity.[64,65] **Given the state's heavy reliance on groundwater resources and the likelihood that climate change and burgeoning water demands will strain the state's water supplies, Mississippi should work to develop a statewide plan for managing water quantity. "No regrets" strategies, such as water conservation and green infrastructure, should play an integral role in water resources planning, as these measures alleviate existing water quantity and quality issues while also building the capacity to adapt to future climate impacts.**

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MISSOURI

Missouri's location at the confluence of the Missouri and Mississippi rivers provides the state with access to significant water resources. While largely beneficial, these resources also afford substantial risks, as was vividly displayed during the spring and summer flooding of 2011. As the result of heavy rains and the melting of winter snowpack, dams upstream of the state in Montana and the Dakotas were forced to release large amounts of water, which caused levees across the state to be breached.[1] Consequently, floodwaters inundated large swaths of farmland and damaged infrastructure and homes across Missouri. As temperatures increase and precipitation patterns shift due to climate change, the state is likely to be exposed to similar flooding risks in the winter and spring, and potential water availability issues during the summer. Recognizing the implications of climate change for the state, Missouri developed a plan in 2002 outlining actions to reduce greenhouse gas emissions but has failed to follow through on these recommendations. **The state should implement measures to reduce statewide greenhouse gas pollution, conduct an assessment of potential climate change impacts, and develop and implement a plan to prepare for these impacts.**

Water Resources Background

Annual precipitation increases diagonally across the state from the northwest to the southeast. Average annual precipitation in the northwest is 34 inches and exceeds 50 inches in the southeast.[2] The seasonality of precipitation also varies significantly by geography, with northwestern areas experiencing a more continental-type climate with strong seasonality in precipitation and southeastern areas tending have less pronounced seasonality due to greater influence from subtropical air masses.[3] Consequently, average June precipitation is more than five times greater than January precipitation in northern portions of the state.[4] Snowfall follows similar geographical gradients. The areas north of the Missouri River can experience up to 24 inches of snowfall a year, but this figure diminishes in the southernmost counties to as little as 8 inches a year.[5]

High-intensity precipitation is common in many parts of the state, with the town of Holt, Missouri, the world record holder, having received 12 inches of rain in a 42-minute period in 1947.[6] The likelihood of high-intensity rainfall events is greater in the southeast than in the northwest of the state.[7] Tributary flooding occurs several times a year, and flash flooding from summer thunderstorms is also fairly regular.[8] While flooding along the main branches of the Missouri and Mississippi rivers is generally uncommon, the state experienced severe flooding along the Missouri during the spring of 2011.[9] The Missouri River near the town of Rulo (on the Nebraska/Missouri border) experienced a record flood crest of 27.26 feet in the spring of 2011.[10] Prolonged drought events do not occur regularly in the state.

Water resources in the state are dominated by the Missouri River, which forms part of the state's western boundary. The Missouri flows across the state into the other main river, the Mississippi, which forms the state's entire eastern border. While the Mississippi River drains a smaller area of the state than the Missouri, its average discharge rate is more than 50 percent larger.[11] The state also has 17 major reservoirs containing more than 12 million acre-feet of water.[12] Missouri, like its midwestern neighbors, is a heavily agricultural state, with farmland accounting for more than 66 percent of the state's total land use in 2007.[13] Like Nebraska, Missouri's agricultural sector relies heavily on irrigation, and almost 98 percent of the state's agricultural irrigation usage is drawn from groundwater sources.[14] However, only approximately 20 percent of Missouri's total water withdrawals come from groundwater supplies.[15] Groundwater in the state is derived from a variety of aquifers, with most of the usable groundwater found south of the Missouri River in the Salem Plateau Groundwater Province, located in central and southeastern Missouri.[16] This formation includes parts of the Ozark and St. Francois aquifers.[17] Other aquifers in the state include the Mississippi River Valley Aquifer and parts of the extensive Cambrian-Ordovician Aquifer in northern Missouri.

Total water usage in Missouri in 2005 was approximately 3.2 trillion gallons (approximately 9.8 million acre-feet).[18] While thermoelectric power plant generation accounts for approximately 70 percent of the state's overall water withdrawal, this use is largely nonconsumptive.[19] The largest consumptive user of water is the agricultural sector, which uses approximately 16.5 percent of the state's total water withdrawal.[20] Some of the state's most common agricultural crops are corn, soybeans, rice, and cotton.[21] The next-largest user is domestic and public supply, at approximately 10 percent of total state withdrawals.[22]

Climate Change Impacts on Water Resources

Missouri already has experienced warming over the past century, with average annual temperatures increasing 0.4°F since 1895.[23] This warming has been most pronounced during spring and winter, with temperature increases of 1°F and 0.8°F, respectively, during these seasons.[24] Further, the state is projected to warm considerably more in the future. Compared with a 1961–1990 historical baseline, Missouri's average summer temperatures are projected to increase between 7°F and 15°F, depending on the emissions scenario, by the end of the century.[25] Precipitation has also changed considerably. Heavy downpours across the region are now twice as frequent as they were a century ago.[26] In Missouri, average annual precipitation has increased 2.6 inches, or approximately 10 to 20 percent (depending on the region), over the past century.[27,28] Summer precipitation, however, has decreased by 0.6 inch during this same period, making Missouri the only state in the Midwest to experience a decrease in summer precipitation.[29] This pattern appears typical of what can be expected in the future, with the seasonality of precipitation shifting to more infrequent and larger storms, less precipitation in the summer, and increased precipitation in the winter and spring. Projections indicate that while summer precipitation is likely to decline by at least 20 percent by the end of the century, spring and winter are expected to be as much as 30 percent wetter.[30,31] In addition, the frequency of heavy rainfall events is expected to increase by 50 to 200 percent by the end of the century.[32]

These projected changes in temperature and precipitation will have wide-ranging implications for Missouri. Reduced precipitation in the summer suggests the likelihood of more frequent short-term droughts as temperatures and evapotranspiration rates increase.[33] These conditions are likely to reduce water levels in rivers, streams, and wetlands, which in turn could decrease groundwater recharge, cause small streams to dry up, and reduce wetland areas.[34] Moreover, the state has 14 public ports and more than 200 private ports that generate in excess of $638 million in annual total economic output. Reduced water levels in major waterways, such as the Missouri and Mississippi rivers, could have grave economic impacts. One drought event, in 1988, resulted in the stranding of over 4,000 barges in the Mississippi.[35,36] In contrast, wetter winters and springs could lead to a substantial increase in flooding risks by the end of the century.[37] Furthermore, streamflows could increase up to 51 percent due to increased rain falling on near-saturated soils.[38] Increased flooding also could lead to deterioration in water quality. The city of St. Louis already discharges 13 billion gallons of untreated sewage into the Mississippi River and its tributaries every year as a result of sewer overflows.[39] Flooding events also can lead to the runoff of pollutants into waterbodies, particularly in urban centers or in agricultural areas that contain fertilizers, pesticides, and other chemicals. Finally, while St. Louis has a fairly robust levee system meant to protect the city from flooding, continued development in the floodplain, due in part to Missouri's weak floodplain laws, suggest there is a very real risk to property and infrastructure from increased flooding due to climate change.[40]

Shifts in the seasonality of rainfall would also have important implications for agriculture, an industry worth nearly $9.3 billion annually.[41] Reductions in precipitation during the important summer growing season would increase the agricultural sector's need for irrigation, which historically has relied almost exclusively on groundwater. The potential increase in agricultural withdrawals could have serious implications for aquifers in the state. In addition, while the growing season is expected to lengthen by up to six weeks, wetter springs could delay planting and increased temperatures could cause heat stress to crops—likely negating any production gains made possible by the longer growing season.[42, 43]

Warmer temperatures, in particular, would also impact aquatic species. In some areas of the Midwest, warmer water temperatures would reinforce the thermal stratification of lakes, leading to reduced oxygen availability in the bottom layers.[44] Populations of coldwater fish are also likely to decline as water temperatures become inhospitable and suitable habitats disappear, while the distribution of warmwater species is likely to expand as conditions become more favorable.[45] These environmental changes are also likely to favor invasive or nonnative species, which generally are better adapted to a wider range of conditions.[46]

Greenhouse Gas Pollution Reduction

Planning for climate change in Missouri began in 1989 with the Missouri Commission on Global Climate Change and Ozone Depletion. The commission's 1991 report concluded that climate change was occurring and was likely to challenge Missouri's ability to adapt. This report led the state to act on two fronts. In 1996 the Department of Natural Resources (DNR) completed an inventory of the state's greenhouse gas emissions. In 1999 DNR released a second report, which provided emissions projections up to 2015. These two projects led to a more detailed report in 2002, Action Options for Reducing Missouri Greenhouse Gas Emissions.[47] This report examined greenhouse gas reduction strategies in five sectors: agriculture and forestry, building energy use, transportation, energy generation, and solid waste. The steering committee for this report, composed of stakeholders from across the state, compiled a list of more than 40 "no regrets" strategies in a variety of sectors.[48] Missouri has not made any recent progress on efforts to reduce statewide greenhouse gas pollution. The Missouri Global Warming Solutions Act of 2008, which would have required the state to establish rules to reduce greenhouse gas emissions and monitor statewide emissions limits, would have been a first step at implementing some of these recommendations; however, it was never voted on by the General Assembly.[49] To reduce the state's contribution to climate change, **Missouri should adopt a greenhouse gas pollution reduction target and update its plan for reducing greenhouse gas pollution statewide.**

State Adaptation Planning

While Missouri has historically been active in planning to reduce greenhouse gas pollution, the state has yet to begin planning for climate change impacts. Like many of its neighbors, Missouri has no statewide or agency-level adaptation planning under way—in the water resources sector or any other sectors. In order to begin adaptation planning, it is necessary first to understand how climate change will specifically impact the state. **Missouri should undertake a state-level climate change impacts and vulnerability assessment as an initial step toward developing a comprehensive adaptation strategy for the state.** Some state agencies, such as the DNR, have made initial attempts at determining the impacts of climate change on water resources. In 2008 the U.S. Environmental Protection Agency (EPA) provided funding to the DNR to conduct a five-year project on how climate change is impacting Missouri's streams and waterways.[50] Similar investigations and assessments should be conducted by a broad range of state agencies. **After the state's vulnerabilities to climate change have been identified, Missouri should develop and implement adaptation strategies to reduce these vulnerabilities.**

Missouri also should integrate climate change considerations into existing planning frameworks, such as the state water plan. The current state water planning process consists of a three-phase approach. The first phase, completed in the 1990s, involved an assessment of the state's current water resource issues, including available water supplies, water use, water quality, and water laws.[51] The second phase, conducted between 1998 and 2002, took a regional approach to identifying problems and opportunities related to water use.[52] The last phase, initiated in 2004, was aimed at developing strategies to address critical regional needs identified during the second phase, but it was never completed due to budgetary issues and staffing reductions.[53] Considering the importance of water to the state and the challenges that climate change and population growth will present, **Missouri should make available the resources necessary to update these documents and complete a plan for ensuring that water resources are sustainably managed for the future. The state should particularly focus on low-cost and flexible "no regrets" solutions,** such as greater water conservation and improved water use efficiency, to utilize existing water supplies more efficiently. **It should also focus on green infrastructure,** which supports groundwater recharge, reduces water demand, and lessens stormwater runoff.

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MONTANA

Warmer temperatures and subsequent changes in streamflow could particularly threaten agriculture, tourism, and recreation in Montana. The state could suffer nearly $80 million in crop losses annually by 2050 as a result of climate change,[1] and the disappearance of glaciers in Glacier National Park and the reduction in suitable habitat for coldwater fisheries could impact the number of visitors—some 10 million annually—who come to the state and contribute billions to the state economy.[2] To date, Montana has not made much progress with regard to planning for water resources in general, let alone planning for likely climate change impacts such as increased drought and flooding. **The state should act now to identify the state's vulnerabilities to climate change and develop and implement an adaptation plan to protect its people, wildlife, and resources. In the interim, there are significant opportunities for Montana to implement "no regrets" strategies, such as greater water conservation and efficiency, which have immediate benefits and also build resilience to climate change impacts.**

Water Resources Background

The headwaters of three major river basins in North America—the Columbia, the Missouri/Mississippi, and the Saskatchewan—are located in Montana.[3] The state can be divided into two major sections, the Northern Rocky Mountain region in the western part of the state and the Great Plains in the east.[4] In Montana, the fourth-largest state in the U.S., precipitation varies considerably and is heavily influenced by topographic features. Peaks in the Rocky Mountains receive up to 100 inches annually, while some regions in eastern Montana receive as little as 6 inches a year.[5] Nearly half of annual average precipitation falls between May and July, and most snowfall occurs between November and March.[6]

The Kootenai, Clark Fork, and Flathead Rivers, which are part of the Columbia River Basin, drain the area west of the Continental Divide in the western half of the state. While the Columbia River Basin drains only about 17 percent of Montana, it accounts for nearly 60 percent of the state's total surface water supply.[7] The remainder of the state is drained by the Missouri River through the Gallatin, Madison, Jefferson, and Yellowstone Rivers, with the exception of a small area in the northwest that is drained by the St. Mary River, part of the Saskatchewan River Basin.[8] The greatest volume of annual streamflow occurs in the late spring and early summer with the melting of mountain snowpack and spring rainfall.[9] Most of the surface water in the state is stored in reservoirs, which were constructed for flood control, hydropower generation, recreation, and irrigation.[10] In Montana, groundwater resources are located mainly along major streams in aquifers composed of alluvial sediment, which are replenished by precipitation and streamflow.[11]

Farms and ranchland occupy nearly two-thirds of the state, with population centers scattered in the valleys of western Montana, in the Yellowstone River Valley, and along the Missouri River.[12] Agricultural irrigation uses more than 95 percent of total water withdrawal in Montana; only about 3 percent is for municipal and industrial uses.[13] Irrigation is mainly for alfalfa, which is used to feed livestock in the winter; other irrigated crops include wheat, barley, hay, oats, sugar beets, potatoes, corn, and cherries.[14] Nearly 98 percent of withdrawn freshwater comes from surface water supplies, with the remainder coming from groundwater resources.[15] In 2000, hydroelectric power plants generated nearly 16 gigawatts of electricity.[16]

Climate Change Impacts on Water Resources

Since the 1950s the average annual temperature in Montana has risen 3°F.[17] The rate of warming during the winter and spring has significantly exceeded the warming in the summer.[18] Precipitation patterns also have changed, with the Northern Rockies experiencing less winter snow and the southeastern plains receiving more spring and fall rain.[19] In addition, eastern Montana has experienced a 10 percent decrease in annual precipitation over the past 100 years.[20] Across the west, peak spring runoff occurred 10 to 30 days earlier in the 1948–2000 period than it did prior to that time.[21] However, the most notable impact of climate change has been the disappearance of alpine glaciers as a result of accelerated melting during the spring and summer season.[22] Of the 37 named glaciers in Glacier National Park, only 25 remain, with 11 of the 12 glaciers lost having disappeared since 1986.[23]

By the end of the 21st century, the average annual temperature of Montana is expected to increase by about 5°F relative to a 1990s baseline.[24] Projections for mean annual precipitation also generally show increases over the 21st century.[25] Warmer temperatures are expected to lead to less snowfall and more rainfall in the winter, increasing winter flooding risks. Previous rain-on-snow events have produced severe runoff, erosion, and damaging floods.[26] More intense precipitation events also could increase the frequency of flooding events.[27] By the 2070s, mean December-to-March runoff in Missouri River sub-basins in Montana are projected to increase by 30 percent; increases of only 3 to 10 percent are expected in mean April-to-July runoff.[28] Reduced snowpack volume and earlier snowmelt would shift the timing of streamflow, with higher flows in the winter and spring, and could potentially lower flows in the summer and fall in the absence of increases in precipitation.[29] Less snowpack and earlier runoff also reduce groundwater recharge, contribute to decreases in summer low flows, and, along with warmer temperatures, increase the risk of drought.[30] By reducing summer and fall streamflow, earlier spring snowmelt also has the potential to disrupt the state's reservoir systems, which are important for hydropower generation, fisheries protection, recreation, and irrigation.[31]

Higher temperatures from climate change could eliminate the remaining five glaciers in the Blackfoot-Jackson Basin in Glacier National Park before 2030.[32] Warmer temperatures also could increase evapotranspiration rates, leading to subsequent increases in irrigation demand. Furthermore, changes in hydrology resulting from climate change could have negative implications for water quality. Such changes concentrate pollutants during low flows and can cause heavy precipitation events that flush pollutants into surface waters.[33] Stream temperature increases that result from warmer air temperatures and reduced streamflow also could have severe impacts on coldwater fisheries.[34] Depending upon the amount of warming, 18 to 92 percent of thermally suitable habitat for bull trout could be eliminated.[35] In addition, suitable habitat for native cutthroat trout is projected to decline by 28 percent by the 2040s and 58 percent by the 2080s across the inland western U.S. due to warmer temperatures and negative interactions with other species.[36] Reductions in coldwater habitat also would have economic repercussions. In Montana, angling generates nearly $300 million a year.[37] Past drought and reduced snowpack events have reduced flows on Bighorn River and decreased brown trout populations from approximately 9,000 to 2,000 per mile.[38]

Greenhouse Gas Pollution Reduction

In 2005 Governor Brian Schweitzer directed the Montana Department of Environmental Quality to form a Climate Change Advisory Committee. The committee released its report in 2007 on options for reducing greenhouse gas emissions statewide.[39] However, broad-based legislation addressing climate change has yet to emerge.[40] In 2007 Governor Schweitzer also developed the 20x10 initiative to reduce energy use in state facilities 20 percent by 2010,[41] a goal that the state was able to achieve through the use of American Recovery and Reinvestment Act funding.[42] In November 2011 Montana formally withdrew from the Western Climate Initiative (WCI), an effort among western U.S. states and Canadian provinces to reduce regional greenhouse gas emissions.[43] Montana is expected to face significant impacts on water resources from climate change. To reduce the state's contribution to climate change, **Montana should implement measures to decrease statewide greenhouse gas pollution.**

State Adaptation Planning

Relative to other states in the western U.S., Montana has taken a somewhat unconventional approach to state water planning. Between 1987 and 2005, the Water Resources Division in the Department of Natural Resources and Conservation developed a two-part state water plan composed of 15 individual sections.[44] The agency based this strategy on an approach used by Kansas, in part due to its flexibility in allowing regular plan updates.[45] Within recent years, the state has moved away from a statewide water policy approach, instead focusing on individual river basins. This approach, however, is beneficial only if the state commits to developing plans for every major river basin in Montana. Thus far it has developed only one plan, for the Clark Fork River Basin, and this plan merely assesses water management in terms of existing demands and supplies.[46]

There is a clear need for more progressive and robust water planning in Montana. Many river basins in the state are "closed" or effectively have no new water appropriations available, leading to a growing reliance on groundwater resources.[47] Furthermore, permitting exemptions for small domestic wells have led to the rapid proliferation of groundwater wells in many areas, causing local water tables to drop.[48] Whether through a statewide or an individual basin approach, **the state should conduct a comprehensive evaluation of how climate change, population growth, and economic growth might impact such things as water supply, water quality, hydropower production, flooding risk, and aquatic species.** In the interim, there are significant opportunities for Montana to implement "no regrets" strategies that have immediate benefits and that also build resilience to climate change impacts. The availability of tax incentives and grants for water conservation and "gray" water systems are small steps in the right direction.[49] **Greater water conservation and efficiency measures in the agricultural and municipal sectors, as well as the use of green infrastructure for water quality and flood protection, are but a few of many actions the state can take now to prepare for a changing climate.**

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NEBRASKA

Nebraska is the largest user of irrigation water in the country, irrigating some 8.5 million acres from more than 90,000 active groundwater wells in 2007.[1] The vast majority of this water comes from the High Plains (Ogallala) Aquifer, which has been historically overutilized. While irrigation helped Nebraska place fifth among all states in terms of agricultural output in 2010, it also has led to declining water levels and impaired water quality.[2,3] These water resource issues will only be exacerbated by warmer temperatures and shifting precipitation patterns from climate change. The state has yet to prepare for these challenges through either greenhouse gas pollution reduction efforts or adaptation planning. Consequently, **Nebraska should develop comprehensive statewide plans for reducing greenhouse gas pollution and adapting to climate change impacts. Furthermore, many planning processes currently under way, such as the Republican River Water Sustainability Task Force and the state flood mitigation plan update, should be considering the impacts of climate change.**

Water Resources Background

Nebraska experiences a wide range in climate because of its mid-continental location. Annual precipitation, the majority of which occurs from April through September, ranges from 13 inches in the west-central panhandle to 36 inches in the southeast.[4] In addition, average annual snowfall varies from 21 inches in the south to 45 inches in the northwest.[5] Floods during summer months due to intense rainfall events and thunderstorms are common, but so are periods of semi-drought due to arid weather and lack of precipitation.[6] The state's vulnerability to severe flooding was evident during the spring and summer 2011. Flooding along the Missouri and Platte rivers caused by melting snowpack and heavy rains in upstream states forced evacuations, damaged infrastructure, and threatened nuclear power plants.[7]

Nebraska's water resources are dominated by two major sources: the Missouri River, which forms the state's eastern boundary and is the principal watershed in the state, and the High Plains (Ogallala) Aquifer, which lies under most of the state and reaches its maximum depth in Nebraska.[8] Agriculture plays a significant role in the state economically as well as in relation to water resources. Farms and ranches cover 93 percent of the state's total land area and contributed more than $15 billion to the state economy in 2009.[9] Nebraska is also the top irrigator in the U.S. according to the U.S. Department of Agriculture (USDA), irrigating more acreage than any other state in the country.[10] In 2007 nearly 70 percent of the state's agricultural output was irrigated, on land comprising almost 40 percent of cropland by acre.[11] Additionally, well over 90 percent of all irrigation is supplied by groundwater.[12] Irrigation is heaviest in the central Platte Valley, where well density averages about 16 wells per square mile.[13] Corn, soybeans, and wheat are among the top commodities in Nebraska, with more than 40 percent of the state's corn crop used for ethanol production, making the state the second-largest ethanol producer in the U.S.[14]

The Ogallala Aquifer is the main source of groundwater for irrigation and is a valuable resource for the central U.S. The aquifer stretches from South Dakota to Texas, irrigating more than 13 million acres of land and supplying water to more than 80 percent of the region's population.[15] Overreliance on the aquifer has led to an average decline in level of 13 feet since 1950, with some parts of Texas, Oklahoma, and Kansas experiencing drops of 100 to 250 feet.[16] Additionally, groundwater quality has deteriorated as the result of increases in nitrates due to runoff from irrigated land finding its way into the aquifer, principally through tile drainage systems, an agricultural practice used to remove excess water from the soil subsurface. Levels of nitrates in many areas exceed drinking water limits established by the Safe Water Drinking Act.[17] An excess of nitrates in drinking water is the leading cause of "blue baby" syndrome (methemoglobinemia), a condition in which the ability of blood to carry oxygen is diminished. The areas most impacted by nitrate issues are in the eastern parts of the state, in the Platte River Valley and the Eastern Sandhills region.[18]

Nebraska uses approximately 4.6 trillion gallons of water (about 14.1 million acre-feet) annually.[19] The vast majority of this withdrawal is used by the agricultural sector for irrigation, which accounted for approximately 67 percent of all water used in 2005.[20] The second-largest user is thermoelectric power generation at approximately 28 percent of total withdrawal.[21] Public and domestic supply make up approximately 3 percent of water withdrawn in Nebraska.[22] As discussed previously, Nebraska heavily relies on groundwater, with well over 60 percent of the state's water withdrawals coming from this source.[23]

Climate Change Impacts on Water Resources

Nebraska has experienced an increase in average temperature of 1.2°F from 1895 to 2009.[24] During this period, winters have warmed 1.8°F, making up the bulk of the state's overall increase, with spring close behind with a rise of 1.5°F.[25] A composite of climate models project that average temperatures could rise 4°F by 2050 and 8°F or higher by 2090 across the High Plains region.[26] Unlike temperature, annual precipitation in Nebraska has increased only marginally, climbing 3 percent over the past century; however, there have been observed seasonal shifts in precipitation with generally drier winters and wetter falls.[27] By the end of the century, northern areas of the Great Plains are expected to become wetter, but the most prominent changes will be in seasonal precipitation, with wetter conditions in the winter and spring and drier conditions in the summer and fall.[28] In particular, Nebraska is projected to have increases in spring precipitation of around 5 to 15 percent by the end of the century under a low-emissions scenario.[29] Additionally, the timing of this precipitation is likely to change, with rain events becoming less seasonal, more infrequent, and more intense. In general, an increase in extreme weather events, such as heavy precipitation and extreme cold, are more likely in Nebraska in the future, as they are in other High Plains states.[30] These events can increase flood risks in floodplain areas and can degrade water quality as runoff from both urban and agricultural areas carries pollutants into receiving water bodies. In addition, as demonstrated during the major flooding in 2011, when Omaha was forced to dump 6 million gallons a day of raw sewage into the Missouri River,[31] flood events can overwhelm wastewater treatment facilities and cause public health risks.

Given the importance of climate and water resources in agriculture, Nebraska could be particularly impacted by climate change. Increasing temperatures could lead to higher rates of evapotranspiration, which decrease soil moisture and increase irrigation needs. In Nebraska where agriculture is highly dependent on groundwater resources, growing irrigation demand is likely to further stress already overutilized water resources, such as the Ogallala Aquifer.[32] Higher temperatures also suggest an increased risk of drought, especially if precipitation remains unchanged or decreases during the fall and summer, which also would increase demand for irrigation water.[33] Heat and water stress from droughts can impact agricultural productivity. Furthermore, projected increases in precipitation during the winter and spring are unlikely to offset decreasing soil moisture due to rising temperatures and reduced water availability due to aquifer depletion.[34] These conditions will likely serve to increase conflict between agricultural and urban areas over limited water resources.[35]

Surface water resources, such as in the Greater Platte Basin, are also likely to be impacted by climate change as snowpack in the Rockies, important for summer streamflow, declines and snowmelt occurs earlier.[36] Climate change also could affect transboundary water issues. Nebraska is party to several interstate water compacts and agreements: the Big Blue River Compact with Kansas, the Republican River Compact with Kansas, the Upper Niobrara River Compact with Wyoming, and the South Platte River Compact with Colorado.[37] A comprehensive study of the compacts determined that climate change impacts in these areas will be, for the most part, severe, and that the agreements are mostly inadequate to address the water needs of the parties given the warming these states will likely experience.[38]

The native prairie pothole ecosystem that characterizes much of the Nebraska landscape is also at risk from the impacts of climate change. These shallow, ephemeral lakes create a distinct environment that helps support diverse plant and animal species, particularly native birds and migrating waterfowl.[39] These lakes are also the main source of recharge for the High Plains' vast aquifer systems.[40] Extensive cultivation and water withdrawal for irrigation have already begun to threaten these unique areas. Climate change is expected to impact these ecosystems by increasing water demands, particularly for irrigation, and by changing runoff and evaporation patterns.[41]

Greenhouse Gas Pollution Reduction

While neighboring states like Kansas have taken steps towards reducing statewide greenhouse gas pollution, Nebraska has yet to do so. The state has not adopted a greenhouse gas pollution reduction target nor a plan for reducing statewide greenhouse gas pollution. **The state should adopt a greenhouse gas pollution reduction target and develop and implement a pollution reduction strategy to reduce the state's contribution to climate change.**

State Adaptation Planning

Nebraska has yet to begin planning for climate change impacts on a broad scale. Statewide or agency-level adaptation planning currently under way is focused almost exclusively on wildlife. In the 2011 update to the state's wildlife action plan, the Nebraska Game and Parks Division evaluated the climate change vulnerability of Tier 1 species (i.e., those species in Nebraska that are globally or nationally at greatest risk of extinction). This included fish species such as blue sucker, lake sturgeon, and sicklefin chub.[42] In addition, the plan proposed reducing non-climate stressors and the restoration and maintenance of ecological processes, habitat, and landscape connectivity as potential adaptation strategies.[43] In light of the potential impacts of climate change on a variety of sectors in Nebraska, especially agriculture, **the state should conduct a vulnerability assessment and develop and implement a comprehensive adaptation plan to address these risks.**

Though not a state agency, the University of Nebraska–Lincoln's Water Center is one of the few places in the state that are examining climate change. The center sponsored a conference on climate change and water impacts and adaptation in October 2011.[44] The center also is funding water-related climate research. The university recently received a $4.1 million grant from the National Institute of Food and Agriculture to study the impact of climate change on animal agriculture.[45]

Nebraska state agencies do have planning processes and programs in place that could readily integrate climate change. The Climate Assessment and Response Committee (CARC) in the Nebraska Department of Agriculture (NDA) would be one logical venue for climate change adaptation planning to take place, given the committee's mandate to provide data collection and analysis of information about drought and other "severe climate occurrences" throughout the state.[46] The CARC is the key drought policy and response committee in Nebraska and was responsible for developing the state's most recent drought mitigation and response plan, in 2000.[47] In the 2011 annual report and plan of work prepared by the Department of Natural Resources (DNR), the Committee's work is explained as developing reports "as warranted by climatic conditions including, but not limited to, problems caused by the lack of moisture; problems caused by excess moisture or flooding conditions; and other related activity like hail, wind storms, tornadoes, and snow storms."[48] Considering the strong nexus between the current responsibilities of the committee and climate change, **the CARC should be leading Nebraska in planning for climate change impacts. The state also should be encouraging the widespread adoption of water conservation and efficiency measures, especially in the agricultural sector.** If effectively implemented, these strategies could serve to reduce the state's vulnerability to drought and climate change.

The DNR also houses the Republican River Basin Water Sustainability Task Force. This task force, created in 2010 by Legislative Bill 1057, is charged with defining water sustainability and creating a plan to manage the Republican River Basin in a sustainable manner for the purposes of avoiding water scarcity in the basin. Unfortunately, the task force's progress report, released in early 2011, does not consider the impacts of climate change.[49] Management of this basin is likely to be impacted in the future by changes in climate, with the area expected to be both warmer and drier, leading to a reduction in streamflow of 5 to 10 percent by mid-century.[50] While the state's efforts to sustainably manage this river are to be commended, failing to include climate change in this planning process is imprudent. **For the final report, the task force should examine the impacts of climate change on water resources in the basin and recommend relatively low-cost and adaptive strategies, such as improved water conservation and use efficiency, especially for the agricultural sector.** In addition, the Nebraska Emergency Management Agency has received a grant from the Federal Emergency Management Agency to update the state's flood mitigation plan.[51] **As part of this update, the state should consider green infrastructure strategies for stormwater management to reduce flooding risks and land use regulations that prevent or severely restrict development in floodplain areas.**

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NEVADA

As the driest state in the nation, Nevada should be doing much more to plan for the impacts of climate change on its already limited water resources. Climate change will only exacerbate existing stresses on water resources posed by an arid climate and rapid population growth. **Nevada should develop a strategy for reducing statewide greenhouse gas pollution and a comprehensive climate change adaptation plan that evaluates the state's vulnerability to climate change impacts and identifies adaptation strategies that will reduce these risks. The state also would benefit significantly from the statewide implementation of "no regrets" approaches like increased water use efficiency and green infrastructure, which not only provide immediate benefits but also build resilience to future climate change impacts.** Fortunately, these waters are not uncharted, as other states—as well as cities in Nevada—have been planning for climate change for many years.

Water Resources Background

With an average precipitation of just 9 inches per year, Nevada is the most arid state in the United States.[1] Precipitation exhibits a strong seasonal pattern, with most precipitation falling during the winter months; however, occasional severe thunderstorms during the summer do occur. Interannual variability is also significant. While surface water supplies are limited in the state, they provide 70 percent of total water supply used in Nevada.[2] The largest river systems include the Colorado, Walker, Carson, Truckee, and Humboldt. The Truckee River, which originates at Lake Tahoe in California, supplies the city of Reno. More than 70 percent of Nevada's population lives in southern part of the state, where the Colorado River provides 90 percent of total water supply.[3] Nevada's apportionment of the Colorado River is 300,000 acre-feet per year that is withdrawn from Lake Mead, with virtually all of this water allocated to the Southern Nevada Water Authority (SNWA).[4] However, because SNWA obtains return credits by discharging treated wastewater through the Las Vegas Wash back to Lake Mead, an amount exceeding the state's allocation is diverted each year.[5] The other major rivers in the state are mainly used for irrigation or wildlife purposes. Only 10 percent of total annual precipitation contributes to streamflow and groundwater recharge, with the remaining 90 percent lost to evaporation and transpiration.[6] Spring and summer snowmelt contributes the greatest amount to annual streamflow, but isolated summer storms also contribute significantly to streamflow in low-altitude basins. Groundwater provides roughly 30 percent of water supply and in some regions is the sole source of water. In many areas, groundwater is used to augment surface water supplies: Groundwater use increases when streamflows are reduced, and conversely, groundwater use decreases when surface water supplies are large.[7]

Climate Change Impacts on Water Resources

Over the past century, the Great Basin region, which covers 75 percent of Nevada, experienced a 0.6°F to 1.1°F increase in temperature.[8] Annual precipitation has increased 6 to 16 percent, snowpack has declined, and the timing of spring snowmelt–driven streamflow is about 10 to 15 days earlier than it was in the middle of the 20th century.[9] By 2100, the western U.S. is expected to warm 3.6°F to 9°F.[10] Projections for total annual precipitation are not as clear, as Nevada's precipitation is heavily influenced by El Niño events; however, the state in general is expected to experience wetter winters and drier summers.[11] According to the 2011 SECURE Water report by the Bureau of Reclamation, the Upper and Lower Colorado River Basins, which are a major source of water for southern Nevada, are expected to increase in temperature 5°F to 6°F by the end of the 21st century, with only minor changes in total annual precipitation.[12]

As a result of temperature increases, changes in total annual runoff and in the seasonality of runoff are expected.[13] In the absence of any changes in total precipitation, increased temperatures will lead to decreased annual runoff as a result of greater evapotranspiration. Increased temperatures are also likely to lead to more precipitation falling as rain in the winter, which will increase winter streamflow, and to cause earlier spring snowmelt. In addition, with more precipitation falling as rain as opposed to snow, snowpack accumulation during the winter will decrease, resulting in diminished snowmelt in the summer. These changes will serve to increase December-to-March runoff while decreasing April-to-July runoff.[14] In addition, earlier spring snowmelt and more precipitation as rain instead of snow will likely increase the risk of winter and spring flooding on the Truckee, Carson, and Walker rivers, leading to greater erosion.[15] Overall, models predict that by 2050, there will be an 8.5 percent decrease (from the 1990s) in annual streamflow of the Colorado River at Lees Ferry, Arizona, the dividing point between the Upper and Lower Colorado River Basins.[16] Decreases in streamflow statewide would have negative implications for hydropower production, water supply, water quality, fish, and recreation.[17] Greater dryness would lead to decreases in groundwater recharge, negatively impacting the state's groundwater resources.[18]

Decreased Colorado River flows and subsequent drops in the level of Lake Mead would have dire consequences for Nevada. At a level of 1,075 feet, reductions to Nevada's apportionment would begin to occur. An additional reduction would take place at 1,050 feet, which would be compounded by the fact that SNWA's first water intake pipe is located at this elevation. A decrease in Lake Mead below this level would lead to a 40 percent loss in SNWA's ability to withdraw water from the lake.[19] A decrease below 1,025 feet would result in an additional reduction of 20,000 acre-feet per year, leaving Nevada's apportionment at 250,000 acre-feet.[20] In early May 2011, the level of Lake Mead stood at 1,095 feet; in November 2010 it stood at less than 1,082 feet—the lowest level since 1937.[21]

Tourism is the largest economic sector in Nevada. In 2010 more than 50 million people visited Nevada, spending in excess of $45 billion.[22,23] Nearly 30 percent of Las Vegas–area visitors engage in golf activities, contributing more than $1 billion to the state's economy.[24] Water-related recreational activities in and around Lake Mead and Lake Mohave bring in about 8 million visitors annually, with tourism revenue of $1 billion a year from Lake Mead alone.[25] Due to the importance of tourism to the state economy, even small reductions in the number of visitors as a result of water shortages could have significant impacts upon the economy and employment. Moreover, a 2004 study commissioned by SNWA found that an interruption of growth in southern Nevada due to water limitations would result in economic losses of $148 billion and a nearly 11 percent decrease in population over 14 years.[26]

Greenhouse Gas Pollution Reduction

In 2008 the Nevada Climate Change Advisory Committee (NCCAC) released its final report on potential opportunities for the state to reduce its greenhouse gas pollution.[27] The committee recommended that a state climate action plan be developed to identify emission reduction targets and strategies. This recommendation has not resulted in any action. Given that Nevada is likely to experience significant impacts from climate change, **the state should take steps to reduce its contribution to the problem by adopting greenhouse gas pollution reduction targets and developing and implementing a more comprehensive plan for achieving these goals.**

State Adaptation Planning

In its 2008 report, the NCCAC very briefly mentioned the potential impacts of climate change on water availability in Nevada and recommended that the Office of the State Engineer (also known as the Nevada Division of Water Resources) review current Nevada water law to ensure that it contains the flexibility to accommodate climate change impacts. This recommendation has not resulted in any discernible action.

The Nevada State Water Plan, designed to guide the development, management, and use of the state's water resources, was completed in 1999. It updated Nevada's first water plan, which had been released some 25 years earlier. While the plan does note that climate plays a large role in the state's water resources, it does not consider potential climate change impacts upon water availability. To meet future increases in water demand as a result of population and economic growth, the plan suggests water conservation measures; use of alternative water sources (reclaimed water, graywater, water reuse); purchases, leases, or transfers from existing water users; and new groundwater appropriations.[28] In 2005, the water planning statutes requiring the development of a state water plan were repealed.[29] **Nevada should commit to updating its state water plan on a more frequent basis to incorporate the growing body of knowledge regarding the impact of climate change on water resources, as well as changes in water demand as a result of population and economic growth. The state also should**

identify any applicable adaptation strategies for implementation. Smaller localities and water suppliers often lack the technical and financial resources to conduct these analyses on their own and would greatly benefit from state-led planning efforts.

Water rights laws in Nevada are based on the principle of beneficial use, whereby users can lose water rights if they do not use them. This inherently discourages conservation.[30] While Nevada does have regulations requiring water suppliers to develop conservation plans, the compliance rate is less than 50 percent.[31] This suggests a lack of enforcement on the part of the state and a lack of technical capacity and/or concern on the part of water providers. Greater awareness on water conservation and efficiency can be accomplished through a statewide public education campaign, which the state currently does not have.[32] **Nevada should follow the lead of neighboring states such as California and Arizona and develop such programs to make water conservation a priority.**

Southern Nevada Water Authority

In contrast with the lack of climate change planning at the state level, the Southern Nevada Water Authority (SNWA) has conducted substantial planning for water supply challenges due to population growth and drought conditions related to climate change. The agency is a member of the Water Utility Climate Alliance (WUCA), a group of large water utilities focused on addressing climate change implications for water resources management. Formed by seven water and wastewater utilities in southern Nevada in 1991 to cooperatively manage water resources in the Las Vegas Valley, SNWA since its inception has placed a high priority on water conservation and has adopted aggressive conservation policies, such as prohibiting turf installation in new residential front yards, limiting days and times for landscape watering, and mandating water budgets for golf courses.[33] These measures in conjunction with incentive programs like the Water Smart Landscapes Rebate Program, which pays property owners to replace grass lawns with water-efficient landscaping, have helped to reduce consumptive use by 21 billion gallons a year from 2002 to 2008 in spite of a population increase of 400,000.[34] In preparation for declining water levels in Lake Mead, SNWA has begun construction of a third intake shaft. The nearly $800 million project, scheduled for completion in 2014, will establish an intake at an elevation of 860 feet, ensuring that SNWA maintains the capability to withdraw from Lake Mead as its level drops.[35,36] To diversify water supplies, SNWA has also banked water locally through aquifer recharge and in agreements with California and Arizona and is pursuing in-state groundwater rights acquisitions.[37]

However, there is at least one effort to incorporate climate change into state planning. One of the long-term goals of the Nevada Department of Wildlife (NDOW) is to develop a climate change adaptation amendment to the state's Wildlife Action Plan.[38] To help achieve this goal, NDOW released a draft revision of the Wildlife Action Plan in January 2012.[39] The draft revision included a climate change vulnerability assessment of wildlife species, which resulted in the addition of several species of conservation priority, including species of chub and trout, among many others.[40] Actions proposed to maintain healthy populations of aquatic species included the restoration and maintenance of aquatic habitats and the reconnection of fragmented stream habitats.[41] The National Science Foundation's Experimental Program for the Stimulation of Competitive Research also awarded a $15 million grant to the Nevada System of Higher Education in 2008 to fund climate change research. This grant has allowed the formation of an interdisciplinary program that supports research in areas such as climate modeling, ecological change, water resources, education and outreach, and policy and decision-making.[42]

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NEW HAMPSHIRE

Changes in temperature, precipitation, snowpack, streamflow, and sea level will have enormous consequences for the people and natural resources of New Hampshire. The state's annual $4.3 billion tourism industry (particularly the $650 million ski industry) and $2.3 billion forestry sector could be especially at risk from these climate change impacts.[1] Within recent years, the state has moved to assess the potential impacts of climate change through efforts such as the New Hampshire Climate Action Plan and New Hampshire Water Resources Primer. Most recently, on Earth Day in 2011, Governor John Lynch issued an executive order establishing the Water Sustainability Commission to develop a water sustainability plan for the state.[2] **This effort represents a significant opportunity for the state to build upon existing adaptation recommendations to develop a robust and comprehensive plan for managing New Hampshire's water resources in the face of climate change.**

Water Resources Background

Average annual precipitation across New Hampshire is between 35 and 45 inches, including mean annual snowfall of 65 to 75 inches.[3] The state has more than 1,000 lakes and ponds and nearly 17,000 miles of rivers and streams.[4] The five major drainage basins in New Hampshire are the Connecticut, Merrimack, Saco, Androscoggin, and Piscataqua rivers. Lake Massabesic in Manchester and Penacook Lake in Concord are used for drinking water supplies; however, most of the state's lakes are used for swimming, boating, and fishing—contributing more than $1 billion annually in revenue from recreation.[5] As in the rest of New England, surface watersand groundwaters in the state are interconnected due to the generally shallow nature of the region's aquifers. Groundwater generally discharges to surface water and replenishes rivers and streams during low-flow periods. This flow can be critical for the survival of coldwater species, such as trout, during dry periods due to the cold nature of groundwater.[6] The state's underground aquifers are recharged predominantly by precipitation; however, surface waters do replenish groundwater on occasion. Groundwater levels drop in the late spring and summer due to greater evapotranspiration and irrigation demands and generally recover from late fall through spring as a result of recharge from snowmelt and decreased withdrawals.[7] The depth of the water table in New Hampshire can vary but is typically 10 to 20 feet below the land surface.[8] Groundwater resources are found throughout the state and supply water to about 60 percent of New Hampshire's population.[9] Statewide, 60 percent of water withdrawals come from surface water supplies and 40 percent come from groundwater sources.[10] Public water suppliers are the largest users, followed by industrial users, self-supplied domestic users, aquaculture, mining, and irrigation.[11] Water also is used for hydropower generation—the Moore Reservoir Dam on the Connecticut River contains the largest conventional hydropower station in New England with a capacity of 192 megawatts.[12]

Floods and droughts are common in New Hampshire. Historically, many communities were located in floodplains due to their relative accessibility and ease to develop.[13] Heavy rainfall and warm temperatures in the spring can trigger rapid snowmelt and lead to flash flood events. In addition, rapid melting can lead to ice jams, where large chunks of ice create a damming effect on rivers and cause flooding in upstream areas.[14] New Hampshire is particularly susceptible to droughts due to the relative lack of surface water storage reservoirs—most of the state's reservoirs were developed primarily for recreation or flood control—and the shallow nature of groundwater resources.[15]

New Hampshire has only 18 miles of Atlantic coastline; however, the two major estuaries in the state, the Great Bay Estuary and Hampton–Seabrook Harbor, contain more than 220 miles of shoreline.[16] These coastal and estuarine areas are important wildlife habitats, popular tourist destinations, and the fastest-growing parts of the state.[17] In 2007, the two coastal counties, Rockingham and Strafford, contributed almost 30 percent of the state's nearly $60 billion GDP.[18] These two counties in conjunction with other counties in the coastal watershed generated more than 85 percent of the state's total GDP in 2007.[19] There is also an active commercial fishing industry in New Hampshire, with American lobster, Atlantic cod, and pollock accounting for 90 percent of the the state's commercial catch, which totals more than $17 million annually.[20]

Climate Change Impacts on Water Resources

Over the past 150 years, the town of Hanover, in central New Hampshire near the Vermont border, has experienced a 3°F increase in average annual temperature and a 4°F rise in average summer temperature.[21] Between 1948 and 2006 the state also saw an increase of more than 80 percent in the frequency of extreme precipitation events.[22] Across the northeastern U.S., there have been more days with temperatures exceeding 90°F, less winter precipitation falling as snow and more as rain, reduced snowpack, earlier breakup of ice on lakes and rivers, and earlier spring snowmelt leading to earlier peak stream flows.[23] Since 1850, the date of spring ice-out (the date when thawing occurs, whose definition can vary among different lakes) has arrived nine days earlier, and peak spring streamflow now occurs one to two weeks earlier.[24]

By 2050, winter temperatures across the Northeast are expected to be 4°F to 7°F higher than the historic average, and summer temperatures are expected to be anywhere from 2°F to 8°F higher, depending upon future emissions levels.[25] Furthermore, winter temperatures are projected to be 5°F to 12°F warmer and summer temperatures 3°F to 14°F warmer by the end of the 21st century.[26] Winter precipitation is also expected to increase over the next century, but no significant precipitation changes are expected in other seasons.[27] Extreme precipitation events are also projected to become both more frequent and more intense.[28]

These projected changes in temperature and precipitation will have numerous impacts upon New Hampshire. Temperature increases could result in a 30 to 50 percent reduction in the snow season by 2050.[29] More precipitation falling as rain in the winter in addition to more extreme and intense precipitation events would increase flooding risks and have subsequent impacts on water quality as wastewater and sewer systems are overwhelmed.[30] Earlier snowmelt and subsequent runoff due to warmer winter and early spring temperatures would also contribute to these greater flooding risks. On the other hand, shifts to earlier peak flows combined with increased evapotranspiration during the summer as a result of higher temperatures would lead to lower summer streamflows, which would coincide with greater irrigation demands and increased groundwater withdrawals. The frequency of drought conditions could also increase as temperatures rise. The changes would impact water availability for drinking and irrigation and industrial uses.[31] In addition, changes in streamflow and water temperature would have ramifications for aquatic species. A projected 50 percent loss in coldwater habitat for fish such as brook, brown, and rainbow trout, which are worth $150 million annually, could occur as water temperature tolerances are exceeded and extreme variations in streamflow impact food availability and reproduction.[32,33]

Between 1929 and 1980, relative sea levels in Portsmouth Harbor rose at a rate of 0.08 inch per year.[34] Under a high-emissions scenario, sea levels are projected to increase by 2 to 4.5 feet above 2005 levels by 2100.[35] To put this into perspective, a sea level rise of 2 feet would result in a future 10-year flood event inundating an area greater than what is currently at risk from a 100-year flood.[36] As a result, more private property and public infrastructure would be susceptible to damage from coastal flooding and erosion. Freshwater supplies could also be risk to rising sea levels and saline intrusion.[37] In addition, sea surface temperatures in the region have increased 1°F since 1900 and are projected to rise an additional 4°F to 8°F by the end of the century.[38] These warmer ocean temperatures could have impacts on the range of commercially important fish species and contribute to the spread of shellfish diseases, harmful algal blooms, and invasive species.[39]

Greenhouse Gas Pollution Reduction

In 2001 then-governor Jeanne Shaheen signed on to the Climate Change Action Plan developed by the New England governors and eastern Canadian premiers. This agreement set statewide greenhouse gas emissions goals of 1990 levels by 2010, 10 percent below 1990 levels by 2020, and 75 to 85 percent below 2001 levels in the long term. It also contributed to the development of the Regional Greenhouse Gas Initiative, a collaboration among nine states to reduce regional greenhouse gas emissions through a cap-and-trade program.[40] In 2009 the New Hampshire Climate Change Policy Task Force released its final report and made recommendations for the state to reduce greenhouse gas emissions and adapt to the impacts of climate change. The Task Force recommended a midterm reduction in greenhouse gas emissions of 20 percent below 1990 levels by 2025 and 80 percent below 1990 levels by 2050. It also outlined 10 overarching strategies to achieve these reductions. **New Hampshire should commit to reducing its contribution to climate change by implementing strategies necessary to meet these pollution reduction goals.**

State Adaptation Planning

With respect to climate change adaptation, the Climate Change Policy Task Force recommended that New Hampshire develop a climate change adaptation plan to support the efforts of public and private partners and state agencies to plan and prepare for future climate impacts. Adaptation actions related to water resources proposed in the Task Force report include the development and dissemination of climate information to policy and decision-makers, strengthening protection of the state's natural resources to improve resilience, enhancing the resilience of infrastructure to extreme events, and exploring economic opportunities that could result from climate change.[41] The Task Force suggested action items such as requiring climate change to be incorporated into building codes, adopting low-impact development techniques to make existing infrastructure more resilient to weather-related changes, and steering development from future flood-prone areas by prohibiting development in floodplains or by providing incentives to develop in non-vulnerable areas.[42]

As part of the state's effort to develop a comprehensive water resources plan, the New Hampshire Water Resources Primer was released in 2008 to inform policymakers about water resources in the state and the challenges associated with management of these resources. The impact of climate change on water quantity and quality, aquatic species, and coastal resources was identified as one of four major management challenges.[43] The primer also made recommendations to stakeholders on how to begin addressing these challenges. To prepare for climate change, these recommendations included developing a coastal adaptation plan, educating water system managers on potential impacts to water infrastructure, taking into account climate change impacts when making infrastructure funding decisions with the Drinking Water State Revolving Loan Fund, and upgrading stormwater infrastructure to manage anticipated increases in extreme precipitation events.[44] The report also recommended improving water use efficiency by reducing outdoor water use and expanding the use of low-impact development for stormwater management.[45] while not presented as a response to climate change explicitly, these strategies address current challenges as well as reduce the impact of future climate risks. **The state should integrate the strategies and actions outlined in the New Hampshire Climate Action Plan and Water Resources Primer into a framework that contains specific tasks and timelines for implementation by state agencies. New Hampshire also should work to integrate climate change and its potential impacts on water supply and demand into the recently announced water sustainability plan.**

Moreover, there are policies and strategies already in place that will enable the state to better manage and adapt to future climate change risks. All facilities that use more than 20,000 gallons of water per day are required to register and report monthly water usage on a quarterly basis to the New Hampshire Department of Environmental Services (DES).[46] Water conservation standards also were enacted in 2003 requiring public water systems that are developing new sources of water to install water meters for all connections, reduce losses from leaks, implement conservation-oriented rate structures, and develop conservation outreach and education initiatives.[47] Conservation rules also were adopted for agricultural and industrial users, requiring the implementation of best management practices for irrigation and industrial processes.[48] In 2007 local municipalities were granted the authority to implement lawn watering restrictions during a state or federally declared drought.[49] Major consecutive flood events also prompted the development of a comprehensive flood management commission in 2007. The commission released its final report on ways to mitigate future flood risks and damages in 2008; it recommended actions including prohibiting the construction of new critical facilities or state facilities in the 100- and 500-year floodplains, preserving floodplains to retain natural storage capacity, integrating floodplain management into existing regulatory programs, and encouraging municipalities to limit development in the 100-year floodplain.[50] **The implementation of policies like these would reduce the damages and costs associated with increases in extreme precipitation and flooding events.**

In recent years, the state has supported coastal adaptation efforts, including the development of an adaptation strategies report for the town of Seabrook.[51] This report recommended that basic planning, zoning, and permitting decisions utilize a minimum 50-year planning horizon with an assumed 1.5-foot rise in sea level and at least a 3- to 5-foot sea level rise over 100 years.[52] The report also recommended that the town consider adopting a zoning overlay that requires new development in areas expected to be affected by sea level rise over the next 50 to 100 years to be subject to more stringent standards for building freeboard height.[53] The state also has supported the efforts of the New Hampshire Coastal Adaptation Workgroup, a collaboration of 16 organizations that offer technical assistance to coastal communities on adapting to extreme weather events and sea level rise.[54] In addition, New Hampshire is working to develop tools to assist local communities in the assessment of local vulnerability to climate change.[55] The state is utilizing a grant from the U.S. Environmental Protection Agency's Climate Ready Estuaries program to model the potential economic impacts from coastal storms in three towns along the Hampton–Seabrook Estuary as the starting point for a larger community discussion on ways to minimize future losses.[56] Furthermore, the Great Bay National Estuarine Research Reserve, funded by the New Hampshire Fish and Game Department and the National Oceanographic and Atmospheric Administration, is completing an assessment of past and future climate in the Great Bay Watershed along with an analysis of potential changes in 100-year flooding events as a result of sea level rise.[57]

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NEW JERSEY

With its location on the Atlantic Ocean and the Delaware River, New Jersey has access to substantial water resources. This access has played a considerable role in the state's economic development; however, population growth over the past two decades has stressed the state's water resources.[1] Climate change is expected to exacerbate these stresses and pose new challenges. Like other states in the region, New Jersey is expected to become warmer and experience more frequent heavy precipitation events. Sea level rise also is projected to put the state's coastal areas at risk of flooding, erosion, and inundation. The state has developed greenhouse gas pollution reduction strategies and adopted reduction targets; however, the state is no longer an active participant in the Regional Greenhouse Gas Initiative (RGGI), an effort to reduce greenhouse gas emissions from power plants. While climate adaptation planning is already under way in a few state agencies and programs, it is not cohesive or well coordinated. **To ensure that the state is efficiently and effectively adapting to climate change, New Jersey should link existing adaptation planning efforts and develop a comprehensive state adaptation plan to guide state agencies.**

Water Resources Background

Although New Jersey is a relatively small state, there is substantial variation in its climate from north to south and from the coastal regions inland. The northern portions of the state are primarily part of the Appalachian uplands, with precipitation provided mainly by air masses moving east from the upper Midwest over the Great Lakes.[2] This region tends to have twice as many severe precipitation events as the more low-lying coastal areas.[3] Along the coastal portions of the state, the moderating effect of the Atlantic Ocean makes the region less prone to extremes. Central and southern portions of the state tend to be warmer and drier.[4]

Annual average precipitation ranges from approximately 51 inches in northern parts of the state to around 40 inches in southern and coastal regions.[5] Fall months tend to be the driest, and thunderstorms provide the most rainfall during the warm season;[6] however, coastal storms, or nor'easters, which are most frequent between October and April, can bring significant amounts of rain and/or snow to the state.[7] Snowfall follows the same geographic distribution as rain, with northern regions seeing more than 50 inches annually while central and southern regions may experience only 10 to 15 inches a year.[8]

In 2005 annual water withdrawals in New Jersey totaled approximately 2.7 trillion gallons (nearly 8.3 million acre-feet), though freshwater usage was roughly 26 percent of this total.[9] Like many other states, thermoelectric power plants are the largest withdrawer of water overall. In New Jersey, this usage accounted for approximately 83 percent of all water withdrawn in the state in 2005.[10] However, nearly 90 percent of New Jersey's cooling water for power plants came from saline sources rather than freshwater resources.[11] At nearly 54 percent of total freshwater withdrawal, water for domestic and public supply represents the largest user of freshwater in the state.[12] Other major withdrawers of freshwater include thermoelectric power plants at about 34 percent, irrigation at about 5 percent, and industrial users at 4.5 percent.[13] Groundwater withdrawals make up approximately 30 percent of the state's total freshwater withdrawals, and this withdrawal is almost entirely for public supply.[14,15]

New Jersey contains 127 miles of beaches and coastline along the Atlantic Ocean and more than 1,800 miles of tidal shoreline along Delaware Bay.[16,17] This area is extremely important for the economy of the state, generating $21 billion in tourism revenue, or 70 percent of the state's total tourism revenue.[18] In addition, the Port of New York and New Jersey is the largest port on the eastern coast of North America and the third-largest port in the U.S.[19] Commercial fishing brings in fish and shellfish worth more than $100 million annually; the state's top harvests are sea scallops, surf clams, ocean quahogs, and hard clams.[20] New Jersey is the country's most densely populated state, and 60 percent of its residents live in coastal counties.[21] The land and property value of the state's four coastal counties totals $106 billion.[22]

Climate Change Impacts on Water Resources

There has been a statistically significant rise of slightly more than 2°F in average statewide temperature over the past century.[23] More than 1.5°F of this warming has occurred since 1970.[24] Both winters and summers have warmed substantially, with winters seeing the most pronounced warming statewide.[25] As a result of these warmer temperatures, the date of ice-out on inland lakes in southern portions of the northeastern U.S., including New Jersey, is now occurring 16 days earlier than it was 150 years ago.[26] The date of highest spring streamflow now occurs earlier as well. Under a high-emissions scenario, the region is projected to warm 7°F to 12°F in the winter and 6°F to 14°F in the summer by the end of the century.[27] As a result of this warming, the winter season in southern parts of New Jersey may last only one to two weeks by the end of the century.[28] Precipitation records also indicate a statistically significant rise in average annual precipitation in New Jersey, with current annual totals approximately 4 inches greater than in 1890.[29] In recent decades, the frequency of extreme rainfall events has also increased measurably.[30] The northeastern U.S. is expected to see an annual precipitation increase of roughly 10 percent by the end of the century.[31] Additionally, winters are projected to have precipitation increases of 20 to 30 percent, with more precipitation falling as rain than snow due to warmer temperatures.[32] Summer precipitation is projected to change very little; however, due to higher evapotranspiration rates, minimum summer streamflows are expected to decrease 10 percent by the end of the century.[33] Even under a low-emissions scenario, heavy rainfall is expected to become more frequent and more intense.[34]

Increasing temperatures will have implications for evaporation, soil moisture, and droughts in New Jersey. Warmer winter temperatures will likely cause snowmelt to occur faster and earlier and advance peak runoff into early spring.[35] Declining summer streamflows have real consequences for water availability, particularly in summer when water is in highest demand. Declining streamflows also impact aquatic species by causing warmer water temperatures, reducing habitat, and changing water quality.[36] Warmer temperatures and reduced streamflow are also likely to increase the occurrence of short- and medium-term droughts.[37] Potential adverse effects from increased water use during drought events include increased pollutant concentrations, declines in reservoir levels, harm to aquatic life through increased eutrophication and sedimentation, and saltwater intrusion into coastal aquifers.[38] In addition, water demand will likely increase during droughts, particularly for irrigation, further reducing the state's surface water and groundwater supplies.[39] More frequent and intense precipitation events could have implications for water quality as well, as heavy rainfall flushes pollutants off urban surfaces and agricultural lands into receiving water bodies.[40] Increased precipitation and more numerous heavy rainfall events can also increase flooding risks and overwhelm water treatment infrastructure, which is generally not designed to handle increasingly heavy and intense storm events.

Because New Jersey is a coastal state, sea level rise is also a concern. Tide gauge data have shown that human contributions to climate change have caused sea level along the coast to rise approximately 0.08 inch (2 mm) per year, or half the total relative sea level rise of about 0.16 inch (4 mm) per year, since the early to middle 20th century.[41] Under a high-emissions scenario, sea levels are projected to rise 0.8 to 2 feet by the end of the century.[42] However, these projections do not take into consideration the recently observed melting of the world's major ice sheets. More recent studies that take into account these factors and the potential for accelerated melting suggest that global sea levels could rise 2.5 to 6.2 feet by the end of the century.[43] This is particularly troubling considering that sea level rise in the northeastern U.S. is expected to be greater than the global average.[44]

The effects of sea level rise will be magnified during storm events such as hurricanes and nor'easters and increase coastal flooding and erosion.[45] In fact, the largest economic effect of climate change on New Jersey is expected to come from the impacts of sea level rise on coastal infrastructure and development.[46] By the end of the century, an estimated 1 to 3 percent of the state's shoreline will be permanently inundated, and with projected sea level rise, 6.5 to 9 percent of New Jersey's total coastal area could be subject to flooding.[47] In addition, urban areas are second only to wetlands in terms of the land types that will be most affected by sea level rise in New Jersey.[48] Atlantic City in particular is projected to experience a 100-year flood every two to four years on average by mid-century due to sea level rise and increased coastal flooding.[49] Additionally, because the state is so densely populated and much of the populace is located close to the shore, there is a risk to important infrastructure such as water treatment and power plants.[50] A study conducted in 1990 by the U.S. Environmental Protection Agency on New Jersey's Long Beach Island calculated that for every 1 to 3 feet of sea level rise, the associated damages could run between $160 million and $790 million for the island's 18-mile coastline.[51] Adaptation measures analyzed included moving whole houses and building levees. Potential damage from a 4-foot sea level rise for the whole state is estimated at more than $10 billion.[52]

Sea level rise and climate change are also likely to have implications for the Delaware River Estuary, which has the largest freshwater tidal prism in the world at about 70 miles long.[53] Sea level rise in conjunction with reduced streamflow will cause salinity changes to the estuary as tidal volumes bring saltwater farther up the estuary. In addition, greater variability in streamflow is likely to cause more variability in estuarine salinity.[54] These changes, along with increased water temperatures, will impact estuarine species, especially bivalve shellfish. Minor and acute exposure to extreme temperatures could inhibit growth and reproduction, while sustained temperature increases could change species distribution.[55] In addition, the two diseases that cause high oyster mortality are more prevalent and virulent in high-salinity conditions.[56] The increasing pH of the oceans due to carbon dioxide uptake could also have impacts on the ability of marine organisms, especially juveniles, to develop and maintain protective shells.[57]

Greenhouse Gas Pollution Reduction

In 2007, then-governor Jon Corzine signed the New Jersey Global Warming Response Act.[58] This act called for reducing greenhouse gas emissions 20 percent below a 1990 baseline by 2020 and 80 percent below 2006 levels by 2050. The act also required the development of strategies to achieve these reductions and enrolled the state in the Regional Greenhouse Gas Initiative (RGGI). This program, which initially included 10 states in the Northeast and mid-Atlantic regions, uses a market-based cap-and-trade program to reduce carbon dioxide emissions from power plants.[59] RGGI sells allowances through public auctions and invests the money in clean energy technologies and energy efficiency programs. As of February 2011, this has led to an investment of more than $700 million in energy programs across the northeastern U.S.[60]

In 2009 a report from the New Jersey Department of Environmental Protection (DEP) containing strategies for reducing greenhouse gas emissions from all major sources to achieve New Jersey's 2020 and 2050 goals was released.[61] Unfortunately, efforts to repeal New Jersey's Global Warming Response Act are making their way through the state legislature.[62] In August 2011, Governor Chris Christie vetoed a bill from the state legislature that would have blocked his decision to withdraw from RGGI,[63] effectively ending the state's active participation in the regional pollution reduction program. To reduce the state's pollution and contribution to climate change, **New Jersey should commit to implementing concrete strategies to achieve the state's 2020 and 2050 greenhouse gas limits.**

State Adaptation Planning

Besides outlining greenhouse gas reduction strategies for the state, the 2009 DEP report also recommended that the state develop adaptation strategies to minimize the impact of climate change.[64] Specifically, the report called for comprehensive state-level adaptation policies to be developed by a diverse group of stakeholders from academia, the nonprofit sector, government, industry, and business.[65] To guide this process, the report identified possible adaptation actions in several key categories, such as public health, freshwater quality and supply, land use, energy, biodiversity, and finance.[66] In terms of water resources, several general adaptation actions were listed, including:

- expanded rainwater harvesting, storage, and conservation;
- water reuse;
- desalination;
- water supply planning;
- land preservation (wetlands);
- dam integrity and safety; and
- integration of state actions with saltwater intrusion monitoring by the New Jersey Geological Survey.

DEP recently formed an interdisciplinary working group to coordinate adaptation activities within the department and to lay the groundwork for an overarching state-level adaptation plan.[67] The agency also has formed a working group to examine water resource issues arising from climate change, which will likely be integrated into the interdisciplinary working group.[68,69] Other adaptation activities within DEP that are currently under way include a look at the economic consequences of inaction on 10 sectors in New Jersey, including water resources and fisheries.[70] In addition, DEP's Office of Coastal Management and Watershed Restoration is utilizing a coastal vulnerability index to identify lands that will be impacted by climate change and sea level rise.[71] This project also includes the use of a resiliency questionnaire to initiate a dialogue on these topics among land use planners, citizens, emergency managers, and municipal officials. As part of this initiative, the New Jersey Sea Grant, DEP, Monmouth University, and Stevens Institute of Technology piloted a demonstration project in three coastal communities: Cape May Point, Little Silver, and Oceanport.[72] A vulnerability map for future scenarios of storm surge and sea level rise that identified infrastructure, natural resources, and populations at risk was developed for each community. Additionally, the project team facilitated a discussion among local representatives on existing actions, disaster preparedness plans, and programs to address coastal hazards and future actions needed to build resilience.

In order to update the state's wildlife action plan, DEP is assessing the vulnerability of wildlife, including aquatic species, to climate change.[73] The DEP is also a cochair of the Sustainable Jersey Climate Change Adaptation Task Force, a certification program for municipalities in the state that want to green their infrastructure planning and become more sustainable.[74,75] The goal of the task force is to identify tools and guidance for communities that want to integrate climate preparedness into their planning decisions.[76] Such tools currently include a self-assessment for communities to identify their vulnerability to climate change as well as visual tools to help communities understand their climate risks.[77] In addition, the state's three municipal planning organizations, in conjunction with DEP, the Department of Transportation, and NJ Transit, are using grant funds to pilot the Federal Highway Administration's vulnerability and risk assessment model on transportation infrastructure along the coast and the Delaware River.[78] Aside from actions in direct response to climate change, DEP also is working to integrate climate change into existing planning documents such as the Statewide Water Supply Plan, which seeks to make recommendations to ensure that the state has sufficient water for a 50-year planning horizon.[79]

Other entities in the state also have made attempts to address climate change issues through their work. In 1992 the New Jersey State Legislature passed the New Jersey State Development and Redevelopment Plan. This plan outlines statewide land use policy that all cities and communities must adhere to when planning. The latest version of this plan includes provisions to increase sustainable land use practices. The New Jersey Office of Planning Advocacy works with communities to help implement this plan and "endorses" successful plans. The office has been working with local communities to adapt to climate change impacts through the development of land use ordinances that reduce vulnerability to flooding and tidal surges by reducing the amount of impervious surface, protecting wetlands, and restoring sand dunes.[80] In addition, the New Jersey Sea Grant College Program has developed a coastal hazard mitigation manual that discusses long-term erosion threats to the shoreline from sea level rise.[81] The manual contains a general discussion of potential mitigation measures to address long-term erosion risks, including beach nourishment, land use regulations, and the proper siting of structures.[82] While climate change adaptation planning appears to be under way in some state agencies like DEP, **New Jersey should develop an overarching state adaptation strategy to ensure that other state agencies (agriculture, public health, etc.) also are planning for climate change impacts and are doing so in a coordinated fashion.**

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NEW MEXICO

Water resources in New Mexico, as in much of the arid and rapidly growing western U.S., are in short supply. Irrigation for agriculture is by far the largest user of water in the state. However, increasing municipal and industrial demands as a result of population growth are likely to intensify conflicts over limited surface water and groundwater supplies that are under siege by climate change. Without action, the economic costs to the state are significant. A business-as-usual approach to climate change could cost New Mexico $18.4 billion annually, or $12,000 per household, by 2080 as a result of increases in energy costs, wildfire risks, and health-related costs.[1] A $300 million annual direct and indirect economic impact to New Mexico's agricultural industry also could occur as agricultural water resources are converted to support escalating urban demand.[2] Furthermore, a 2010 study by researchers at Sandia National Laboratories found that the state could suffer a loss of $26 billion in GDP and lose more than 200,000 jobs by 2050 as a result of reduced water availability caused by climate change.[3] **To reduce these costly impacts, the state should begin preparing now by developing a state adaptation plan that contains specific strategies and actions for implementation.**

Water Resources Background

As in much of the west, precipitation in New Mexico varies drastically across the state due to topographical differences. Precipitation ranges from just several inches a year in the northwest to more than 20 inches annually in higher-elevation areas of the state.[4] New Mexico receives moisture and precipitation from a variety of regions. In the springtime, humid air from the Gulf of Mexico delivers precipitation to the eastern part of the state. The summer is the wettest part of the year as humid, low-level winds from the south cause thunderstorms with locally heavy precipitation across the state. During the winter, most precipitation comes from eastward-moving frontal systems that originate over the Pacific Ocean. Winter snowpack at high elevations is an important source of water for New Mexico as melting snow fills reservoirs and replenishes groundwater supplies.[5] Of the precipitation that falls in the state, 97 percent is lost to evaporation or plant transpiration, leaving only 3 percent for surface water supplies.[6]

Major surface water sources in the state include the Rio Grande, Colorado, and Pecos river basins. According to the Upper Colorado River Basin Compact of 1948, New Mexico receives 11.25 percent of the water available to the Upper Division states, which also include Colorado, Utah, and Wyoming. Interstate compacts also govern New Mexico's allocations of the Rio Grande and Pecos river basins.[7] However, most of New Mexico's freshwater resources are located in underground aquifers. Aquifer recharge from precipitation generally occurs more slowly than groundwater is withdrawn, resulting in declining water levels.[8] In response to severe depletion of groundwater resources, municipalities in recent years have developed projects to increase the utilization of surface water resources. One example, the San Juan–Chama Project, was completed in 2008 to bring water from the San Juan River, part of the Colorado River Basin, to the Rio Grande for use primarily by the city of Albuquerque.[9]

Ninety percent of municipal water supply historically has come from groundwater resources.[10] Surface water, however, represents slightly more than half of total freshwater withdrawals statewide due to large surface withdrawals by agriculture.[11] Agriculture is the largest water use sector in New Mexico, responsible for more than 75 percent of total water withdrawals. Public water supply accounts for nearly 8 percent, followed by power generation, mining, and livestock with about 1.5 percent each.[12] In addition, continued population growth in the Rio Grande Corridor, which contains the cities of Albuquerque, Santa Fe, and Las Cruces, is expected to place additional pressure on the state's limited water resources.[13]

Climate Change Impacts on Water Resources

Since the 1960s, temperatures in New Mexico have increased 2°F in the cold season and 3°F in the warm season.[14] This rate of warming is significantly greater than observed global mean temperature changes over the 20th century.[15] Moreover, a shift to earlier spring snowmelt and streamflow since the middle of the 20th century has been observed in western North America.[16] By the end of the 21st century, models for a midrange emissions scenario predict a temperature increase of more than 5°F in the winter and about 8°F in the summer.[17] Changes in average annual precipitation are uncertain, but more extreme events, such as intense rainfall and droughts, are likely.[18]

Temperature increases would have several major impacts on snowpack, including the acceleration of snowmelt, shortening of the snow season, decreases in total snowfall, and earlier seasonal runoff.[19] Moreover, earlier snowmelt and more precipitation falling as rain would increase the risk of winter and spring flooding and summer water shortages if the capacity to store earlier runoff is limited.[20] Increases in temperature also would lead to greater evaporative losses from streams and lakes, increased evapotranspiration from soil and plants, and decreased runoff.[21] These effects cumulatively could contribute to greater frequency, intensity, and duration of drought events and reductions in groundwater recharge.[22]

Currently, the limited surface water supplies in New Mexico are almost completely allocated through water compacts and/or water rights agreements.[23] Therefore, any decreases in water availability could intensify existing water conflicts and competition. The predicted changes in climate during the 21st century would lead to reductions in New Mexico's rivers, which are supplied largely by melting snowpack.[24] A 2011 SECURE Water Act report by the U.S. Bureau of Reclamation (USBR) projects an 8.5 percent decrease, relative to the 1990s, in Colorado River flow at Lees Ferry, Arizona, the dividing point between the Upper and Lower Colorado River Basins, by 2050.[25] In addition, New Mexico's allocation of the Rio Grande is based on streamflow at the Otowi gauge, with any water shortages shared by New Mexico and Texas.[26] The USBR study projects a nearly 20 percent reduction in flow at Otowi relative to the 1990s, by 2070.[27] A reduction of this magnitude would have severe implications for the agricultural and municipal users that rely on the Rio Grande for water, as well as for the endangered silvery minnow. Decreases in streamflow also could have negative implications for aquatic species by increasing water temperatures and pollutant concentrations and favoring the spread of nonnative species.[28]

Greenhouse Gas Pollution Reduction

In 2005 then-governor Bill Richardson issued Executive Order 2005-033, which set statewide greenhouse gas emissions reduction targets of 2000 emission levels by 2012, 10 percent below 2000 levels by 2020, and 75 percent below 2000 emission levels by 2050. In late 2006 the New Mexico Climate Change Advisory Group released a report containing 69 policy options to meet the state's emissions targets.[29] In late 2010 the New Mexico Environmental Improvement Board (EIB) approved statewide cap-and-trade and greenhouse gas emissions reduction regulations.[30] However, the replacement of all members of the EIB by recently elected Governor Susana Martinez has put the future of the state's greenhouse gas regulations in doubt.[31] In February 2012 the EIB voted unanimously to repeal regulations related to the cap-and-trade program and greenhouse gas emissions reporting, and the board is likely to repeal a carbon cap that would have gone into effect in 2013 and required 3 percent annual reductions in carbon dioxide emissions.[32,33] In November 2011 New Mexico also withdrew from the Western Climate Initiative (WCI), a collaborative effort among western U.S. states and Canadian provinces to reduce regional greenhouse gas emissions.[34] To reduce the state's contribution to climate change, **New Mexico should seriously commit to implementing policies to reduce the state's greenhouse gas pollution.**

State Adaptation Planning

Executive Order 2005-033 also directed the Office of the State Engineer (OSE) to analyze the impact of climate change on the state's water supply and its ability to manage water resources.[35] In conjunction with the Interstate Stream Commission (ISC), OSE released a report in 2006.[36] It noted that a reactive approach to climate change can be ultimately more costly than a proactive approach that anticipates and plans for potential future conditions. To adapt water management to climate change, the report made several recommendations, including incorporating climate change projections into strategic planning, implementing highly adaptive management capacity at the watershed scale, using technology and infrastructure to develop new water supplies and new approaches to water storage, and managing demand through conservation and efficiency. It remains to be seen how the state will incorporate these recommendations. Moreover, the report noted that while the 2003 State Water Plan does not explicitly address climate change, it does identify many of the policies and strategies that will be necessary to manage water resources under a variety of conditions.

In the 2003 State Water Plan, the OSE and ISC identified water conservation and efficiency as important tools in maximizing the state's water supply.[37] The plan noted that although water conservation efforts in the state have historically focused on municipal and industrial users, significant opportunities exist for agricultural water conservation and efficiency. To encourage municipal and industrial water conservation, the OSC and ISC in 2003 released a guide of best management practices for water conservation that identifies such actions as setting landscape and irrigation restrictions and providing incentives for installation of appliances and fixtures that conserve water.[38] Additional strategies identified in the State Water Plan include expediting the water rights transfer process, developing water banks to ensure economic viability, improving government coordination, and integrating regional water plans into state planning.[39] As part of the State Water Plan update currently in progress, OSE and ISC will prioritize the impact of climate change on water availability and management.[40] **The plan should also acknowledge the benefits that "no regrets" strategies, such as water conservation and green infrastructure, provide in the face of changing hydrologic and climatic conditions.**

Recognizing that water planning at the regional level is vital, the New Mexico Legislature developed a regional water planning program to be administered by the ISC. All 16 of the water planning regions in the state have submitted a regional water plan that identifies current water supplies and demands and, in the case of water deficits, identifies strategic alternatives to address supply challenges.[41] The regional water plans will form the basis of the next state water plan update. Only four regional water plans include some discussion of climate change implications for water resources, with the plan for the Jemez y Sangre region (which encompasses Los Alamos County and parts of Santa Fe and Rio Arriba counties) containing the most comprehensive evaluation of climate change impacts. In the 2009 Phase II update, the regional planning council recommended that contingency planning for climate change focus on drought preparation, minimizing flood damage and water quality impacts from extreme precipitation events, evaluating agricultural vulnerability, and improving watershed health.[42] **The ISC should make it a priority to work with each regional water planning council to update its water plan to include climate change considerations. It can lead by example by including climate change in the State Water Plan update.**

In 2010 the Governor's Blue Ribbon Water Task Force, a citizen advisory group to the governor and state agencies on water issues, identified seven priority recommendations for New Mexico. These included conducting long-range, integrated planning on issues relating to water, land use, energy, and economic development; collaborating with Native American tribal groups and other stakeholders to proactively address problems; resolving water rights adjudication suits; replacing and rehabilitating aging water infrastructure; promoting widespread adoption of water conservation and water reuse; using healthy watersheds and ecosystems for flood control, water quality improvement, and groundwater recharge; and pursuing partnerships with the private and research sectors, such as using the climate change modeling capabilities of the Los Alamos and Sandia national laboratories to anticipate future stresses on natural resources.[43] While many of these priority recommendations do not specifically address climate change, they can help to build the state's resilience to climate change impacts.

Within recent years, drought planning has taken on renewed importance as drought conditions have persisted in the state. The New Mexico Drought Task Force conducted a summit on climate change and its implications for drought in the state in 2006. In 2003 the New Mexico Legislature passed legislation requiring water providers that supply at least 500 acre-feet of water per year to develop and submit a water conservation plan that includes drought management provisions in order to be eligible for financial assistance after 2005.[44] Unfortunately, since this provision is mandatory only for water providers seeking funding from the New Mexico Finance Authority, the state has little knowledge of how many conservation plans have been developed, not to mention the content or robustness of these plans.[45] To ensure that water conservation and drought management are fundamental components of water management statewide, **New Mexico should require all water providers to prepare and submit plans to OSE for review and approval. The state also should ensure that adequate resources exist at OSE to grant technical assistance to providers in the development of these plans.**

While some of the strategies and policies necessary to address water supply issues as a result of climate change have been established at the local, regional, and state levels, the state lacks a central planning resource. **New Mexico should develop a comprehensive climate change adaptation plan that not only integrates these ideas into a central planning document, but also addresses other potential water-related impacts, such as greater flooding risks, more extreme precipitation events, water quality degradation, and threats to aquatic species.** Although the state's wildlife action plan took a step in this direction by identifying climate change as a problem affecting habitats and species, it also noted that additional research is needed to determine the impact on species distribution and community and ecosystem-level dynamics.[46] **The state also would substantially benefit from implementing more robust water conservation policies across all sectors, in addition to adopting green infrastructure for stormwater management.** These "no regrets" strategies have immediate benefits, in addition to reducing the state's overall vulnerability to climate change impacts.

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NEW YORK

The effects of climate change can already be seen across New York in the form of warmer temperatures, more frequent extreme precipitation events, and higher sea levels. These trends are projected to intensify in the future, leading to reduced snow cover and increased risks of flooding, summertime droughts, and coastal inundation. Because the state has the second-highest coastal population in the U.S.,[1] sea level rise is expected to be particularly damaging. New York has responded proactively to these challenges by reducing greenhouse gas pollution and planning for climate change impacts. A wealth of adaptation strategies have been identified by the New York State Climate Action Council, the New York State Energy Research and Development Authority's ClimAID project, and the New York State Sea Level Rise Task Force. While these planning efforts are a vital step in ensuring that the state is prepared for climate change, adaptation ultimately hinges upon effective implementation, and it is not yet clear how state agencies will move forward on implementation. **New York should prioritize and support the implementation of adaptation strategies by state agencies across all sectors to minimize its vulnerability to climate change.**

Water Resources Background

New York can be divided into several different climate regions. In general, the state has fairly uniform precipitation throughout the year due to moisture from the Gulf of Mexico and the Atlantic Ocean, with no distinct dry or wet seasons.[2] In the principal highland regions of the Adirondack Mountains in the northeast and the Catskill Mountains in the south, temperatures are cooler overall than in the rest of the state.[3] As a result, the frost-free period in these areas may last only 100 to 120 days.[4] Additionally, the great bulk of precipitation in these areas comes from snowfall, which is abundant across the entire state.[5] In the Adirondacks, average annual snowfall exceeds 90 inches while annual average precipitation exceeds 50 inches. [6,7] In the important agricultural areas of the Hudson River Valley and the Great Lakes shore area, temperatures are warmer and the growing season can last up to 180 days due to the moderating effects of Lakes Erie and Ontario.[8] In these areas, precipitation is greatest in the spring and fall.[9] These areas also receive substantial lake-effect snowfall—in excess of 24 inches a month in some winters.[10]

The timing and availability of precipitation in the state generally ensure an adequate water supply for municipal, industrial, transportation, recreation, and other uses.[11] Rainfall is generally sufficient during the growing season, and severe droughts are rare. Lack of adequate precipitation may occur occasionally, which can be particularly problematic for water supplies and can increase moisture stress in crops.[12] Extreme weather events, such as floods and snowstorms, are relatively common throughout the state, but major floods have historically been infrequent.[13] The likelihood of flooding is greatest during the spring, when melting snowpack greatly increases streamflows over a short period of time. This kind of flood is less frequent in streams draining to the St. Lawrence River in upstate New York because cooler temperatures lead to a slower rate of snowmelt.[14] Areas in the Adirondacks are also particularly prone to flash floods in the summer from intense rainfall.[15] Severe thunderstorms and tornadoes are generally rare; the greatest storm hazard in the state is extreme snowfall during winter months.[16]

As a result of generally substantial precipitation, New York contains a wealth of water resources. The state adjoins two Great Lakes, Erie and Ontario, and Lake Champlain. It also contains several large lakes in the Finger Lakes region and Lake George, Lake Oneida, and Chautauqua Lake.[17] Major rivers include the St. Lawrence, Delaware, and Hudson Rivers. With these significant water resources and a large population, it is not surprising that New York's water use is relatively high when compared with that of other states. In 2005 New York used approximately 3.8 trillion gallons (nearly 11.5 million acre-feet) of freshwater.[18] The state also withdrew approximately 1.8 trillion gallons (about 5.5 million acre-feet) of saline water, which was almost entirely for thermoelectric generation.[19] Power generation was the largest withdrawer of water, representing nearly 80 percent of the state's total water withdrawals and almost 70 percent of total freshwater withdrawals in 2005.[20] The next-largest withdrawer of freshwater was public and domestic supply at nearly 26 percent, followed by the industrial sector at approximately 3 percent.[21] While agriculture occupies approximately 25 percent of the state's total land area and generated more than $5 billion in 2007, the vast majority of crops in the state do not require irrigation and rely mainly on precipitation.[22] Consequently, the state's agricultural water use is relatively low. Groundwater withdrawals made up a small fraction of overall supply, representing slightly more than 8 percent of total freshwater withdrawals.[23]

New York's most productive aquifers lie in unconsolidated sediments throughout the state; the Long Island Aquifers, which supply drinking water to more than 2.7 million people, are among the most productive in the entire U.S.[24] In recent years, growing concerns have arisen over the use of hydraulic fracturing techniques (hydrofracking) to extract natural gas from the Marcellus Shale, which underlies parts of the state. Hydrofracking involves the injection of millions of gallons of water, along with sand and chemicals, into underground rock formations to release natural gas deposits. This technique poses significant public health and environmental risks. The large quantities of water required can affect local water supplies, and the chemicals used can contaminate drinking water supplies either through spills, during the drilling and hydrofracking process itself, or afterwards if the flow-back and produced water, which also contains naturally occurring contaminants, is stored, handled, or disposed of improperly.[25]

Coastal areas play an important role in New York. The state has the third-longest coastline in the U.S., and 85 percent of the state's total population, or more than 15 million people, reside in coastal areas.[26] Long Island Sound, which is shared by New York and Connecticut and covers more than 1,300 square miles, contains a wealth of biodiversity and provides an estimated $8.9 billion annually to the local economy.[27] The Hudson River Estuary stretches from Albany to New York City, and nearly half the entire population of New York is located in the 15 counties that border it. The estuary serves as an important spawning and nursery ground for species like striped bass, American shad, and blue crab.[28] In 2010 total commercial marine fisheries landings were valued at more than $34 million, with the most valuable catch from longfin squid and golden tilefish.[29] Port commerce is also an economic driver in the state, with the Port of New York and New Jersey handling nearly 61 million tons of bulk cargo, providing almost 45,000 jobs in the state, and generating $7.5 billion in business activity in 2008.[30] In addition, New York has in excess of 700 miles of shoreline along the Great Lakes, and the Lake Erie, Lake Ontario, and St. Lawrence river basins drain more than 40 percent of the state's total area.[31]

The Great Lakes Compact

The Great Lakes contain six quadrillion gallons of water (about 18.4 billion acre-feet), more than one-fifth of the world's surface supply of freshwater and more than 95 percent of the surface freshwater supply in the U.S.[32] Although the volume of the Great Lakes is vast, less than 1 percent of its waters are renewed annually through precipitation, runoff, and infiltration.[33] The Great Lakes Basin ranks third in terms of total freshwater use out of the 21 major watersheds in the U.S.[34] Lake levels are expected to decline over the next century in each of the Great Lakes, from 1 foot on Lake Superior to as much as 3 feet on Lakes Michigan and Huron.[35] Management and use of water in the eight Great Lakes states is governed by the Great Lakes–St. Lawrence River Basin Water Resources Agreement and Compact.[36] In ratifying the Compact, each state agreed to undertake a series of actions, including the establishment of thresholds governing new or increased withdrawals of water; implementation of a permitting process for new withdrawals; development of water conservation and efficiency programs, including the establishment of state-specific goals and objectives to guide individual states' programs; and improved data gathering and sharing across the Basin. In addition, the Compact directs states to "[g]ive substantial consideration to climate change or other significant threats to Basin Waters and take into account the current state of scientific knowledge, or uncertainty,"[37] and to take appropriate measures, such as adaptive management, to address these threats.

Climate Change Impacts on Water Resources

Average annual temperatures in the northeastern U.S. have risen more than 1.5°F since the 1970s.[38] Winter temperatures have risen the most and are now approximately 4°F warmer than they were in 1970.[39] In New York State, annual average temperatures and average winter temperatures have increased approximately 2.4°F and 4.4°F, respectively, over the same period.[40] Average annual temperatures in New York are projected to increase between 4°F and 9°F by the 2080s, depending on the emissions scenario.[41] While there have been no observed changes in annual average precipitation for the state as a whole, heavy downpours have increased in recent decades.[42] Annual average precipitation is projected to increase by 5 percent by the 2020s, 10 percent by the 2050s, and up to 15 percent by the 2080s.[43] However, this increase in rainfall is not likely to be evenly distributed throughout the year; more precipitation is expected during the winter months and less precipitation is possible for late summer and early fall.[44] In addition, the amount of precipitation falling during heavy rainfall events is expected to increase.

Warmer temperatures and changing precipitation patterns will have impacts across New York. Because snow is such an important part of the state's economy for winter recreation, warmer temperatures could lead to more precipitation falling as rain instead of snow during the winter, leading to a drop in winter recreation revenue.[45] In addition, higher temperatures could cause snow to melt earlier in the spring. If a high-emissions scenario prevails, the Adirondacks region could see the length of the winter season cut in half by the end of the century.[46] New York has more ski areas than any other state in the U.S.; an annual average of four million visitors contribute $1 billion to the economy each year and support jobs for 10,000 people.[47] Rising temperatures coupled with minimal changes (or even decreases) in total summer precipitation are also likely to increase the frequency of short-term droughts and impact water availability.[48] In particular, water systems that have limited storage or do not have storage reservoirs are likely to be the most at risk.[49] Additionally, areas in New York that are high in agricultural output, such as the Great Lakes shore area, may require irrigation for crops in response to declining soil moisture levels.[50] Increases in temperatures are also expected to decrease dairy production in the Susquehanna River Valley, increase electricity demand for cooling (which increases water withdrawal for power generation), and change the distribution of important crops throughout the state.[51]

More numerous heavy precipitation events could have important implications for water quality, as more intense downpours lead to increased streamflows, which can lead to deposits of sediments and pollutants in waterways. Heavy rainfall events also can lead to combined sewer overflows in cities, such as New York City, when stormwater runoff exceeds the treatment capacity of combined sewer systems, resulting in the discharge of untreated sewage.[52] In addition, heavy rainfall events can contribute to widespread flooding and jeopardize vital transportation infrastructure like roads and rail lines.[53] Furthermore, warmer temperatures are likely to reduce winter ice cover and increase evaporation from the Great Lakes, which would increase shoreline erosion risks and lead to reduced water levels.[54] Reduced water levels could impact commercial sectors by limiting the amount of cargo that vessels can carry and municipal water supplies by affecting the amount of water available for withdrawal.[55] Warmer water temperatures and changes in water quality could also alter the distribution of aquatic species within the Great Lakes and favor the spread of nonnative or invasive species.[56]

Since 1900 sea level has risen approximately 1 foot along New York's coastline.[57] Models that do not consider rapid ice melt project that sea levels in New York could rise 1 to 5 inches by the 2020s, 5 to 12 inches by mid-century, and 8 to 23 inches by the 2080s.[58] If rapid ice melt of polar regions occurs, sea levels could rise between 4 and 10 inches, 17 to 29 inches, and 37 to 55 inches for these same time frames, respectively.[59] Moreover, these projections are still relatively conservative compared with recent studies indicating that global sea level rise on the order of 30 to 75 inches (2.5 to 6.2 feet) is possible by the end of the century.[60]

Rising sea levels will increase incidences of coastal flooding and intensify erosion risks. New York's coastal areas are extremely densely populated and contain the nation's most populous city, New York City. Coastal areas also contain large amounts of critical infrastructure such as energy, communication, and transportation facilities, which could be at risk to inundation and flooding from sea level rise.[61] The New York City area currently contains more than $320 billion in assets at risk from a 100-year coastal flood.[62] What is now considered a once-in-a-century coastal flood is predicted to occur twice as often by mid-century and 10 times as often—once per decade—by the end of the century.[63] Flood events of this magnitude would have severe ramifications for the 500,000-plus people in New York who currently live within the 100-year coastal floodplain.[64] In Long Beach, a city on a barrier island just south of Long Island, sea level rise in conjunction with a 100-year coastal flood could place $6.4 billion of property at risk by 2020 and $7.2 billion by 2080.[65] In the New York City area, a sea level rise of slightly more than 2 feet by 2050 would increase assets exposed to the 100-year coastal flood to nearly $1.9 trillion.[66] Higher sea levels also could increase the extent of coastal areas subject to storm surges during storms, causing saltwater intrusion into freshwater aquifers and estuaries, which would impact drinking water supplies.[67] In addition, rising seas could inundate coastal wetland habitats, which would impact fish and shellfish populations.[68] Warmer water temperatures could also have an effect on marine species in New York. By midcentury, the Long Island Sound lobster fishery could completely disappear due to rising water temperatures.[69]

Greenhouse Gas Pollution Reduction

In August 2009, then-governor David Paterson issued Executive Order No. 24, which established a statewide greenhouse gas emissions reduction goal of 80 percent below 1990 levels by 2050. It also established the New York State Climate Action Council to develop a climate action plan that contains both short- and long-term actions to reduce greenhouse gas emissions.[70] In November 2010, the council released an interim report containing reduction strategies for a variety of sectors including residential, industrial, commercial, transportation, and power supply and delivery.[71] The council was composed primarily of the heads of various state agencies, many of whom resigned at the end of Governor Paterson's administration. Since the inauguration of Governor Andrew Cuomo in January 2011, the council has not reconvened, nor has state agency staff been directed to complete a climate action plan.[72] Because climate change is expected to bring wide-ranging impacts to the state, **New York should reduce its contribution to climate change by prioritizing the completion and subsequent implementation of a final climate action plan.** Also, the state is part of the Regional Greenhouse Gas Initiative (RGGI), a cooperative effort among nine northeastern and mid-Atlantic states aimed at reducing carbon dioxide emissions from power plants. RGGI sells allowances through public auctions and invests the money in clean energy technologies and energy efficiency programs. From the 14 auctions held, New York has received nearly $345 million in proceeds to fund various energy-efficiency programs throughout the state.[73,74]

State Adaptation Planning

Early on New York realized the need to prepare for climate change impacts. In the state's comprehensive wildlife conservation strategy developed in 2005, climate change was identified as a threat to wildlife species and habitats.[75] A statewide climate change vulnerability assessment of natural resources and additional research to understand the implications of climate change for species of greatest concern were recommended in this strategy.

In addition to pollution reduction strategies, the Climate Action Council's 2010 interim report contained potential adaptation strategies for New York that built upon the ClimAID project sponsored by the New York State Energy Research and Development Authority (NYSERDA). ClimAID is a comprehensive project intended to provide state-level decision-makers with the best available climate science and detailed analysis of the state's vulnerabilities to climate change. The project also aims to enable the creation of adaptation strategies that are informed by both local and scientific knowledge. Cross-cutting adaptation themes identified by the adaptation working group (within the Climate Action Council) included the dissemination of relevant climate information to all decision-makers, development of capacity to monitor climate change indicators, establishment of a statewide framework for assessing and reporting adaptation progress, evaluation of emergency response networks in light of climate change, and the identification of groups that will be disproportionately impacted by climate change.[76] This report also included policy options for adaptation in eight specific sectors, including water resources and coastal zones.[77] Adaptation strategies for water resources and coastal areas identified by the adaptation working group are listed in Tables 1 and 2, respectively.

Table 1. Water resources adaptation policy options identified in the interim report of the Climate Action Council.[78]

1. Enact into law Governor's Program Bill 2010 #51—Water Withdrawal Regulation (S.8280-A/A.11436-B) to authorize implementation of a comprehensive statewide water withdrawal permitting program.
2. Build greater resilience to projected climate change impacts into drinking water and wastewater infrastructure systems. A. Prepare detailed inventories of critical water infrastructure and conduct climate vulnerability assessments. B. Update permit and design standards at the state and local level for drinking water and wastewater infrastructure to factor in projected climate impacts.
3. Adopt statewide and region-wide comprehensive sustainable water resources management strategies that consider climate change. A. Ensure that all water-related permit programs and policies minimize alterations and disruptions to the natural hydrologic cycle to the extent possible. B. Create mechanisms to foster development and state approval of regional intermunicipal watershed management plans that address expected climate change impacts.
4. Allow "room for rivers." Acknowledge the dynamic nature of rivers in the landscape and strive to reduce risk to critical infrastructure and human development as the risk of flooding increases with climate change. A. Coordinate with key federal and local stakeholders such as the Federal Emergency Management Agency (FEMA), U.S. Department of Agriculture, and county soil and water conservation districts to identify and map areas of greatest current risk from riverine flooding and erosion due to movement of rivers across the landscape. B. Work with federal agencies to reduce new development in areas at high risk of riverine flooding, and undertake long-term managed relocation or elevation of existing structures in these areas. Restructure disaster recovery policies to ensure that redevelopment efforts strive to reduce long-term risk.
5. Incorporate water-related climate projections into state and local emergency management planning.

Table 2. Coastal zone adaptation policy options in the Climate Action Council's interim report.[79]

1. Endorse a coordinated set of projections for sea level rise and associated changes in flood recurrence intervals in all coastal areas, including the Hudson River estuary, for use by state and local agencies and authorities for planning and decision-making purposes.
2. Integrate sea level rise and flood recurrence interval projections into all relevant agency programs and decisions.
3. Identify and map areas of greatest current risk from coastal storms and sea level rise to support risk reduction actions in those areas.
4. Reduce vulnerabilities in coastal areas at risk from sea level rise and storms (coastal risk management zone) and support increased reliance on nonstructural measures and natural protective features to reduce impacts from coastal hazards. A. Develop Coastal Resilience Plans. B. Assist in funding measures to reduce risk.
5. Develop a long-term interagency mechanism to regularly evaluate climate change science; set research priorities to foster adaptation; coordinate actions; and assess progress.

The adaptation working group also identified adaptation options for the agriculture, ecosystems, energy, public health, transportation, and telecommunications sectors. The most common adaptation options for these sectors were to identify assets vulnerable to climate change and to integrate state-approved climate change projections into all relevant decision-making.

In November 2011, NYSERDA's Integrated Assessment for Effective Climate Change Adaptation Strategies in New York State (also known as ClimAID) project published a final technical report that analyzed key impacts and adaptation strategies for a variety of sectors, including water resources. Adaptation actions included relocating important water treatment infrastructure out of flood areas; upgrading combined sewer systems to decrease the chance of overflows; conserving water through leak detection programs; encouraging streamflow regulations, such as mandatory minimum flows that take into account the natural cycles of the streams; developing more comprehensive drought management programs; and establishing basin and watershed level commissions to take leadership on these issues.[80] In particular, given some uncertainty regarding specific climate change impacts on water quality, the report highlighted the use of green infrastructure practices as an effective water quality management strategy that generally has broad community support because of the additional benefits, such as air quality and aesthetic improvements; urban heat island mitigation; energy efficiency; and carbon sequestration, that these measures provide.[81] The report also recommended water conservation strategies that improve water availability without the development of new infrastructure.[82] Conservation measures include the installation of low-flow fixtures and appliances, restrictions on car washing and lawn irrigation, the use of rain barrels for gardens, and the implementation of smart metering (i.e., meters that charge different rates when overall water system demand is higher).[83] To reduce the state's vulnerability to climate change, **New York should begin to implement adaptation strategies identified in the NYSERDA ClimAID and Climate Action Council reports**. Because of their relative low cost and flexibility, **the state should prioritize the implementation of green infrastructure and other "no regrets" strategies, such as water conservation and efficiency measures.** These strategies would help New York to achieve its requirements under the Great Lakes Compact.

New York also has acted to address threats arising specifically from sea level rise. In 2007 the state legislature established the New York State Sea Level Rise Task Force to examine issues concerning climate change, sea level rise, and coastal flooding and to recommend adaptive measures to combat these risks.[84] The task force released a final report in December 2010, finding that sea level rise is already affecting certain coastal communities such as Montauk and areas near the Hudson River, and that the state's vulnerability is likely to increase over time.[85] In particular, the task force noted that current land use policy in the state is encouraging development in areas that are vulnerable to these impacts. According to the task force, solutions to these issues are likely to require a combination of structural and nonstructural fixes.[86] The task force recommended several adaptation strategies, which were divided into four categories: ecosystems, public works and infrastructure, communities, and climate justice. "Nonstructural" solutions included the elevation and relocation of structures and the conservation of natural protective features such as barrier islands, wetlands, and dunes. Strategies specific to water resources included mapping the most at-risk areas, developing backup measures for critical infrastructure such as water and wastewater treatment plants, helping the public explore alternative drinking water sources, and encouraging low-impact and green infrastructure practices to allow stormwater and coastal floodwaters to infiltrate the ground.[87] The report also included several strategies to protect freshwater ecosystems, such as mandating minimum streamflows and using basin-level commissions to protect water quality and promote conservation in these ecosystems.[88] Finally, the task force recommended changing or revising land use policies to help mitigate sea level rise impacts by revising flood zone areas and regulating where important new critical infrastructure is built.[89]

New York should create a legislative and regulatory framework that acknowledges and addresses the impacts of climate change, as recommended by the Sea Level Rise Task Force. Like the rest of the country, New York State's land use and natural resource laws and regulations were adopted prior to the realization of the potential impacts of climate change. Without considering the increased vulnerability of coastal areas in a warming world, current land use practices encourage unwise and risky development and growth. Moreover, increasing density along New York's coasts puts added pressure on fragile coastal ecosystems; ecosystems that human communities rely on, amongst myriad other things, to serve as natural protections against coastal storms and flooding. To address this problem, the New York State Sea Level Rise Task Force recommended that New York State amend "laws and change and adopt regulations and agency guidance documents to address sea level rise and prevent further loss of natural systems that reduce the risk of coastal flooding."[90] New York must act now to ensure that its coastal communities, both human and natural, can adapt to the impacts of rising seas and warming temperatures.

The Sea Level Rise Task Force also highlighted several areas as "adaptation champions" in the state.[91] One of these is the Hudson River Valley, where the Nature Conservancy's Rising Waters Program brought together stakeholders from across the public and private sectors to brainstorm ways to tackle river level rise and its impacts on the community. This group's final report was released in May 2009.[92] During the process, the group developed four future scenarios to examine ways the community could adapt. These scenarios included a future in which no changes are attempted; a future in which public demand for increased regulation improves local adaptive capacity; a future in which structural solutions, such as shoreline hardening, dominate; and a future in which shoreline hardening is limited and other nonstructural solutions are pursued.[93] These scenarios generated more than 80 responses from participating stakeholders, which were used to develop recommended adaptation actions. Some of these recommendations included improving community planning and preparedness by incorporating climate change information into planning activities, changing the setback requirement from the Hudson River to at least 75 feet, creating financial incentives to encourage planning in areas that are not flood prone, requiring flood audits of infrastructure, establishing climate change funding at the state level for community-level adaptation, and managing natural ecosystems to help mitigate future impacts.[94]

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NORTH CAROLINA

Rising sea levels are eroding North Carolina's shoreline, and saltwater intrusion into aquifers in the Coastal Plain is already threatening valuable groundwater resources. These impacts, along with drought and flood events, are projected to worsen as temperatures increase and precipitation patterns change. A recent study estimates the state could lose more than $60 billion in GDP and over 490,000 jobs in the next 40 years as a result of reduced water availability caused by climate change.[1] In recognition of the risk that climate change poses to North Carolina's resources, the Department of Environment and Natural Resources and others are pursuing an adaptation strategy to address impacts to the state. **To ensure the effectiveness of this strategy in reducing the state's vulnerability to climate change, North Carolina should develop specific objectives and goals, identify implementation mechanisms and a timeline for completion, and provide the staffing and financial resources necessary for implementation.**

Water Resources Background

More than 500 miles across, North Carolina has three distinct physiographic regions: the Coastal Plain, the Piedmont, and the Blue Ridge Mountains.[2] Within the Coastal Plain and Piedmont, annual average precipitation ranges from 40 to 60 inches;[3] the range is even greater in the mountain region, where annual precipitation averages as little as 38 inches in Asheville and more than 90 inches in Macon County.[4] The state does not have distinct wet and dry seasons, but monthly average precipitation does vary, with July being the wettest month.[5] Summer generally has the most precipitation, with rain occurring as a result of showers and thunderstorms, whereas autumn is the driest season.[6] Spring and winter precipitation is generated by migratory low-pressure systems.[7] Average annual snowfall ranges from 1 inch along the Outer Banks to 16 inches in the southern mountains to as much as 50 inches on high mountain peaks.[8]

Most of North Carolina drains into the Atlantic Ocean via the Roanoke, Tar, Neuse, Cape Fear, Yadkin, and Catawba rivers. The western portion of the state drains into the Mississippi River system through the French Broad and Tennessee rivers.[9] Maximum streamflow occurs in the late spring, and lowest flows during the fall.[10] While many rivers traverse the Coastal Plain, most of the population in this region relies on underground aquifers because the flat terrain does not readily lend itself to reservoir development, and saline intrusion is common in rivers during low-flow periods.[11] Groundwater is a significant source of water statewide, with more than half the state's population relying on underground aquifers for water supply.[12] The Coastal Plain is the agricultural center of the state, with major crops including tobacco, cotton, soybeans, peanuts, potatoes, sweet potatoes, corn, and wheat. There are also livestock operations—for hogs, turkeys, and chickens—that now exceed the economic value of traditional field crops.[13] Much of the area is irrigated to ensure optimum yields, and this allows some crops to have two harvests per year.[14] The Piedmont is the manufacturing center and most heavily populated region in the state.[15] In 2005 the thermoelectric sector accounted for nearly 74 percent of total freshwater withdrawals statewide.[16] Other major users were aquaculture at 9 percent, public supply at 8 percent, industry at 3.5 percent, and irrigation at 2.6 percent.[17]

Coastal resources in North Carolina are of significant economic and natural value. The state has more than 4,000 miles of shoreline and the largest estuarine system of any state on the Atlantic Ocean.[18,19] A wide range of estuarine rivers, creeks, sounds, inlets, and ocean bays support both northern and southern oceanic species, including brown shrimp, mackerel, scallops, herring, and cod.[20] In total, an estimated 4,000 full-time commercial fishermen and two million recreational anglers rely on the state's marine fisheries.[21] Tourism is also a substantial economic driver in the state, with more than $22 billion in total expenditures in 2008.[22] During the summer months, the state's barrier islands are popular tourist destinations, with seasonal visitors swelling populations to 3 to nearly 60 times their year-round size.[23] Coastal communities in North Carolina have traditionally consisted of small residential neighborhoods and beach towns; however, rapid population growth is changing the character of many of these areas.[24] There is also a large military presence in the towns of Jacksonville and New Bern.[25]

Climate Change Impacts on Water Resources

Over the past century, annual average temperatures in North Carolina have demonstrated three distinct trends: a slow warming from 1895 to 1950, rapid cooling between 1950 and 1970, and a general warming since 1970.[26] Across the southeastern U.S., average annual temperatures have risen about 2°F since 1970, with the greatest warming occurring during the winter months.[27] There have been few changes in total annual average precipitation; however, interannual variability appears to be increasing, and there has been a shift in seasonal distribution, with a slight drying in the summer and a wetter fall.[28] By the end of the 21st century, climate models project a warming of 4°F to 5°F in the winter and a warming of 6°F in the remaining seasons relataive to the 1971-2000 norm.[29] Climate projections are less clear regarding precipitation, however, though a slight increase (10 percent) is most likely in winter precipitation.[30]

Increased temperatures are likely to contribute to greater climate variability and extremes: more dry days and drought, and more intense precipitation and flooding.[31] Changes in precipitation in conjunction with increased evapotranspiration as a result of warmer temperatures could impact streamflow patterns, lake levels, and groundwater recharge rates and challenge conventional reservoir management practices.[32] Consequently, mounting water availability challenges due to climate change and population growth are likely to stress urban, industrial, and agricultural users. In 2007, drought led more than half of all public water systems to institute water use restrictions.[33] In the Coastal Plain, where groundwater extraction rates have already exceeded net recharge rates and caused declining aquifer levels and saline intrusion, the state has had to impose limits on groundwater withdrawals.[34] Changes to groundwater recharge rates as a result of precipitation changes and warming temperatures could exacerbate existing water availability issues in the region. Hydropower production would also be affected by changes in the timing and volume of streamflow, and conventional power plants that rely on surface water for cooling could also be impacted by streamflow changes.[35] Changes in streamflow patterns could have impacts on aquatic species as well, through increased sedimentation, pollution, and nutrient loading from greater runoff during flood events.[36] Furthermore, increasing water temperatures would limit the habitat of coldwater species such as brook trout.[37]

Relative sea level rise along the North Carolina coast during the 20th century ranged from 0.6 to 1.6 feet.[38] Higher rates of sea level rise have been observed along the northern coast than in the south due to local geology and crustal subsidence and uplift.[39] By 2100, sea levels are projected to rise 1.3 to 4.6 feet.[40] Significant portions of the coast would be at risk to rising sea levels—the area between Cape Lookout and the mouth of the Chesapeake Bay represents the third-largest land area vulnerable to sea level rise in the U.S.[41] Furthermore, the land elevation of three of the state's counties are almost entirely within 10 feet of high tide.[42] Sea level rise could contribute to greater coastal inundation and flooding; erosion, land loss, and shoreline retreat; increased vulnerability to coastal storms; and saltwater intrusion.[43] An analysis of property value losses for Dare County, a highly developed area in the north, estimates that by 2030, a 4-inch rise in sea level (below the low end of most estimates) would result in more than $650 million in property value losses from permanent inundation.[44] In addition, the total cost of lost recreational and tourism opportunities for southern North Carolina beaches would range from $93 million to $197 million by 2030 and $223 million to $826 million by 2080.[45] Sea level rise in addition to stronger tropical cyclones would lead to greater storm surges along the coast. An increase of 1.8°F in sea surface temperature could cause a 31 percent increase in the number of category 4 and 5 hurricanes.[46] In fact, North Carolina ranks fourth nationwide in the total number of recorded hurricane strikes, with 50 landfalls between 1851 and 2006.[47] In the first decade of this century, eastern North Carolina was hit by eight hurricanes and six tropical storms.[48]

Coastal habitats are also likely to be impacted by climate change. Inundation from sea level rise is projected to cause habitat loss, and changes in salinity, temperature, and acidity will affect coastal ecosystems. Warming ocean temperatures will likely change the range of aquatic species, increase the occurrence of harmful algal blooms, and increase the severity of infectious diseases in fish and invertebrate populations.[49] In particular, the oyster diseases of Dermo and MSX are very sensitive to water temperature, with more outbreaks reported after warming.[50,51] Increasing ocean acidity as a result of rising levels of atmospheric carbon dioxide may also inhibit marine organisms from developing protective shells and skeletons.[52]

Greenhouse Gas Pollution Reduction

The state has not adopted greenhouse gas reduction targets, but the North Carolina Climate Action Plan Advisory Group (CAPAG) released a final report in 2008 on ways to reduce emissions statewide.[53] Because the state is projected to face a wide range of climate impacts, **North Carolina should adopt emission reduction targets and implement strategies identified in the CAPAG report to reduce the state's contribution to climate change.**

State Adaptation Planning

As one of its six crosscutting recommendations, CAPAG suggested that North Carolina develop, adopt, and implement a state climate adaptation plan.[54] The Legislative Commission on Global Climate Change also recommended in its final report that the state develop a comprehensive adaptation plan.[55]

To implement CAPAG's recommendations, climate change mitigation and adaptation are featured as a goal in the Department of Environment and Natural Resources' (DENR) 2009-2013 Strategic Plan.[56] DENR has developed the Climate Change Initiative, which is being implemented with oversight by the department's Climate Change Steering Committee.[57] As part of this initiative, adaptation strategies regarding sea level rise, climate-sensitive ecosystems, water management, public health impacts, emergency management preparedness, and land use planning and development were identified.[58] To address sea level rise, the state is updating the Coastal Habitat Protection Plan (CHPP), improving coastal management, and participating in the Climate Ready Estuaries program. With respect to climate-sensitive ecosystems, the state is identifying climate change risks to biodiversity and wildlife, forestry, agriculture, and aquatic habitats and working with federal and state partners to control invasive species. On water management issues, North Carolina is pursuing actions that maintain natural hydrology, ensure effective long-term use of water resources, and reduce flooding risks. To address waterborne illnesses, protocols are being implemented to counter the increased spread of pathogenic species as a result of flooding and warmer temperatures and to respond to water shortage and drought conditions. The state also is pursuing activities that include planning for increased storm intensity and drought impacts to improve emergency management preparedness. Last, DENR is working in conjunction with other state partners to promote planning and development that is more compact and utilizes green infrastructure; the agency is also working with local governments to incorporate policies that address mitigation and adaptation into local land use plans. **The state should recognize the benefits of "no regrets" strategies like water conservation and green infrastructure, which address existing water quality and quantity issues in addition to building resilience to future climate impacts.**

The Climate Change Initiative Strategy Framework is a first step in developing a comprehensive adaptation strategy for the state; however, many of the goals and objectives identified are largely lacking in specificity and details on implementation. One example is the goal to work with federal and local governments to better protect against flooding.[59] The strategy lacks detail on what action items this objective entails. To effectively increase the resilience of North Carolina's resources to climate change, **the Climate Change Steering Committee should develop more specific goals and objectives along with implementation actions in the strategy framework. In addition, if not already being done, DENR should coordinate with other state agencies and set a timeline for completion of these activities.** This will allow the state to more efficiently track progress toward achievement of these goals and ensure that other relevant sectors (transportation, public health, etc.) also are planning for climate change.

Other state entities have worked to incorporate consideration of climate change into program operations and planning. In 2010 the North Carolina Wildlife Resources Commission supported the development of a report on the impacts of climate change on fish and wildlife.[60] The report also included general adaptation strategies, such as conserving habitat, promoting habitat connectivity, and minimizing non-climate threats. The state Fisheries Reform Act of 1997 instructs DENR to prepare CHPPs to provide for the long-term enhancement of coastal fisheries associated with six fish habitat categories: water column, shell bottom, submerged aquatic vegetation, wetlands, soft bottom, and hard bottom.[61] In 2010 DENR updated the CHPP to include a discussion of how sea level rise and climate change may impact each habitat. For example, in the wetlands chapter, the CHPP notes that sea level rise will inundate large areas of the Pamplico-Albemarle peninsula and that saline intrusion into freshwater peats could also accelerate the collapse of peatlands.[62] The CHPP states that Coastal Resources Commission (CRC) and DENR policies need to be developed regarding sea level rise adaptation and that CRC land use planning guidelines need to be revised.[63]

In 2010 the CRC Science Panel, at the behest of the Division of Coastal Management, developed an assessment of relative sea level rise for North Carolina, ultimately recommending that a sea level rise of 1 meter (39 inches) by 2100 be utilized for policy development and planning purposes.[64] In the wake of the panel's recommendation, the CRC initially developed a draft sea level policy that required the 20 coastal counties to use a planning benchmark of a 1 meter rise in sea level by 2100;[65] however, in response to feedback and criticism from local governments and other groups, the CRC in a revised draft removed the planning benchmark and now only encourages coastal communities to consider projected rates of sea level rise in land use and planning decisions.[66,67] This significant reversal could lead to haphazard planning for sea level rise among coastal communities and leave populations in less proactive communities more vulnerable. The CRC sea level policy is likely to be finalized through the administrative process by the end of 2012.[68] Given the significant amount of coastal development at risk to rising seas, **the CRC should establish policies that reduce future risks consistently across all coastal counties, such as the adoption of a set of sea level rise scenarios for state and local agencies to consider in project planning and design, as is being done in California and Delaware.**

State agencies also are working with local communities in the Albemarle-Pamlico region through the U.S. Environmental Protection Agency's Climate Ready Estuaries Program. The Albemarle-Pamlico National Estuary Program (APNEP), in concert with other partners including the Nicholas Institute at Duke University, initiated a pilot project in 2009 to educate public and local officials in five coastal counties (Beaufort, Dare, Hyde, Tyrrell, and Washington) on potential risks from climate change. As part of this project, the Nicholas Institute issued recommendations on how to overcome obstacles to effective climate change adaptation in the APNEP region.[69] These included improving climate change information for local decision-making, improving multiagency coordination, and taking immediate implementation steps to build the resilience of local communities. In addition, the DENR, through the Natural Heritage Program, is conducting an assessment of the likely effects of climate change on the state's ecosystems and species as part of the process to update the Wildlife Action Plan.[70]

In 2009 the North Carolina Office of Geospatial and Technology Management Floodplain Mapping Program initiated a study to examine the changes in coastal flooding hazards by 2100 due to changes in storm intensity and sea level rise, using a $5 million grant from the Federal Emergency Management Agency.[71] The Sea Level Rise Risk Management Study is using a scenario-based approach to determine impacts on infrastructure and ecosystems from coastal flooding in 2025, 2050, 2075, and 2100. The study, scheduled for completion in 2012, will include a discussion of short- and long-term strategies to mitigate coastal flooding risks.

Alligator River National Wildlife Refuge

The Alligator River National Wildlife Refuge consists of 154,000 acres of low-lying land on the Albemarle Peninsula in Dare and Hyde counties.[72] Due to the low elevation, lands in the refuge are particularly susceptible to inundation and erosion from sea level rise. Models have shown that up to 469,000 acres of the peninsula could be flooded with a 1-foot rise in sea level.[73] The North Carolina chapter of the Nature Conservancy, along with the U.S. Fish and Wildlife Service, are testing the effectiveness of three adaptation strategies: using oyster reefs to dissipate wave energy, using water control structures to restore the natural hydrology and prevent saline intrusion, and planting salt- and flood-tolerant vegetation to stabilize shorelines. Parts of Point Peter, where the oyster reef is being built, erode at a rate of 30 feet per year; however, the marsh located behind the reef is eroding at a much slower rate.[74] In addition, 20,000 cypress trees have been planted in an attempt to create a habitat for the red wolf, black bear, and other animals whose habitats have eroded.[75] The Nature Conservancy is conducting ongoing monitoring on erosion rates, water quality, water flow, and the growth rates of planted vegetation in order to determine the effectiveness of these adaptation strategies.[76]

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NORTH DAKOTA

North Dakota flooding in 2011 damaged critical infrastructure and property and caused losses of more than $500 million.[1] In addition to flooding caused by heavy rain and rising river levels, many residents had to contend with flooding caused by high water tables seeping into basements.[2] This type of event is likely to be more frequent in the future due to climate change. North Dakota, like other High Plains states, is already experiencing warmer temperatures. With approximately 90 percent of the land in North Dakota used for agriculture, the state faces substantial risks posed by climate change.[3] Warmer temperatures will strain water resources by increasing irrigation demand and affecting water supplies. **North Dakota is not currently prepared to meet these challenges and should initiate statewide efforts to reduce greenhouse gas pollution and prepare for climate change impacts. The widespread implementation of "no regrets" strategies like water conservation and green infrastructure will enable the state to address existing water supply and quality issues while also improving its ability to deal with climate impacts.**

Water Resources Background

Like its neighbors on the High Plains, North Dakota has a climate characterized by highly variable weather patterns, with extreme changes in temperature and precipitation. Annual mean precipitation ranges from approximately 13 inches in the northwest to more than 20 inches in the south and southeastern portions of the state.[4] North Dakota has two primary drainage basins separated by the Northern, or Laurentian, Divide: the Hudson Bay Basin in the northeastern part of the state and the Missouri River Basin in the southwestern part of the state.[5] Streamflow in these basins depends on precipitation and snowpack and varies seasonally. Flow is greatest in the spring due to snowmelt and precipitation, and it is not uncommon for some rivers to completely dry up in the summer, when there is less rain.[6] The annual runoff of the Missouri River is substantially greater than that of other rivers in the state. Indeed, the combined total annual runoff of the Red River at Fargo, the Sheyenne River at Valley City, the James River at Jamestown, and the Souris River at Minot represents about 4 percent of the annual flow of the Missouri River at Bismarck.[7] While the Missouri contains about 96 percent of North Dakota's total surface water supplies, the state's population is concentrated in the Red River Valley.[8]

The actual volume of water that falls as rain in the state can vary by as much as 50 percent between wet and dry years, ranging from around 60 million to 90 million acre-feet to around 30 million to 60 million acre-feet.[9] Consequently, cyclical droughts are a prominent feature of North Dakota's climate.[10] The worst drought in North Dakota's modern history occurred recently, lasting from 2000 to 2006.[11] This prolonged drought severely stressed public water supplies. In late 2006, the U.S. Army Corps of Engineers increased the flow from Garrison Dam to raise the low water levels of the Oahe Reservoir along the Missouri River.[12] Lower lake levels also affected hydropower production and indirectly contributed to the worst fire season on record.[13]

Normal reservoir storage capacity in North Dakota is roughly 19 million acre-feet, with 97 percent of this capacity located in Lake Sakakawea and Lake Oahe.[14] There are also several water distribution projects in the state that aim to address regional water shortages. These include the Northwest Area Supply Project, the Red River Valley Water Supply Project, and the proposed Southwest Pipeline Project.[15] These projects transfer water from wet areas of the state to drier portions through a series of constructed conveyances. While these water diversion projects have the ability to alleviate water scarcity issues in parts of the state, they also have the potential to transfer nonnative biota. In fact, the Canadian province of Manitoba filed a lawsuit over this issue in 2002, arguing that North Dakota's Northwest Area diversion would increase the risk of introducing nonnative species to the Hudson Bay watershed. In 2009 the State of Missouri also filed suit, arguing that the diversion also would negatively affect downstream water levels in the Missouri River.[16] A federal judge ordered the U.S. Bureau of Reclamation in 2010 to conduct additional studies on the potential environmental impact of the water diversion project.[17]

In the state, groundwater typically occurs in unconsolidated deposits and in bedrock. An estimated 60 million acre-feet of water is available in major unconsolidated deposits, and an estimated 435 million acre-feet is available in bedrock aquifers.[18,19] Groundwater quality in the state is extremely variable, with many areas having marginal water quality.[20] Through the Cloud Modification Project (currently in six counties), the state attempts to prevent hail damage and increase precipitation[21] by harnessing some of the significant quantities of water vapor that pass through the state during summer months. Previous analysis by the state has shown that this project reduces hail damage by approximately 45 percent and increases precipitation by 5 to 10 percent.[22]

In North Dakota, groundwater is typically used for irrigation and for municipal, rural, and industrial uses, whereas surface water is typically used for industrial and municipal uses.[23,24] The greatest withdrawer of water in the state is the industrial sector, accounting for 87 percent of total surface water withdrawals and approximately 80 percent of total freshwater withdrawals.[25] This amount is largely nonconsumptive, however, and primarily used for power plant cooling. Irrigation is the largest consumptive user of water, accounting for approximately 11 percent of the state's total water withdrawals.[26] Irrigation is also the largest user of groundwater, accounting for 63 percent of total groundwater withdrawals.[27] North Dakota ranks first nationally in the production of many crops, including durum wheat, barley, sunflowers, flaxseed, and canola, and total agricultural output in 2010 was approximately $7.6 billion.[28,29] Municipal users are the next-largest groundwater user, with 45 percent of the state population relying on groundwater for drinking water supply;[30] Groundwater is the primary source of water for communities that are not served by the Missouri River and practically the sole source for rural areas.[31]

Climate Change Impacts on Water Resources

North Dakota is experiencing the most significant warming among the six High Plains states, with an average temperature increase of approximately 2.2°F in the spring and almost 5°F in winter over the past century.[32] Rising temperatures cause increasing evapotranspiration, which leads to a decrease in soil moisture. This can lead to an increased demand for irrigation water and potentially put new stress on water resources, particularly where groundwater is used. North Dakota could experience summer warming of 6°F to 10°F by the end of the century, depending upon the emissions scenario.[33]

Precipitation has not changed significantly in North Dakota, with an increase of approximately 4 percent over the past century.[34] However, there has been marked seasonal variability in precipitation in the region, with most High Plains states experiencing a significantly drier winter and wetter fall than in the past.[35] Models project a 10 to 30 percent increase in the amount of spring precipitation in North Dakota by the end of the 21st century.[36] However, it is unclear if this projected increase in precipitation will be able to compensate for higher rates of evapotranspiration and increased demand for irrigation water. An increase in extreme precipitation events is also more likely in the future across the High Plains region.[37] There was near-record flooding in North Dakota along the Souris and Missouri rivers in 2011, and events similar to this could be more prevalent in the future as a result of increased precipitation and more-intense heavy rainfall events. Floods pose substantial risks to people, property, infrastructure, and agriculture located near rivers and streams.

The native prairie pothole ecosystem that characterizes much of the North Dakota landscape is also at risk from the impacts of climate change. These shallow, ephemeral lakes create a distinct environment that helps support diverse plant and animal species, particularly native birds and migrating waterfowl.[38] These pothole lakes also are the main source of recharge for the High Plains' vast aquifer systems.[39] Extensive cultivation and water withdrawal for agricultural activities have already begun to threaten these unique areas. Climate change is expected to impact these ecosystems by increasing water demand, particularly for irrigation.[40] Increased withdrawals combined with greater evapotranspiration could spell the end of these ecosystems if they are not carefully managed.

Greenhouse Gas Pollution Reduction

North Dakota has not adopted greenhouse gas pollution reduction targets or developed a plan for reducing greenhouse gas pollution in the state. **The state should reduce its contribution to climate change by adopting greenhouse gas pollution reduction targets or goals and developing a strategy for reducing emissions.** Considering the substantial greenhouse gas emissions associated with energy production and development in North Dakota, the state should make certain that any strategy addresses this sector**.**

State Adaptation Planning

North Dakota Governor Jack Dalrymple is a member of the Western Governors' Association (WGA), and the WGA has a specific climate change and adaptation initiative that aims to streamline integration among federal and state agencies in addressing climate change impacts, especially in the water sector. [41] However, the state does not appear to have pursued any adaptation initiatives. **North Dakota should undertake an initiative to develop a comprehensive and crosscutting plan to adapt to climate change impacts.**

North Dakota does have several planning programs that should consider climate change impacts. In 2009 the State Water Commission (SWC) updated the State Water Management Plan (SWMP). This SWMP contains information on current and future water use, areas where water is available for new uses, and water resources management, development opportunities, and challenges.[42] The plan includes water use projections through 2020 based on available population projections. Notably, industrial water use is projected to increase dramatically as a result of ethanol development and oil well development in the Bakken Shale Formation. An estimated 3 to 6 gallons of water is needed to produce 1 gallon of ethanol. Accordingly, a 100-million-gallon ethanol plant requires as much water as the cities of Devils Lake or Wahpeton use in an entire year.[43] Bakken oil wells require a water-intensive extraction process known as hydraulic fracturing, which can utilize millions of gallons of water for a single well. More than 10,000 new wells in the Bakken Formation are expected to be drilled by 2020, increasing total water use by nearly 51,000 acre-feet.[44] Climate change and its potential impacts on the state's water resources are mentioned only in passing and not comprehensively considered in the SWMP. In future updates to the SWMP, **North Dakota should include a thorough and robust analysis of potential climate change implications for water resources.**

Unfortunately, most of the water development projects included in the SWMP are "hard" infrastructure projects, such as pipelines and dams.[45] Without taking into consideration the impacts of climate change now, there is substantial risk of wasting money on infrastructure that does not perform as intended in the future or is sited in a vulnerable area. The SWMP also has a rather limited discussion of water conservation and efficiency strategies. The SWMP noted that the city of Fargo has enacted water use restrictions for lawn watering during the summer months, leading to annual water savings of 2.5 million gallons;[46] however, the state has not required statewide water conservation or efficiency measures. As the plan noted, there are significant opportunities for water conservation in the state, especially in the agricultural sector, the largest user of water statewide. **North Dakota should incorporate water conservation and efficiency requirements into the state's water permitting program.**

The effective integration of climate change into the SWC's Watershed Planning and Coordination Program, which helps communities develop watershed management plans in coordination with the state, could benefit North Dakota in the long term. The SWC in recent years has provided technical assistance on water management and watershed planning to the Devils Lake, Upper Sheyenne, Red, and Missouri River joint water boards.[47] Watershed management planning refers to a way of managing water quality and supply together on a scale that makes hydrologic sense. Because activities within a watershed affect water in that area, these planning initiatives usually involve co-management of several different areas in the same planning process, as when addressing pollution runoff from urban, suburban, and agricultural areas. These defined watershed management areas could easily function as planning units for a state-level adaptation planning effort. In addition, **North Dakota should recognize the benefits that "no regrets" strategies, such as green infrastructure, provide with regard to water quality and flood protection.** Green infrastructure, such as permeable pavement, green roofs, and rain gardens, reduces runoff and pollutant loads, among numerous other benefits.

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OHIO

Ohio, like its neighboring states in the Great Lakes region, already is experiencing increases in temperature and precipitation. Further temperature increases, changes in the seasonality of precipitation, and more extreme precipitation events from climate change are likely. One of the state's most valuable water resources, Lake Erie, will not be immune to the impacts of climate change. Between 2010 and 2050, the state could lose up to $27 billion in GDP and 167,000 jobs from reduced water availability due to climate change and subsequent impacts on economic sectors, employment, personal income, and interstate migration.[1] Despite these grave risks, the state has yet to develop strategies to reduce statewide greenhouse gas pollution or to adapt to potential climate change impacts. **Ohio should seek to assess the state's vulnerability to climate change and implement measures to reduce statewide greenhouse gas pollution and to prepare for inevitable climate impacts.**

Water Resources Background

Ohio is affected by air masses from both Canada and the tropics. This results in a wide range of climates in the state, with cold, dry winters and hot, humid summers. In addition, northern parts of the state experience lake-effect weather from Lake Erie, particularly during the winter. Annual average precipitation ranges from 32 to 42 inches across the state, with greater amounts in the southern portion of the state, which is more strongly influenced by the climate of the Gulf of Mexico.[2] The extreme northeastern counties, whose climate is influenced by Lake Erie, remain an exception to this geographic distribution and receive on average 40 to 42 inches annually.[3] The driest months are typically October and January/February, and the wettest months are April through July.[4] Precipitation between October and March generally results from mid-latitude low-pressure systems; during the remainder of the year, rainfall is associated with thunderstorms.[5] Snowfall varies across the state, with as little as 16 inches a year in the south to more than 90 inches a year in the northeast, which is dominated by lake-effect snow from Lake Erie.[6]

The state's water resources are dominated by Lake Erie to the north and the Ohio River to the south. The state's eight coastal counties have 312 miles of coastline along Lake Erie, which is the most biologically productive of all the Great Lakes.[7] The lake supplies drinking water for three million people in the state.[8] It is also an important part of Ohio's economy, with tourism bringing in almost $11 billion per year, commercial fisheries valued at $800 million annually, and lakefront ports handling important commodities like steel, iron ore, and coal.[9] In between the two dominant water sources, the state has 29,000 miles of perennial streams and rivers and almost 120,000 acres of publicly owned lakes.[10] Ohio's 10 major watersheds drain into either Lake Erie or the Ohio River.[11] In addition, Ohio has three major types of aquifers: sand and gravel, sandstone, and carbonate.[12] Sandstone aquifers are generally found in the eastern half of the state and carbonate aquifers in the western half, while sand and gravel aquifers are found throughout the state.[13]

In Ohio, electrical generation and public supply are the dominant water withdrawers.[14] In 2009 total withdrawals were approximately 3.5 billion gallons (approximately 10.6 million acre-feet).[15] Thermoelectric power plant withdrawals made up approximately 79 percent of this total, and public supply accounted for approximately 14 percent.[16] Agriculture and irrigation are not as predominant water users in Ohio as they are in other midwestern states, representing only 0.5 percent of total withdrawals.[17] Additionally, groundwater usage makes up only approximately 9 percent of total withdrawals in the state, although it is an important source of drinking water for 5.7 million Ohioans.[18] The remainder is withdrawn from surface water resources.[19]

The Great Lakes Compact

The Great Lakes contain six quadrillion gallons of water (about 18.4 billion acre-feet), more than one-fifth of the world's surface supply of freshwater and more than 95 percent of the surface freshwater supply in the U.S.[20] Although the volume of the Great Lakes is vast, less than 1 percent of its waters are renewed annually through precipitation, runoff, and infiltration.[21] The Great Lakes Basin ranks third in terms of total freshwater use out of the 21 major watersheds in the U.S.[22] Lake levels are expected to decline over the next century in each of the Great Lakes, from 1 foot on Lake Superior to as much as 3 feet on Lakes Michigan and Huron.[23] Management and use of water in the eight Great Lakes states is governed by the Great Lakes-St. Lawrence River Basin Water Resources Agreement and Compact.[24] In ratifying the Compact, each state agreed to undertake a series of actions, including the establishment of thresholds governing new or increased withdrawals of water; implementation of a permitting process for new withdrawals; development of water conservation and efficiency programs, including the establishment of state-specific goals and objectives to guide individual states' programs; and improved data gathering and sharing across the basin. In addition, the Compact directs states to "[g]ive substantial consideration to climate change or other significant threats to Basin Waters and take into account the current state of scientific knowledge, or uncertainty,"[25] and to take appropriate measures, such as adaptive management, to address these threats.

Climate Change Impacts on Water Resources

The climate of Ohio has changed measurably over the past several decades. In the past century, annual average temperature in the state has increased by 0.8°F, with most of this warming occurring during the winter and spring seasons.[26] As the result of these warmer temperatures, the melting of ice and snow is occurring earlier in the spring.[27] Under high-emissions scenarios, summer temperatures are projected to rise 2°F to 4°F by 2040 and 5°F to 12°F by the end of this century.[28] Average annual precipitation has also increased in Ohio at a rate of 2.7 inches over the past century.[29] In addition, heavy rainfalls are already twice as frequent in the Midwest as they were a century ago.[30] Cincinnati could experience an increase of 30 percent in the frequency of these events over the next few decades, and a doubling of these events by the end of the century under a high-emissions scenario.[31] Additionally, winters and springs in Ohio are projected to become wetter, with models showing 30 percent more precipitation during these seasons by the end of the century.[32] These changes could increase flooding risks to communities and agricultural areas in floodplains.[33] In contrast, summers are projected to receive 5 percent less rain and are likely to be drier because of higher temperatures.[34] This decrease in rainfall is expected to lead to decreases in soil moisture, indicating that drought could be more common in Ohio's future.[35] River, stream, and lake levels are expected to drop during summer months because of anticipated warming, further contributing to drought conditions.[36] Overall, short-term droughts are projected to increase in frequency while long-term droughts, those lasting several years, are expected to decline.[37]

Climate change is also likely to present challenges to water quality. A projected increase in heavy rainfalls could lead to increased overflows from wastewater treatment systems and the release of untreated sewage into receiving water bodies, which could increase public health risks for waterborne diseases.[38,39] Cincinnati typically experiences overflows of approximately 14 billion gallons a year, and this figure is likely to increase in the future as severe rain events occur more frequently.[40] In addition, runoff from urban and agricultural areas transports pollutants into neighboring waterbodies. This is also likely to increase in the future with increased precipitation and more heavy-rainfall events.[41] These changes in water quality, in addition to warmer water temperatures, are likely to have an impact on aquatic species. Warmer water temperatures could prolong the stratification of some lakes and lead to oxygen-poor conditions in the bottom layers.[42] Warmer water temperatures and increases in nutrient runoff also may lead to increases in harmful algal blooms, which can cause human illness and contaminate seafood.[43] Furthermore, populations of coldwater fish, such as brook trout and lake trout, are likely to decline as suitable habitats disappear while warmwater species, such as smallmouth bass, expand.[44]

The impacts of climate change on agriculture, a $7 billion annual industry in Ohio, could be particularly profound. One in every seven people in Ohio is employed in the agricultural sector, and more than half the state is designated prime farmland.[45] Although the growing season is expected to lengthen by three to seven weeks, depending on the emissions scenario, the longer growing season will be accompanied by higher temperatures, decreased soil moisture, and increased extreme weather events.[46] These changes will result in heat stress for crops and an increase in the quantity of irrigation water needed.[47] This could present numerous challenges, as less than 1 percent of crops in Ohio are currently irrigated.[48] Therefore, irrigation infrastructure will likely need to be expanded.

Lake Erie also will be impacted by climate change. Toward the end of the century, water levels in Lake Erie are projected to decline, from less than 1 foot under a low-emissions scenario to almost 1.5 feet under a high-emissions scenario, as a result of greater evaporation during the summer and reduced ice cover in the winter.[49] Lower water levels would impair commercial shipping in the Great Lakes, with an estimated load reduction of 99 to 127 tons for a cargo ship for every 1-inch decline in lake level.[50] Lower lake levels could also affect tourism and recreation by limiting access to docks, boat ramps, and ferry landings.[51] In addition, reduced winter ice cover would increase coastal shoreline erosion risks from wave action, especially during storms.[52] Warmer water temperatures associated with climate change are also expected to change the distribution of fish species in the Great Lakes, with some warmwater species moving 400 miles northward while other species disappear entirely.[53] Invasive species could also expand since they are more adaptive to a wider range of environmental conditions.[54]

Greenhouse Gas Pollution Reduction

Ohio has not adopted greenhouse gas pollution reduction targets or developed a plan for reducing statewide greenhouse gas pollution. To reduce the state's contribution to climate change, **Ohio should adopt a greenhouse gas pollution reduction goal and develop and implement a strategy to achieve it.**

State Adaptation Planning

Ohio does not have a state climate adaptation plan, nor does adaptation planning appear to be under way in any state regulatory agency. Considering the potential impacts of climate change on Ohio, **the state should be actively assessing its vulnerabilities and developing and implementing strategies to adapt to climate change impacts.** The Ohio Sea Grant, however, is addressing some climate change issues. Building hazard resilience in coastal communities is one of the key focus areas in the Sea Grant's 2010-2014 Strategic and Implementation Plan.[55] To achieve this goal, the Sea Grant is educating communities about coastal hazards (including climate change), developing tools to determine how climate change might impact communities, and training communities on mitigation and adaptation planning. The Ohio Sea Grant also hosts Ohio State University's Changing Climate website, which contains climate change research information.[56] The website also offers webinars on climate change topics, such as a recent one titled "Climate Change Impacts on Great Lakes Water Levels," to help inform the community about climate change issues.

While the state's hazard mitigation plan notes that climate change may lead to more frequent and severe drought and flood events, the plan neglects to include flexible and adaptive strategies to reduce flood vulnerability and does not contain any strategies to reduce drought vulnerability.[57] **Because green infrastructure can substantially reduce the volume of stormwater runoff and consequently decrease flooding risks, Ohio should encourage widespread adoption of green infrastructure as a flood mitigation technique**. **The state also should work to encourage the widespread implementation of water conservation and efficiency measures.** This could be accomplished by adopting a permitting program requiring facilities that currently must report water usage annually to the Department of Natural Resources (those capable of withdrawing more than 100,000 gallons per day)[58] to meet conservation and efficiency metrics—which also would help to meet the state's obligations under the Great Lakes Compact.

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OKLAHOMA

Across the southern Great Plains over the past year, extreme drought conditions have devastated agricultural areas by reducing pastureland for cattle and damaging crop production.[1] In Oklahoma, exceptionally low rainfall in conjunction with record-breaking high temperatures has caused more than $2 billion in livestock and grain production losses.[2] Furthermore, the period from January to August 2011 was the second-driest such period since recordkeeping began in 1895.[3] Similar drought conditions are likely in the future as warmer temperatures increase rates of evapotranspiration. In recognition of the devastating impacts that drought can have on the state, Oklahoma is working to improve water resources planning and is considering how climate change might impact water demand and supply over the next 50 years. This is a prudent and proactive step in the right direction. However, **Oklahoma also should reduce statewide greenhouse gas pollution, expand its assessment of potential climate change impacts to all sectors, and develop and implement a comprehensive plan for preparing for these impacts.**

Water Resources Background

The state's continental climate is heavily influenced, particularly in the southeast, by warm, moist air from the Gulf of Mexico.[4] Consequently, precipitation across Oklahoma is characterized by a substantial decrease from the east to the west. Average annual precipitation ranges from approximately 56 inches in the southeast to 17 inches in the western panhandle.[5] Seasonal precipitation patterns also vary; winter precipitation is more widespread and is caused by large-scale weather systems, while summer precipitation is produced almost entirely by convective thunderstorms.[6] Snow is much more common in the western panhandle, with annual averages of about 30 inches compared with less than 2 inches in the southeast.[7] Flooding and drought are both common events in Oklahoma. Flood events are most likely to occur during the spring and fall as the result of heavy rains associated with slow-moving storm systems or stalled cold fronts.[8] Droughts generally occur in response to decadal-scale dry periods, as most of the usable surface water comes directly from rainfall within the state.[9] Since 1920 the state has experienced five multiyear or decadal drought events.[10]

Oklahoma's two main rivers, the Arkansas River in the north and the Red River in the south, are part of the Mississippi River drainage basin.[11] The Beaver/North Canadian, a tributary of the Arkansas, is the longest river in the state at 752 miles.[12] Other tributaries of the Arkansas include the Verdigris, Grand (Neosho), Illinois, Cimarron, and Canadian rivers.[13] The state's two largest lakes, Texoma and Eufaula, contain 2.6 million acre-feet and 2.3 million acre-feet of conservation storage, respectively.[14] The state also has vast groundwater supplies stored in 23 major aquifers. The largest, the Ogallala or High Plains Aquifer, in western Oklahoma, contains approximately 86.6 million acre-feet of water;[15] however, the use of this aquifer has become unsustainable as population has grown and irrigation needs have increased. Since 1950, aquifer levels have dropped an average of 13 feet with reductions of as much as 100 to 250 feet in heavily irrigated parts of Texas, Oklahoma, and Kansas.[16]

Geographic variations characterize patterns of water use in the state. In the western third of Oklahoma, where agriculture is the main withdrawer of water, groundwater is the dominant source, whereas in the eastern two-thirds of the state, public supply is the prevailing user and most water comes from surface supplies.[17] Statewide in 2005, 82 percent of water for public supply came from surface water sources, and 73 percent of water for irrigation came from groundwater.[18] Approximately 63 percent of total freshwater withdrawal statewide came from surface water sources, and the remaining 37 percent came from groundwater.[19] The three largest withdrawals were for public supply, irrigation, and livestock and aquaculture, at 41 percent, 32 percent, and 12 percent, respectively.[20] More than 472,000 acres were irrigated in 2005.[21] In the panhandle, the two main crops are wheat and corn.[22]

Climate Change Impacts on Water Resources

Over the latter half of the 20th century, average annual temperatures in Oklahoma (relative to the 1950-to-1999 mean) actually declined while precipitation generally increased.[23] However, in recent decades, average annual temperatures in the state have increased.[24] Across the Great Plains, average annual temperatures over the past few decades have increased an average of 1.5°F relative to a 1960s-to-1970s baseline, with the greatest warming occurring during the winter season and in northern areas and precipitation also increasing over most of the region.[25] By the end of the century, average annual temperatures in the Great Plains are projected to increase by 2.5°F to 13°F over the 1960s-to-1970s baseline.[26] For Oklahoma specifically, climate models project a roughly 4°F to 8°F increase in average annual temperature over the 1950-to-1999 mean by the end of the century, with increases in all seasons but more warming in the spring and summer than in the fall and winter.[27] Projections also indicate greater warming in the northern and western parts of Oklahoma, with the panhandle showing the most warming.[28]

Unlike temperature, precipitation projections are not nearly as uniform, with the exception of the expectation of more heavy rainfall events.[29] The southern portion of the Great Plains is expected to become drier and northern areas wetter.[30] For Oklahoma specifically, however, there is no clear trend among climate models regarding future precipitation.[31] In many river basins in the state, warmer temperatures are expected to drive increases in evapotranspiration. By 2100 evapotranspiration is projected to increase 17 to 36 percent in the Blue River Basin, leading to declines in annual runoff of 10 to 30 percent.[32] Furthermore, some months could experience declines of more than 50 percent, increasing the likelihood of the river running dry in future periods.[33] Oklahoma is party to four interstate water compacts: the Canadian River Compact with New Mexico and Texas, the Kansas-Oklahoma Arkansas River Compact, the Arkansas-Oklahoma Arkansas River Compact, and the Red River Compact with Arkansas, Louisiana, and Texas.[34] By mid-century, all of these river basins are projected to see reductions of 5 to 10 percent in streamflow, which could impact the allocation of water under these compacts.[35]

As a result of these changes, the frequency and severity of drought is expected to increase, particularly during the summer.[36] Heat waves and droughts could induce heat and water stress in crops and decrease their yield.[37] Furthermore, decreases in soil moisture as the result of warmer temperatures will lead to greater irrigation needs for agriculture.[38] Changes in established patterns of hydrology will have impacts on the users that rely on these resources for water and could exacerbate competition for dwindling supplies. In particular, reductions in stream runoff could increase reliance on groundwater resources, which in many parts of the state are already overutilized. Additionally, increases in the intensity of rainfall events could lead to more runoff and flash flooding risks, especially in urban areas.[39]

Climate change also could have impacts on aquatic ecosystems. Temperature and precipitation changes impact biodiversity by influencing reproduction, food supply, and habitat.[40] Past drought events have led to observed shifts in the species composition of freshwater mussels from thermally sensitive species to more thermally tolerant ones.[41] Environmental changes can also facilitate the spread of invasive species, which generally are more adaptable to changes in environmental conditions.[42] In particular, playa lakes in Oklahoma, which are ephemeral in nature and supplied by runoff or rainfall, support diverse wildlife and plant communities, especially migratory birds.[43] These lakes are scattered across northwestern Oklahoma and the panhandle region and, prior to cultivation, served as the main source of recharge to the Ogallala Aquifer because of their lack of outflow and internal drainage.[44,45] Changes in temperature and precipitation are expected to alter the characteristics of playa systems and by doing so impact the wildlife and plants that are a part of these ecosystems.[46]

Greenhouse Gas Pollution Reduction

Oklahoma has not established a greenhouse gas pollution reduction target or a plan to reduce pollution in the state. To reduce the state's contribution to climate change, **Oklahoma should adopt a greenhouse gas pollution reduction target and develop and implement a strategy for reducing statewide greenhouse gas pollution.**

State Adaptation Planning

While the state has not developed a comprehensive and crosscutting plan to adapt to climate change, Oklahoma has started to examine the risks that climate change may pose to water resources. After a five-year development process, the state has finalized the 2012 Oklahoma Comprehensive Water Plan (OCWP), whose goal is to provide a reliable source of water for users for the next 50 years.[47] To facilitate development of the OCWP, 82 planning basins were consolidated into 13 regional planning reports that contained data on water demand and supply, forecasted water supply shortages, and potential solutions for addressing those shortages.[48] By 2060 statewide water demands are expected to grow nearly 34 percent.[49] Two-thirds of the planning basins are projected to have deficits between demand and surface water supply by 2060, nearly 80 percent are projected to have alluvial groundwater depletions, and more than 40 percent are projected to have bedrock groundwater depletion.[50]

As part of this analysis, the state evaluated the impact of five climate change scenarios on surface water availability in 2030 and 2060: hot and dry, warm and dry, hot and wet, warm and wet, and a scenario representing the central tendencies of the four other scenarios.[51] In order to best represent the range of temperature and precipitation changes possible in the future, the two most extreme scenarios, hot and dry and warm and wet, were used to determine potential implications for demand—particularly with respect to the irrigation and municipal and industrial (M&I) sectors—and surface water supply.[52]

Table 1. Projected changes in statewide total irrigation and M&I demand under two climate change scenarios in acre-feet per year (AFY).[53]

Year	Baseline (AFY)	Hot and Dry (AFY)	% Change	Warm and Wet (AFY)	% Change
2030	1,488,503	1,610,968	8.2	1,522,741	2.3
2060	1,670,237	1,887,061	13.0	1,731,955	3.7

To determine the potential deficit between demand and surface water supplies, projections of demand and modeled surface water flows under climate change for all 82 OCWP basins were input into the Oklahoma H2O tool, a database and spatial analysis tool.[54] For the hot and dry scenario, increases in surface water deficits when compared with the 2060 baseline, which was based off historical climate and assumptions about water use in each basin, were particularly severe in the central and northeastern areas of the state.[55] Under the warm and wet scenario, there were projected reductions in surface water deficits for many areas in Oklahoma, particularly the panhandle region.[56]

At the statewide level, four options were evaluated to address water deficits: expanded conservation, new reservoir development, the use of marginal-quality water, and artificial recharge projects.[57] At the basin level, five options for meeting water deficits were evaluated: demand management, out-of-basin transfers, additional reservoir development, increased use of surface water, and increased use of groundwater.[58] All of these five options, except for increased surface water use, were considered either typically or potentially effective for most of the state's planning basins.

At the statewide level, the impacts of implementing moderately to severely expanded conservation measures for irrigation and the M&I sectors, such as conservation pricing and high-efficiency plumbing codes, could result in an 18 to 27 percent reduction in M&I demand and an approximately 8 to 22 percent reduction in irrigation demand compared with the 2060 baseline.[59] The plan also noted that the use of treated wastewater effluent and stormwater is potentially viable and cost-effective for non-potable M&I uses because supplies and potential users are generally in the same locations (urban and developed areas).[60] Additionally, five sites were identified in the plan as feasible for artificial aquifer recharge demonstration projects.[61] **Many of the strategies and options identified in the OCWP, particularly increased water conservation and reuse, would help Oklahoma to meet the potentially greater water deficits caused by climate change.**

The inclusion of climate change in the Oklahoma Comprehensive Water Plan is a promising step toward preparing and planning for climate impacts in the state; however, additional efforts are needed. As recommended by the Oklahoma Climatological Survey in its 2007 statement on climate change, **the state should assess vulnerabilities to climate change, reduce demand for energy, and invest in renewable energy technologies like solar and wind.**[62] **The state also should develop a comprehensive adaptation plan that not only builds upon strategies identified in the 2012 OCWP to address water supply risks, but also identifies strategies (such as green infrastructure) to reduce future flood risks as well as strategies for protecting aquatic species.**

While many state agencies have yet to consider and plan for climate change impacts, groups like the Southern Climate Impacts Planning Program have worked to engage Oklahoma communities on adaptation issues. In December 2009 the Oklahoma Climatological Survey and the Southern Climate Impacts Planning Program conducted a workshop on climate adaptation planning that included participants from state and federal agencies, Native American tribes, and local communities.[63] This workshop sought to determine the informational and decision-support needs of stakeholders in order to integrate climate change considerations into planning. A follow-up meeting was held in May 2011 to gather more information on how best to communicate climate information to stakeholders and on informational needs for climate models and tools.[64]

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OREGON

Warmer temperatures and greater atmospheric greenhouse gas pollution levels could have significant impacts on water availability, water quality, and coastal and aquatic ecosystems in Oregon. A 2009 study by the University of Oregon estimates that a business-as-usual approach to climate change potentially could result in annual economic losses of nearly $10 billion, or $3,500 per household, by 2080.[1] The state's recently developed adaptation framework is a step toward building a foundation for Oregon's future adaptation work; however, progress on implementation of the adaptation framework appears to have been put on hold with the election of a new governor and state resource limitations. **The development of more detailed and comprehensive strategies around water resources, and their subsequent implementation, are needed to reduce the state's vulnerability to climate change.**

Water Resources Background

Precipitation in Oregon varies spatially and by season. The Cascade Mountains essentially divide the state into two regions: the wet west and arid east. Western Oregon is more populated and receives four to seven times as much annual precipitation as the eastern regions.[2] The smaller mountain ranges along the coast and the Blue-Wallowa ranges in the northeast also influence climate in the state.[3] Annual average precipitation varies from more than 200 inches along the coast and the Cascades to just a few inches in parts of central and eastern Oregon. The Willamette Valley, home to 70 percent of the state's total population, receives on average 40 to 50 inches annually.[4] Across Oregon, total annual precipitation averages 28 inches, with most falling between October and March.[5, 6]

Because of significant seasonal variations in precipitation, the state relies heavily on the melting of snowpack during the late spring and summer to sustain streamflows. The flow characteristics of particular rivers, however, are influenced by different climate and vegetation regimes (rain-fed, snow- and rain-fed, or snowmelt-fed).[7] Major river basins in the state include the Willamette and Lower Columbia in the west; the Middle Columbia, Deschutes, and Snake in eastern Oregon; and the Klamath in south-central Oregon.[8] The Columbia River drains five of these major river basins: the Lower and Middle Columbia, Deschutes, Snake, and Willamette. The most populous river basin, the Willamette, is home to Oregon's three largest cities: Portland, Eugene, and Salem. Annual runoff from the basin averages 26 million acre-feet, and the river is used for municipal, industrial, domestic, agricultural, hydroelectric, and navigation purposes.[9] The Lower Columbia is used for navigation, the Middle Columbia for both navigation and hydropower generation, and the Snake River for hydropower, navigation, and agriculture.[10] The Klamath provides water to agricultural and wildlife refuge lands and hydropower generation.[11] The state also has significant groundwater resources, which make up approximately 95 percent of total freshwater resources in Oregon.[12]

Irrigation is the largest user of water in the state, accounting for nearly 80 percent of total water use statewide; in dry eastern Oregon, 97 percent of water withdrawals are for irrigation.[13] Domestic uses constitute less than 6 percent of total water use, but as population rises, water demand also is expected to increase.

Although Oregon's coast is sparsely populated, it contains 400 miles of beaches and dunes that play a vital role in attracting tourism.[14] Historically the coastal region's economy has depended on fishing, farming, and logging; however, in recent years, tourism has grown as a component of the economy.[15] Oregon's commercial ocean fishery contributes approximately $220 million annually to the state economy, and recreational fishing and wildlife viewing provide almost $900 million more.[16] Resource-based industries have largely declined due to decreasing availability of natural resources for production, shifts in how natural resources are perceived (with greater value now placed on recreational or natural uses), and declining prices for fish products.[17] However, in some counties, like Tillamook and Coos, they remain considerable contributors to the economy.[18]

Climate Change Impacts on Water Resources

From 1920 to 2000, a warming trend of 1.5°F per century was observed in the Pacific Northwest.[19] Throughout the historical record, regionally averaged precipitation has varied, with no discernible trends in total annual precipitation or extreme precipitation events. As the result of a 40 percent decline in April 1 snowpack from 1961 to 2009 in the Upper Klamath River Basin, dry-season (April to September) and summer (July to September) streamflow have declined 16 percent and 38 percent, respectively.[20] Between 1900 and 2004, glaciers in Oregon have lost between 40 and 60 percent of their area as a result of warming temperatures.[21] In particular, glaciers on Mount Hood have declined as much as 61 percent in length over the past century.[22] Over the 20th century, relative sea level rise in the Pacific Northwest has increased at a rate of nearly 0.10 inch per year.[23]

Temperature in the Pacific Northwest is projected to increase 4.5°F to 6.1°F in temperature by the 2080s. Projections for annual precipitation, however, show no clear consensus, with models showing both decreases and increases.[24] Seasonal trends in the climate models are more distinct, with the greatest precipitation decreases projected for the summer months and greatest precipitation increases projected for the winter.[25] There is also some indication that extreme precipitation events will increase in frequency over the course of this century, potentially placing urban areas at greater risk to flooding.[26,27]

As a result of increasing temperatures, snowpack in the Cascades is expected to decline by more than 50 percent by 2050.[28] Because snow in this region accumulates close to the melting point, warming could readily lead to a shift from a snow-dominated winter precipitation regime to a rain-dominated regime.[29] This change, in turn, would increase winter peak flows and decrease summer low flows. A 2011 study by the U.S. Bureau of Reclamation (USBR) projects an increase of nearly 30 percent in mean December-to-March flow and an 8 percent reduction in mean April-to-July flow by 2050 for the Williamson River (part of the Klamath River Basin).[30] Because many reservoirs in Oregon are also operated for flood control, increased flows during the winter may prompt changes in reservoir management to allow for greater flood capacity in the winter—changes that may come at the expense of dry season supplies.[31] Summer streamflow is also most vulnerable to greater losses from evapotranspiration as a result of warming.[32] Reduced summer flows would have severe implications for agriculture, recreation, fisheries, hydropower, and many other sectors. In addition, studies have projected that spring peak streamflow will occur up to a month earlier by 2050 as a result of warming in snowmelt-dominated regions of the western U.S.[33] Increased evapotranspiration rates as a result of warmer temperatures may also lead to reduced groundwater recharge as less runoff is available to percolate below plant roots.[34] As surface water supplies become less reliable, greater groundwater pumping is likely, leading to further depletion of underground aquifers.

Climate change also is likely to lead to increases in water demand as annual consumption patterns show increases in warmer, drier months and in warmer, drier years.[35] In fact, summer water use generally can be up to three times the yearly average in urban areas.[36] Moreover, a temperature increase of 1.8°F is projected to result in at least a 10 percent increase in irrigation demand in arid and semi-arid areas.[37] Consequently, water stress as a result of reduced surface water supplies in the summer may be exacerbated by greater demand. In the notorious Klamath River Basin, conflicts over water have existed for many decades among agricultural users, Native American tribes, and environmental interests, including those who wish to protect threatened and endangered fish populations. In 2001 USBR shut off irrigation water to 1,400 farms in order to meet minimum water level requirements in the Upper Klamath Lake for the endangered Lost River sucker and short-nosed sucker.[38] In 2002 low flows resulting from upstream water diversions, in concert with other factors, resulted in the death of more than 33,000 fish in the Lower Klamath River.[39] Conflicts like these will only intensify as changes in water supply and demand, in the absence of infrastructure modifications, require trade-offs among hydropower generation, reservoir storage, flood control, and in-stream flows for fish.[40]

Changes in hydrology as a result of climate variability are also likely to have impacts on water quality. In Oregon water temperatures are largely impacted by riparian vegetation through shading and by streamflow. Water temperatures historically have been highest during July, August, or September.[41] Reductions in summer streamflow, in the absence of increases in vegetation cover, could lead to increased water temperatures, which would have impacts on the range of coldwater aquatic species. Late-summer flow reductions would be especially detrimental as salmon move into spawning areas in September because such reductions could limit how far upstream the fish can swim.[42] Furthermore, greater winter streamflows are likely to lead to greater winter sediment and nutrient loading.[43]

Higher turbidity would also have direct impacts on the operations of surface water treatment facilities by reducing overall capacity and increasing treatment costs.[44] Water quality in estuaries, particularly salinity, is also likely to be impacted by changes in freshwater inflow and sea level rise. Moreover, the frequency and range of waterborne diseases are expected to increase with rising temperatures and increased flooding.[45]

The active plate tectonics of the Pacific Northwest, where oceanic plates are sliding beneath the continental plate, is altering land elevations along Oregon's coast. As a result, some shore areas are rising at rates faster than the rate of sea level rise.[46] Nonetheless, the projected increase in rates of sea level rise is expected to exceed the rates of land uplift along the Oregon coast by the middle of the 21st century.[47] In areas of the coast with little uplift, projections for relative sea level rise are 1.8 feet by 2050 and 4.2 feet by 2100.[48] Interannual variations in sea level are also significant along the Pacific Northwest coast. Strong El Niño events in the past have led to increases in sea level of more than 1.25 feet during the winter months.[49] Sea level rise as a result of climate change over the long term, in addition to short-term fluctuations resulting from El Niño and winter storm events, has the potential to pose significant erosion and inundation risks to coastal areas. Over the past 150 years, an estimated 70 to 90 percent of tidal wetland habitat in Oregon has been altered or lost as a result of anthropogenic activity.[50] Sea level rise will cause further losses in wetland areas, reducing the wildlife habitat, flood control, and water quality benefits of such areas. In addition, infrastructure (roads, airports, stormwater systems, etc.) and private and public property along the coast would be at risk to higher sea levels, coastal erosion, and flooding.[51] Increased temperatures in the ocean and acidification from higher carbon emissions would also impact the distribution and abundance of marine species.[52]

Greenhouse Gas Pollution Reduction

In 2004 the Governor's Advisory Group on Global Warming released its final report containing a strategy for reducing statewide greenhouse gas emissions.[53] In 2007 then-Governor Ted Kulongoski signed House Bill 3543, which set statewide greenhouse gas emissions targets of 10 percent below 1990 levels by 2020 and 75 percent below 1990 levels by 2050.[54] However, the state has failed to adopt regulatory mechanisms to bring emissions down to these levels and is no longer an active participant in the Western Climate Initiative (WCI), a collaboration aimed at reducing regional greenhouse gas emissions through a cap-and-trade program.[55] Establishing greenhouse gas reduction targets is a step in the right direction; nevertheless, **Oregon should develop regulatory tools to ensure that the state achieves these pollution reduction levels.**

State Adaptation Planning

In 2008 the Climate Change Integration Group (CCIG) appointed by Governor Kulongoski released a broad framework to guide Oregon's climate change activities in four key areas: preparation and adaptation, mitigation, education and outreach, and research.[56] This report built upon earlier state efforts on mitigation and laid the foundation for the state's future activities on adaptation. The CCIG urged the state to include climate change considerations in current planning and decision-making processes, to utilize a holistic approach to planning and decision-making that acknowledges interconnected systems, and to establish a dynamic planning process that has adaptation as a cornerstone.[57] In this report, the CCIG identified 10 key themes. Within the preparation and adaptation area, these themes included acting immediately to prepare for climate change, developing localized climate change assessments, and assisting organizations and individuals in responding to climate change.[58] This initial framework was largely lacking in detail regarding specific actions that Oregon should undertake to adapt to climate change.

To further advance adaptation planning, the governor directed state agencies in October 2009 to develop a climate change adaptation plan. The Oregon Climate Change Adaptation Framework, released in December 2010, is the result of this interagency initiative, which was designed to complement the Oregon Climate Change Research Institute's in-depth report on potential climate change impacts in the state. Eleven climate risks are identified and ranked according to their likelihood of occurrence within the next 40 to 50 years. In light of state budgetary concerns, only short-term actions considered to be of low cost and high benefit were identified as priorities in this framework.[59] Six of the eleven priority climate risks were directly related to water resources, with two other risks focused broadly on plants and wildlife and disease and pest incidence. The report identifies changes in hydrology and water supply, including changes in water quality and the timing of water availability, as a climate risk that is very likely to occur (greater than 90 percent probability) through 2050.[60] Priority actions recommended for implementation within the next two to three years included maintaining the capacity to provide assistance to landowners for the restoration of areas, such as wetlands, that increase natural water storage; improving real-time forecasting to improve reservoir management; and increasing the capacity to provide technical assistance and incentives to increase storage capacity, conservation, reuse, and efficiency among all water users.[61] The remaining water-related climate risks were all considered either likely to occur (greater than 66 percent chance) or more likely than not (greater than 50 percent chance). These climate risks included changes to marine water quality (temperature, pH, etc.), increased incidence of drought, increased coastal erosion and inundation from sea level rise, loss of wetland ecosystems, and increases in damaging floods and extreme precipitation events.[62] The priority actions for these climate risks largely revolved around better research, monitoring, inventorying, and mapping of climate change vulnerabilities and risks.[63]

While this adaptation framework is more specific than the CCIG framework developed in 2008, it is still lacking with regard to specific measures that Oregon can implement to begin adapting to climate change impacts now. While the interagency group acknowledged the benefits that greater water conservation, efficiency, and reuse measures would provide if adopted by all water users, the framework lacked details on what specific measures would be most beneficial or practicable for adoption in the short term. **Recommended measures could include such things as a statewide per capita water conservation goal, like the one adopted by California, or an assessment of barriers to greater use of recycled water, as has been done in Arizona.** This lack of detail is also seen in the report's discussion of changes in abundance and distribution of plant species and wildlife habitats. The short-term action suggested for this climate risk is to identify ways to manage ecosystems that improve their resilience to changes in climate—an extremely general recommendation. While certainly well intentioned, recommendations that are not well defined do not readily translate into concrete actions.

In addition, the issue of economics is a recurring theme throughout the framework report. The interagency group not only noted that information about the costs and benefits of adaptation actions is lacking, but also developed its list of priority short-term actions based upon what is perceived to be implementable given current budgetary restraints. The concern over limited state resources appears to handicap what otherwise could have been a comprehensive, well-developed, and detailed adaptation plan. As the framework itself notes, adapting and preparing for climate change is not necessarily about developing new programs and processes, but about including climate change considerations (that is, mainstreaming climate change) into existing planning and decision-making processes. Establishing a foundation for future adaptation work by assessing climate risks and vulnerability is important; however, **there are many "no regrets" strategies that can be implemented now, such as increasing the efficiency of water distribution networks or developing an on-site stormwater retention standard, that provide benefits in the short term while also building resilience over the long term.** Furthermore, omitting potential climate change impacts as a component in land use, permitting, and infrastructure planning decisions inherently increases climate risks and vulnerability. **In future planning efforts, Oregon should push for a wider-ranging adaptation plan that contains specific policies and actions the state can undertake to reduce risks from a changing climate.**

Unfortunately, progress on implementation of the adaptation framework appears to have been put on hold with the election of a new governor and state resource limitations. While the state's adaptation framework has not yet been formally implemented, Oregon is conducting local- and regional-scale adaptation studies. In October 2010, Oregon State University, the University of Oregon, and Portland State University began a five-year study on how population growth, economic growth, and climate change may alter water availability and use patterns over the course of this century in the Willamette River Basin.[64] The state, in partnership with Washington State, will also be ranking climate risks identified in the adaptation framework through a collaborative process as part of a regional contribution to the next National Climate Assessment.[65] Oregon is also hoping to conduct pilot assessments at the regional and local levels to develop quantitative data regarding climate risks to support adaptation planning at a smaller scale.[66]

Aside from the adaptation framework, there are several other climate change adaptation efforts ongoing at the state level. As required by the legislative assembly, the Oregon Water Resources Department, Department of Environmental Quality, Department of Fish and Wildlife, and Department of Agriculture are developing an integrated water resources strategy to help the state meet future water needs in terms of quantity, quality, and ecosystem functions; it will include a discussion of how climate change may impact future water supplies and demands.[67] In December 2011, a discussion draft was released for public comment. This draft identified climate change as a critical issue and recommended that the state continue to support basin-scale climate change research and assist with the development of adaptation and resiliency strategies.[68] The final strategy is scheduled for completion by December 2012 for implementation and evaluation during the 2012-2017 period. In 2008 the Subcommittee on Fish, Wildlife, and Habitat Adaptation of the Oregon Global Warming Commission released a report containing guiding principles for fish and wildlife adaptation.[69] These principles included maintaining and restoring key ecosystem processes, ensuring habitat connectivity, evaluating management actions in light of anticipated climate impacts, and coordinating across political and jurisdictional boundaries. In October 2010, the Oregon Parks and Recreation Department released its guidance plan for mitigating, responding to, and adapting to climate change.[70] Notable items in this report included the continued promotion of natural shoreline protection measures; consideration of longer timescales when making major planning and infrastructure investments; and avoiding development in highly vulnerable floodplains, erosion hot spots, and fire-prone areas. The Oregon Watershed Enhancement Board is also funding a joint study with the states of California and Washington by the National Academy of Sciences on sea level rise estimates for 2030, 2050, and 2100.[71]

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PENNSYLVANIA

Pennsylvania possesses substantial water resources, from its many rivers and lakes to its shores on Lake Erie to the Delaware River Estuary. However, climate change is likely to exacerbate existing challenges of increasing water demand and water quality issues and to pose new problems for the state's water resources. Like other states across the northeastern U.S., Pennsylvania is expected to become warmer and wetter and to experience more short-term droughts and floods. The state has responded proactively to these challenges by beginning to address climate change issues through the development of a greenhouse gas pollution reduction plan and an initial adaptation strategy. However, it is not clear how much implementation will occur due to staffing reductions in state agencies and the lack of political support at the executive and legislative levels. The state's preliminary adaptation plan is intended to be integrated into the next iteration of the state's climate action plan, due in October 2012. **Moving forward, Pennsylvania should ensure that the adaptation plan's recommendations are more robustly developed, included in future planning efforts, and implemented by the relevant state agencies.**

Water Resources Background

Across Pennsylvania, annual precipitation averages 35 to 54 inches per year, with most precipitation occurring during the spring and summer.[1] However, annual snowfall averages from about 20 inches in the southeast to more than 100 inches along Lake Erie.[2] During the warm season, coastal storms bring heavy rains; in the winter they can bring both heavy snow and rain.[3] In the summertime, thunderstorms are responsible for most of the rainfall. The Blue Ridge Mountains and the Allegheny Mountains, the most prominent geographical features, split the state into several climatic zones. The Coastal Plain and Piedmont Plateau along the Delaware River in the east have a more moderate climate due to the river; they also experience greater precipitation than other parts of the state due to the prevalence of coastal storms.[4] In contrast, the mountainous regions in the center of the state receive 3 to 4 more inches of precipitation on average than the rest of the state and tend to be cooler and more prone to temperature extremes since they lack the moderating effects of the Delaware River.[5] The third region in the state, the Allegheny Plateau, which makes up approximately half the state, extends north and west from the mountains to the state's border with Ohio and New York. This region generally receives about the same amount of precipitation as the statewide average but in the form of more frequent and smaller storms.[6]

Pennsylvania has about 86,000 miles of streams and rivers, 120 miles of shoreline on Lake Erie and the Delaware Estuary, and almost 4,000 lakes, ponds, and rivers.[7] Major watersheds in Pennsylvania include the Delaware River, which forms the state's eastern boundary, the Susquehanna River in the central portion of the state, the Ohio River in the west, and small parts of the Great Lakes and Potomac River watersheds in the north and south, respectively. The state also has substantial groundwater resources, which are approximately 30 times greater than total surface water resources.[8] Underground aquifers are generally recharged between November and May, when infiltration exceeds evapotranspiration, with 15 to 20 percent of annual recharge typically occurring in March.[9] Furthermore, the state's surface waters and groundwaters are interconnected, with about 65 percent of total streamflow coming from base flow, or the discharge of groundwater to surface water.[10]

Pennsylvania water users withdrew approximately 3.5 trillion gallons (approximately 10.9 million acre-feet) in 2008.[11] With just over 70 percent of total withdrawal, thermoelectric power generation is the largest overall withdrawer of water in the state.[12] The second-largest water withdrawer is public supply, which accounts for approximately 15 percent of total statewide withdrawals, followed by industrial use at 12 percent.[13] Mining and agriculture are both very small overall users of water, with only 2 percent and 1 percent, respectively, of total withdrawals. While groundwater is a relatively small source of water, providing less than 6 percent of total water withdrawals in 2005, it is an important source of water for industry, agriculture, mining, and drinking.[14,15] Aquifers supply drinking water to 4.5 million people, approximately 37 percent of the state's total population.[16]

Pennsylvania's most recent state water plan, released in 2009, identifies population changes and growing demand for energy as two factors that may affect water usage in the future. With nearly 12.5 million people, the state ranks sixth in the nation in population, though growth has been fairly slow in recent years. Rather than overall growth, a shift in population is more of a concern for water resources, with counties in the northern and western portions of the state losing population to urban and suburban areas in the east.[17] Disproportionate population growth can lead to uneven geographic demand for water, which can be a challenge from a water resource planning perspective.[18] Because power generation is such a large withdrawer of water in the state, growing energy demands could potentially place additional stresses on water resources.

In addition, the hydraulic fracturing (hydrofracking) technique currently being used to recover natural gas from the Marcellus Shale, part of which underlies Pennsylvania, utilizes substantial amounts of water, as do bioethanol facilities—and both sectors are expected to grow in the near future.[19] Hydrofracking involves the injection of millions of gallons of water, along with sand and chemicals, into underground rock formations to release natural gas deposits. This technique poses significant public health and environmental risks. The large quantities of water required can affect local water supplies, and the chemicals used can contaminate drinking water supplies either through spills, during the drilling and hydrofracking process itself, or afterwards if the flow-back and produced water, which also contains naturally occurring contaminants, is stored, handled, or disposed of improperly.[20]

The Great Lakes Compact

The Great Lakes contain six quadrillion gallons of water (about 18.4 billion acre-feet), more than one-fifth of the world's surface supply of freshwater and more than 95 percent of the surface freshwater supply in the U.S.[21] Although the volume of the Great Lakes is vast, less than 1 percent of its waters are renewed annually through precipitation, runoff, and infiltration.[22] The Great Lakes Basin ranks third in terms of total freshwater use out of the 21 major watersheds in the U.S.[23] Lake levels are expected to decline over the next century in each of the Great Lakes, from one foot on Lake Superior to as much as three feet on Lakes Michigan and Huron.[24] Management and use of water in the eight Great Lakes states is governed by the Great Lakes−St. Lawrence River Basin Water Resources Agreement and Compact.[25] In ratifying the Compact, each state agreed to undertake a series of actions, including the establishment of thresholds governing new or increased withdrawals of water; implementation of a permitting process for new withdrawals; development of water conservation and efficiency programs, including the establishment of state-specific goals and objectives to guide individual states' programs; and improved data gathering and sharing across the basin. In addition, the Compact directs states to "[g]ive substantial consideration to climate change or other significant threats to Basin Waters and take into account the current state of scientific knowledge, or uncertainty,"[26] and to take appropriate measures, such as adaptive management, to address these threats.

Climate Change Impacts on Water Resources

Pennsylvania's annual average temperature has increased by more than 0.5°F over the past century.[27] During the next century, temperatures are expected to increase at an accelerated pace. Annual average temperatures are projected to warm by 2.5°F over the next few decades.[28] By the end of the century, average temperatures under a high-emissions scenario could rise as much as 8°F in the winter and 11°F in the summer, relative to historic averages.[29] In addition, the state has experienced a precipitation increase of 5 to 20 percent over the past century, with average statewide annual precipitation rising from 38 inches to more than 44 inches.[30] Since 1970, winter, spring, and fall have become generally wetter while summer has become drier.[31] This general trend is projected to continue. Under both low- and high-emissions scenarios, Pennsylvania is projected to receive approximately 5 percent more rainfall by mid-century and 12 percent more by the end of the century, with seasonal increases in the spring and fall.[32] The occurrence of heavy precipitation events is also expected to become more frequent.[33] While annual precipitation totals have increased, interior areas of the state have seen a decline in average seasonal snowfall of several inches since 1970.[34] As temperatures warm, the length of the snow season is projected to decline as snow arrives later in the fall and melts earlier in the spring.[35]

These changes in climate will impact a variety of sectors in Pennsylvania. Warmer temperatures and subsequent declines in snow cover could adversely impact the state's $160 million annual snowmobile industry and $370 million annual skiing industry.[36] Increases in temperature could lead to increased rates of evapotranspiration and decreased soil moisture levels, which could have potentially severe implications for the agricultural sector. These changes are likely to increase crop irrigation needs, particularly if precipitation levels decline. Pennsylvania is the leading producer of mushrooms in the U.S.; other important crops include wheat, potatoes, other grains, and fruit.[37] Higher summer temperatures coupled with little change in summer precipitation could increase the frequency of short-term droughts, primarily in the north-central mountains and the Poconos.[38] In these areas, short-term droughts could be an annual occurrence by the end of the century under a high-emissions scenario.[39] However, climate change also could be potentially beneficial to agriculture by lengthening the growing season. While projections for more precipitation overall suggest that Pennsylvania might experience increased water supplies through greater streamflow and runoff, the projected increases in temperature and changing streamflow patterns could lead to decreased supplies during the summer.[40] Moreover, precipitation increases during the winter and spring could impact water quality and increase flooding risks.[41] In older cities like Pittsburgh, dozens of combined sewer overflows (CSOs) occur each year, and more precipitation during the spring and winter could contribute to more frequent CSOs in the future.[42] CSOs occur when the volume of wastewater and stormwater exceeds the capacity of the treatment system, leading to discharges of untreated water, which contains bacteria and other pollutants, into receiving water bodies. In addition, more heavy rainfall events are likely to render many municipal combined sewer systems inadequate.[43]

The warming of waters is affecting the state's bass and trout populations, which require cold water temperatures to thrive. Brook, brown, and rainbow trout species are particularly sensitive to warm temperatures and streamflow changes during the reproductive and juvenile stages.[44] Spawning and embryo survival typically require temperatures below 50°F.[45] Moreover, water temperature is one of the primary limiting factors affecting the range of smallmouth bass. Warmer water and changes in water quality in prime habitats like the Susquehanna River are likely to alter the distribution of bass species.[46]

Although Pennsylvania has relatively little shoreline (compared with other states) along Lake Erie and the Delaware Estuary, these water resources play a vital role in the state's economic well-being. The estuary provides drinking water to millions of people in Pennsylvania and contains the Delaware River Port Complex, which generates $19 billion annually and is the largest freshwater port in the world.[47] In addition to being a significant water source, Lake Erie is an important recreational fishery, particularly for steelhead, with approximately 1.5 million fish caught annually by anglers.[48] It also contains the state's only coastal beach, Presque Isle, a source of recreation and fishing.[49] Climate change is likely to have wide-ranging impacts upon these water resources. Sea level rise is expected to cause salinity changes by bringing saltwater farther up the estuary, which would impact the estuarine ecosystem in addition to degrading source water quality for drinking water supplies.[50] Furthermore, warmer temperatures are likely to reduce winter ice cover and increase evaporation from the Great Lakes, which would increase shoreline erosion risks and lead to reduced water levels.[51] Reduced water level could impact commercial sectors by limiting the amount of cargo that vessels can carry; it could also affect recreation by altering access to marinas. Large vessels lose up to 240 tons of cargo capacity for every inch of draft (the distance between the bottom of a ship and the water line) lost.[52] Warmer water temperatures and changes in water quality also could alter the distribution of aquatic species within the Great Lakes and favor the spread of nonnative or invasive species.[53]

Greenhouse Gas Pollution Reduction

With the Pennsylvania Climate Change Act of 2008, the Pennsylvania Department of Environmental Protection (DEP) and the state's Climate Change Advisory Committee were authorized to prepare a report recommending actions the state could take to reduce greenhouse gas pollution. This report, the "Pennsylvania Climate Change Action Plan," was released in 2009. This plan recommended that the state establish a greenhouse gas emissions reduction target of 30 percent below 2000 levels by 2020.[54] To date, the state has not adopted this greenhouse gas reduction target or any other. **Pennsylvania should reduce its contribution to climate change by adopting a greenhouse gas pollution reduction target and enacting strategies from the state's climate action plan to meet this goal.**

State Adaptation Planning

Pennsylvania has begun planning for climate change impacts. Although it was not required by the Climate Change Act, the Climate Change Advisory Committee decided to create a companion state adaptation plan. In March 2010, the adaptation planning process was initiated with the idea that its recommendations would be incorporated into the next iteration of the state's climate action plan, which is statutorily required to be updated every three years.[55,56] A preliminary report outlining these options, the Pennsylvania Climate Adaptation Planning Report, was released in January 2011. This report was developed by convening a broad cross-section of stakeholders, and water resources were addressed by both an Infrastructure Working Group and a Natural Resources Working Group.[57] DEP made several cross-cutting recommendations, such as implementing "no regrets" actions like green infrastructure strategies to manage climate change impacts while simultaneously providing energy savings and other co-benefits, conserving wildlife habitat to build resilience, and establishing a state adaptation team within state government to oversee plan implementation.[58] In particular, DEP noted that green infrastructure can reduce the flow of sediment and pollutants to receiving waterways. As an example of the effectiveness of green infrastructure, the report highlighted Philadelphia's efforts to control combined sewer overflows through the Green City, Clean Waters program.[59] This program encourages the use of strategies that do not rely on infrastructure expansion, such as rain barrels, rain gardens, green streets, and bioretention areas, to filter runoff and reduce the estimated 80 to 90 percent of river pollution caused by stormwater.[60] The plan has been approved by DEP and is receiving a $30 million loan from the state's PENNVEST program.[61]

Another action recommended by DEP is to integrate "no regrets" water efficiency and conservation improvements into water resources planning.[62] Furthermore, the report recommended integrating a climate change 'lens' into existing state agency planning and providing adaptation strategies and training to water and wastewater utilities.[63] DEP also recommended supporting flood management assessments of state infrastructure and prioritizing natural floodplain restoration and funding to high-hazard facilities.[64] The report also recommended that the state include public health response in the climate action plan and address public health impacts from floods and droughts through preventive, awareness, response, and recovery measures.[65] Unfortunately, since the release of the adaptation plan, there have been significant reductions in staffing for DEP's Climate Change Program, and the department has been unable to conduct outreach to local and municipal governments on adaptation issues.[66] While adaptation strategies identified in this report and others are worked into the next iteration of the state's climate action plan, due in October 2012, **Pennsylvania should develop an interagency and stakeholder climate adaptation team. State agencies also should focus on implementing strategies identified in the plan in the near term to jump-start adaptation, as is being done with green infrastructure in Philadelphia.**

Several authorities throughout Pennsylvania have authority over water resources management and have been active in climate change planning. These include DEP, the Department of Conservation and Natural Resources (DCNR), the Pennsylvania Fish and Boat Commission (PFBC), the Pennsylvania Infrastructure Investment Authority (PENNVEST), the Department of Community and Economic Development, the Delaware River Basin Commission, the Susquehanna River Basin Commission, and others.[67] Most of these authorities generally have either assessed climate change impacts independently (in the case of the two river basin commissions) or were involved in the creation of the adaptation report (in the case of the state agencies). **Because water is a cross-cutting issue, it will**

be important for these agencies and commissions to continue to work together to make sure climate change preparedness is integrated and uniformly implemented across Pennsylvania.

In addition to the adaptation planning report, a separate, parallel effort to assess adaptation priorities was undertaken by DCNR, the Pennsylvania Game Commission, PFBC, and the Nature Conservancy. Their report, "Weathering Climate Change: Framing Strategies to Minimize Impacts on Pennsylvania Ecosystems and Wildlife," was released in 2010.[68] To develop this report, interviews were conducted with stakeholders in the conservation field regarding climate change adaptation.[69] Specific recommendations included promotion of "on-the-ground" actions, such as riparian buffers, to help the public realize local opportunities for climate adaptation and the development of "no regrets" strategies that would benefit the environment generally while also minimizing climate impacts.[70]

Pennsylvania has worked to integrate climate change into existing planning frameworks and processes as well. The 2009 State Water Plan specifically called for integrating climate change impacts into water resource planning decisions and also mentions that the status quo for water resources planning, relying on the historical record to predict patterns and future conditions, is likely to be ineffective in a future affected by climate change.[71] In order to address the issues that climate change, population growth, and other factors may pose in the future to water resources, the plan recommended that integrated water resources management be adopted; that water conservation and efficiency measures be improved through incentives, metering, and pricing changes; that water use registration and reporting regulations be reformed; and that the flooding sections of the state's hazard mitigation plan be revised and updated.[72] The plan also identified alternative water sources, such as water reuse and stormwater capture, for decreasing potable water demand, regionalization of water systems to improve reliability and flexibility, and groundwater recharge through natural or artificial methods.[73] Because the demand for new energy-generation facilities is expected to grow in the future and considering the water-intensive nature of power generation, DEP also recommended that all new and existing facilities recycle their process water to meet future cooling water demands.[74]

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RHODE ISLAND

Greater climate variability and rising sea levels pose a significant risk to Rhode Island: Between 2010 and 2050, the state could lose $700 million in GDP and more than 3,000 jobs as a result of reduced water availability.[1] During the Great Flood of 2010, the state received nearly 9 inches of rain during a two-day period.[2] Following an abnormally wet winter, this torrential amount of rain led to the displacement of 2,000 people and an unprecedented cresting of the Pawtuxet River at nearly 21 feet—more than twice its flood level of 9 feet.[3] Precipitation projections point to the increasing likelihood of similar extreme events in the future. Within recent years, the state has undertaken several initiatives to address climate change impacts. One such example is the state's push to explicitly consider sea level rise in the siting, design, and implementation of coastal programs and projects. **Rhode Island should work to better understand the implications of climate change for water supply and water quality and develop a comprehensive adaptation plan to ensure that the people and resources of the state are better prepared for these impacts.**

Water Resources Background

The state's close proximity to Narragansett Bay and the Atlantic Ocean has a moderating impact on climate. Precipitation is fairly evenly distributed throughout the year, with an annual average of approximately 42 inches.[4] Coastal storms are responsible for the most severe weather, and thunderstorms contribute the most to precipitation between May and August.[5] Lakes, ponds, and reservoirs cover more than 20,000 acres of the state, with Watchaug Pond, Flat River Reservoir, Worden Pond, and Scituate Reservoir being the four largest surface water bodies.[6] Throughout the state, surface water reservoirs provide 85 percent of the total water withdrawn for public consumption, and groundwater supplies the rest.[7] However, in areas in the southern and western portions of the state, underground aquifers provide drinking water to 100 percent of the population, and overall, two-thirds of all municipalities utilize groundwater resources.[8,9] The state's most substantial and productive aquifers lie in glacial deposits of stratified drift west of Narragansett Bay in southern Rhode Island.[10] Groundwater and surface water resources in Rhode Island are well interconnected: Groundwater is recharged by surface waters and also provides base flow to streams.[11] As a result of contamination and aging infrastructure at other water sources, the Scituate Reservoir now supplies 60 percent of the state's population—an increase of 300 percent in just 50 years.[12] According to 2005 data from the U.S. Geological Survey, nearly 90 percent of total freshwater withdrawals in Rhode Island are utilized for municipal and domestic purposes.[13] Additionally, residential water use in the summer doubles or triples as landscape irrigation demands increase.[14] This substantial seasonal peak in water demand has caused some rivers, such as the Hunt, to almost run dry in the summer.[15]

While the state's direct ocean economy contributes only 3 percent to the total state GDP, the entire state lies within the coastal zone, and therefore the coastal economy includes all economic activity within Rhode Island—worth nearly $47 billion annually.[16] The state's 400 miles of shoreline and more than 100 beaches provide support for the tourism and recreation industry, the fourth-largest industry in the state.[17] Moreover, Narragansett Bay, a central physical and cultural component of the state, has an economic impact of billions of dollars annually.[18]

Climate Change Impacts on Water Resources

From 1905 to 2006, annual mean temperature in Providence increased at an average rate of 0.17°F per decade; however, between 1961 and 2006, warming occurred at a faster rate of 0.56°F per decade.[19] As a result of these temperature increases, spring is arriving earlier, summers are hotter, and winters have less snow.[20] Across the region there has also been an increase in heavy precipitation events, less winter precipitation falling as snow and more as rain, earlier breakup of winter ice on lakes and rivers, and earlier spring snowmelt.[21] Overall, during the 1905-to-2006 period, there was a 32 percent increase in precipitation in the state.[22] Under a high-emissions scenario, temperatures are projected to rise 6°F to 14°F in the summer and 8°F to 12°F in the winter across the Northeast by the end of the century.[23] In addition, by 2100, annual precipitation is expected to increase by 10 percent, with winter precipitation rising by 20 to 30 percent and a greater proportion of precipitation falling as rain rather than snow.[24] Precipitation projections also suggest that both the frequency and the intensity of extreme precipitation events will increase—signifying that more of the total annual precipitation will occur in heavy events.[25] Due to these climatic changes, flooding risks are expected to increase as high-flow events become more frequent in response to earlier and faster snowmelts. Heavy precipitation events also can have implications for water quality because stormwater runoff frequently contains pollutants and nutrients and can also overwhelm wastewater treatment facilities, leading to the discharge of untreated sewage, as seen during the flooding in 2010.[26] The period of low flows during the summer is also expected to lengthen due to peak flows occurring earlier.[27] The occurrence of short and medium-term droughts could also increase.[28]

As a result of increasing air temperatures, sea surface temperatures along the New England coast have warmed 2.2°F to 4°F since the 1960s.[29] These temperatures are projected to increase 4°F to 8°F by the end of 2100.[30] Ocean temperatures have a significant influence on the spatial distribution and reproduction of marine species and also play a role in the occurrence of algal blooms, marine diseases, and the spread of invasive species.[31] In Narragansett Bay and Rhode Island Sound in particular, a gradual transition from a fish-dominated to an invertebrate-dominated community was observed between 1959 and 2005 as a result of temperature increases.[32]

As measured by tide gauges in Newport between 1930 and 2008, sea level has risen at a rate of 0.10 inch per year as a result of land subsidence, thermal expansion of the ocean, and melting of land-based ice sheets.[33] Depending on future emissions scenarios, global sea level is projected to rise 0.6 to 2 feet by 2100; however, these estimates are probably conservative since they do not take into account the recently observed melting of major ice sheets or the potential for accelerated melting.[34] More recent studies that consider these factors project global sea level rise on the order of 2.5 to 6.2 feet by the end of the century.[35] Sea level rise could contribute to erosion and flooding that threatens coastal habitat, property, and infrastructure. As a consequence of warmer ocean temperatures, the intensity of tropical cyclones is also expected to increase.[36] In concert with higher sea levels, this could lead to more damaging storm surges and coastal flooding. Ocean acidification, which could threaten marine animals with calcium carbonate shells or skeletons and increase the corrosion of marine infrastructure and vessels, is also a growing concern as more carbon dioxide is absorbed by the oceans.[37]

Greenhouse Gas Pollution Reduction

In 2001 Rhode Island committed to reducing greenhouse gas emissions by 10 percent below 1990 levels by 2020 and as much as 85 percent below 1990 levels over the long term under the New England Governors' and Eastern Canadian Provincial Premiers' Climate Change Action Plan.[38] To achieve these goals, the state developed a greenhouse gas action plan in 2002.[39] **Rhode Island should update this action plan as necessary to reduce statewide pollution and the state's contribution to climate change.** The state also is a member of the Regional Greenhouse Gas Initiative, a collaboration among nine states in the northeastern and mid-Atlantic U.S. to reduce regional greenhouse gas emissions through a cap-and-trade program.[40]

State Adaptation Planning

In 2010, the state General Assembly created the Rhode Island Climate Change Commission through passage of the Rhode Island Climate Risk Reduction Act.[41] The commission is tasked with studying the projected impacts of climate change on the state, developing strategies to adapt to these impacts, and determining mechanisms to incorporate climate adaptation into existing state and municipal programs. Although the act set a March 2011 due date for the commission's report, the commission met for the first time in December 2011 and will submit a brief progress report to the General Assembly in May 2012.[42] The creation of a formal commission to develop a comprehensive adaptation plan is a promising step forward. **Rhode Island should fully support the work of the commission so that comprehensive strategies and actions to address climate change impacts in the state can be developed and implemented.**

Fortunately, there are other efforts at the state level to prepare for climate change, particularly in coastal areas. The Rhode Island Coastal Resources Management Council (CRMC) adopted a policy in 2008 stating that the agency would integrate climate change and sea level rise into operations and accommodate a 3- to 5-foot rise in sea level in the siting, design, and implementation of public and private coastal projects.[43] While regulations requiring new development to plan for this amount of sea level rise have not been developed, the state building commission did adopt, in July 2008, International Building Code standards that call for 1 foot of freeboard and more stringent building requirements in special hazard coastal areas.[44]

In December 2010, CRMC also developed a special area management plan (SAMP) to protect the state's ocean resources, which are defined in the plan as being between 500 feet offshore and the three-nautical-mile state water boundary. Climate change and its impact on the ocean are extensively discussed within this document, the Ocean SAMP. In accordance with the plan, CRMC will evaluate how climate change could affect the future feasibility, safety, and effectiveness of projects and uses proposed within the Ocean SAMP area.[45] In addition, CRMC will convene a scientific panel biannually to assess the status of current climate science for the region and its impact on coastal and offshore resources and forward these findings to the Rhode Island Climate Change Commission.[46] According to the plan, CRMC also will prohibit proposed development projects that, after an evaluation of sea level rise, either threaten public safety or do not perform as designed. In addition, CRMC will require public infrastructure projects to analyze historic and projected rates of sea level rise and resulting public safety and environmental impacts.[47] To reduce the state's vulnerability to sea level rise and other climate impacts, **Rhode Island should prioritize the implementation of measures identified in the Ocean SAMP.**

The Rhode Island Sea Grant also has been active on climate change issues. Along with several other agencies, the Sea Grant is involved in the Flood Awareness and Climate Change Taskforce, which provides outreach and training on coastal construction and the retrofitting of floodprone structures and has also worked with coastal communities such as the town of North Kingstown to identify assets vulnerable to sea level rise.[48,49] The state also has recently signed on to the StormSmart Coasts Network, a resource to help community decision-makers deal with the impacts of coastal storms, flooding, sea level rise, and climate change.[50]

While not developed in response to concerns over climate change, the state water resources board does require water suppliers that produce more than 50 million gallons per year to submit a plan every five years that details such items as the volume of water withdrawn and all activities relating to water use, water quality, and supply and demand management.[51] The Rhode Island Water Resources Board (WRB) also recently adopted a new water use and efficiency rule for major public water suppliers that requires suppliers to develop a plan and report annually on progress in achieving a residential average annual water use of 65 gallons per capita per day, full metering of all water delivered, and a leakage rate of no more than 10 percent.[52] Optional methods for achieving these targets include conservation pricing and seasonal rates, landscape irrigation limitations, and replacing existing water-using appliances and fixtures with more efficient models.[53] The Rhode Island Division of Planning and the WRB are also involved in long-term water supply planning that will consider the effects of climate change. Given the wide climate variability that the state has experienced recently, the WRB is working to develop new water storage options and new sources of water.[54] In addition, the Division of Planning is embarking on a project to develop a long-range plan for potable water supplies in the state, Rhode Island Water 2030. Climate change will be included in this plan for the first time.[55] **In this plan, Rhode Island should recognize the benefits that "no regrets" strategies, such as green infrastructure and water conservation and efficiency, provide in terms of addressing existing water quality and quantity issues while also building the resilience of the state to future climate impacts.**

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SOUTH CAROLINA

Within the past several years, severe droughts have demonstrated the influence that climate can have on a variety of industries and services in South Carolina, from agriculture to recreation to public water supplies. Warmer temperatures in the future as a result of climate change are likely to cause greater incidence of drought as evapotranspiration increases.[1] By 2050 the state could lose up to $24 billion in GDP and more than 235,000 jobs due to reduced water availability and its impact on economic sectors and employment in South Carolina.[2] Rising sea levels also will place infrastructure, property, and people along the coast at risk from inundation, flooding, and erosion. With the recently established Blue Ribbon Committee on Shoreline Change, the state has an opportunity to address vulnerability to sea level rise. **However, to reduce potential damage to the people, economy, and natural resources of the state from other climate change impacts, South Carolina should identify its vulnerabilities to climate change across all sectors and develop and implement strategies to reduce these vulnerabilities.**

Water Resources Background

Throughout the state, precipitation is fairly evenly distributed during the year. March and July are generally the wettest months, and October and November the driest.[3] Average annual precipitation across the state is approximately 48 inches, with the mountainous northwest getting the most and the central area the least.[4] Rates of evapotranspiration also vary geographically, with the highest rates along the coast and in warmer southern areas, and the lowest rates in the northwest.[5]

South Carolina's water resources are unevenly distributed within the state. Nearly all of the freshwater in the state is found in underground aquifers; only about 1 percent occurs as surface water.[6] Most of the state's groundwater resources are located in the Coastal Plain, while most surface water resources are held in man-made reservoirs located on major rivers.[7] The state has four major river basins: the Yadkin-Pee Dee, Catawba-Santee, Savannah, and the Ashepoo-Combahee-Edisto (ACE).[8] The three largest reservoirs in the state are Lake Hartwell, Lake Thurmond, and Lake Murray, all of which are utilized for public water supply, hydroelectric power, and recreation.[9] Although the quantity of groundwater in the state far exceeds that of surface water, 70 percent of the state's population relies on surface water supplies for drinking water supplies.[10] Water resources are usually the most plentiful in the spring, when streamflow and groundwater levels are at their highest, and are the lowest in the late summer and early fall as the result of increased evapotranspiration coupled with increased withdrawals.[11]

Users withdrawing more than 3 million gallons per month are required to submit annual usage data to the Department of Health and Environmental Control. For these users, 99.5 percent of withdrawals came from surface sources and the rest from groundwater in 2010.[12] The largest users were hydroelectric facilities at approximately 77 percent, followed by thermoelectric plants at 20 percent and water suppliers at 1.4 percent.[13] Other major users of water include industry, agriculture irrigation, golf course irrigation, and mining.[14]

South Carolina's Atlantic coast is of enormous importance to the people, economy, and natural resources of the state. More than a million people (slightly over 20 percent of the state's population) live in one of the the eight coastal counties.[15] Tourism in the three most populated coastal counties—Horry, Charleston, and Beaufort—generated more than $5 billion in revenue and supported nearly 68,000 jobs in 2009.[16] In addition, the ports of Charleston and Georgetown kept more than 280,000 people employed and had an economic impact of $45 billion in 2010.[17] South Carolina also has two national estuarine research reserves: North Inlet-Winyah near Georgetown and the ACE Basin near Beaufort. These two reserves protect approximately 147,000 acres of marshland, beaches, and waterways that provide habitat for several threatened and endangered species.[18,19]

Climate Change Impacts on Water Resources

Since 1957 average annual temperatures in South Carolina have increased nearly 1°F, and precipitation has decreased 6 percent.[20] Across the Southeast U.S., there has been an increase in heavy downpours in many parts of the region as well as increases in the extent of spring, summer, and fall drought.[21] Climate models project an increased rate of warming—more than double the rate since 1975—for the remainder of the 21st century, with the greatest increases likely during the summer months.[22] By the 2080s, average temperatures in the region are projected to be 4.5°F to 9°F higher, depending on the emissions scenario.[23] These climate models do not provide a clear indication of future precipitation; however, warmer temperatures will increase evapotranspiration rates and are likely to lead to increases in the frequency, duration, and intensity of droughts.[24]

Climate change could have wide-ranging repercussions for the state's water resources. Changes in precipitation patterns and rates of runoff are likely to alter streamflow regimes. In addition, increasing demand for water for irrigation, energy production, cooling, and recreation could impact water availability; it is not known if supplies will be able to meet demand.[25] Water quality could also deteriorate as drier conditions create oxygen-starved lakes and streams and wetter conditions increase the threat of pollution from runoff.[26] Changes in groundwater recharge and rising sea levels may also lead to increasing salinity in shallow coastal aquifers.[27] Furthermore, increases in extreme precipitation events could raise flooding risks under some scenarios.[28]

Over the past 80 years, relative sea level has risen 10 inches in Charleston Harbor, a rate of about 1 foot per century.[29,30] This rate is faster than the global average sea level rise due to land subsidence in the harbor area.[31] Relative sea levels across the southeastern U.S. are projected to rise at least 2 feet by the end of the 21st century.[32] In fact, recent studies suggest that a rise of 2.5 to 6.2 feet by the end of the century is possible due to the rapid melting of ice sheets,[33] which could mean even greater relative sea level rise across the Southeast. Higher sea levels in conjunction with more powerful tropical cyclones will increase coastal inundation, erosion, and storm surge risks.[34] More than 57 miles of the state's 186 miles of ocean beaches are already deemed to be "critically eroding,"[35] and rising sea levels will only exacerbate existing vulnerabilities. The inundation of wetlands and barrier islands, which provide a buffer against storm surge and provide habitat to wildlife, would further increase risks to the coastal region.[36] For the Charleston area alone, sea level rise during this century could cause up to $2.5 billion in damage.[37] In addition, increased water temperatures and salinity changes as a result of sea level rise and streamflow variability could reduce shellfish and fish populations.[38] Warmer water temperatures could also lead to more frequent outbreaks of shellfish-borne diseases in coastal waters, changes in the distribution of aquatic species, and an influx of nonnative species.[39]

Greenhouse Gas Pollution Reduction

In 2007 then-governor Mark Sanford issued an executive order establishing the Governor's Climate, Energy, and Commerce Advisory Committee (CECAC) to develop an action plan for reducing the state's greenhouse gas pollution. In July 2008 the committee released the Climate, Energy, and Commerce Action Plan, which contained 51 recommendations to reduce greenhouse gas emissions.[40] The CECAC also recommended that the state establish a voluntary greenhouse gas emissions reduction goal of 5 percent below 1990 levels by 2020.[41] To reduce the state's contribution to climate change, **South Carolina should formally adopt greenhouse gas pollution reduction targets and implement concrete strategies for achieving this reduction.**

State Adaptation Planning

One of the six crosscutting recommendations by the CECAC was that the state establish a Blue Ribbon Committee on Adaptation to Climate Change tasked with developing a state adaptation plan.[42] Unfortunately, more than three years later, the state still has not established the committee, let alone drafted a state plan for adapting to climate change impacts. The Department of Natural Resources has, however, developed a draft report on the potential impacts of climate change on natural resources in the state.[43] **South Carolina should undertake an initiative to identify its vulnerabilities to climate change impacts across all sectors, not only natural resources, and identify adaptation strategies as recommended by the CECAC.**

Despite the lack of progress on development of a comprehensive adaptation strategy, the state has been active in coastal management as a result of continued concern over severe beach erosion and shoreline development issues for the past 20 years. A Blue Ribbon Committee on Beachfront Management—convened in 1987—made recommendations on beach management policies that were later adopted into law through the Beachfront Management Act of 1988.[44] The act established a comprehensive statewide program that, among other things, severely restricted the use of "hard" erosion-control devices (such as seawalls) and established a 40-year retreat policy, requiring a setback of 40 times the average annual erosion rate from an established baseline.[45] To assess current research needs and evaluate the effectiveness of existing policies and other alternatives, the Office of Ocean and Coastal Resource Management established the Shoreline Change Advisory Committee in 2007. In its April 2010 final report, the committee made recommendations under four overarching goals: (1) minimizing future risks to beachfront communities; (2) improving the planning of beach nourishment projects; (3) limiting the use of hard stabilization structures; and (4) enhancing the management of sheltered coastlines.[46]

Table 1. Examples of policies recommended by the Shoreline Change Advisory Committee[47]

Goal	Recommendations	Policy Examples
1. Minimize future risks to beachfront communities	Prevent the seaward expansion of beachfront development	Disallow seaward movement of the DHEC-OCRM Baseline
	Strengthen the state's beachfront setback area	Increase the minimum setback distance
	Eliminate inconsistent public subsidies	Designate "no subsidy" zones in hazardous areas
	Strategically acquire beachfront lands and/or easements	Establish state and local voluntary acquisition strategies
	Strengthen the role of local governments in beach management and planning	Develop stronger guidance, new elements, and OCRM assistance for local comprehensive beach management plans
2. Improve the planning of beach nourishment projects	Develop and implement regional sediment management plans	Develop and implement Rregional sediment management plan with U.S. Army Corps of Engineers
	Strengthen reviews of nearshore dredging and other alterations	Heighten reviews and monitoring of projects within 1 mile of shoreline
	Improve beach nourishment monitoring	Require pre- and post-monitoring for all projects
3. Limit the use of hard stabilization structures	Refine criteria for emergency orders and sandbags	Establish new criteria for "emergency"—e.g., disaster—declarations
	Improve guidelines for groins and breakwaters	Establish technical committee to recommend siting/design criteria
	Expand beachfront real estate disclosure requirements	Expand real estate disclosure requirements for approval by SC Real Estate Commission

4. Enhance the management of sheltered coastlines	Manage erosion control in estuaries	Map and characterize estuarine shorelines
	Establish non-beachfront shoreline buffer areas	Establish 25-foot minimum buffer for all new developments along non-beachfront shorelines

The recently created Blue Ribbon Committee on Shoreline Management has been tasked with considering the recommendations of the Shoreline Change Advisory Committee and developing statutory, regulatory, and policy improvements regarding estuarine and beachfront management.[48] **The Blue Ribbon Committee should pay particular attention to the threat that sea level rise poses to coastal areas and seek to discourage development in vulnerable areas.** The Office of Ocean and Coastal Resource Management is also leading an effort to develop adaptation guidance for coastal planners based on case studies of four coastal counties: Horry, Georgetown, Charleston, and Beaufort.[49] The adaptation guidance document was expected to be ready for release in early 2012.

The state also has a few programs that could prove beneficial for addressing long-term climate change risks. As a result of interstate water disputes and growing concern over drought,[50] the state in 2010 passed a law instituting a permitting process for surface water withdrawals.[51] Prior to the passage of this law, surface water users that withdrew more than 3 million gallons per month were only required to register and report usage annually.[52] With this new regulation, new surface water users proposing a withdrawal of more than 3 million gallons per month must apply for a permit; however, existing registered surface water withdrawers are grandfathered and may maintain withdrawals at the highest reported level or at the design capacity of the intake structure when the new rule went into effect (January 1, 2011). This new permitting regulation for surface water follows a similar regulation for groundwater withdrawals of more than 3 million gallons per month in designated capacity use areas (areas where the state has determined that excessive groundwater withdrawals or other conditions pose a threat to future use or integrity of the source)—currently 15 counties near the coast.[53] While these water withdrawal permitting programs do not directly address climate change risks yet, if effectively administered, they can aid in managing water sustainably. **This permitting program should be used to require the adoption of improved water conservation and efficiency practices, which build resilience to future water availability challenges that may result from climate change.**

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SOUTH DAKOTA

During the spring and summer of 2011, record levels of snowpack coupled with unexpectedly heavy rains filled reservoirs along the Missouri River. Consequently, the U.S. Army Corps of Engineers was forced to release unprecedented volumes of water from reservoirs in the upper Missouri, which led to flooding in downstream communities.[1] Similar flooding is likely in the future due to climate change as more extreme precipitation events occur. South Dakota is currently experiencing the second-largest increase in temperature among all High Plains states.[2] Higher temperatures could increase irrigation demand for water and present water supply challenges. Unfortunately, the state has not taken serious measures to address climate change. Instead, the South Dakota Legislature in 2010 passed a concurrent resolution raising concerns about the "prejudiced" scientific investigation of climate change and urging public schools to present climate change in "a balanced and objective" manner.[3] Considering the potential impacts of climate change on the state's water resources, **South Dakota should take steps to reduce statewide greenhouse gas pollution, coordinate a comprehensive effort to assess its climate change vulnerabilities, and develop and implement strategies to reduce these vulnerabilities. In the meantime, the widespread adoption of "no regrets" strategies like water conservation and green infrastructure would address existing water resource issues and prepare the state for climate impacts.**

Water Resources Background

South Dakota is roughly bisected north to south by the Missouri River, its most important water resource, providing water to approximately 50 percent of the state.[4] Along this natural delineation the state's climate experiences a transition, with average annual precipitation levels ranging from approximately 25 inches in the southeast to less than 13 inches in the northwest.[5] This large variability is consistent with South Dakota's continental climate, which is very similar to that of other High Plains states such as North Dakota and Minnesota. Droughts are not unusual given the state's semi-arid climate.[6]

Most of the rain in the state falls during the crop season of April through September, with precipitation generally peaking in June and dropping off sharply in July.[7] Severe weather events, such as tornadoes, thunderstorms, and hailstorms, are also common during the summer months. [8] The Black Hills area of South Dakota has a unique climate arising from strong topographical gradients; the region is particularly vulnerable to flash flooding caused by severe summer thunderstorms. Severe flooding in the state is usually caused by rapid melting of snowpack and not by precipitation, though heavy summer rain events can cause flooding of small tributaries, particularly in the eastern portion of the state.[9]

Groundwater is a tremendously important source of water in South Dakota. More than 54 percent of all water withdrawn in the state came from groundwater in 2005.[10] Several large aquifers are utilized extensively, particularly for irrigation, livestock, and public supply. The largest aquifer in the country, the High Plains or Ogallala Aquifer, partly lies within the state. Several other aquifers, such as the Big Sioux, Madison, and Minnelusa, also are important.[11] Water quality of these aquifers is generally good, although degradation from point and nonpoint sources can be localized in some areas.[12] As in North Dakota, agriculture in South Dakota is one of the state's most important industries, producing more than $8 billion in revenue in 2009.[13] Agriculture (irrigation, livestock, and aquaculture) is also the largest water withdrawer in the state, accounting for nearly 75 percent of total water withdrawals (both surface water and groundwater) in 2005.[14] The next-largest withdrawal was for public and domestic supply at more than 21 percent, followed by mining at about 2 percent.[15]

Population growth has not been the major driver for water resources planning in South Dakota.[16] In general, the eastern side of the state has the greatest population and also adequate water supplies, while the western side is less populous but in need of greater water distribution capabilities.[17] In the future, issues associated with restoring and maintaining habitat for endangered species, specifically along the Missouri River, may prove difficult to resolve and may create uncertainty with regard to water resources planning and development.[18]

Climate Change Impacts on Water Resources

South Dakota is experiencing the second-greatest warming among the six High Plains states, with an average temperature increase of approximately 2.2°F overall and a particularly notable winter warming of almost 4°F over the past century.[19] The state is very likely to experience further warming in the coming decades, which could have significant impacts on water resources. Higher temperatures lead to greater evapotranspiration and decreases in soil moisture, which can lead to an increased demand for irrigation water and greater stress on water resources. Such stresses are particularly likely if groundwater, which takes longer to recharge than surface water, is used for irrigation. The U.S. Global Change Research Program projects that South Dakota could see warming in the summer of 6°F to more than 10°F by the end of the century, depending on the emissions scenario.[20]

There has not been a substantial change in precipitation trends in the state, with an increase of only about 2 percent over the past century.[21] However, across the High Plains region, most states have experienced stronger seasonal variability, with a drier winter and wetter fall than in the past.[22] Additionally, models project a general increase in the amount of spring precipitation in South Dakota by the end of the century, with southern areas possibly receiving 5 to 25 percent more precipitation and northern portions of the state receiving 10 to 35 percent more.[23] An increase in extreme precipitation events is also more likely in the future across the High Plains region.[24]

Streamflow is likely to be impacted by climate change. A study of streamflow trends in the Missouri River Basin by the U.S. Geological Survey (USGS) has shown that mean annual streamflow and minimum streamflow have both trended upward in South Dakota during the past 50 years.[25] One of the impacts associated with warmer temperatures is the melting of snowpack earlier in the spring. This earlier, more abrupt melting can cause a temporary increase in streamflow, which also has implications for water quality as faster streamflow can scour stream banks and riverbanks, increasing sedimentation and dissolved solids in the water. In addition, there has been a observed trend towards earlier spring runoff in streams across the state, such as the Cheyenne River at Edgemont, whose "center of volume" date (the date by which roughly half of annual streamflow has passed) has moved from early June in the 1950s to mid-March by 2006.[26]

Flooding along the Missouri River is more likely in the future, given the increase in extreme weather events expected with climate change. This trend, coupled with the change in the variability and timing of weather, could be especially problematic for agricultural operations in the state. During the second half of May 2011, the upper Missouri River Basin received nearly a year's worth of rainfall in a short period of time.[27] In addition, snowmelt runoff was 212 percent above normal across the upper portion of the watershed.[28] The severe flooding that resulted forced residents along the river in South Dakota to evacuate their homes, and thousands of people were displaced.

The native prairie pothole ecosystems that characterize much of the High Plains landscape are also at risk from the impacts of climate change. These shallow, ephemeral lakes create an important environment that supports diverse plant and animal species, particularly native birds and migrating waterfowl.[29] They are also the main source of recharge for the High Plains' vast aquifer systems.[30] Extensive cultivation and water withdrawal by agricultural activities are already threatening these ecosystems. The higher temperatures of climate change are expected to increase water demands, particularly for agricultural irrigation,[31] and also to increase evapotranspiration, deepening the threat. These changes are particularly important in South Dakota as the state contains a large share of the remaining prairie pothole ecosystems.[32]

Greenhouse Gas Pollution Reduction

South Dakota has not adopted a greenhouse gas pollution reduction target or goal or a plan for reducing its greenhouse gas pollution. **The state should decrease its contribution to climate change by adopting a greenhouse gas pollution target and developing and implementing a pollution reduction strategy.**

State Adaptation Planning

The state does not appear to have initiated any effort to adapt to climate change impacts, even though South Dakota Governor Dennis Daugaard is a member of the Western Governors' Association (WGA), which has a climate change and adaptation initiative aimed at streamlining the work of federal and state agencies in addressing climate change impacts in western states, especially in the water sector.[33] Considering the potential impacts of climate change on the state's water resources, **South Dakota should coordinate a comprehensive effort to assess its vulnerabilities, then develop and implement strategies to reduce these vulnerabilities.**

South Dakota is also largely lacking in statewide planning programs that can be utilized for climate adaptation. The State Water Plan has two components: a listing of potential water projects, known as the facilities plan, and a listing of large, costly water projects that require federal funding and/or authorization.[34] In contrast to many other states' water plans, South Dakota's does not contain an overarching discussion of the state's management of water resources, how water supply and demand needs may be met in the future, what management challenges the state might be facing, or many of the other topics commonly found in other states' water plans.

In addition, the grant system under the state water plan is rather complicated and favors structural or "hard" solutions to water resource issues, such as expanding treatment regimes at wastewater treatment plants and expanding water distribution systems. **Investments in traditional "hard" or "gray" infrastructure that do not explicitly consider potential changes in hydrology may lead to systems that do not perform as intended and that increase the costs of adapting in the long -term.** However, one grant program, the Green Project Reserve, potentially could be used to direct money from the state's revolving fund to implement "no regrets" solutions, such as water conservation and efficiency and green infrastructure projects, which are relatively low-cost and remain flexible in the face of changing hydrologic conditions. Many particularly effective adaptation strategies also could be realized through agricultural reforms.[35] For example, using mixed cropping-livestock systems could decrease the need for irrigation water. Diverse cropping systems and increased water efficiency in irrigation technology also could help the state adapt to a future with greater water scarcity.[36] To date, however, many of the projects funded from this reserve have only involved water line replacement to reduce water loss.[37] **South Dakota should utilize the Green Project Reserve to promote more "no regrets" strategies like green infrastructure for stormwater management and improvements in irrigation efficiency for agriculture and municipal landscapes.** These strategies also help to reduce the state's vulnerability to drought events. Green infrastructure can reduce water demand, promote groundwater recharge, and also decrease flooding risks by decreasing stormwater runoff.

Despite a general lack of state-level climate planning, there are collaborative groups addressing climate change risks to the state's prairie pothole ecosystems. The Prairie Pothole Joint Venture (PPJV), an effort among federal and state agencies, non-governmental organizations, and other groups, and the Plains and Prairie Potholes Landscape Conservation Cooperative (PPP LCC) are funding development of high-resolution climate model projections to help migratory bird and waterfowl managers in eastern South Dakota.[38] Generally, climate change circulation models have resolution issues when global models are downscaled to the size necessary for decision-making, such as the state level. To address the need for better resolution, this project is combining dynamic regional climate models with hydrologic and vegetation models to show scientists and managers how wetlands may be impacted by climate change. This, in turn, will allow managers to better manage habitat. Managers in northeastern South Dakota will use these model results to determine where to pursue future easement acquisitions to help maintain prairie pothole ecosystem integrity and provide a safe nesting place for the waterfowl of these habitats.[39]

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TENNESSEE

Recent events have illustrated Tennessee's vulnerability to climate extremes. Over a 48-hour period in May 2010, upwards of 20 inches of rain fell in parts of the state—equivalent to a greater-than-1,000-year rainfall event for many areas.[1] Due to this torrential rain, 24 people died in the state, and the city of Nashville alone suffered more than $2 billion in damage to homes, businesses, and infrastructure.[2] Conversely, the summer of 2007 was one of the driest in at least 350 years, causing an extreme drought that wreaked havoc on agriculture and led some towns to run out of water.[3,4,5] This drought prompted the state to develop a framework for regional water planning to address anticipated deficits over the next 20 years. However, the state has yet to address climate change issues in a significant way. **Tennessee should work to incorporate climate change more directly into regional water planning studies and develop a comprehensive statewide initiative to reduce the state's greenhouse gas pollution and adapt to climate impacts.**

Water Resources Background

The geographical distribution of precipitation in Tennessee is affected by topography and proximity to the Gulf of Mexico.[6] Annual average precipitation statewide exceeds 50 inches, but regional averages range from about 40 inches in parts of the Great Valley of East Tennessee to more than 80 inches along the state's mountainous eastern border.[7,8] Across most of the state, precipitation totals are the highest during the winter and early spring due to the passage of frontal storms that produce precipitation over a span of several days;[9] however, convective thunderstorms during the summer also deliver considerable rainfall.[10] Groundwater aquifers are typically recharged during the winter, when precipitation is less intense and results in less runoff.[11] Snowfall in the winter ranges from an annual average of 4 to 6 inches in most areas of the state to more than 10 inches in the northern Cumberland Plateau and eastern mountains.[12] Despite generally ample precipitation statewide, dry spells during the summer and fall are not uncommon.[13]

Almost the entire state lies within the Mississippi River drainage basin. While a few small rivers in western Tennessee flow directly to the Mississippi, most of the state is drained by either the Cumberland River or the Tennessee River.[14] The Cumberland originates in Kentucky and flows through north-central Tennessee before turning north back into Kentucky and emptying into the Ohio River near the Illinois border.[15] The Tennessee River, the largest tributary of the Ohio, is created by the confluence of the Holston and French Broad rivers in Knoxville and flows southwesterly into Alabama before flowing northward into Kentucky.[16] Other important tributaries of the Tennessee include the Little Tennessee, Hiawassee, Elk, and Duck rivers.[17] The Tennessee Valley Authority (TVA), an independent, federally owned entity, manages several reservoirs and dams on the Tennessee and Cumberland for navigation, flood control, hydroelectric power production, and, to a lesser extent, downstream water supply.[18] Flood risks are greatest during the winter and early spring, when frontal storm systems bring high-intensity rains, and in the summer, when heavy rainfall from thunderstorms trigger flash-flooding.[19] Tennessee makes up about 50 percent of the area of the Tennessee River watershed.[20] Six major aquifers are located within the Tennessee Valley region and provide drinking water to more than half of the region's residents; however, declining water levels in central and western areas of the state suggest that aquifers are being overused.[21]

Surface water sources provided more than 95 percent of total water withdrawn in 2005, with the remainder coming from underground aquifers.[22] The largest sector for water withdrawals was thermoelectric power generation at more than 82 percent of the total, followed by public and domestic supply at almost 9 percent and industry at 7 percent. All thermoelectric withdrawals and 95 percent of industrial withdrawals were from surface water sources, whereas nearly 39 percent of public and domestic water supplies came from groundwater sources. Although agriculture and forestry utilize about 80 percent of all land in the state, these industries generally rely directly on rainfall and do not irrigate.[23,24]

Climate Change Impacts on Water Resources

Since 1970 average annual temperatures across the southeastern U.S. have increased almost 2°F, with most of this warming occurring during the winter.[25] In addition, average fall precipitation has increased by 30 percent since 1901, and extreme precipitation events have become more frequent in the region.[26] The percentage of the region experiencing moderate to severe drought also has increased in the past 30 years.[27] For the southeastern U.S., climate models project the rate of warming to increase through the century. By the 2080s, average annual temperatures could rise 4.5°F to 9°F, with the greatest warming projected for the summer.[28] Current climate model projections for precipitation in Tennessee are not consistent, with some indicating that more precipitation is likely and others suggesting less precipitation.[29] However, models that project precipitation increases do so for the winter, with little change in summer precipitation.[30] The trend of more frequent extreme precipitation events is also likely to continue.[31]

Warmer temperatures cause greater rates of evapotranspiration from plants and soil, suggesting that the frequency, intensity, and duration of droughts are likely to grow.[32] Similarly, higher temperatures are likely to lead to greater demand for irrigation.[33] Furthermore, warmer temperatures could reduce snow availability and lead to earlier snowmelt in the Appalachian Mountains, which could reduce streamflow and groundwater recharge during the dry summer months.[34] Hydrologic changes in the Cumberland and Tennessee rivers could potentially have severe consequences for the many users that rely on these surface water resources. For example, shifts in river discharge would impact reservoir operations and potentially affect such activities as hydropower production and water supply. Increased flooding risks are also likely in low-lying areas as a result of extreme rainfall events and more precipitation falling as rain than snow in upstream areas.[35] Heavy rainfall episodes can also result in the degradation of water quality due to the runoff of pollutants into water bodies. Furthermore, climate change could have impacts on aquatic species by decreasing dissolved oxygen availability, increasing water temperatures, and degrading water quality.[36] Brook trout could be at particular risk as cold headwaters warm.[37]

Greenhouse Gas Pollution Reduction

Tennessee completed a climate change action plan in 1999.[38] Since this initial plan, the state has not developed a coordinated plan for reducing greenhouse gas pollution or set reduction targets; however, there were several initiatives to improve energy efficiency and conservation during the tenure of former governor Phil Bredesen, such as the Tennessee Clean Energy Future Act of 2009.[39] **Tennessee should adopt greenhouse gas pollution reduction targets and implement strategies to reduce the state's contribution to climate change.**

As one of the largest emitters of greenhouse gases in the state, the TVA will play a prime role in this effort. TVA's 2011 20-Year Integrated Resource Plan (IRP) Recommended Planning Direction includes a positive shift to greater energy efficiency and lower-emitting resources, a significant step toward reducing its carbon emissions.[40] However, there is much room for improvement within the Planning Direction adopted (there is a wide range of energy given for each resource) and beyond the high end of the ranges. The IRP calls for energy efficiency and demand-side resources between 11,400 and 14,400 gigawatt-hours.

The TVA has made an important commitment to become an energy efficiency leader in the Southeast. Its goals for energy efficiency are in line with other commitments made by utilities in states across the region. However, the TVA's IRP does not incorporate all cost-effective energy efficiency into any of its scenarios or model runs and lags behind national leaders in energy efficiency. **TVA should take full advantage of all energy efficiency as a real resource by setting annual energy (GWh and MMTherm) and demand (MW) saving targets based on rigorous analyses of the achievable cost-effective potential in TVA's service territory.** TVA is beginning to move in this direction and released its energy efficiency potential study in February 2012.[41]

State Adaptation Planning

Tennessee also lacks an integrated plan to adapt to potential climate change impacts, although there is at least one state agency that has assessed potential risks from climate change. In 2009 the Tennessee Wildlife Resources Agency (TWRA) released an update to the state wildlife action plan that examined the potential implications of climate change for wildlife in Tennessee. In this update, TWRA also adopted seven approaches as an initial adaptation strategy for climate change: (1) Protect key ecosystem features; (2) reduce anthropogenic stresses; (3) ensure representation of a diverse assemblage of species to promote resilience; (4) ensure replication of ecosystem types; (5) restore habitats and ecosystems; (6) create refugia or areas less impacted by climate change; and (7) relocate organisms to bypass physical barriers.[42] However, **more detailed implementation actions are needed to effectively and successfully adapt to climate change**.

As a federally owned corporation, the TVA is incorporating climate change adaptation planning into agency operations in accordance with Executive Order 13514 and will develop a climate adaptation plan by June 2012.[43] Specifically, this plan will evaluate the impact of climate change on TVA's mission to serve the Tennessee Valley and identify actions and mechanisms to improve the agency's ability to adapt to climate change.[44] Following the lead of TWRA and TVA to address climate change, **Tennessee should undertake a coordinated and comprehensive initiative to develop and implement strategies to adapt to climate change impacts such as increased flooding and drought events.**

The state currently does not have a comprehensive framework for water resources planning. With regard to water quality, Tennessee utilizes a watershed approach to manage water quality in the state's 55 distinct watersheds.[45] For water quantity, the state only requires users that withdraw more than 10,000 gallons per day to register and report usage annually.[46] However, recognizing the impact of recent droughts and population growth on water resources, the Department of Environment and Conservation and other partners have initiated a regional water resources planning pilot for two areas in the state: the southern part of the Cumberland Plateau and the northern part of middle Tennessee. These studies examine the most cost-effective way to meet regional water supply needs over the next 20 years.

The first of these studies, the South Cumberland planning study, was completed in June 2011.[47] Unfortunately, climate change and its potential impact on water supplies and demands were not directly factored into the analysis. Instead, the pilot study used a value for reliable yield that was defined as the maximum amount of water available on a daily basis that also preserves 20 percent of usable storage during the worst drought in recorded history—effectively, the largest amount of water that can be withdrawn without running dry.[48] To address projected gaps between demand and supply, the study evaluated four options: demand management, water sharing among utilities, improvement to existing sources, and the development of new sources.[49] The study concluded that the least costly and most practicable option to meet water supply needs over the planning horizon is to increase the capacity of an existing reservoir and modify downstream release requirements.[50] Even though water conservation and regionalization are not deemed sufficient to overcome projected shortages, these strategies are recommended as relatively low-cost alternatives that promote better use of current resources while also building resilience to drought impacts.[51] The second study, the North Central Tennessee planning study completed in December 2011, also used reliable yield to account for the impact of "climate variability" on water availability.[52]

Given that climate change is altering historic patterns of hydrology, past drought events may not be a reliable indicator of future drought scenarios.[53] Consequently, in future regional water planning studies, **Tennessee should directly model the potential impacts of climate change on water supply and consider the impact of climate change on water demands. The state also should consider green infrastructure strategies to reduce potable water demand and promote local groundwater recharge.**

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TEXAS

Texas is in the midst of the worst one-year drought on record, and July 2011 was the warmest month ever recorded since data collection began in 1895.[1] As of mid-September 2011, more than 99 percent of the state was under severe to exceptional drought.[2] As a result of these record-breaking dry conditions, wildfires caused more than $100 million in damage, and livestock and crop losses of at least $5.2 billion were incurred.[3] In addition, nearly 20 percent of all public water systems in the state were forced to implement water use restrictions.[4] These drought impacts clearly reveal the state's vulnerability to higher temperatures and changes in precipitation patterns, which are projected to intensify due to climate change. **To reduce the state's vulnerability to impacts from warmer temperatures, more precipitation extremes, and rising sea levels, Texas should reduce statewide greenhouse gas pollution, assess its climate risks, and develop and implement adaptation strategies to build the resilience of human and natural systems to these impacts.**

Water Resources Background

Given Texas's large geographic expanse, annual average precipitation varies significantly across the state. Eastern Texas receives far more precipitation on average than the western part, with Beaumont in the east receiving in excess of 55 inches and El Paso in the far west averaging less than 10 inches annually.[5] The Gulf of Mexico has the greatest influence on climate and provides the major source of moisture for the state.[6] Areas near the Gulf coast generally display two distinct rainy seasons, the spring and fall, as a result of warm, dry air from northern Mexico colliding with moist air from the Gulf of Mexico.[7] The majority of Texas has a semi-arid climate, with evaporation exceeding precipitation except in the easternmost portion of the state.[8] Despite this general aridity, the state contains important surface water resources in 15 major river basins and 8 coastal basins.[9] The five largest river basins by average annual flow include the Brazos, Sabine, Trinity, Neches, and Red rivers.[10] Texas is able to utilize surface water resources for water supply because of reservoir development. The state has nearly 200 major reservoirs that provide almost 9 million acre-feet of water per year.[11] In addition, Texas has 9 major and 21 minor aquifers that provide a majority of the state's consumptive water supply.[12] Of these aquifers, the Ogallala Aquifer is the largest source of groundwater, which is mainly used for irrigation.[13] Historically, the state's reliance on groundwater resources has increased in response to drought conditions; however, models suggest that the amount of groundwater available for future withdrawals will decline more than 30 percent by 2050.[14] Indeed, the annual rate of pumping from the Ogallala Aquifer is approximately four times the rate of annual recharge.[15] Of total freshwater withdrawals in 2005, approximately one-third came from groundwater sources and the remaining two-thirds from surface waters; however, nearly 80 percent of freshwater withdrawn for irrigation came from groundwater.[16]

In 2009, according to the state's annual water use survey, irrigation was the largest consumptive user of water in Texas, followed by municipal supply and manufacturing.[17] Texas is the largest producer of cotton in the U.S., and other notable crops include corn, wheat, and hay.[18] Overall, agriculture contributes more than $80 billion to the Texas economy annually and is the second-largest industry in the state.[19] In recent years, there has been growing concern over the water use associated with hydraulic fracturing, a technique used to recover oil and gas from geologic formations.[20] A typical well in the Barnett Shale area of Texas utilizes 1.2 million to 3.5 million gallons of water; wells in the Eagle Ford Shale require as much as 13 million gallons each.[21,22] There are more than 5,600 active wells in the Barnett Shale region, and many thousands more are expected in the future.[23] Water use is projected to increase by more than 140 percent in the Barnett Shale and by more than 700 percent in the Eagle Ford Shale by 2020.[24]

Texas has 367 miles of coastline, more than 3,300 miles of shoreline, and seven major estuaries.[25,26] Approximately 25 percent of the state's total population lives in one of the 18 coastal counties.[27] Galveston Bay is home to the sixth-largest metropolitan area in the U.S. (Houston−Sugar Land−Baytown) and the nation's largest concentration of oil refineries and chemical production facilities.[28] In addition, Texas contains 3 of the 10 largest ports in the U.S. by cargo volume.[29] The unique mixture of freshwater and saltwater and the nutrients and sediments found in Texas's bays and estuaries also provide vital habitat for aquatic species. Commercial fisheries contribute more than $170 million annually, and tourism spending totals more than $7 billion annually in coastal counties.[30] The coast, while vastly beneficial to the state, is also subject to persistent hazards. Rates of coastal erosion in Texas are among the highest in the U.S.: 64 percent of the Texas coast is eroding at an average rate of 6 feet per year, with erosion in some areas exceeding 30 feet annually.[31] On average, the coast as a whole is eroding at a rate of more than 2 feet per year.[32] The high rate of erosion can be attributed in part to land subsidence of more than 1 inch per year, caused by groundwater withdrawal and, to a lesser extent, the extraction of oil and gas.[33] In coastal areas with thick, unconsolidated Holocene sediments, land subsidence can also be attributed to ground compaction.[34] In addition to exacerbating coastal erosion, land subsidence has increased the area vulnerable to flooding associated with tidal and storm surge from tropical storms and hurricanes.[35]

One example of the compounding effect of these factors can be seen in the Brownwood neighborhood in Baytown. Originally built in 1938 at about 10 feet above sea level, Brownwood by the late 1970s was repeatedly subject to flooding due to total land subsidence exceeding 8 feet.[36] In 1983, after Hurricane Alicia brought storm surges of 11 feet, Brownwood was completely abandoned; it remains a wetland area today.[37] Historically, an average of three tropical storms or hurricanes affect the Texas coast every four years.[38] In the 2000s, a total of five tropical storms and five hurricanes struck Texas, making it one of the most active decades in more than 150 years.[39] One of the most costly storms in U.S. and Texas history, Hurricane Ike, came ashore near Galveston in 2008, bringing nearly total devastation to the communities of Crystal Beach, Gilchrist, and High Island and causing almost $20 billion in damage statewide.[40]

Climate Change Impacts on Water Resources

During the last two to three decades of the 20th century, mean annual temperatures in Texas demonstrated a warming trend that has continued into the 21st century.[41] This trend has been the most pronounced in the far west part of the state, where the rate of warming has been 1.1°F to 2.2°F per century.[42] Across the Great Plains, average annual temperatures have increased by 1.5°F relative to a 1960s-to-1970s baseline, with the most warming occurring during the winter.[43] Furthermore, summer temperatures in the region are projected to increase 5°F to more than 10°F by the end of the century.[44] In Texas, annual temperatures are projected to increase 2°F during the 2020–2039 period and nearly 4°F for the 2040–2059 period, relative to the late-20th-century average.[45] Over the course of the 20th century, precipitation has generally increased across Texas, although significant interannual variation is common.[46] Increases have been the most pronounced between December and March.[47] Overall, the rate of change has ranged from about 5 percent per century in the panhandle, the plains, and far western Texas to approximately 20 percent per century in south Texas and in the southeastern part of the state.[48] However, southern regions of the Great Plains are generally projected to become drier as evapotranspiration rates increase (in response to warmer temperatures) while total precipitation changes only minimally.[49] These factors suggest that more frequent droughts are likely. More precipitation is also expected to occur during heavy rainfall events separated by longer dry spells.[50,51]

These changes in climate could impact the state's water resources. More intense rainfall events could result in increased runoff and escalating flood risks, particularly in urban areas, which are covered with impermeable surfaces.[52] Greater runoff could also lead to decreases in groundwater recharge as less water infiltrates the soil; this would impact water availability, particularly in fractured and karstic aquifers that are shallow and highly permeable, such as the Edwards Aquifer.[53,54] Increased runoff as a result of heavy rainfall events could also have water quality implications as pollutants are flushed into waterways. In addition, higher evapotranspiration rates will lead to decreases in soil moisture and groundwater recharge, especially during the summer, and will likely lead to greater irrigation demands at the same time as groundwater supplies become less reliable.[55] By 2100, increases of more than 50 percent in water demand are likely for the agricultural sector due to higher potential evapotranspiration.[56] Climate models suggest that mean annual runoff could decrease by 10 to 30 percent by 2050 for most of Texas, with the exception of coastal areas, which could experience little or no change to increases of more than 30 percent.[57]

Texas is party to five interstate water compacts that could potentially be affected by climate change: the Canadian River, Pecos River, Red River, Rio Grande, and Sabine River compacts.[58] As a result of greater evapotranspiration and less precipitation in some areas, streamflow is expected to decline 5 to 10 percent by 2050 for the Canadian, Pecos, Red, and Rio Grande.[59] Reductions on the order of 5 percent are projected by mid-century for the Sabine.[60] Furthermore, the state's ability to use and store water from these rivers could be at risk, considering increased water demand from population growth and climate change coupled with reductions in streamflow and the largely inadequate nature of these compacts to address climate change.[61] In addition, changes to historic patterns of streamflow could lead to increased reliance on groundwater supplies, which in many areas are already being overdrafted, leading to further depletion of these aquifers.[62] Moreover, shallow ephemeral lakes, known as playa lakes in Texas, play an integral role in supporting native wildlife and plants. These lakes traditionally have also been important in recharging the Ogallala Aquifer, but changes in temperature and precipitation in addition to growing urbanization and agricultural water demand could threaten these valuable ecosystems.[63]

Climate Change Impacts in Coastal Areas

Over the past 100 years, relative sea level has risen nearly 2 feet in Galveston.[64] Global sea level rose only an average of 7 inches over this same time period,[65] which illustrates the high degree of land subsidence that afflicts portions of coastal Texas. Due to land subsidence and sea level rise, more than 26,000 acres of wetlands have been converted to open water and barren flats, and shoreline erosion has averaged 2.4 feet per year.[66,67] Rates of sea level rise are expected to accelerate during this century due to thermal expansion of the oceans and the melting and loss of land-based ice.[68] The most recent report from the Intergovernmental Panel on Climate Change projects that global sea level rise will measure 0.59 to 1.93 feet relative to the 1980–1999 baseline by the end of the century.[69] However, more recent studies have suggested that global sea level rise on the order of 2.5 to 6.2 feet for the 1990–2100 period is possible as the result of accelerated ice melt.[70] Assuming that rates of subsidence remain constant (approximately 0.18 inch per year), this would translate to a relative sea level rise of about 4 to 7.7 feet by 2100 for the Galveston area. Although the city has a 17-foot-high seawall, which was initially built in response to the Galveston Hurricane of 1900 and expanded after subsequent hurricanes, sea level rise would reduce the level of protection provided by the seawall absent any modifications.[71] In the Galveston Bay Region, a study using the HAZUS model estimates that a sea level rise of nearly 5 feet would displace about 99,000 households and result in almost $12.5 billion in property damage in Chambers, Harris, and Galveston counties.[72] In addition, 16 wastewater treatment facilities and 17 hazardous waste, Superfund, or municipal waste facilities would be threatened.[73] Projections for increased intensities of Atlantic hurricanes will only exacerbate the flooding and erosion risks already present in coastal areas.[74] Areas of coastal Texas have historically had problems arising from saltwater intrusion into underground aquifers as the result of groundwater overdraft.[75] Rising sea levels could lead to further encroachment of saline water into coastal aquifers and could also lead to the inundation and erosion of barrier islands and wetland habitats.[76,77] Changing freshwater inflows in conjunction with sea level rise could also have severe implications for estuarine ecosystems.[78]

Greenhouse Gas Pollution Reduction

While cities like Austin and Houston have developed action plans to reduce greenhouse gas pollution, the state of Texas has not done so.[79,80] In fact, the state has filed suit against the U.S. Environmental Protection Agency (EPA), challenging the agency's authority to regulate greenhouse gases under the Clean Air Act.[81] However, in response to Senate Bill 184, the Comptroller of Public Accounts developed a report for the Texas Legislature on greenhouse gas emissions reduction strategies that result in net savings and can be achieved without imposing financial costs to businesses or consumers.[82] Because climate change is expected to have severe repercussions for the state, **Texas should adopt statewide greenhouse gas reduction targets and implement concrete strategies to reduce the state's contribution to climate change.**

State Adaptation Planning

Texas does not currently have a state adaptation plan, and recent efforts to pass legislative bills to require state entities to develop climate adaptation plans have been unsuccessful.[83] Recognizing that climate change poses significant risks to the people and resources of Texas, **the state should seek to systematically identify climate change vulnerabilities and develop and implement strategies to prepare for these risks.**

The state does, however, have a few existing programs and planning processes in place that could prove useful in addressing climate change impacts. The state water planning process draws upon the water plans of Texas's 16 regional water planning groups.[84] Regional water plans typically include a determination of water demands, a determination of available water supplies during the drought of record (i.e., the 1950s drought), an analysis of future water needs, an estimate of the socioeconomic impacts of not meeting needs, and specific strategies to address near-term deficits.[85] In early 2011, the Texas Water Development Board (TWDB) approved the 16 regional water plans that form the basis of the 2012 State Water Plan. The regional water plans did not attempt to estimate the impact of climate change on water availability or on water demand through greater irrigation needs or greater cooling-water needs for thermoelectric power plants; however, some regions included strategies to provide water supplies beyond projected water demands to account for uncertainty and climatic variability.[86]

The most recent state water plan, Water for Texas, was released in January 2012 and proposed strategies for ensuring that sufficient water supplies exist to meet growing demand through 2060. The report estimated that the state will need an additional 8.3 million acre-feet of water by 2060 due to population growth and the loss of some existing supplies to groundwater depletion.[87] Proposed strategies in the plan included water conservation, development of new surface water and groundwater supplies, improved management of existing supplies, and water reuse.[88] **Many of these strategies, especially water conservation and water reuse, are "no-regrets" strategies that address existing water management issues while also building resilience in the long term to water scarcity concerns arising from climate change.**

The 2012 version of the state water plan did mention climate change as a challenge and uncertainty affecting water supply planning; however, the report did not recommend any adaptation strategies to address climate change and concluded that regional planning groups can continue to rely on the "drought of record" until better information to determine the impacts of climate variability on water supplies becomes available.[89] The plan also referred to climate change, along with natural disasters and terrorism, as "ambiguous risks" or risks that "are so uncertain that it is not known when they will happen, what their impacts will be, or even whether they will occur at all."[90] The report further noted that challenges and uncertainty can be addressed through the five-year regional water planning cycle.[91] However, capital investments in traditional "gray" or "hard" water infrastructure are costly and require long lead times. Without taking into consideration the impacts of climate change now, there is substantial risk of wasting money on infrastructure that either does not perform as intended in the future or is sited in a vulnerable area.

Furthermore, Texas's reliance on the worst drought on modern record as the water planning benchmark is potentially troublesome. Given that climate change is altering historic patterns of hydrology by changing precipitation and rates of evapotranspiration, the worst drought on record today may not adequately represent the severity and extent of future drought events.[92] Indeed, tree ring studies reveal that parts of Texas may have experienced more severe drought in the 1700s than the 1950s drought of record.[93] Consequently, **Texas should give explicit consideration to the impact of climate change on water demand and supply in regional and state**

water plans. The regional water plans and the 2012 State Water Plan also rely heavily on capital-intensive and inflexible "hard" or "gray" infrastructure, such as water pipelines and dams, to provide necessary future water supplies. Instead, **Texas should be prioritizing relatively low-cost and adaptive strategies like improved water conservation and efficiency and green infrastructure to meet long-range water supply needs.** The state does require users applying for a new water right or an amendment to an existing water right, non-agricultural water-right holders of 1,000 acre-feet or more annually, and agricultural water-right holders of 10,000 acre-feet or more annually to submit water conservation and drought contingency plans.[94] These entities also are required to submit an annual progress report on the implementation of the conservation plan to the TWDB. However, **effective oversight by TWDB and the Texas Commission on Environmental Quality of the development and implementation of these plans is crucial in ensuring meaningful reductions in water use.**

In recognition of the threat that coastal erosion poses to the state, Texas developed a coastal management program and passed the Coastal Erosion Planning and Response Act (CEPRA) in the late 1990s to fund erosion response projects and studies.[95] CEPRA projects, which have included beach nourishment, dune restoration, and habitat restoration, are funded through legislative appropriations biennially.[96] For the first six biennial cycles, only $76.72 million was allocated for project requests totaling more than $585 million.[97] Another source of funding is the Coastal Impact Assistance Program (CIAP), a federally supported program administered by the Bureau of Ocean Energy Management (BOEM). BOEM distributes federal royalties from offshore oil and gas leases to states that have been impacted by exploration and development along the Outer Continental Shelf (OCS) for coastal conservation, restoration, and protection projects, among others. For fiscal years 2009 and 2010, project applications of nearly $208 million were received for allocations of slightly over $46 million.[98] Also supporting erosion response projects are federal Coastal Zone Management Act funds administered by the Texas Coastal Management Program, which amount to about $2.2 million annually.[99] The need for funds to address coastal issues far exceeds the money that has been allocated thus far. The state's hazard mitigation plan also acknowledges the effect that sea level rise and climate change will have on coastal hazards;[100] however, the state has not developed an action plan for addressing the impact of climate change on coastal erosion and flooding risks. **Considering the land subsidence issues endemic to the region and projections of future sea level rise, coastal areas in Texas would benefit greatly from the development and implementation of a sea level rise strategy.**

However, there are other groups that are working to address these risks. The Texas Sea Grant, in conjunction with the other Gulf of Mexico Sea Grant programs, is funding research studies that explore the legal implications of sea level rise adaptation strategies and that develop models for storm surge and wave action that take into consideration sea level rise.[101] Texas Sea Grant also is working with five communities in the Galveston area through the Climate Community of Practice, an effort to help local communities develop adaptation strategies.[102] The Texas Coastal Watershed Program (TCWP), a part of Sea Grant and the Texas AgriLife Extension Service, has developed several tools for local communities to use in mitigating coastal hazards, including sea level rise. One such tool, the Community Health and Resource Management model, helps communities visualize the impacts of various climate change and development scenarios on community resilience and natural resources.[103] TCWP also has published a series of documents on using policy frameworks, such as rolling easements and building codes, to adapt wetlands and urban environments to climate change and population growth.[104,105]

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UTAH

Utah is the second-driest state in the U.S., trailing only its neighbor to the west, Nevada.[1] Consequently, climate change is expected to pose significant risks to the state's water resources. Utah was engaged in action to address climate change issues until recently. In 2007 the Governor's Blue Ribbon Advisory Council on Climate Change released its report outlining measures the state could take to reduce greenhouse gas pollution. However, in recent years, the state has taken steps backwards on climate change action, with the passing of joint resolutions such as HJR 12 in 2010, which claimed that climate change was not occurring. With a potential loss of $10.5 billion in GDP and 72,200 jobs by 2050 due to reduced water availability,[2] **Utah should begin planning now for climate change impacts by developing a comprehensive adaptation plan and integrating climate change into water resources planning. In the interim, the state should prioritize the implementation of "no regrets" strategies, such as green infrastructure and greater water conservation and efficiency, which will help to address existing water resource issues while building resilience to future climate impacts.**

Water Resources Background

Nearly 82 percent of Utah's total water supply comes from surface water sources.[3] The state as a whole receives an annual average of 12 inches of precipitation, but there is a wide disparity geographically in precipitation totals.[4] Annual precipitation ranges from a few inches in lowland areas to more than 60 inches on some peaks in the Wasatch Mountains.[5] Most of the precipitation falls as snow in the mountainous regions during the winter.[6] This snow accumulates as snowpack in the mountains, acting effectively as a large reservoir. As the snow melts in the spring and early summer, the meltwater flows into streams and rivers that terminate in the Great Basin's water bodies, the most notable being the Great Salt Lake.[7] Approximately 87 percent of the precipitation that falls in Utah is lost to evapotranspiration, with the remainder making its way to surface water bodies as well as percolating to underground aquifers.[8]

Utah's first settlements were located near substantial sources of water. The early Mormon pioneers established communities at the base of snow-covered mountains, like the Wasatch Range, and on top of large groundwater aquifers to supplement water supplies when meltwater was low in late summer, fall, and winter.[9] However, due to significant interannual variability in precipitation and population growth, the development of water storage reservoirs became necessary to ensure stable water supplies.[10] Both federal and state projects, such as the Provo River Project and Sevier Bridge Reservoir, have been developed to support agricultural, municipal, and industrial water uses.[11]

Utah's allocation of the Colorado River is governed by the Upper Colorado River Basin Compact of 1948. Under this compact, the state receives 23 percent of the water remaining, or approximately 1.4 million acre-feet, after the Lower Division states of New Mexico, California, and Arizona receive their annual allocation of 7.5 million acre-feet.[12] The state currently is using nearly 1 million acre-feet of its Colorado River allocation for agricultural purposes.[13] Utah is also working on the development of a pipeline from Lake Powell to supply southwestern Utah with 100,000 acre-feet of the state's unused allocation.[14]

Climate Change Impacts on Water Resources

Across the western United States, climate change impacts such as an earlier and warmer spring, earlier spring snowmelt and runoff, and more spring precipitation falling as rain than as snow have been observed in the past 50 years. Over the past decade, Utah's average temperature was higher than during any comparable period in the last century and 2°F higher than the 100-year mean.[15]

By the end of the 21st century, Utah is projected to experience an 8°F increase in annual mean temperature.[16] While there is greater uncertainty with respect to future precipitation, climate models generally predict more frequent heavy precipitation events separated by prolonged dry spells for Utah and the western U.S.[17] As temperatures increase, Utah's mountain snowpack is likely to diminish, leading to decreases in spring and early-summer streamflow and, consequently, less water available for surface water and groundwater recharge. Water supplies will also be at risk from increased evapotranspiration and changes in the seasonality of streamflow as temperatures increase. The annual water balance (precipitation minus evapotranspiration) is projected to decrease by 30 percent by 2060, indicating a water deficit.[18] According to the 2011 SECURE Water report issued by the U.S. Bureau of Reclamation, current models predict an 8.5 percent decrease from the 1990s in annual runoff for the Colorado River at Lees Ferry, Arizona—the dividing point between the Upper and Lower Colorado River Basins—by 2050.[19]

Higher temperatures also are likely to lead to more precipitation falling as rain than as snow, causing decreases in winter snowpack and potentially impacting winter recreation and tourism. In addition, increased temperatures are likely to lead to the warming of rivers and lakes, with resulting impacts on aquatic species.[20] Decreases in streamflow as a result of higher temperatures also could lead to a drop in the level of the Great Salt Lake and increases in salinity that could negatively impact wetlands and wildlife.[21]

Greenhouse Gas Pollution Reduction

In 2008 Utah's Department of Environmental Quality announced a statewide greenhouse gas emissions reduction goal of 2005 levels by 2020. Also in 2008, the Governor's Blue Ribbon Advisory Council (BRAC) on Climate Change released a report containing options for reducing the state's greenhouse gas emissions. In 2009 the Nicholas Institute at Duke University conducted an assessment of the avoided emissions potential of 16 of the options in the BRAC report.[22] This assessment found that electricity measures have the largest potential for avoided emissions. Unfortunately, the state does not appear to have implemented any significant measures aimed at reducing greenhouse gas pollution. In addition, in November 2011 Utah formally withdrew from the Western Climate Initiative, a regional effort among western states and Canadian provinces to reduce regional greenhouse gas emissions.[23] **To reduce its contribution to climate change, Utah should implement concrete measures to decrease statewide greenhouse gas pollution.**

State Adaptation Planning

The 2008 BRAC report also recommended that the state develop and implement an adaptation strategy that focuses on the impacts of climate change on water, drought, and reduced snowpack. While Utah has not developed a comprehensive state adaptation strategy, the state has developed other strategies and plans that can be utilized to build resilience to climate change impacts.

In the 2001 State Water Plan, the state formally outlined a water conservation goal of a 12.5 percent reduction in per capita water demand from community systems by 2020 and a 25 percent reduction before 2050.[24] To support the achievement of this goal, the state requires water conservancy districts and retailers with more than 500 connections to submit a water conservation plan and update it every five years.[25] To date, all of the required water retailers have completed at least an initial plan.[26] However, **effective state oversight of the implementation of these plans is necessary for achieving concrete reductions in water use.** In 2007, the state released a drought planning document, Drought in Utah: Learning from the Past—Preparing for the Future, to support the development of a mitigation-oriented approach to drought management. This report noted that temperature increases statewide as a result of climate change are likely to lead to greater drought incidence. To mitigate drought vulnerability, several strategies were proposed, including redistributing water supplies from agriculture to meet municipal and industrial demand, conjunctively managing surface and groundwater supplies, interconnecting water systems, developing additional water storage, managing demand, and increasing water reuse.[27] To reduce water demand, the report proposed greater public awareness, a transition to alternative landscaping techniques that utilize less water, and the adoption of water pricing schemes that incentivize efficiency.[28]

Most of the water conservation and efficiency focus in Utah appears to be directed toward the municipal and industrial sectors. Because nearly 83 percent of the total freshwater withdrawn statewide in 2005 was used for agricultural irrigation, **the state also should be working with the agricultural industry to increase water efficiency.** Even small improvements could result in significant reductions in the total amount of water consumed. The potential for water reuse in Utah is also substantial. As of a 2005 report, the state was using less than 10 percent of its available reuse volume.[29] Although the state is not currently utilizing its full Colorado River allocation, the river as a whole is over,allocated and with climate change likely to lead to even greater reductions in flow, **Utah should not rely on the Colorado River as a reliable source of water to sustain future growth.** Statewide improvements in efficiency, conservation, and reuse are ways to utilize existing supplies in a more sustainable manner.

In its state water plan and its planning documents for water conservation, river basins, and drought, Utah already possesses some strategies that will be necessary to adapt to climate change; however, **the state should develop a comprehensive adaptation plan that integrates these strategies.** This adaptation plan should not only consider impacts to water supply, but also consider the impacts of more intense precipitation events on stormwater infrastructure and flooding risks as well as potential climate change impacts on aquatic species. **Any subsequent updates to Utah's state water plan or the plans for its 11 major river basins also should consider the implications of climate change for water resources.** The inclusion of climate change in these plans and their successive implementation will help to reduce the risks that the state faces from a changing climate. **In the interim, the state should prioritize the implementation of "no regrets" strategies, such as green infrastructure and greater water conservation and efficiency, which will help to address existing water resource issues while building resilience to future climate impacts.**

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VERMONT

In August 2011, Tropical Storm Irene brought torrential rain and flooding to Vermont, destroying numerous homes, businesses, roads, and bridges in the worst natural disaster to hit the state since 1927.[1] As a result of warming temperatures, Vermont is projected to continue experiencing similar impacts in the form of increases in annual precipitation, more extreme rainfall events, and shifts in the timing and duration of seasonal flooding events. In addition, the state is expected to face reduced snowpack and lake ice and more frequent short-term droughts.[2] Reduced water availability from climate change could cost the state $700 million in GDP and more than 5,000 jobs by 2050.[3] In recent years the state has worked to position itself to address climate change by developing a comprehensive energy plan and participating in several pollution reduction initiatives, such as the Regional Greenhouse Gas Initiative (RGGI). Many state agencies, such as the Agency of Natural Resources and Agency of Transportation, also are developing adaptation action plans. **In order to ensure consistency and avoid duplication, the recently created Governor's Climate Cabinet should work to develop a comprehensive climate change adaptation plan that integrates the adaptation work of the various state agencies. The Climate Cabinet also should lead and coordinate the implementation of this adaptation plan to reduce the state's vulnerability to climate impacts.**

Water Resources Background

The climate of Vermont is influenced by a combination of elevation, terrain, and the state's proximity to the Atlantic Ocean and Lake Champlain.[4] Total mean annual precipitation among the state's three climate divisions ranges from 38 to 45 inches. Precipitation is generally evenly distributed throughout the year, except that winter precipitation is markedly less than summer precipitation in the northern and western parts of the state.[5] Snow cover is generally persistent in the winter as a result of snowfall from nor'easters, blizzards, lake effect storms, and frontal storm systems.[6] Snowpack is an important source of water during the spring and summer as it melts and runs into surface waters.[7] The Connecticut River forms the eastern border of the state and drains the majority of Vermont. In the northwest, rivers drain to Lake Champlain or the St. Lawrence River, and a small southwestern portion of the state drains into the Hudson River. Mean annual runoff for streams ranges from 10 inches in the Lake Champlain basin to 40 inches in southern Vermont.[8] Major surface water supplies in Vermont include Lake Champlain, Lake Memphremagog, the Harriman Reservoir, and the Connecticut River.[9] Groundwater stored in underground aquifers is also an important water supply in the state and contributes to streamflow.[10] While nearly 90 percent of total water withdrawn in Vermont in 2005 came from surface water sources, groundwater is a particularly important source for drinking water, supplying two-thirds of the population.[11,12] Of total water withdrawal in 2005, 78 percent was used for power plant cooling, 9 percent for public supply, 5 percent for domestic self-supply, and the remainder for industrial, commercial, and agricultural uses.[13] The state also has more than 80 megawatts of hydropower generating capacity.[14]

Climate Change Impacts on Water Resources

Across the northeastern U.S., average temperatures have increased more than 1.5°F since 1970, with winter temperatures rising 4°F.[15] As a result, there have been increased heavy precipitation events due to more atmospheric moisture, less winter precipitation falling as snow and more as rain, reduced snowpack, earlier breakup of winter ice on lakes and rivers, and earlier spring snowmelt leading to shifts in streamflow.[16] Over the past 50 years, precipitation has increased by 15 to 20 percent in Vermont, and the amount falling in heavy precipitation events has increased by 67 percent in the northeastern U.S.[17] There have also been increases in annual mean streamflow in the past 50 years in the state, with particularly significant increases from July to December.[18] Some lakes in Vermont are frozen on average for four weeks less than they were 40 years ago.[19]

Under a high-emissions scenario, temperatures in Vermont are projected to be 9°F to 13°F warmer than the historical average in the winter and 7°F to 14°F higher in the summer by the end of the century.[20] Across the

Northeast, precipitation is expected to increase 20 to 30 percent during the winter;[21] in Vermont, it is expected to increase in all seasons except summer.[22] Higher temperatures will likely exacerbate climate change impacts that are already being observed. The length of the winter snow season is projected to be reduced by half, and the summer season will probably increase in length.[23] Short-term droughts are likely to occur as often as annually as a consequence of higher summer temperatures with no corresponding change in rainfall.[24] Winter recreation such as skiing and snowmobiling, which contribute more than $1 billion annually to the state economy, could be particularly impacted as the length of the ski and snowmobile season declines by 70 percent by the end of the century.[25] Flooding is already a common occurrence in the state due to seasonal triggers including large storms, ice jams, snowmelt, rainfall on frozen ground, saturated soils, and the remnants of tropical storms.[26] Increases in winter precipitation coupled with earlier snowmelt as well as more intense precipitation events would amplify potential flooding risks.[27] Shifts in streamflow hydrology would also have implications for water supply and hydropower generation capabilities. Water quality might be at risk as increased stormwater runoff carries pollutants into rivers and lakes, wastewater facilities are inundated, and warmer waters contribute to cyanobacterial blooms and *E. coli* bacteria growth.[28] Aquatic species would also be impacted by warmer water temperatures and subsequent reductions in dissolved oxygen, and changes in streamflow could impact the life cycle of migratory fish species.[29]

Greenhouse Gas Pollution Reduction

Vermont has adopted by state statute the goal of reducing greenhouse gas emissions from a 1990 baseline by 25 percent by 2012, 50 percent by 2028, and 75 percent by 2050.[30] In order to help achieve these goals, the state is a participant in the Regional Greenhouse Gas Initiative (RGGI), an effort to reduce carbon emissions through a cap-and-trade program.[31] In addition, the Vermont Climate Collaborative has developed a climate action plan for the transportation sector and is finalizing an energy plan.[32] The Governor's Commission on Climate Change (GCCC) released its final report on policy recommendations for reducing Vermont's greenhouse gas emissions in 2007.[33] **To reduce its contribution to climate change, Vermont should commit to implementing concrete measures to decrease statewide greenhouse gas pollution.**

State Adaptation Planning

The GCCC recommended that the state create a climate change adaptation commission to develop a plan that identifies short-term, mid-term, and long-term impacts of climate change and strategies for addressing those impacts.[34] While a comprehensive state adaptation plan has not been developed yet, the state has produced adaptation white papers on how various sectors will be impacted by climate change, what programs are in place to address those challenges, and what actions are needed to continue to adapt.[35] For the water resources sector, existing strategies that may be useful in addressing climate change impacts include the promotion of vegetated buffers for rivers, lakes, and wetlands; river corridor, floodplain, and shoreline protection efforts to reduce encroachment; the promotion of low-impact development for stormwater management; and upgrades to existing infrastructure near waterways.[36] **While many of these strategies can be seen as "no regrets" measures because of the benefits they provide in the absence of climate change, investments in infrastructure (e.g., new reservoirs, highways, or bridges) that do not explicitly consider future changes in hydrology may be more expensive over the long term and make adaptation more difficult.** Among other ideas, the water resources adaptation white paper recommends that climate change be included in water resources policy and decision-making and that policies requiring further setback from water bodies for new infrastructure be established.[37]

Many state agencies also are in the process of devising adaptation strategies. In 2008 the Vermont Agency of Transportation (VTrans) released a climate action plan that included a section on protecting transportation infrastructure from the effects of climate change.[38] In order to better assess the threats to infrastructure from increased flooding, erosion, and extreme precipitation events, VTrans recommended that climate scientists and transportation professionals increase collaboration and that the state identify critical infrastructure that may be vulnerable to climate change and prioritize adaptation in these areas.[39] The Vermont Agency of Natural Resources is using the adaptation white papers as the first part of a three-part process to develop an adaptation plan. The second component of this process, a detailed vulnerability assessment of climate change impacts on forestry, water resources, and fish and wildlife, should be completed by the end of 2012. The final step of this process, the development of a state adaptation plan, will integrate information from the adaptation white papers and natural resources vulnerability assessment.[40]

In 2008, then-governor Jim Douglas and the University of Vermont created the Vermont Climate Collaborative, a partnership among government, academic, and private entities to address climate change and build Vermont's "green economy."[41] The collaborative was retired in 2011 by Governor Peter Shumlin with the establishment of the Vermont Climate Cabinet to coordinate activities by state agencies to reduce greenhouse gas emissions and adapt to climate change.[42] Vermont has established an initial road map for adapting to climate change. **The state should make it a priority to complete the climate change vulnerability assessment and develop and implement an adaptation plan to prepare for a changing climate.**

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VIRGINIA

Over the last century in Virginia, temperatures have increased, precipitation patterns have changed, and sea levels have risen. Continuation and even acceleration of these trends as a result of climate change will put much of the state's resources at risk from higher temperatures, drought, extreme precipitation events, flooding, storm surge, and erosion. A study by researchers at Sandia National Laboratories estimates that between 2010 and 2050, Virginia could lose more than $45 billion in GDP and more than 314,000 jobs due to the impact of reduced water availability on economic sectors, personal income, and interstate migration.[1] By executive order in 2007, the state began to assess the implications of climate change for the people, wildlife, and economy of Virginia and to develop a plan for action. However, recent political changes at the state level have all but halted these efforts. Fortunately, local governments and regional organizations along the Chesapeake Bay realize the threats that climate change poses to their communities and are acting now. **To ensure that communities in other areas of the state are prepared for the impacts of climate change, Virginia should work to integrate climate change into existing state planning processes and develop comprehensive strategies for addressing vulnerabilities and risks.**

Water Resources Background

Virginia's annual average precipitation is nearly 43 inches, with much of it resulting from frontal storms.[2] Rainfall is generally evenly distributed throughout the year, but geographic variations do occur.[3] Annual precipitation averages range from 36 to 55 inches around the state.[4] The Appalachian and Blue Ridge mountain ranges in western Virginia have a particular influence on regional precipitation patterns. The New River and Shenandoah valleys are in the rain shadow of the Appalachian Mountains when airflow is from the west and in the rain shadow of the Blue Ridge Mountains when airflow is from the east.[5] Consequently, these valleys are the driest areas in the state. During the winter, snowfall generally occurs in the Piedmont and mountainous regions of Virginia and rarely in coastal regions.[6]

Virginia's approximately 31,000 miles of rivers and streams are significant sources of water.[7] Nearly two-thirds of the state drains into the Chesapeake Bay through the James, York, Rappahannock, and Potomac rivers.[8] The New River and Tennessee-Big Sandy rivers, in the western part of the state, drain into the Gulf of Mexico, while the Roanoke and Chowan rivers in southern Virginia drain directly into the Atlantic Ocean.[9] Groundwater resources are also a significant source of water, particularly for drinking water supplies. Out of Virginia's 95 counties, 38 rely solely on groundwater for their public supplies, and 55 utilize groundwater for at least half of their public supplies.[10] In certain areas of the state, such as the eastern shore, groundwater depletion has led to the establishment of designated groundwater management areas where large water withdrawals (greater than 10,000 gallons per day) require permits.[11] Of large water withdrawals (excluding power plants) reported to the state in 2009, groundwater wells provided 13 percent of total water withdrawals, and reservoirs, streams, and rivers provided the remainder; however, more than one-third of total groundwater withdrawals were for public water supplies.[12] Of total water withdrawals, public water supplies accounted for 60 percent and manufacturing for 35 percent.[13]

Coastal resources contribute substantially to the culture and economy of the state. Virginia's coastal zone covers approximately one-quarter of the state and contains more than 10,000 miles of tidal shoreline.[14] More than 60 percent of the state's population lives in the coastal zone, and more than 75 percent of total state GDP comes from coastal zone counties.[15] In addition, nearly 68 percent of total tourism dollars spent statewide in 2010 was received in coastal zone counties.[16] The Chesapeake Bay also is a substantial component of the state's coastal resources. The bay is the largest estuary in the U.S. at approximately 200 miles in length, and the port of Hampton Roads is the third-largest container port on the East Coast, handling 15 million tons of cargo valued at nearly $49 billion dollars in 2010. [17,18] Moreover, the state's commercial fisheries for menhaden, striped bass, flounder, oysters, clams, scallops, blue crabs, and other species from the Bay and the Atlantic Ocean are valued at more than $500 million annually.[19]

Climate Change Impacts on Water Resources

Across the southeastern U.S. since 1970, the annual average temperature has risen 2°F, with the greatest seasonal increase occurring during the winter.[20] While average precipitation in the fall has increased by 30 percent since 1901, summer and winter precipitation has decreased by nearly 10 percent in eastern areas including Virginia.[21] Many parts of the Southeast have experienced increases in heavy rainfall events and drought.[22] Over the course of the 21st century, average temperatures in Virginia are projected to warm 5.6°F, and annual precipitation is projected to increase by 11 percent under a moderate-emissions scenario.[23] The greatest temperature increases are expected to occur in the summer.[24] As a result of warmer temperatures in conjunction with population growth, water availability is likely to be negatively impacted.[25] In addition, as groundwater recharge rates and runoff decline, saline intrusion into coastal aquifers is likely to occur.[26] Other changes that are likely as a result of climate change include a decline in dissolved oxygen in streams, lakes, and shallow aquatic habitats; altered distribution of plants and animals; and displacement of native species by invasive ones.[27] Furthermore, climate models suggest that 40 to 100 percent of Virginia's brook trout habitat could be lost by 2090.[28]

Since 1927, sea level has risen at a rate of 1.46 feet per century at Sewells Point in the Hampton Roads region of Virginia.[29] This rate of relative sea level rise, greater than the global average and among the highest along the East Coast, is due to local land subsidence associated with melting of the Laurentide ice sheet, sediment compaction resulting from freshwater withdrawal from coastal aquifers, and megablock faulting and subsidence from a crater formed by a comet or asteroid collision 35 million years ago.[30,31] By 2100, sea levels are projected to rise 2.3 to 5.2 feet in the Chesapeake Bay region.[32]

Continued sea level rise would have wide-ranging implications for the state's coastal areas and aquatic habitats, including submergence of low-lying lands, conversion of wetlands to open water, and increasing salinities in estuaries and freshwater aquifers.[33] Along the bay, Virginia already loses hundreds of acres a year to erosion.[34] For every 1 foot of sea level rise, approximately 50 to 200 feet in shoreline would be subject to erosion.[35] Sea level rise poses a severe threat to property and infrastructure located along the coast. A recent study estimated that more than 740 square miles of land would be vulnerable to inundation as the result of a 2-foot rise in sea level.[36] The Virginia Beach-Norfolk metropolitan area ranks 10th worldwide in assets at risk to sea level rise.[37] A study conducted by the Middle Peninsula Planning District Commission, which covers six counties situated between the Rappahannock and York rivers, estimates that between $187 million and nearly $250 million worth of infrastructure and wetland functions could be at risk from a 1-foot rise in sea level by 2050.[38] Rising sea levels would also subject additional areas to storm surge from tropical cyclones and coastal storms. A U.S. Department of Transportation study estimates that more than 170 miles of major roads and railway and 35 percent of total port land area in Virginia would be at risk to inundation and storm surge after a nearly 2-foot rise in sea level.[39] As sea surface temperatures rise, the intensity of tropical cyclones is also projected to increase.[40] Extratropical storms can cause considerable storm surge, and the frequency of intense extratropical cyclones is projected to increase, generally with stronger winds and higher wave heights; however, projections for specific regions like the mid-Atlantic are not yet known.[41]

Surface temperatures in the Chesapeake Bay have increased at a rate of about 0.5°F per decade since the 1960s.[42] Because the bay lies at the boundary between cold-temperate and warm-temperate species habitat, future warming could impact the distribution of aquatic species. Warm-temperate species, such as Atlantic menhaden, may expand their range in the bay as water temperatures increase, whereas cold-temperate species like the soft clam, already at the southern edge of its range, could be eliminated from the bay entirely.[43] Seasonal changes in ocean currents, salinity, nutrient availability, and dissolved oxygen levels that result from climate change may also have implications for the reproduction and life cycle of aquatic species.[44] Increasing acidification in the bay caused by carbon dioxide uptake by the ocean could also impact the development of the shells of juvenile bivalves, such as the eastern oyster, thereby exposing them to predation or other mortality factors.[45] Submerged aquatic vegetation, such as eelgrass, could also be threatened by rising water temperatures.[46] These underwater grass beds provide vital habitat and serve as a source of food for fish, shellfish, and waterfowl; they also offer erosion protection to adjacent shorelines.[47]

Greenhouse Gas Pollution Reduction

In 2007 then-governor Timothy Kaine issued an executive order establishing a commission to identify actions to reduce greenhouse gas emissions and to prepare for the likely consequences of climate change.[48] This executive order also established a greenhouse gas emissions reduction goal of 30 percent below business-as-usual projections by 2025.[49] In December 2008, the Governor's Commission on Climate Change released its final report, a climate change action plan for Virginia that contained strategies for reducing statewide greenhouse gas emissions. Given recent executive-level changes, it is not clear if the state is moving forward with implementation of these strategies. Because the impacts of climate change are projected to be particularly detrimental Virginia, **the state should commit to implementing concrete measures to reduce greenhouse gas pollution and its contribution to climate change.**

State Adaptation Planning

While the commission's report focused largely on greenhouse gas reduction measures, there were also several recommendations concerning adaptation. These included adopting a living shorelines policy, developing an adaptation plan to minimize impacts on the state economy and critical infrastructure, requiring projects that use state funds to assess climate change vulnerability, developing a sea level rise adaptation strategy, use of policies and regulations to discourage development in vulnerable areas, and the inclusion of climate change into local, regional, and state water supply planning.[50]

Unfortunately, with the election of a new governor in 2010, there appears to be little progress in the implementation of these recommendations, as the administration of Governor Robert F. McDonnell has seen no need to continue the work of the commission.[51] The state has even filed suit against the U.S. Environmental Protection Agency to overturn federal regulation of carbon dioxide emissions.[52] In light of these developments, there are very few efforts at the state level aimed at preparing the state for climate change impacts. Given the range of climate change impacts projected for Virginia, **the state should follow through with the climate change commission's recommendation to develop an adaptation plan.**

The most notable exceptions to this lack of action consist of a strategy to promote living shorelines and help local communities to prepare for sea level rise, and an update to the state's wildlife action plan. Living shorelines employ natural elements to protect against erosion while also serving as habitat for wildlife and providing water quality benefits.[53] As part of a five-year project to advocate for greater use of living shorelines, the Virginia Coastal Zone Management (CZM) Program has conducted case studies and developed guidance resources for individuals and local governments.[54] Furthermore, CZM has just begun its next five-year Section 309 strategy, which will focus on the development of local management plans to further promote living shorelines.[55]

In addition, Virginia CZM has provided funding to three coastal planning district commissions (Hampton Roads, Middle Peninsula, and Northern Virginia) to assess vulnerability to sea level rise and develop response policies.[56] The Virginia General Assembly has also passed legislation instructing the Marine Resources Commission to develop and implement a permitting program that authorizes and encourages the use of living shoreline techniques for shore stabilization.[57] The commission, with technical assistance from the Virginia Institute of Marine Science, also will be developing shoreline management guidance for regulatory agencies and local governments.[58] In November 2009 the Department of Game and Inland Fisheries released guidance on initial steps to conserve wildlife and habitats in the state considering the implications of climate change.[59] This guidance revolved around three main strategies: conserving species and habitats, addressing data and modeling needs, and expanding public outreach.

Local Climate Change Adaptation Efforts—Hampton Roads

Due to the significant amount of infrastructure in low-lying areas and a rate of relative sea level rise that is among the highest in the U.S., the Hampton Roads region in many respects has been leading the state in planning for climate change. With the support of Virginia CZM, the Hampton Roads Planning District Commission (HRPDC), which is composed of 16 local governments, has embarked on a three-year project on adapting to climate change. The first year of the project focused on understanding general impacts of climate change in the region and engaging local stakeholders.[60] The focus during the second year has shifted to understanding storm surge vulnerability and public outreach.[61] The final year of the project involves development of policy recommendations and completion of a regional framework for climate change mitigation and adaptation.[62] The Hampton Roads area was also one of five regions selected by the Federal Highway Administration to test a pilot model for conducting a climate change vulnerability and risk assessment of transportation infrastructure in coordination with the Virginia Department of Transportation, HRPDC, the Hampton Roads Transportation Planning Organization, and the University of Virginia.[63] Specific cities in the region are also addressing climate change risks. The city of Norfolk, for instance, is working with a Dutch coastal engineering firm to develop a flood forecast model that will be utilized to develop a flood mitigation plan for the future.[64]

Despite the lack of adaptation planning at the state level, there are planning and regulatory frameworks in existence that can be utilized to address climate change risks. The Ground Water Management Act of 1992 directs the state to regulate groundwater withdrawals in specific management areas: the Eastern Shore and Eastern Virginia Groundwater Management Areas. Water users that withdraw more 300,000 gallons per month must apply for a permit that requires the development of a water conservation and management plan.[65] In addition, the Local and Regional Water Supply Planning Regulation, issued in 2005, requires that all counties, cities, and towns in Virginia either submit a local water supply plan or participate in a regional water supply plan. Plans are required to include information on existing water sources, water use, and conservation practices; drought response and contingency planning; and the adequacy of existing water sources to meet projected demands over the next 30 to 50 years.[66] These plans are not currently required to consider climate change impacts, such as sea level rise.[67] As recommended by the Governor's Commission on Climate Change, **the state should require that local and regional water supply plans assess climate change as a factor in future water supplies and demands.** Once all local and regional water supply plans have been submitted to the state, the Office of Water Supply Planning in the Department of Environmental Quality (DEQ) will develop a state water supply plan.[68] According to Virginia DEQ officials, it is likely that the state plan will consider climate change impacts in some way—most likely through the development of a climate change scenario for use in a water availability model.[69] Considering the risks that climate change could pose to the state's water supplies, **Virginia should make it a priority to consider the potential impacts of climate change on water resources and identify strategies to reduce these risks in the development of the state water plan.** In addition, "no regrets" strategies like water conservation and green infrastructure should feature prominently in the plan as ways to address existing water resource issues while also building resilience to future climate impacts.

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WASHINGTON

A business-as-usual approach to climate change could cost the state of Washington nearly $13 billion a year, or $2,750 per household, by 2080 as a result of increased health costs, reduced recreational opportunities, reduced salmon populations, and increased wildfire risks, among other things.[1] Concern over climate change impacts such as reduced water supply, sea level rise, and increased extreme precipitation events have prompted state agencies to begin planning. The state is in the process of finalizing a comprehensive climate change adaptation plan due out for public comment in spring 2012. **While this is an important component in ensuring that the state is prepared for the impacts of climate change, the successful implementation of strategies in this plan will ultimately determine the degree to which the state can reduce vulnerabilities to climate risks. In addition, the state should not wait for completion of the adaptation plan to implement "no regrets" strategies, such as improved water conservation and use efficiency and green infrastructure, which provide environmental benefits while also enhancing the capacity to adapt to a changing climate.**

Water Resources Background

Precipitation across the state varies dramatically as a result of differences in topography. The Cascade Mountains divide Washington into two distinct climate regions. The region west of the Cascades receives an average of 50 inches of annual precipitation, and the eastern region averages slightly more than one-quarter of that amount.[2] Potential evaporation is generally less than precipitation in western Washington, whereas in eastern Washington, the reverse is true.[3] Approximately 75 percent of annual precipitation falls in the Cascades during the cool season (October through March).[4] Like most western states, Washington relies on snowpack that accumulates during the cool season to sustain streamflow in the warm season (April through September).

The Columbia River, with a drainage basin of 259,000 square miles, drains all of eastern Washington, the eastern slope of the Cascades, and most of southwestern Washington. It also forms much of the state's boundary with Oregon as it runs to the Pacific Ocean.[5] The river originates in the Rocky Mountains in British Columbia and is the largest river in the Pacific Northwest, with an annual average runoff of 200 million acre-feet.[6] The river is important for irrigation and aquatic habitat and is navigable by vessels traveling to ports in Vancouver and Portland and barges traveling to eastern Washington. It is important for hydropower generation as well; in fact, the Columbia River Hydropower System accounts for nearly 80 percent of energy generated in the Pacific Northwest.[7] Principal tributaries of the Columbia in Washington include the Pend Oreille, Yakima, Spokane, Snake, and Cowlitz rivers.[8] Overall, the Columbia has a total reservoir capacity exceeding 18 million acre-feet from 54 active reservoirs.[9] Major rivers that drain into Puget Sound include the Nooksack, Skagit, Stillaguamish, Snohomish, Puyallup, and Nisqually rivers. The Chehalis, Queets, Hoh, and Quillayute drain into the Pacific Ocean, and the Elwha and Dungeness drain into the Strait of Juan de Fuca.

In 2005 surface water accounted for 74 percent and groundwater accounted for 26 percent of total freshwater use statewide.[10] Irrigation constituted nearly 61 percent of total water use statewide, followed by domestic, industrial, and thermoelectric use at 11 percent, 9 percent, and 8 percent, respectively.[11] More than 80 percent of water for irrigation comes from surface water sources.[12]

There are 15 counties in the state that border either the Pacific Ocean or Puget Sound.[13] The Pacific Ocean coastal area is characterized by narrow, rocky beaches in the north and wide, sandy beaches in the south. Intertidal estuaries along the southern coast, formed by the confluence of major rivers and the ocean, provide habitat for a wide variety of wildlife.[14] Shallow estuaries, such as Grays Harbor and Willapa Bay, are vital areas for shellfish cultivation and support marine fishing fleets. In addition to fishing and recreational facilities, the Columbia River estuary contains port facilities to support international commerce.[15] The Puget Sound region, located between the Cascade Mountains and Olympic Mountains in northwestern Washington, contains the state's most populated corridor. Approximately 4.3 million people (nearly two-thirds of the state's total population) live in the 12 counties that border Puget

Sound.[16] The region is an important contributor of crab, shrimp, mussels, oysters, geoducks, and other clams to Washington's shellfish industry—one of the largest in the U.S.[17] Tourism and recreation are also major contributors to the regional economy, providing in excess of $9.5 billion annually in spending. Additionally, the ports of Seattle and Tacoma make Puget Sound the second-largest harbor for container traffic in the U.S.[18]

Climate Change Impacts on Water Resources

Regionally averaged, the Pacific Northwest has increased 1.5°F in temperature over the past century.[19] There has not been, however, a discernible trend in precipitation.[20] As a result of increasing temperature, mountain glaciers in the North Cascades have lost 18 to 32 percent of their total volume since 1983, and 53 glaciers in this area have disappeared completely.[21] In addition, peak spring runoff has shifted from a few days earlier to as much as 30 days earlier in some areas over the past 50 years.[22] Multiple drought events have occurred since 1971, resulting in dry streambeds, crop losses, fish die-off, and declining groundwater levels.[23] As a result of reduced sediment supply, sea level rise, and a northward shift in the track of Pacific winter storms, areas such as Washaway Beach in southwest Washington have eroded at an average rate of 65 feet per year since the 1880s.[24] More than 100 homes in the region have fallen into the ocean within the past 20 years, including the whole town of North Cove.[25]

Climate models for the Pacific Northwest on average predict future warming of 2°F by the 2020s, 3.2°F by the 2040s, and 5.3°F by the 2080s, relative to the 1970-1999 average.[26] Moreover, the Columbia River Basin as a whole is projected to increase 6°F to 7°F by the end of the 21st century.[27] These models also project minimal changes in annual precipitation but potentially more enhanced seasonal cycles (wetter winters and drier summers). They also generally indicate the likelihood of increased extreme rainfall events, which could increase flooding risks and impact stormwater infrastructure, leading to water quality deterioration and public health threats. Higher temperatures in the fall and winter would cause more precipitation to fall as rain instead of snow, contributing to earlier snowmelt, reduced snowpack, and decreased water availability during the warm season.[28] In addition, April 1 snowpack—a key indicator of water storage available for the warm season—is projected to decline across Washington by approximately 40 percent by the 2040s and nearly 60 percent by the 2080s.[29] In the Puget Sound watersheds, where more than 69 percent of Washington's population lives, April 1 snowpack is projected to be nearly nonexistent by the 2080s.[30] This change will lead to decreased spring snowmelt and a greater winter stream runoff.

Despite these hydrologic changes, models have projected high water system reliability in the Puget Sound region as long as demand does not increase significantly; however, seasonal reservoir storage regimes may be negatively impacted.[31] Decreases in snowpack may also lead to decreased summer baseflow and decreased groundwater infiltration.[32] Temperature increases could lead to changes in streamflow runoff, with increases in the winter and early spring and declines in late spring, summer, and early fall.[33] Within this century, runoff is projected to occur 20 to 40 days earlier than it does now.[34] Furthermore, warm-season runoff is projected to decrease by 30 percent or more by mid-century on the western slopes of the Cascades as a result of earlier snowmelt, reduced snowpack, and increased evapotranspiration.[35] Greater winter runoff is also expected to increase wintertime flooding.[36]

The state's water supply infrastructure was built under the assumption that snowpack would act as a natural reservoir for summer water supplies. As a result, the total storage capacity of reservoirs in the state ranges from only 10 to 30 percent of total annual runoff.[37] Reductions in surface water availability would have severe ramifications for the agricultural, municipal, and industrial users that rely upon a dependable and uninterrupted supply and could place increased stress on groundwater resources if they are used to supplement surface water shortages. More than 300 crops are grown in Washington, sustaining a large food processing industry that contributes more than $34 billion to the state economy each year.[38] The potential impacts of climate change on agriculture are severe. Expected annual crop losses in the Yakima Valley could range from 1.4 percent to 8.8 percent of total annual output by 2050 as a result of water shortages.[39]

Storage reservoirs have an important role in flood control, and increases in winter flooding would force the release of water, further jeopardizing supplies for the warm season. Climate change will also have implications for hydropower generation, which provides nearly three-fourths of the electricity used in the state. Warmer temperatures in the summer will increase the demand for electricity at the same time that reduced streamflow will result in reduced capacity for hydropower generation.[40] By the 2080s, summer hydropower production is projected to decrease by 18 to 21 percent, while energy demand associated with cooling is expected to increase by a factor of 10 to 20 due to both climate change and population growth.[41] However, increased streamflow during the cool season may lead to additional opportunities for hydropower.

Coldwater species, like salmon, will be at risk due to climate change. Increased winter streamflow, as a result of more precipitation falling as rain, could damage spawning nests and wash away incubating eggs.[42] These streamflow increases also could force juvenile salmon to estuaries before they are physically mature enough to fend off predators and environmental stresses. In addition, lower summer streamflows and warmer water temperatures could create migration barriers for salmon and other coldwater species, as well as increase disease risk and mortality.[43] Wild Pacific salmon populations in the Columbia River system are already down 90 percent, and it is expected that one-third of the current coldwater species habitat will be lost by the end of the century.[44] A 2009 report by researchers at the University of Oregon estimated that by 2080 the state would incur a $3 billion loss associated with declining salmon populations.[45]

Sea level rise as a result of climate change will increase erosion and inundation along the more than 3,000 miles of coastline in Washington as well as lead to saltwater intrusion into coastal aquifers.[46] Near-shore habitats will be restricted and eliminated by rising sea levels and armored beaches.[47] Vulnerable areas like south Puget Sound, which contains the cities of Olympia, Tacoma, and Seattle, are expected to experience a sea level rise of 3 to 22 inches by 2050 and 6 to 50 inches (0.5 to 4.2 feet) by 2100.[48] Landslides on coastal bluffs are also a concern as increased winter precipitation along with erosion from sea level rise could lead to slope instability. In the Puget Sound region, nearly 90 percent of shoreline either already contains residential development or is available for development.[49] Major ports like Seattle and Tacoma, which are transfer points between ocean ships and land-based cargo carriers, also would be at risk from sea level rise, potentially leading to significant disruption of commerce.[50] Furthermore, increases in ocean temperature and acidity will have negative implications for shellfish and other marine species. As a result of declining pH levels, decreases in calcification rates for mussels, clams, and oysters are expected.[51] In addition, studies show that some species of economically valuable juvenile fish and shellfish have higher mortality rates at higher carbon dioxide concentrations.[52]

Greenhouse Gas Pollution Reduction

In 2007 Governor Christine Gregoire issued Executive Order 07-02, which established greenhouse gas pollution reduction goals for the state, and directed departments to develop specific steps to address climate change impacts on public health, agriculture, coastline and infrastructure, forestry, and water supply and management. These goals were formally adopted by the Washington State Legislature in 2008 as part of the state's climate change framework, which enacted greenhouse gas emissions reduction limits into law: a rollback to 1990 levels by 2020, 25 percent below 1990 levels by 2035, and 50 percent below 1990 levels by 2050.[53] The framework also directed the Department of Ecology to develop a comprehensive plan to reduce greenhouse gas emissions. The state's Climate Advisory Team released a greenhouse gas emissions reduction strategies report, "Leading the Way on Climate Change: The Challenge of Our Time," in early 2008.[54] In late 2008, the Department of Ecology released its comprehensive plan, "Growing Washington's Economy in a Carbon-Constrained World," which it followed with a subsequent comprehensive plan in 2010, "Path to a Low-Carbon Economy."[55]

With the state's failure to implement a cap-and-trade program, however, it is unlikely that the 2020 emissions reduction goal will be met.[56] Washington also is no longer an active participant in the Western Climate Initiative, a collaboration aimed at reducing regional greenhouse gas emissions through a cap-and-trade program.[57] While establishing greenhouse gas pollution targets is a step in the right direction, **Washington should develop and implement the necessary regulatory tools to ensure that it achieves these pollution reduction levels.**

State Adaptation Planning

The Climate Advisory Team's report contained a chapter on adaptation recommendations for five sectors made by Preparation/Adaptation Working Groups (PAWGs). With regard to water and agriculture, the report recommended that research on water storage options and conservation and efficiency programs be expanded.[58] The recommendations for coastal areas included ensuring that local government planning utilizes sea level rise estimates and other climate change information, revising land use and shoreline planning statues and regulations to address sea level rise and other climate impacts, pursuing nonstructural shoreline protection measures, and assessing vulnerability to sea level rise for the entire Washington coast.[59] Regarding water supply and management, the report's recommendations included identifying existing policies, agreements, and laws that may restrict the ability to manage challenges arising from climate change; developing additional water sources and reducing demand; establishing a statewide water conservation program; and ensuring that climate change is included in long.-range planning.[60]

The Washington Climate Change Impacts Assessment (WACCIA) report, completed in 2009 in response to HB 1303, a bill that directed state agencies to complete a report on climate change impacts on the state, contained a chapter on adaptation strategies meant to supplement the earlier recommendations made by the PAWGs and serve as a foundation for a more comprehensive state adaptation strategy. The WACCIA report listed specific examples of adaptation actions or activities in the water sector that build adaptive capacity with respect to diversifying existing water supplies, developing new water supplies, reducing demand and improving efficiency, implementing operational changes, increasing the ability to transfer water between users, improving drought preparedness, and reducing winter flood impacts. A few notable examples included the removal of obstacles to flexible water reallocation, expanding water reuse, and altering flood insurance programs to incorporate changing risks.[61] The report also cited reducing development in areas vulnerable to sea level rise and including climate change impacts in structural design requirements as potential coastal adaptation actions.[62]

In 2009 Governor Gregoire signed legislation passed by the Washington State Legislature requiring the Departments of Ecology, Agriculture, Commerce, Fish and Wildlife, Natural Resources, and Transportation to develop an integrated climate change response strategy by December 2011.[63] Along with the Department of Health, these agencies will develop this strategy on the basis of interim recommendations made in early 2011 by four topic advisory groups: the built environment; human health and security; ecosystems, species, and habitats; and natural resources.[64] The built environment group made very specific recommendations regarding water supply, water quality, floodplain management, and sea level rise. Some of these recommendations included prioritizing low-cost, no-regrets options such as increased conservation, efficiency, and expanded use of non-potable water, and requiring water infrastructure projects funded by the state to consider climate change impacts in their planning and design.[65] The group also recommended that low-impact development and green infrastructure strategies be utilized for stormwater management. Moreover, the group suggested that land use and infrastructure planning and permitting decisions be required to consider vulnerability to sea level rise and flooding risks.[66]

The human health and security group's recommendations broadly focused on improving surveillance systems, improving education and outreach, and recognizing that social inequities impact the capacity to prevent and adapt to climate change-related health impacts.[67] Notably, the ecosystems, species, and habitats group's recommendations were organized in a manner that aids in their implementation. Key adaptation goals were identified along with priority strategies and the necessary near-term actions to achieve these goals. The group also identified existing tools and programs to implement policies, new programs or policies that may be needed, and barriers to implementation.[68] For example, one strategy identified by the group is to increase the climate resilience of lakes and wetlands by restoring natural functions. Existing programs and tools that may aid in the implementation of this strategy include water pollution laws and regulations and lake management plans. Additional programs needed include better statewide monitoring for lakes. The challenges identified by the group included resource limitations for developing a statewide coverage network for monitoring and modeling.[69]

The natural resources advisory group's recommendations regarding water availability focused on developing additional storage, enhancing existing distribution systems, implementing agricultural conservation and efficiency measures, modifying water regulations, and expanding data on supply and demand.[70] The group advised the state to accelerate efforts to develop small and medium-size reservoirs, which are less expensive and have smaller environmental impacts than large reservoirs. Natural structures like beaver ponds, which improve water quality in addition to regulating flow, were considered by the group as potential water storage solutions due to their environmental and potential agricultural benefits. Efforts to reduce water loss and evaporation from existing infrastructure were also suggested because they can result in significant water savings. Most notably, the group contended that water laws will need to be modified to allow market forces to drive the price of water and incentives for using water more efficiently, but that this should be done in a manner that protects agricultural and environmental needs.

To develop Washington's climate change response strategy, the seven state agencies will evaluate the recommendations made by the four advisory groups in addition to input from other stakeholders.[71] A draft for public comment in spring 2012, with a final strategy anticipated in spring of that year. In addition to the comprehensive strategy being developed, the Department of Ecology, in concert with other agencies, has developed hydrologic climate change scenarios for more than 300 streamflow locations on the Columbia River and coastal drainages west of the Cascades for the 2020s, 2040s, and 2080s.[72] These scenarios allow planners to consider how management may be impacted by climate change-driven hydrologic changes. The state also has partnered with California and Oregon to fund a study by the National Academy of Sciences to develop sea level rise estimates for 2030, 2050, and 2100.[73] Additionally, the Washington State Department of Transportation is piloting the Federal Highway Administration's conceptual model for assessing the vulnerability of transportation infrastructure to climate change.[74]

While planning and research efforts are an important initial step, effective climate change adaptation ultimately hinges on transforming strategies and policies into concrete, effective actions. Because adaptation is largely an uncharted area and projecting specific climate change impacts currently involves significant uncertainties, strategies that are flexible and iterative are likely to be the most successful in most instances. **The state of Washington should prioritize the completion of the integrated climate change response strategy and take advantage of opportunities to implement "no regrets" strategies now, such as green infrastructure for stormwater management and more stringent water conservation measures, which have immediate benefits while also building resilience to future climate change impacts.**

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WEST VIRGINIA

Increasing temperatures and changes in precipitation as a result of climate change could have severe repercussions for the people, economy, and natural resources of West Virginia. Between 2010 and 2050, the state could lose nearly $46 billion in GDP and more than 306,000 jobs due to reductions in water availability driven by climate change.[1] The state's mining and manufacturing industries are particularly vulnerable to climate change, as they need reliable water supplies for operations. The rapid growth of urban populations and water-intensive hydraulic fracturing techniques to recover natural gas in the Marcellus Shale are placing additional stresses on water resources. Despite the high stakes, the state has yet to conduct a climate change vulnerability analysis and develop strategies to manage and reduce risks. **West Virginia should assess its vulnerability to the impacts of climate change and develop an adaptation plan. The current development of a state water resources plan also provides a substantial opportunity for the state to integrate climate change as a factor impacting future water supply and demand, and this opportunity should not be missed. Furthermore, the state can implement water conservation and efficiency and green infrastructure measures that are beneficial now, as well as in the face of changing hydrologic and climatic conditions.**

Water Resources Background

Like many states in the eastern U.S., West Virginia has substantial water resources. Annual average rainfall throughout the state is nearly 40 inches;[2] however, significant geographic variation occurs as a result of the state's topography. Yearly average rainfall ranges from 30 inches in the western part of the eastern panhandle to more than 55 inches along peaks of the Allegheny Mountains.[3] Snowfall is also significant statewide, with annual averages ranging from 20 to 60 inches.[4] This precipitation sustains approximately 9,000 streams and rivers and 100 lakes and reservoirs.[5] The eastern panhandle is drained by the Potomac River and its tributaries; the remainder of the state is drained by the Ohio River, a tributary of the Mississippi.[6] Groundwater resources in the form of unconfined alluvial deposits and karst formations are also significant, supplying nearly one-third of the state's population.[7] The remaining two-thirds of West Virginia's population obtain water from surface resources, as do most of the state's industrial operations.[8] Nearly three-quarters of total surface water withdrawals in the state come from the Kanawha River Valley, home to the city of Charleston as well as Elkem Metals, the largest single user of surface water in the state.[9] According to self-reported data by large water users (drawing more than 750,000 gallons per month) provided to the West Virginia Department of Environmental Protection (WVDEP), thermoelectric generation accounted for nearly 70 percent of total water withdrawn statewide in 2009, followed by the industrial sector at nearly 21 percent, chemical industries at almost 5 percent, water utilities at 2.5 percent, and agriculture at 1.6 percent.[10]

In the past several years, there has been growing concern over the use of hydraulic fracturing (fracking) techniques to recover natural gas in the Marcellus Shale formation. Fracking requires the use of large volumes of water—as much as 2.4 million to 7.8 million gallons per well[11]—which may constrain local supplies. In 2009, 125 wells were completed in West Virginia (out of a total of 426 permitted); these wells consumed a total of 625 million gallons of water, or approximately 5 million gallons per well.[12] The fracking process utilizes chemicals that can place groundwater aquifers at risk of contamination during fracturing; it also generates a substantial quantity of wastewater, or flowback water, that can threaten groundwater resources if spilled or leaked.[13] Approximately 60 to 80 percent of the water, sand, and chemical mixture ("slick water") injected into a wellbore returns to the surface as flowback water.[14] In addition to the chemicals in the injected water, flowback water contains chemical compounds from the shale formation.[15] The potentially large volume of chemical-laden water generated through the process can impact water quality if not disposed of properly through underground injection or wastewater treatment, or reused.[16]

Climate Change Impacts on Water Resources

Over the course of the 20th century, average annual temperatures increased 1.1°F in West Virginia, and precipitation increased by up to 10 percent in many parts of the state.[17] Across the mid-Atlantic region, temperatures are likely to increase 2°F by 2030 and 3°F to 8°F by 2100.[18] In West Virginia specifically, temperatures are projected to warm 4.5°F to 5°F in the southern portion of the state and 5°F to 5.6°F in the northern areas by mid-century under a medium-emissions scenario.[19] While precipitation may increase, net drying is still projected to occur as evapotranspiration rates increase in response to warmer air temperatures.[20,21] There may also be slight increases in the frequency and intensity of winter storms, droughts, and extreme precipitation events.[22,23] As a result of an increasingly warmer climate, an earlier spring snowmelt could occur and lead to higher streamflows in the late winter and early spring.[24] In addition, this shift could result in lower flows and lake levels in the summer and fall, potentially jeopardizing surface water supplies at a time when streamflows are already reduced as a result of increased evapotranspiration during the growing season.[25,26] Because of lower streamflows coupled with warmer temperatures, water quality conditions could deteriorate as pollutants become concentrated.[27] Groundwater supplies could also be impacted by lower spring and summer recharge rates.[28] Increased precipitation could mitigate these impacts but could also increase flooding, erosion and pollutant runoff to waterways.[29,30] Aquatic species also would be vulnerable to climate change effects as increasing temperatures lead to direct habitat loss through drying and warming and as streamflow regimes are disrupted by changes in runoff.[31]

Greenhouse Gas Pollution Reduction

West Virginia has not adopted pollution reduction targets or developed a strategy for reducing greenhouse gas pollution. **West Virginia should decrease its contribution to climate change by adopting greenhouse gas pollution reduction targets and developing and implementing a strategy for achieving them.**

State Adaptation Planning

West Virginia does not appear to have any adaptation efforts under way at the state level to address risks associated with water-related impacts of climate change. The one exception is the Department of Natural Resources' (DNR) project to assess the vulnerability of plant and animal species to climate change. DNR assessed and ranked the relative climate change vulnerability of 185 plant and animal species and developed management strategies, such as increasing habitat connectivity and protecting water quality and streamflow, to incorporate into the state's next wildlife action plan.[32] This project found that the most vulnerable taxonomic group is amphibians, followed by fish, mollusks, and rare plants.[33] **West Virginia should develop and implement a plan to reduce its vulnerability to climate change impacts across all water-related sectors.**

The state is, however, beginning to establish a water resources planning framework. In 2004 the Water Resources Protection Act codified the state's right to regulate water and directed the Department of Environmental Protection (DEP) to conduct a statewide water use survey to assess the quantity of surface water and groundwater resources and consumptive and nonconsumptive withdrawals and to identify areas of residential and industrial growth, among numerous other items.[34] The results and conclusions from this initial assessment informed the subsequent revisions to the act in 2008, when it was renamed the Water Resources Protection and Management Act.[35] This legislation requires DEP to develop a state water resources management plan by 2013 that considers the interconnections and relationships between water and groundwater; regional- or watershed-level water resource needs, objectives, and priorities; federal, state, and interstate water resource policies, plans, objectives, and priorities; needs and priorities of county or municipal governments as reflected by comprehensive plans and zoning ordinances; the water quantity and quality necessary to support reasonable and beneficial uses; a balancing and encouragement of multiple uses of water resources; the distinctions between short-term and long-term conditions, impacts, needs, and solutions; and the equal and uniform treatment of all water users without regard to political boundaries.[36] **West Virginia should consider the potential implications of climate change on water demand and supply as part of this process.** The 2008 revision also requires large water users (those that withdraw more than 750,000 gallons per month) to report water usage to DEP annually.[37] As is being done in many other states, **West Virginia should require these users to develop water management plans that include water conservation, reuse, and efficiency measures.**

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WISCONSIN

A wealth of water resources has been an important contributor to both the identity of Wisconsin and its economic development. However, these resources are threatened by the climate change impacts the state is already experiencing, as well as expected changes in terms of warmer temperatures and more frequent extreme precipitation events. In recognition of the grave threat that climate change poses to the state, the Wisconsin Initiative for Climate Change Impacts (WICCI) released a comprehensive state adaptation plan in February 2011. Consequently, Wisconsin is ahead of other midwestern states in tackling climate change. However, this plan is just a critical first step, and recent changes in state government appear to have slowed the state's progress on implementation. **In order to ensure that it is best positioned to adapt to a future with greater climatic variability, Wisconsin will need to direct resources and focus on implementing strategies identified in its comprehensive plan.**

Water Resources Background

Like much of the northern midwestern states, Wisconsin's climate is continental. Lakes Michigan and Superior provide some influence on climate, although not to the degree experienced in Michigan. Mean annual precipitation ranges from between 30 and 34 inches in the north and west to around 28 inches along the state's border with Lake Michigan.[1] Two-thirds of total precipitation falls during the growing season, which generally runs from May through early September.[2] Snowfall varies considerably within the state. Along the border with Illinois, it averages around 30 inches per year, but northern portions of the state can receive up to 160 inches.[3] Flooding is not uncommon and is most likely during the spring snowmelt in April, although it can also occur in small tributaries during strong thunderstorms in the summer.[4]

Wisconsin's water resources are dominated by several water bodies. The St. Croix and Mississippi Rivers form the state's western border with Minnesota. The Wisconsin River, a tributary to the Mississippi, runs north to south, bisecting almost the entire state. In addition to these larger rivers, the state contains dozens of other important waterways such as the Menominee River in the north along Michigan's Upper Peninsula and the Eau Claire and Chippewa rivers in the south. The state also has lakeshore along Lake Michigan to the east and Lake Superior to the north. All together, the state has more than 15,000 lakes, 12,600 streams and rivers, and 5.3 million acres of wetlands.[5] These substantial water resources provide Wisconsin with billions of dollars in tourism revenue as well as a backbone for the state's largest agricultural sector, the dairy industry. Recreational fishing brings in an estimated $2.75 billion and provides more than 30,000 jobs in the state.[6] Groundwater plays a relatively minor role in the state and comes mainly from the Cambrian-Ordovician Aquifer, which runs under Wisconsin, Minnesota, Iowa, and parts of Michigan.

Daily water usage in Wisconsin was approximately 8.6 billion gallons (26,400 acre-feet) in 2005.[7] Of that amount, 89 percent was withdrawn from surface water sources and the rest from groundwater.[8] Cooling at thermoelectric power plants was the largest user of water in the state, constituting approximately 80 percent of all water withdrawn.[9] The second-largest user of water was public supply, at approximately 6.4 percent, followed by industrial and agricultural use at nearly 5.5 percent and 4.7 percent, respectively.[10] Between 1950 and 2005, water use in Wisconsin increased 333 percent, with the greatest increases in public supply, industrial, and irrigation uses.[11]

The Great Lakes Compact

The Great Lakes contain six quadrillion gallons of water (about 18.4 billion acre-feet), more than one-fifth of the world's surface supply of freshwater and more than 95 percent of the surface freshwater supply in the U.S.[12] Although the volume of the Great Lakes is vast, less than 1 percent of its waters are renewed annually through precipitation, runoff, and infiltration.[13] The Great Lakes Basin ranks third in terms of total freshwater use out of the 21 major watersheds in the U.S.[14] Lake levels are expected to decline over the next century in each of the Great Lakes, from 1 foot on Lake Superior to as much as 3 feet on Lakes Michigan and Huron.[15] Management and use of water in the eight Great Lakes states is governed by the Great Lakes-St. Lawrence River Basin Water Resources Agreement and Compact.[16] In ratifying the compact, each state agreed to undertake a series of actions, including the establishment of thresholds governing new or increased withdrawals of water; implementation of a permitting process for new withdrawals; development of water conservation and efficiency programs, including the establishment of state-specific goals and objectives to guide individual states' programs; and improved data gathering and sharing across the basin. In addition, the compact directs states to "[g]ive substantial consideration to climate change or other significant threats to Basin Waters and take into account the current state of scientific knowledge, or uncertainty,"[17] and to take appropriate measures, such as adaptive management, to address these threats.

Climate Change Impacts on Water Resources

Wisconsin already is experiencing a broad array of climate change impacts. From 1950 to 2006, the average annual temperature in the state increased by 1.1°F.[18] The most warming during this period, 2.5°F, occurred in the northwestern part of the state.[19] Annual average temperatures in the state are projected to increase between 4°F and 9°F by the middle of the century.[20] Northern Wisconsin is expected to warm the most, and the Lake Michigan coastal area the least.[21] Like most midwestern states, the warming trend is expected to be more pronounced in the winter than in the summer.[22,23] In fact, northwestern Wisconsin has already seen a temperature increase in winter, with warming of 4.5°F between 1950 and 2006.[24] As a result of these warmer temperatures, winters are also growing shorter, with the frost-free period in the region now a week longer than it was in the early 1900s.[25] This warming has also caused the growing season to extend two to three weeks in some parts of Wisconsin, with the average growing season statewide lengthening by 12 days between 1950 and 2006.[26] Average winter temperatures are projected to increase between 5°F and 11°F by mid-century.[27]

Average annual precipitation increased 3.1 inches, or 10 percent, between 1950 and 2006.[28] The precipitation trend in the state has been varied, with small parts of the north seeing localized drying while much of the rest of the state becomes noticeably wetter.[29] This trend is modest, and there is some uncertainty regarding whether it is due to anthropogenic climate change or natural variability.[30] However, climate models indicate that average annual precipitation is very likely to rise by mid-century, with increases probable in the winter, spring, and fall.[31] During winter months, average annual snowfall is expected to decline by 14 inches a year, with the largest decreases coming at the edges of the snowfall season, November and March to April, as rain replaces snowfall.[32] Reductions in the amount of snowfall, in addition to increased snowmelt from rising temperatures, are likely to dramatically reduce snow depth by mid-century.[33] For the month of March, a 50 percent increase in the amount of precipitation falling as rain as opposed to snow is projected by mid-century.[34] The frequency and magnitude of extreme precipitation events was also on the rise from 1950 to 2006.[35] For example, the city of Madison now experiences twice as many days per decade with precipitation exceeding 2 inches than in the past.[36] These intense rain events are projected to increase significantly during the winter and spring from December to April and occur 25 percent more frequently by mid-century.[37,38]

These changes in temperature and precipitation will have many implications for Wisconsin's water resources. Warming is expected to increase evapotranspiration rates, and this, coupled with a trend for precipitation to occur more in heavy rainfall events, could increase the likelihood of seasonal droughts.[39] Higher rates of evapotranspiration also lead to a decrease in soil moisture, reduced streamflows, and other impacts. This can cause crop stress and harm habitat quality for fish and other aquatic species. It can also lead to increased stress on water resources as irrigation demand increases, especially in areas like the Central Sands region, where groundwater resources are relied on for drinking water and irrigation.[40] Increases in the intensity and frequency of heavy rainfall events also could increase flood magnitudes in the state's streams and rivers and in urban areas, overwhelm stormwater infrastructure, and lead to sewer overflows.[41] A previous heavy rainfall event in 1993 resulted in combined sewage overflows (CSOs) that exposed 400,000 people to *Cryptosporidium*, a pathogen, and caused 54 deaths.[42] While a similar pathogenic outbreak has not occurred since, many CSOs occur each year. In addition, in areas where groundwater recharge occurs too quickly, localized groundwater flooding could damage basements, homes, and septic systems.[43]

Lake environments particularly are expected to be impacted by climate change as increased stormwater runoff leads to deposition of greater sediment and pollutant loads; ice cover is reduced; lake levels fall; and aquatic species are impacted. Over the past 150 years, the average duration of ice cover on Lake Mendota has declined from four months to three months per year.[44] The loss of ice cover would allow longer periods of wave action to erode shoreline areas and, coupled with storm events, could cause greater risks of damage to coastal property, infrastructure, and recreational facilities.[45,46] Reductions in lake levels could be particularly significant for ship transport and commerce by limiting access to ports and harbors or reducing cargo-carrying capacities.[47] Warmer air temperatures could serve to deplete oxygen levels in bottom layers of deep lakes by delaying fall mixing (the process through which oxygen is redistributed to deeper lake waters), leaving coldwater fish without oxygenated waters in their required temperature range.[48] Furthermore, warmer water temperatures in lakes, rivers, and streams could alter species composition by allowing nonnative species to proliferate and by limiting coldwater species. For example, an increase of just over 5°F in average summer air temperatures is projected to result in the elimination of up to 95 percent of suitable brook trout habitat across the state.[49]

Greenhouse Gas Pollution Reduction

In July 2008 the Governor's Task Force on Global Warming, established by then-governor Jim Doyle, released its final report containing policy recommendations to reduce the state's greenhouse gas emissions.[50] In 2010 the Clean Energy Jobs Act, which contained the Task Force's recommendations, including a 75 percent reduction in greenhouse gas emissions by 2050, was introduced into the Wisconsin State Legislature but failed to be considered for a vote by either legislative body.[51] **Wisconsin should adopt a statewide greenhouse gas pollution reduction target, as has been done by numerous other states, and implement the Task Force's recommendations to achieve this reduction in pollution.**

State Adaptation Planning

The Wisconsin Initiative on Climate Change Impacts (WICCI) was formed in 2007 as a collaboration between the University of Wisconsin–Madison's Nelson Institute for Environmental Studies and the Wisconsin Department of Natural Resources (DNR). The two partners were already independently pursuing work on climate change science, impacts, and policy, and they decided to collaborate to further advance the understanding of climate change impacts in Wisconsin as well as develop strategies and adaptation measures for addressing these changes.[52] To ensure a broad and comprehensive effort, WICCI was divided into 15 working groups: adaptation, agriculture, central sands hydrology, climate, coastal communities, coldwater fish and fisheries, forestry, Green Bay, human health, Milwaukee, plants and natural communities, soil conservation, stormwater, water resources, and wildlife. In February 2011, WICCI released the culmination of these efforts, Wisconsin's Changing Climate: Impacts and Adaptation. This report details many of the potential impacts of climate change on the state's water resources, natural habitats and biodiversity, agriculture and soil, coastal resources, and people. The report also highlights adaptation strategies for tackling these impacts. Notably, many of these strategies are ecosystem-based approaches, which are more flexible and adaptive.

The WICCI Water Resources Working Group identified six major impacts and corresponding adaptation strategies to address them. These are summarized in Table 1.

Table 1. Six major water-related impacts and proposed adaptation strategies.[53]

Impact	Adaptation Strategies
Increasing occurrences of blue-green algae	• Increase monitoring of inland beaches • Develop better prediction tools for blue-green algal toxins • Develop statewide standards for blue-green algal toxins and take appropriate action to protect public health
Flooding impacts on infrastructure and agricultural land	• Identify, map, and prioritize potentially restorable wetlands in floodplain areas • Restore prior-converted wetlands in upland areas to provide storage and filtration • Mitigate storm flows and nutrient loading downstream • Develop both long-term and short-term changes to community infrastructure
Increasing demand for water and groundwater	• Encourage major water users such as power plants to locate in areas with adequate and sustainable water sources, including large rivers or the Great Lakes • Encourage rural and urban water conservation through incentives and regulation; and promote integrated water management by planning water use based on long-term projections of supply and demand and by tying water use to land use and economic growth forecasts
Changes to seepage lakes, with corresponding changes to aquatic chemistry, habitat, and shoreline	• Enhance and restore shoreline habitat to withstand variations in water levels • Enhance infiltration in headwater areas by reducing impervious surfaces in urban and riparian areas and changing land management practices • Change planning and zoning for lakeshore development to account for changes in water levels • Adjust and modify expectations and uses of lakes, especially seepage lakes, by recognizing that some lakes are not suited for all uses

Increased sediment and nutrient loading	• Resize manure storage facilities, wastewater facilities, stormwater drains, and infrastructure to accommodate increased storm flows • Reverse the loss of wetlands; restore prior-converted wetlands to provide storage and filtration by mitigating storm flows and nutrient loading • Protect recharge and infiltration areas and riparian buffers to reduce overland flow of polluted runoff; and incorporate water management strategies based on climate projections into farm-based nutrient management plans
Increased spread of aquatic invasive species	• Identify potential pathways for invasive species migrations under changing climate regimes and take preventive action • Encourage regulatory activities aimed at preventing future invasions of exotic and invasive species likely to thrive in warmer temperatures • Continue exotic and invasive species education/awareness programs for boaters, anglers, and others • Develop rapid response planning and implementation methods to improve existing aquatic invasive species control programs

The WICCI report highlights some additional adaptation strategies for use in the water resources sector. These include using integrated water resources management, increasing infiltration areas by decreasing impervious surfaces, continuing regulatory controls for nutrient loading, improving hydrological models, and coordinating with local government and providing them financial and technical assistance.[54]

Since the release of the report in February 2011, it is not clear if the state has moved strongly toward broad implementation. However, the DNR recently approved workshop presentations on climate change impacts and adaptation strategies for various program areas (forestry, wildlife management, water resources, etc.) for mid-level department management. The WICCI Stormwater Working Group also has worked to implement the report's recommendations regarding flooding by helping communities throughout the state determine vulnerabilities and develop strategies to respond to extreme precipitation events.[55] The group also is working with Rock County to establish an urban floodplain to address anticipated increased flooding damage along the Rock River.[56]

The DNR's 2010 Water Division Report also identifies climate change impacts as an emerging future issue for water resources in the state.[57] The Water Division created four goals to address these impacts: minimizing threats to public health caused by extreme storm events like floods and droughts, increasing the resiliency of aquatic ecosystems to withstand climate change impacts, managing water in the state as an integrated resource and supporting sustainable and efficient water use, and promoting water quality by reducing nutrient and sediment loading.[58] The report also identifies key actions for implementing these goals, including accommodating climate change impacts in rulemaking and budget processes, working with WICCI to understand impacts and suggest adaptation strategies, conducting pilot watershed projects to evaluate and optimize water resource decisions in the context of climate change, and enhancing the Water Division's communication of climate change strategies.[59] Over the next 18 months, DNR is planning to develop a department-wide adaptation plan that builds off the strategies identified in this report as well as the WICCI report.[60] **Wisconsin should direct the necessary resources and prioritize the implementation of adaptation strategies identified in its comprehensive plan to ensure that all state agencies are working to reduce vulnerabilities to climate change impacts.**

In addition, Wisconsin Sea Grant, which is part of the national Sea Grant consortium funded by the National Oceanic and Atmospheric Administration, is currently studying how climate change will impact Wisconsin's lakeshore communities as well as how these communities can adapt to these impacts.[61] The Sea Grant program is also developing models of how climate change will affect the Great Lakes and hosting a speaker series around Wisconsin to help communicate climate change impacts on the Great Lakes to the public. Finally, Sea Grant has established a "Coastal Climate Wiki" message board to enhance communication and collaboration among Sea Grant climate scientists and their extension outreach network around the state.[62]

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WYOMING

A recent study of the economic impacts of climate change for Wyoming estimated that between 2010 and 2050, the state could suffer a $3 billion loss in GDP and a loss of 19,000 jobs due to reduced water availability from climate change.[1] With so much at stake from increasing temperatures and reduced water supplies, the state should be actively integrating climate change impacts into water resources planning at the state and regional levels instead of combating efforts to regulate greenhouse gas pollution. **Wyoming should conduct a systematic evaluation of how warmer temperatures and changes in precipitation may impact the state's water supply, water quality, infrastructure, and wildlife. After doing so, the state can begin to identify and implement strategies and actions to reduce vulnerabilities to climate change impacts. In particular, "no regrets" strategies, such as increased water conservation and green infrastructure, will benefit Wyoming now while also helping to address future climate risks.**

Water Resources Background

Wyoming contains the headwaters of four major river basins in the West: the Missouri, the Colorado, the Great Basin, and the Columbia. The state is the fifth-driest in the nation, but as is common in the West, average annual precipitation varies dramatically across the state. Higher mountain ranges receive from 20 to more than 40 inches of precipitation per year, predominantly in the form of snow during the winter, while the eastern plains receive 9 to 16 inches, mainly between April and July, and the western desert basins receive 6 to 9 inches annually.[2] Of the total annual precipitation that falls in Wyoming, only about 22 percent is available for surface water replenishment or groundwater recharge.[3] Approximately 70 percent of the state's surface water supply comes in the form of snow.[4] Consequently, snowpack that develops in the winter and melts during the late spring and early summer is an important source of water for the state.

The Green and Little Snake rivers in southwestern Wyoming are part of the headwaters of the Colorado River. Under the Upper Colorado River Compact, Wyoming receives 14 percent of the water remaining in the Colorado River after the Lower Basin states receive their annual 7.5 million acre-feet allocation.[5] Wyoming's water rights to other rivers, such as the Laramie, North Platte, and Bear Rivers, are also governed by interstate agreements.[6]

While agriculture almost exclusively uses surface water sources, public water supply uses slightly more groundwater than surface water. As in much of the West, irrigation for agriculture is the largest user of water—nearly 90 percent of total water use in Wyoming is for irrigation.[7] Much of the agricultural water is used to produce forage and feed for the livestock industry.[8] After irrigation, the largest users are mining, thermoelectric generation, public supply, self-supplied domestic, and industrial. The state also has the second-highest per capita freshwater use in the entire nation: 10,000 gallons per day per person.[9]

Climate Change Impacts on Water Resources

Since the 1960s and 1970s, the average temperature over the Great Plains region of the U.S. has increased 1.5°F.[10] Over the past 50 years, August streamflow discharge across the Central Rocky Mountains region generally has declined due to changes in air temperature.[11] By the end of the century, the average summer temperature for Wyoming is expected to increase by 7°F to more than 10°F.[12] While the trend for annual precipitation in the future is not as distinct, conditions are generally expected to become wetter in the northern Great Plains region.[13]

Future temperature increases could have severe implications for Wyoming's water resources. The majority of the state's snowpack accumulates in areas above 10,000 feet in elevation. Because of the small relative size of Wyoming's watersheds, there are limited opportunities to capture snowmelt before it is transported to other states downstream. With increased temperatures as a result of climate change, the amount of snowpack and characteristics of snowmelt are likely to change. Even small increases in temperature would lead to more precipitation falling as rain instead of snow and earlier spring snowmelt. Much of the snow in Wyoming falls as "warm snow," or snow near the freezing point, in late spring. This snow would be extremely susceptible to conversion to rain as a result of increased temperatures.[14] A change from a snow-dominated precipitation regime to one of rain would lead to changes in seasonal streamflow, with peak flows higher and occurring earlier, as well as lower low flows in the late summer.[15] These changes in streamflow could lead to substantial challenges for reservoir managers, who must balance flood control and water supply demands. Increases in temperature would also lead to greater evapotranspiration and a greater incidence of drought.[16] Furthermore, additional precipitation as rain could have implications for groundwater recharge because rain has a tendency to run off instead of infiltrating the ground.[17] According to the 2011 SECURE Water report by the U.S. Bureau of Reclamation, current models predict an 8.5 percent decrease from the 1990s in annual runoff for the Colorado River at Lees Ferry, Arizona—the dividing point between the Upper and Lower Colorado River Basins—by 2050.[18] Decreases in flow from the Colorado as well as other interstate rivers could impact Wyoming's negotiated allocations and increase conflict among existing users.

Because the state's economy is heavily dependent upon agriculture, livestock, and tourism, climate impacts upon these sectors would have wide-ranging repercussions.[19] As a result of temperature increases, irrigation demand will rise as greater evapotranspiration leads to soil moisture loss. Furthermore, decreases in water supply could lead to decreases in crop production. Climate change also could impact coldwater fisheries by driving these species into new ranges or causing extirpation or extinction, while warmwater fisheries could expand as water temperatures rise.[20] In the North Platte River drainage area, thermally suitable habitat for coldwater species could decline by 7 to 76 percent due to warmer air temperatures.[21] The distribution of nonnative species, such as walleye, also could expand as climatic and hydrologic conditions change and favor species that are more tolerant and adaptive.[22]

Greenhouse Gas Pollution Reduction

Wyoming has not developed a climate change pollution reduction plan or established reduction goals for statewide greenhouse gas pollution. As the largest coal-producing state and the state with the highest energy consumption per capita in the U.S.,[23] **Wyoming should adopt pollution reduction goals and enact measures to reduce greenhouse gas pollution. Given the wide range of impacts that it may experience, the state should take concrete measures to reduce its contribution to climate change.** Instead, the Wyoming Legislature recently passed a joint resolution calling on the U.S. Congress to stop the U.S. Environmental Protection Agency (EPA) from regulating greenhouse gases or adopting new air quality regulations.[24]

State Adaptation Planning

Wyoming has not developed a comprehensive adaptation plan, but the state has included a general discussion of potential climate change impacts on wildlife in the state's wildlife action plan. The plan's recommendations include developing a structure for integrating climate change into the planning and monitoring activities of the Game and Fish Department, assessing the climate change vulnerability of species at greatest risk, and promoting habitat connectivity as an ongoing strategy.[25] Given the potential impacts of climate change on a range of sectors in Wyoming, **the state should initiate actions to determine how climate change might impact water resources and develop and implement a strategy for reducing these vulnerabilities.** The Wyoming Climate Issues Committee in the Department of Agriculture could be a potentially relevant group to lead these efforts as the committee is responsible for addressing current climate-related impacts as well as possible future impacts.[26]

In addition, there are existing strategies in place that can be improved and implemented to respond to climate change impacts. The 2007 State Water Plan identified several opportunities for water conservation in the agricultural, industrial, and municipal sectors. Because agriculture is by far the largest user of water in the state, there are substantial opportunities for water conservation through the use of more efficient irrigation methods. Flood irrigation remains a popular practice despite its inefficiency. The plan notes that many areas have converted to more-efficient sprinkler irrigation since the 1970s. **Drip or micro irrigation methods, however, that directly deliver**

water to plant roots are even more efficient, and the conversion to these types of irrigation would undoubtedly lead to greater water savings. For industrial water conservation, the plan notes that the use of dry cooling for power plants would save large volumes of water. In addition, water recycling and reuse for some industries may be feasible. The plan suggests that greater progress could be made with regard to municipal water conservation, noting that there are still many water providers that do not meter water delivery because it is politically unpopular.[27] To improve municipal water conservation statewide, **Wyoming should require water utilities to complete water conservation plans, as is the practice in other western states, and should develop a state public information campaign to promote water conservation.** As part of the state water planning process, individual water plans have been completed for the seven major river basins in Wyoming. These plans evaluated potential future water supplies in each basin. Some proposed strategies to meet future demand included transferring surplus water from basins that are underutilized to those that are in need, allowing the temporary transfer of water rights to users that are willing to enter leasing agreements, and evaluating additional water storage options.[28] **Wyoming should prioritize the implementation of nonstructural and "no regrets" strategies that are relatively low-cost and likely to remain flexible in the face of changing hydrologic conditions. Traditional "gray" or "hard" infrastructure is capital intensive and may inhibit effective adaptation in the long term.**

The 2007 State Water Plan did note that future updates to the state water framework plan and individual basin plans should evaluate the effects of climate change on water resources.[29] The Green River Water Basin Plan update completed in December 2010 contains a small and inadequate discussion of climate change. In this section, the plan suggests that in order to address "climatic variation,"[30] irrigators should ensure that the most productive lands have the most senior water rights so that benefits are maximized when water supplies are constrained, and municipalities should have programs that place restrictions on water use during times of limited supply. The inclusion of climate change in these planning documents is a step, albeit small, in the right direction; however, **Wyoming should conduct a systematic evaluation of how temperature increases and changes in precipitation may impact its water supply, water quality, infrastructure, and wildlife.** In doing so, the state can begin to identify and implement strategies and actions, such as increased water conservation and green infrastructure, that will benefit Wyoming now while also reducing vulnerability to future climate change impacts.

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