

PUBLIC REVIEW DRAFT

NATIONAL WATER PROGRAM STRATEGY: Response to Climate Change



**Office of Water
U.S. Environmental Protection Agency
March 2008**

Acknowledgments

This document was prepared by the **National Water Program Climate Change Workgroup**. The Workgroup is chaired by Deputy Assistant Administrator for Water, Michael Shapiro, and includes:

William Anderson; Office of Water
Jeremy Arling; Office of Wastewater Management
Jeff Besougloff; American Indian Environmental Office
Rona Birnbaum; Office of Air and Radiation
Linda Boornazian; Office of Wastewater Management
James Brown; Region 6
Robert Cantilli; Office of Science and Technology
Ann Codrington; Office of Groundwater and Drinking Water
Elizabeth Corr; Office of Groundwater and Drinking Water
Andy Crossland; Office of Wastewater Management
Katharine Dowell; Office of Water
Wendy Drake; Office of Water
Rachel Fertik; Office of Wetlands, Oceans and Watersheds
Katie Flahive; Office of Wetlands, Oceans and Watersheds
Sarah Hilbrich; Office of Wastewater Management
Dina Kruger; Office of Air and Radiation
Kathleen Kutschenreuter; Office of Wetlands, Oceans and Watersheds
Tom Laverty; Office of Wastewater Management
Fred Leutner; Office of Science and Technology
Cheryl McGovern; Region 9
Karen Metchis; Office of Wastewater Management
Mike Muse; Office of Groundwater and Drinking Water
Douglas Pabst; Region 2
Stephen Perkins; Region 1
Jeff Peterson; Office of Water
Gene Reetz; Region 8
Linda Rimer; Region 4
Suzanne Rudzinski; Office of Science and Technology
Joel Scheraga; Office of Research and Development
Karen Schwinn; Region 9
Martha Segall; Office of Wastewater Management
Surabhi Shah; Office of Water
William Swietlik; Office of Science and Technology
Bonnie Thie; Office of Wetlands, Oceans and Watersheds
Paula VanHaagen; Region 10
John Wilson; Office of Wetlands, Oceans and Watersheds

Disclaimer

This *National Water Program Strategy: Response to Climate Change* provides an overview of the likely effects of climate change on water resources and the Nation's clean water and safe drinking water programs. It also describes specific actions the National Water Program intends to take to adapt program implementation in light of climate change. As such, we hope this document provides useful information and guidance to the public regarding those matters. To the extent the document mentions or discusses statutory or regulatory authority, it does so for informational purposes only. The document does not substitute for those statutes or regulations, and readers should consult the statutes or regulations themselves to learn what they require. Neither this document, nor any part of it, is itself a rule or a regulation. Thus, it cannot change or impose legally binding requirements on EPA, States, the public, or the regulated community. The use of words like "should," "could," "would," "will," "intend," "may," "might," "encourage," "expect," and "can," in this document means solely that something is intended, suggested or recommended, and not that it is legally required, or that any expressed intention, suggestion or recommendation imposes legally binding requirements on EPA, States, the public, or the regulated community. Agency decision makers remain free to exercise their discretion in choosing to implement the actions described in this Strategy.

Table of Contents

Foreword

Executive Summary	i
I. Introduction	1
II. Climate Change Impacts on Water Resources	
1. Climate Change Basic Science	5
2. Air and Water Temperature Change Impacts	6
3. Rainfall/Snowfall Levels and Distribution Change Impacts	9
4. Storm Intensity Change Impacts	11
5. Sea Level Rise Impacts	14
6. Coastal/Ocean Characteristic Change Impacts	17
7. Changes in Energy Generation	19
III. National Water Program: Climate Change Goals and Response Actions	
1. Greenhouse Gas Mitigation Related to Water	24
2. Adapting Water Programs to Climate Change	37
3. Climate Change Research Related to Water	59
4. Water Program Education on Climate Change	64
5. Water Program Management of Climate Change	67

Appendices

1. Climate Change Impacts on Water in Regions of the United States
2. Summary List of Climate Change Actions
3. Adaptations for Alaska Water Infrastructure
4. EPA Global Climate Change Research Related to Water
5. Potential Climate Change/Water Research Needs
6. Glossary of Water Program and Climate Change Terms
7. Water Program and Climate Change Acronyms
8. References and Further Reading

Foreword

For the past thirty years, Federal, State, Tribal, and local governments have worked hard to identify and address water pollution problems. This effort has made our drinking water safer, improved the quality of rivers, lakes, and coastal waters, and protected critical wetlands.

Today, the scientific consensus on climate change is changing our assumptions about water resources. Over the coming years, we in the United States can expect:

- shorelines to move as a result of sea level rise;
- changes in ocean chemistry to alter aquatic habitat and fisheries;
- warming water temperatures to change contaminant concentrations in water and alter aquatic system uses;
- new patterns of rainfall and snowfall to alter water supply for drinking and other uses and lead to changes in pollution levels in aquatic systems; and
- more intense storms to threaten water infrastructure and increase polluted storm water runoff.

There remains significant uncertainty about the exact scope and timing of climate change–related impacts on water resources, but the National Water Program and its partners need to assess emerging climate change information, evaluate potential impacts of climate change on water programs, and identify needed responses.

This ***National Water Program Strategy: Response to Climate Change*** is an initial effort to evaluate how best to meet our clean water and safe drinking water goals in the context of a changing climate. The ideas and response actions outlined here are the product of a cooperative effort among EPA water program managers in national and Regional offices. The EPA Offices of Air and Radiation and Research and Development provided valuable support for this work. And, a wide range of stakeholders participated in initial “listening session” meetings.

A changing climate in the years ahead will raise new challenges for improving the quality of the Nation’s waters. This ***Response to Climate Change*** starts us in the direction of understanding and addressing these challenges. I hope that you will join us in making this important work a success.

Benjamin H. Grumbles
Assistant Administrator for Water

Executive Summary

A long-term, international investment in scientific study of the Earth's climate is now resulting in a scientific consensus concerning climate change and its impacts on water resources. This **National Water Program Strategy: Response to Climate Change** provides an overview of the potential effects of climate change on water resources and the Nation's clean water and safe drinking water programs. It also describes specific actions the National Water Program will take to adapt program implementation in light of climate change.

Why is the Earth Warming?

The Earth absorbs energy from the Sun and radiates energy back into space. Much of the energy going back to space, however, is absorbed by "greenhouse gases" in the atmosphere. Because the atmosphere then radiates much of this energy back to the Earth's surface, the planet is warmer than it would be if the atmosphere did not contain these gases. As levels of greenhouse gases increase, partly as a result of human activity, the Earth will continue to warm.

EPA Administrator Stephen Johnson has identified "clean energy and climate change" as a top Agency priority, and EPA national and Regional offices are working to define strategies and actions in this area. This **Response to Climate Change** is intended to support the Administrator's priority as well as complement the EPA Office of Air and Radiation's leadership of climate change policy and program development and the Office of Research and Development's management of climate change-related research.

Climate change will have numerous and diverse impacts, including impacts on human health, natural systems, and the built environment. Many of the consequences of climate change relate to water resources, including:

- warming air and water;
- change in the location and amount of rain and snow;
- increased storm intensity;
- sea level rise; and
- changes in ocean characteristics.

It is important to note that not all the near-term impacts of climate change are expected to be disruptive, and this **Strategy** focuses on impacts that are of concern for water programs.

Water Impacts of Climate Change: Summarized

Detailed information about water-related impacts of climate change is documented in reports of the Intergovernmental Panel on Climate Change (IPCC) and described in detail in Section II of this **Strategy**. These impacts vary in different parts of North America, but can be briefly summarized as follows:

1. **Increases in Water Pollution Problems:** Warmer air temperatures will result in warmer water. Warmer waters will:
 - hold less dissolved oxygen making instances of low oxygen levels and “hypoxia” (i.e., when dissolved oxygen declines to the point where aquatic species can no longer survive) more likely; and
 - foster harmful algal blooms and change the toxicity of some pollutants.

The number of waters recognized as “impaired” is likely to increase, even if pollution levels are stable.

2. **More Extreme Water-Related Events:** Heavier precipitation in tropical and inland storms will increase the risks of flooding, expand floodplains, increase the variability of streamflows (i.e., higher high flows and lower low flows), increase the velocity of water during high flow periods and increase erosion. These changes will have adverse effects on water quality and aquatic system health. For example, increases in intense rainfall result in more nutrients, pathogens, and toxins being washed into waterbodies.
3. **Changes to the Availability of Drinking Water Supplies:** In some parts of the country, droughts, changing patterns of precipitation and snowmelt, and increased water loss due to evaporation as a result of warmer air temperatures will result in changes to the availability of water for drinking. In other areas, sea level rise and salt water intrusion will have the same effect. Warmer air temperatures may also result in increased demands on drinking water supplies and the water needs for agriculture, industry, and energy production are likely to increase.
4. **Waterbody Boundary Movement and Displacement:** Rising sea levels will move ocean and estuarine shorelines by inundating lowlands, displacing wetlands, and altering the tidal range in rivers and bays. Changing water flow to lakes and streams, increased evaporation, and changed precipitation in some areas, will affect the size of wetlands and lakes, including the Great Lakes.
5. **Changing Aquatic Biology:** As waters become warmer, the aquatic life they now support will be replaced by other species better adapted to the warmer water (i.e., cold water fish will be replaced by warm water fish). This process, however, will occur at an uneven pace disrupting aquatic system health and allowing non-indigenous and/or invasive species to become established. In the long-term (i.e., 50

years), warmer water and changing flows may result in significant deterioration of aquatic ecosystem health in some areas.

- 6. Collective Impacts on Coastal Areas:** Most areas of the United States will see several of the water-related effects of climate change, but coastal areas are likely to see multiple impacts of climate change. These impacts include sea level rise, increased damage from floods and storms, changes in drinking water supplies, and increasing temperature and acidification of the oceans.

These overlapping impacts of climate change make protecting water resources in coastal areas especially challenging.

Response to Climate Change: Goals and Strategic Choices

The National Water Program has an obligation to recognize and address the threats to water resources posed by climate change. This **Response to Climate Change** is an initial effort to describe climate change impacts on water programs, define goals and objectives for responding to climate change, and to identify a comprehensive package of specific response actions. This document expresses the National Water Program's commitment to work in cooperation with national partners, State and local government, and public and private stakeholders to understand the science, develop tools, and implement actions to address the impacts of climate change on water resources.

The National Water Program has established climate change–related goals in each of the three key climate change topic areas already identified by EPA:

- **Mitigation;**
- **Adaptation; and**
- **Research.**

In addition, this **Strategy** includes two supporting goals addressing education of water program professionals on climate change issues and management of climate change work within the National Water Program.

Goals for the National Water Program in each of these five areas are discussed below in terms of the strategic issue that is presented and the National Water Program's conclusion concerning the issue. At the highest “big picture” level, this document represents a “strategic choice” by the National Water Program to change programs and invest resources based on a growing understanding of climate change (i.e., climate change matters to water programs and demands a response). The five goals described below reflect another level of strategic choices, including the decision to expand water program efforts related to greenhouse gas mitigation rather than focus only on water program adaptation and the decision to have a sustained management focus on climate change issues.

Goal 1: Water Program Mitigation of Greenhouse Gases: Use core water programs to contribute to greenhouse gas mitigation

Strategic Issue: The severity of impacts on water resources will depend on greenhouse gas emissions over the long-term. The National Water Program has a range of opportunities to contribute to the goal of reducing greenhouse gases, including water and energy efficiency and assuring that sequestration of carbon protects human health and the environment.

Conclusion: The National Water Program will expand existing programs that result in greenhouse gas mitigation and expand efforts related to geologic and biological sequestration of carbon dioxide. EPA will use the best available science and technology to support responsible operation of water treatment and delivery systems through water conservation and energy efficiency. EPA will also support carbon sequestration related to energy production and industrial processes.

Goal 2: Water Program Adaptation to Climate Change: Adapt implementation of core water programs to maintain and improve program effectiveness in the context of a changing climate and assist States and communities in this effort.

Strategic Issue: EPA, States, and Tribes implementing core water programs will need to continue to meet drinking water, clean water, and wetlands protection goals as the climate changes. Warmer air and water, changes in weather patterns, and rising sea levels will create challenges that may require modifications to programs and new tools in order to sustain past progress and avoid new risks to human health and aquatic ecosystems.

Conclusion: The National Water Program will implement a range of actions to tailor existing water programs to the challenges posed by climate change. The National Water Program will:

- measure, minimize and manage the impacts of climate change on water resources using effective adaptation approaches and will be responsive in our standards and permitting programs;
- be proactive in adapting watershed protection, wetlands, and infrastructure programs in light of climate change;
- develop tools, standards and guidelines, and identify best practices to understand and measure the nature and magnitude of chemical, biological, and physical effects of climate change on water resources; and
- apply environmental science, technology, and information to guide and support proactive climate change planning and management.

Goal 3: Climate Change Research Related to Water: Strengthen the link between EPA water programs and climate change research.

Strategic Issue: Given the significance of climate change impacts on water and water quality, these impacts have been relatively little studied. In addition,

communication of water-related research findings to water program managers has been inconsistent.

Conclusion: The National Water Program will identify and complement climate research by others that supports water programs and this **Strategy**. The National Water Program will expand participation in inter-agency and intra-Agency research planning related to climate change and will adjust core water program research to climate issues as needed.

Goal 4: Water Program Education on Climate Change: Educate water program professionals and stakeholders on climate change impacts on water resources and water programs.

Strategic Issue: EPA water program staff in national and Regional offices need to better understand the anticipated impacts of climate change on water to manage programs effectively. Also, given the range of impacts of climate change around the country, State, Tribal, and local water program partners need information and technical assistance to understand the likely impacts on watersheds, water supply, water infrastructure, and water quality.

Conclusion: The National Water Program will invest in climate change education on water issues for water program managers and partners, will support sharing of information about State and local responses to water impacts of climate change, and will provide tools and technical assistance to support this effort.

Goal 5: Water Program Management of Climate Change: Establish the management capability within the National Water Program to engage climate change challenges on a sustained basis.

Strategic Issue: Prior to creation of the Workgroup that produced this **Strategy**, the National Water Program had not had a comprehensive effort to monitor climate change science, systematically assess climate change impacts on water programs, work with other Federal agencies on this topic, or develop response actions. Implementation of this **Strategy**, however, will require creation of new management capabilities in these areas.

Conclusion: The National Water Program will maintain a Climate Change Workgroup, support EPA Regions' efforts to supplement this **Strategy**, and reach out to other Federal agencies with climate change interests.

Each of these five goals is supported by more specific objectives and "Key Actions." Some of these Key Actions involve existing water program work that has climate change implications while other actions involve new activities, or changes in the direction of current activities, in response to climate change. Key Actions will be initiated in the FY 2008 and 2009 timeframe. In some areas, longer-term actions under consideration are also identified.

Implementation of these new Key Actions assumes level funding (i.e., no new funding for "climate" actions). Given this assumption, this **Response to Climate Change**

represents a further refinement of the “big picture” strategic choices associated with the five major goals by virtue of the allocation of the Key Actions among the five goals. For example, although greenhouse gas mitigation through water programs is a major goal, many more Key Actions are allocated to the water program adaptation goal.

Response to Climate Change: Crosscutting Themes

In developing Key Actions to support the five major goals, several important crosscutting themes emerged (see the introduction to Section III of this **Strategy** for more detailed description of these themes). Understanding these themes was useful in the process of weighing different possible response actions and adding strategic focus to this **Strategy**. These themes offer another perspective on the “strategic choices” made in the development of the **Strategy** and new insight into the substantive, new directions called for in this document.

1. **Develop Data to Adapt to Climate Change:** Water managers need information and baseline data to understand how climate change is altering the environment and inform long-term planning.
2. **Plan for Extreme Water Events:** Water managers need to expand efforts to plan for and respond to extreme weather events resulting from climate change, including storms, an excess of water, and a lack of water.
3. **Increase Watershed Sustainability and Resilience:** Many elements of a “watershed approach” will increase the resiliency of watersheds to climate change and increase the sustainability of aquatic systems.
4. **Develop Analytic Tools:** Water managers need a wide range of new analytic tools to understand and address water resources impacts of climate change.
5. **Strengthen Partnerships:** Water program managers need the help of many partners, including Federal agencies and State, Tribal, and local governments.

I. Introduction

Protecting the quality of the Nation's water resources, and the recreational, ecological and environmental values that water resources support, is an important goal for the country. The growing understanding of climate change is leading to the recognition that a changing climate will affect the protection of the quality of water resources. This ***National Water Program Strategy: Response to Climate Change*** outlines how the National Water Program will respond to climate change.

The National Water Program

The National Water Program is a cooperative effort by Federal, State, Tribal, and local governments to implement core laws, including the Safe Drinking Water Act and the Clean Water Act, to protect and improve the quality of the Nation's waters. Key elements of this effort are intended to:

- assure that water provided by public water systems is safe to drink;
- protect and restore the quality of rivers, lakes, and streams;
- improve the quality of estuarine, coastal, and ocean waters;
- protect wetlands; and
- restore the quality of large aquatic ecosystems around the country such as the Chesapeake Bay, the Great Lakes, and the Gulf of Mexico.

For over thirty years, EPA has worked with other Federal agencies and State, Tribal, and local governments to implement a wide range of programs to protect the Nation's waters. EPA works closely with other Federal agencies, such as the Department of Agriculture, Department of Interior, and Department of Commerce. Many of the Federal water quality programs authorized by Congress are now delegated to States and Tribes that implement the programs with the support of grants from EPA. Local governments play a critical role in this effort as the managers of the drinking water and waste treatment infrastructure and are supported with financing assistance through the State Revolving Fund (SRF) loan programs.

Climate Change and Water

Over the past several years, new information about climate change has emerged from the scientific community. First, recent reports of the United Nations Intergovernmental Panel on Climate Change (IPCC) and the interagency U.S. Climate Change Science Program (CCSP) express a growing consensus on climate change.

Second, it is increasingly clear that climate change may have impacts on water resources and affect the programs designed to protect the quality of these resources. Not all of the near-term impacts of climate change, however, are expected to be

disruptive, and this **Strategy** focuses on impacts that are of concern for water programs. Some of the primary consequences of climate change for water resources include rising sea levels, warming water temperatures, and changes in the amounts and location of rain and snow.

Purpose and Structure of this Document

The purpose of this **Response to Climate Change** is to describe the effects of climate change on water resources and define goals for the National Water Program in responding to the challenges posed by climate change.

“Clean energy and climate change” has been identified by EPA Administrator Stephen Johnson as a top Agency priority, and EPA national and Regional offices are working to define strategies and actions in this area. This **Response to Climate Change** is intended to support the Administrator’s priority as well as complement the EPA Office of Air and Radiation’s leadership of climate change policy and program development and the Office of Research and Development’s management of climate change–related research.

Following this Introduction, Section II of the document describes the primary impacts of climate change on water resources including:

- air and water temperature increases;
- changes in levels and distribution of rainfall and snowfall;
- storm intensity increases;
- sea level rise; and
- changes in coastal/ocean characteristics.

Section III of the document describes five general goals for the National Water Program response to climate change impacts on water resources:

Goal 1: Water Program Mitigation of Greenhouse Gases: use water programs to contribute to greenhouse gas mitigation;

Goal 2: Water Program Adaptation to Climate Change: adapt implementation of core water programs to maintain and improve program effectiveness in the context of a changing climate;

Goal 3: Climate Change Research Related to Water: strengthen the link between EPA water programs and climate change research.

Goal 4: Water Program Education on Climate Change: educate water program professionals and stakeholders on climate change impacts on water resources and programs; and

Goal 5: Water Program Management of Climate Change: establish the management capability within the National Water Program to engage climate change challenges on a sustained basis.

Each of these five goals is supported by a series of objectives and “Key Actions” that the National Water Program will implement in cooperation with partners. Although the Key Actions defined in this **Strategy** are a blueprint for accomplishing the five goals described above, in a larger sense, the success of the **Strategy** depends on water program staff taking responsibility for understanding climate change impacts and helping adapt their programs to address these impacts.

Process of Developing this Document

This **Response to Climate Change** was developed by a Climate Change Workgroup established by the Assistant Administrator for Water at the EPA. The Workgroup is chaired by the Deputy Assistant Administrator for Water and includes senior water program managers from national and Regional offices of EPA, including the Office of Air and Radiation and Office of Research and Development.

The Workgroup began meeting in April 2007 and, in May, June, and August conducted a series of “listening sessions” with a range of stakeholders. This draft **Strategy** is now available for public comment, and the comments will be considered in preparing the final document.

Next Steps

With the publication of the final **Response to Climate Change** document, the National Water Program will affirmatively implement the Key Actions described in Section III and will monitor the implementation of these actions, provide periodic public reports of progress, and review and revise the document as needed over time.

Throughout this process, the EPA Office of Water will continue to work to strengthen linkages with other EPA offices; EPA Regional offices; other Federal agencies; State, local, and Tribal partners; and others to continue to improve the understanding of both the impacts of climate change on water resources and the range of actions that might further improve the National Water Program response to climate change. In addition, EPA Regional Offices may supplement this **Strategy** with actions designed to address the most significant climate change impacts in the Region.

II. Climate Change Impacts on Water Resources

A first step in understanding how the National Water Program should respond to climate change is to understand the basic science of climate change and the consequences of climate change for water resources. Some of the primary effects of climate change for water resources include:

- Air and Water Temperature Increases;
- Changes in Levels and Distribution of Rainfall and Snowfall;
- Storm Intensity Increases;
- Sea Level Rise; and
- Changes in Coastal/Ocean Characteristics.

Each of these five primary ways climate change impacts water resources is described briefly below. Much of the information in this section is drawn from EPA's climate change website and is supplemented with water-related

information from research reports prepared by U.S. EPA's Office of Research and Development (ORD) and the Intergovernmental Panel on Climate Change (IPCC). The description of the impacts of climate change on water resources and water programs is based on the collective experience and best professional judgment of EPA scientists.

EPA Climate Change Website: EPA's Climate Change website provides useful summaries of a wide range of climate change-related information:
<http://www.epa.gov/climatechange/>

In addition to a general description of potential effects on water resources, some of the specific impacts expected in North America are described and effects on a range of water programs are identified. More specific information on impacts in different areas of the country is included in Appendix 1.

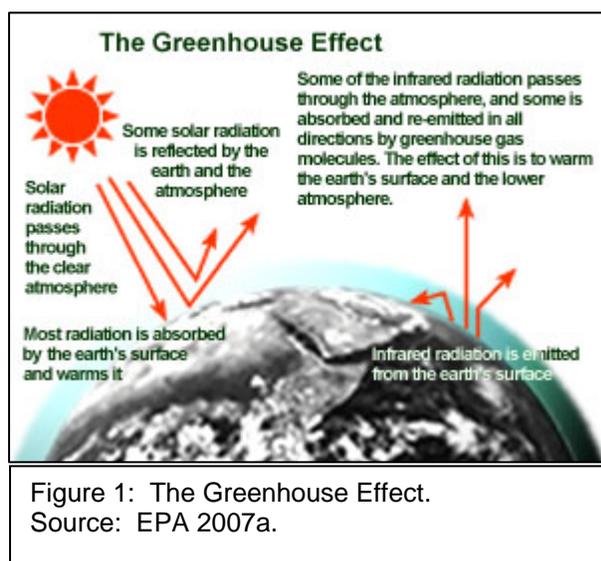
The Intergovernmental Panel on Climate Change (IPCC): Established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988, the IPCC assesses scientific, technical, and socio-economic information relevant to climate change.

Finally, it is increasingly likely that one response to climate change will be a shift in the methods of producing energy (e.g., increased demand for biofuels). Some of these changes in the methods of energy production may affect water resources and water protection programs. Some of the expected impacts on water resources due to shifts in energy production are described at the close of this section.

1. Climate Change Basic Science

Climate change refers to significant change in measures of climate (such as temperature or precipitation) lasting for an extended period (decades or longer).

Energy from the Sun drives the Earth's weather and climate. The Earth absorbs energy from the Sun and also radiates energy back into space. However, much of this energy going back to space is absorbed by “greenhouse gases” in the atmosphere (see Figure 1: Greenhouse Effect). Because the atmosphere then radiates most of this energy back to the Earth's surface, the planet is warmer than it would be if the atmosphere did not contain these gases. Without this natural “greenhouse effect” temperatures would be about 60°F lower than they are now, and life as we know it today would not be possible (EPA 2007a).



Climate change may result from:

- natural factors, such as changes in the sun's intensity or slow changes in the Earth's orbit around the sun;
- natural processes within the climate system (e.g., changes in ocean circulation); and
- human activities that change the atmosphere's composition (e.g., through burning fossil fuels) and the land surface (e.g., deforestation, reforestation, urbanization, desertification)

During the past century, humans have substantially added to the amount of greenhouse gases in the atmosphere by burning fossil fuels such as coal, natural gas, oil and gasoline to power cars, factories, utilities and appliances. The added gases—primarily carbon dioxide and methane—are enhancing the natural greenhouse effect and likely contributing to an increase in global average temperature and related climate changes (EPA 2007a).

The Intergovernmental Panel on Climate Change (IPCC) concluded in its 2007 report on climate change:

“Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and water temperatures, widespread melting of snow and ice, and rising global average sea level” (IPCC 2007a, Working Group I *Summary for Policymakers*, p. 5).

2. Air and Water Temperature Increases

Temperatures are changing in the lower atmosphere—from the Earth’s surface all the way through the stratosphere (9 to 14 miles above the Earth’s surface) (EPA 2007b). Most climate change scenarios project that greenhouse gas concentrations will increase through 2100 with a continued increase in average global temperatures (IPCC 2007a, as found in EPA 2007c).

A. Background

According to EPA’s climate change website (EPA 2007b) and data from NOAA and NASA (NOAA 2007, NASA 2006):

- since the mid 1970s, the average surface temperature has warmed about 1°F;
- the Earth’s surface is currently warming at a rate of about 0.32°F per decade or 3.2°F per century; and
- the five warmest years over the last century have likely been: 2005, 1998, 2002, 2003, and 2006. The top 10 warmest years have all occurred since 1990.

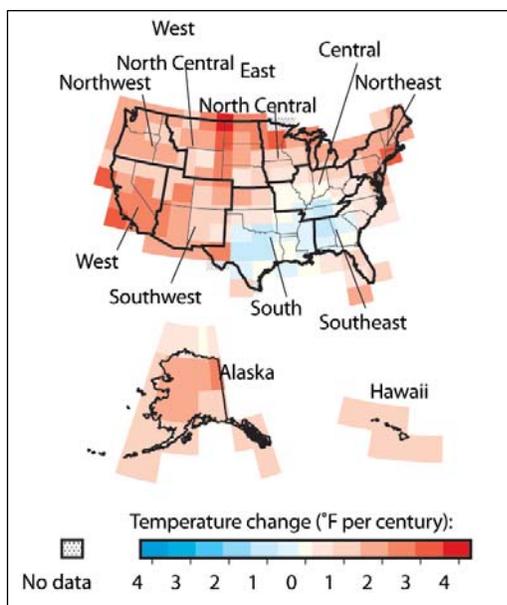


Figure 2. Annual mean temperature anomalies, 1901-2005. Red shades indicate warming over the period, and blue shades indicate cooling over the period. Source: NOAA/NESDIS/NCDC, as found in EPA 2007b.

Looking ahead, the IPCC recently concluded that: “All of North America is very likely to warm during this century, and the annual mean warming is likely to exceed the global mean warming in most areas” (Christensen et al. 2007, p. 887). More specifically, the IPCC finds that “[w]arming in the USA is expected to exceed 2°C by nearly all the models...” (Christensen et al. 2007, p. 889). Climate models project regional variation of warming—for example, some models project that warming in parts of Alaska could reach 10 degrees C (Christensen et al. 2007, p. 889)). See Figure 2 for a graphic depiction of temperature trends in the continental United States for the last century based on data from the National Oceanographic and Atmospheric Administration’s (NOAA’s) National Climatic Data Center (NCDC). NCDC’s observations indicate that in the last century, temperatures rose at an average rate of 0.11°F per decade (1.1°F per century) in the continental United States.

Water temperatures have also been rising, and increases have been observed in both freshwater

and salt water. For example, the IPCC reported recently that: “There is compelling evidence that the heat content of the World Ocean has increased since 1955. In the North Atlantic, the warming is penetrating deeper than in the Pacific, Indian and Southern Oceans...” (Bindoff et al. 2007, p. 420). Ocean surface temperatures are predicted to increase over the next hundred years (IPCC 2007a, see Working Group I *Technical Summary*, p. 72). Further, inland water temperature projections indicate that “[s]imulated future surface and bottom water temperatures of lakes, reservoirs, rivers, and estuaries throughout North America consistently increase from 2 to 7°C ... with summer surface temperatures exceeding 30°C in Midwestern and southern lakes and reservoirs” (Field et al. 2007, p. 629).

B. Impacts on Water Resources

Warmer air temperatures are expected to have several impacts on water resources including diminishing snow pack and increasing evaporation, which affects the seasonal availability of water (Field et al. 2007, p. 619).

A key impact of warmer air temperatures is warmer water temperatures. Some impacts of warmer water temperatures are:

- a shift in aquatic species distribution and population, including increased risk of extinction of species already listed as threatened (Field et al. 2007, p. 631);
- “[h]igher stream temperatures affect fish access, survival and spawning (e.g., west coast salmon) (Field et al. 2007, p. 629);
- higher temperatures reduce dissolved oxygen levels, which can have an effect on aquatic life (EPA 2007h), and according to the IPCC, “warming is likely to extend and intensify summer thermal stratification, contributing to oxygen depletion” in lakes and reservoirs (Field et al. 2007, p. 629);
- increased concentrations of some pollutants (e.g., simulations in the Bay of Quinte in Lake Ontario indicated that 3 to 4°C warmer water temperatures contribute 77 to 98 percent increases in summer phosphorus concentrations (Field et al. 2007, p. 629)); and
- “[h]igher surface water temperatures will promote algal blooms and increase the bacteria and fungi content”, which “... may lead to a bad odor and taste in chlorinated drinking water and the occurrence of toxins” (Kundzewicz et al. 2007, p. 188).

Some aquatic organisms are particularly sensitive to temperature. For example, the breeding cycle of many amphibians is closely related to temperature and moisture, and reproductive failure can occur when breeding phenology—periodic biological phenomena correlated with climate—and pond-drying conditions are misaligned (Field et al. 2007, p. 630). Further, many coral reefs are surviving at or close to their temperature tolerance levels, so rising sea surface temperatures are creating more hostile conditions for the corals (EPA 2007k). Saltwater and freshwater fisheries are also affected by climate change; in 2001, the IPCC stated that “[p]rojected climate

changes have the potential to affect coastal and marine ecosystems, with impacts on the abundance and spatial distribution of species that are important to commercial and recreational fisheries” (Cohen et al. 2001, as referenced in Field et al. 2007, p. 620). Further, “[c]old-water fisheries will likely be negatively affected by climate change; warm-water fisheries will generally gain; and the results for cool-water fisheries will be mixed, with gains in the northern and losses in the southern portions of ranges” (Field et al. 2007, p. 631). Although temperature increases may favor warm-water fishes, such as smallmouth bass, “changes in water supply and flow regimes seem likely to have negative effects” on these fishes (Field et al. 2007, p. 632).

C. Impacts on Water Programs

As air and water temperatures warm, water resource managers will likely face significant challenges:

- increased pollutant concentrations and lower dissolved oxygen levels will result in additional waterbodies not meeting water quality standards and, therefore, being listed as impaired waters requiring a total maximum daily load (TMDL);
- increased growth of algae and microbes will affect drinking water quality;
- discharge permits and nonpoint pollution control programs may need to be adjusted to reflect changing conditions;
- States and EPA may need to consider the effects of changing air and water temperatures on water quality;
- increased water use will put stress on water infrastructure and demands on the clean water and drinking water State Revolving Funds; and
- drinking water and wetlands managers will need to account for water losses due to increased evapotranspiration rates.

Air and Water Temperature Increases: Effects on Water Programs (Shaded areas reflect programs most affected by air and water temperature increases)

Drinking Water Standards	Surface Water Standards	Technology Based Standards	Emergency Planning
Drinking Water Planning	Clean Water Planning	Water Monitoring	Water Restoration/ TMDLs
Underground Injection Control Permits	Discharge Permits	Storm Water Permits	Wetlands Permits
Source Water Protection	Nonpoint Pollution Control	Coastal Zone	National Estuaries Program
Drinking Water SRF	Clean Water SRF	Ocean Protection	Combined Sewer Overflow Plans

3. Rainfall/Snowfall Levels and Distribution

According to the IPCC, an increase in the average global temperature is very likely to lead to changes in precipitation and atmospheric moisture because of changes in atmospheric circulation and increases in evaporation and water vapor (EPA 2007e). The effects of increases in temperature and radiative forcing, a measure of irradiation in the tropopause, “alter the hydrological cycle, especially characteristics of precipitation (amount, frequency, intensity, duration, type) and extremes” (Trenberth et al. 2007, p. 254).

Climate models suggest an increase in global average annual precipitation during the 21st century, although changes in precipitation will vary from region to region (IPCC 2007a, as found in EPA 2007e). Regional precipitation projections from climate models, however, must be considered with caution since their reliability at small spatial scales is limited (EPA 2007e).

A. Background

The IPCC has concluded that: “Increases in the amount of precipitation are *very likely*¹ in the high latitudes, while decreases are *likely*² in most subtropical land regions...continuing observed patterns in recent trends [emphasis in original]” (IPCC 2007a, see Working Group I *Summary for Policymakers*, p. 16). See Figure 3 for a depiction of precipitation trends in the continental United States in the last century.

Increases in temperature can affect the amount and duration of snow cover which, in turn, can affect timing of streamflow. Glaciers are expected to continue retreating, and many small glaciers may disappear entirely (EPA 2007i). Peak

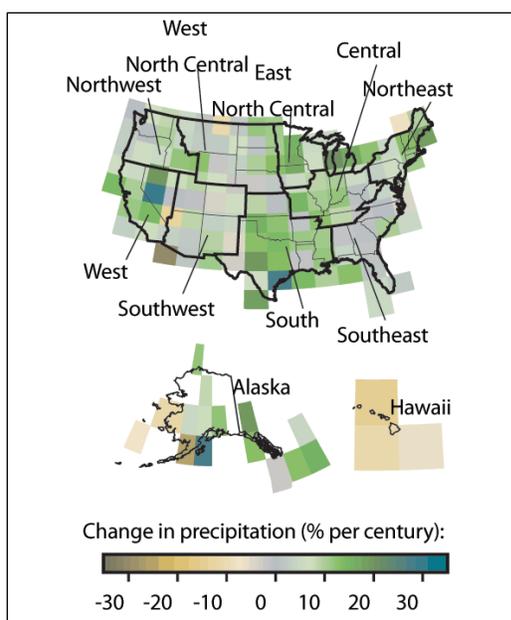


Figure 3. Annual precipitation trends, 1901-2005. Green shades indicate a trend towards wetter conditions over the period, and brown shades indicate a trend towards dryer conditions. No data are available for areas shaded in white. Source: NOAA/NESDIS/NCDC, as found in EPA 2007d.

¹ IPCC used the following terms to indicate the assessed likelihood, using expert judgment, of an outcome or a result: *virtually certain* > 99% probability of occurrence, *extremely likely* > 95%, *very likely* > 90%, *likely* > 66%, *more likely than not* > 50%, *unlikely* < 33%, *very unlikely* < 10%, *extremely unlikely* < 5% (IPCC 2007a, see Working Group I, *Summary for Policymakers*, p. 3).

² See footnote 1 for the IPCC Working Group I’s use of the term “likely”.

streamflow may move from late spring to early spring/late winter in those areas where snowpack is important in determining water availability (EPA 2007i). For example, studies in the western United States typically show a decline in winter snowpack and earlier snowmelt as a result of regional warming (Christensen et al. 2007, p. 891).

These precipitation trends are expected to continue. The IPCC reported this year that: "Annual mean precipitation is very likely to increase in Canada and the northeast USA, and likely to decrease in the southwest USA" (Christensen et al. 2007, p. 887). The IPCC also concluded that: "Snow season length and snow depth are very likely to decrease in most of North America..." (Christensen et al. 2007, p. 887).

B. Impacts on Water Resources

Changing precipitation patterns are expected to have several impacts on water resources including:

- increased frequency and intensity of rainfall in some areas will produce more pollution and sedimentation due to runoff (EPA 2007h);
- potential increases in heavy precipitation, with expanding impervious surfaces, could increase urban flood risks and create additional design challenges and costs for stormwater management" (Field et al. 2007, p. 633);
- flooding can affect water quality, as large volumes of water can transport contaminants into waterbodies and also overload storm and wastewater systems (EPA 2007h);
- in general, in areas where precipitation increases sufficiently, net water supplies may increase while in other areas where precipitation decreases, net water supplies may decrease (EPA 2007i); and
- the net impact on water supplies will depend on changes in precipitation (including changes in the total amount, form, and seasonal timing of precipitation) (EPA 2007i).

C. Impacts on Water Programs

Changing precipitation patterns pose several challenges for water program managers:

- limited water availability and drought in some regions will require drinking water providers to reassess supply facility plans and consider alternative pricing, allocation, and water conservation options;
- increased rainfall, especially more intense rainfall, will result in increased storm water runoff and may make overflows of sanitary sewers and combined sewers more frequent, putting increased demands on discharge permit programs and nonpoint pollution control programs;
- increased storm water runoff will wash sediment and other contaminants into drinking water sources, requiring additional treatment;

- additional investments in water infrastructure may be needed to manage both decreases in rainfall (e.g., expanded retention facilities) and increases in rainfall (e.g., increases in pipe and storm water management facilities), and these demands could strain water financing generally including the State Revolving Funds;
- in areas with less precipitation, demand for water may shift to underground aquifers and prompt development of new reservoirs or underground injection of treated water for storage;
- in areas with less precipitation, lower streamflow and limited groundwater recharge will make meeting water quality goals more challenging; and
- increased incidence of wildfire as a result of reduced precipitation can reduce the amount of water retained on the land, increase soil erosion, increase water pollution, increase risk of flooding, and pose a threat to water infrastructure.

Rainfall and Snowfall Levels/Distribution: Effects on Water Programs

(Shaded areas reflect programs most affected by rainfall and snowfall levels)

Drinking Water Standards	Surface Water Standards	Technology Based Standards	Emergency Planning
Drinking Water Planning	Clean Water Planning	Water Monitoring	Water Restoration/TMDLs
Underground Injection Control Permits	Discharge Permits	Storm Water Permits	Wetlands Permits
Source Water Protection	Nonpoint Pollution Control	Coastal Zone	National Estuaries Program
Drinking Water SRF	Clean Water SRF	Ocean Protection	Combined Sewer Overflow Plans

4. Storm Intensity

According to the IPCC, “[t]he frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapor” (IPCC 2007a, Working Group I *Summary for Policy Makers*, p. 8). Further, “[b]ased on a range of models, it is *likely*³ that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea surface temperatures [emphasis in original]” (IPCC 2007a, Working Group I *Summary for Policymakers*, p. 15).

³ IPCC used the following terms to indicate the assessed likelihood, using expert judgment, of an outcome or a result: *virtually certain* > 99% probability of occurrence, *extremely likely* > 95%, *very likely* > 90%, *likely* > 66%, *more likely than not* > 50%, *unlikely* < 33%, *very unlikely* < 10%, *extremely unlikely* < 5% (IPCC 2007a, see Working Group I, *Summary for Policymakers*, p. 3).

A. Background

There is large natural variability in the intensity and frequency of mid latitude storms and associated features such as thunderstorms, hail events and tornadoes. To date, there is no long-term evidence of systematic changes in these types of events over the course of the past 100 years (IPCC 2007a, as found in EPA 2007d). Analyses of severe storms are complicated by factors including the localized nature of the events, inconsistency in data observation methods, and the limited areas in which studies have been performed (EPA 2007d).

The frequency and intensity of tropical storm systems have also varied over the 20th century on annual, decadal and multi-decadal time scales. For example, in the Atlantic basin, the period from about 1995-2005 was extremely active both in terms of the overall number of tropical storm systems including hurricanes as well as in storm intensity. However, the two to three decades prior to the mid-1990s were characterized as a relatively inactive period (EPA 2007d).

Following the Atlantic hurricane season of 2005, which set a record with 27 named storms, a great deal of attention has focused on the relationship between hurricanes and climate change. Numerous studies have been published on possible linkages, with a range of conclusions (EPA 2007d). To provide an updated assessment of the current state of knowledge of the impact of global warming on tropical systems, the World Meteorological Organization's hurricane researchers published a consensus statement. Their conclusions include (WMO 2006, as found in EPA 2007d):

- “Though there is evidence both for and against the existence of a detectable anthropogenic signal in the tropical cyclone climate record to date, no firm conclusion can be made on this point.”
- “There is general agreement that no individual events in [2004 and 2005] can be attributed directly to the recent warming of the global oceans...[but] it is possible that global warming may have affected the 2004-2005 group of events as a whole.”

Mid-latitude storm tracks are projected to shift toward the poles, with increased intensity in some areas but reduced frequency (EPA 2007e). Tropical storms and hurricanes are likely⁴ to become more intense, produce stronger peak winds, and produce increased rainfall over some areas due to warming sea surface temperatures (which can energize these storms) (IPCC 2007a, as found in EPA 2007e). The relationship between sea surface temperatures and the frequency of tropical storms is less clear (EPA 2007e).

⁴ IPCC used the following terms to indicate the assessed likelihood, using expert judgment, of an outcome or a result: *virtually certain* > 99% probability of occurrence, *extremely likely* > 95%, *very likely* > 90%, *likely* > 66%, *more likely than not* > 50%, *unlikely* < 33%, *very unlikely* < 10%, *extremely unlikely* < 5% (IPCC 2007a, see Working Group I, *Summary for Policymakers*, p. 3).

B. Impacts on Water Resources

The primary impacts of increasing storm intensity on water resources is coastal and inland flooding, complicated in the case of coastal storms by storm surges. Many of these impacts will vary regionally and can be influenced by other factors such as the level of development in the watershed. Some of the key water impacts of this flooding are the following:

- water quality changes may be observed in the future as a result of "... water infrastructure malfunctioning during floods" (Kundzewicz et al. 2007, p. 189); and
- flood magnitudes and frequencies will very likely increase in most regions—mainly a result of increased precipitation intensity and variability—and increasing temperatures are expected to intensify the climate's hydrologic cycle and melt snowpacks more rapidly (IPCC 2007b, as found in EPA 2007h).



Figure 4: Coastal flooding.

In addition to flooding, increased storm frequency and/or intensity may result in the following:

- adverse effects in surface and ground water quality and contamination of water supply (IPCC 2007b, Working Group II *Summary for Policymakers*, p. 18);
- water quality changes may be observed in the future as a result of "overloading the capacity of water and wastewater treatment plants during extreme rainfall" (Kundzewicz et al. 2007, p. 189);
- "[w]ater-borne diseases will rise with increases in extreme rainfall" (Kundzewicz et al. 2007, p. 189); and
- "[a]ll studies on soil erosion have suggested that increased rainfall amounts and intensities will lead to greater rates of erosion unless protection measures are taken" (Kundzewicz et al. 2007, p. 189).

C. Impacts on Water Programs

Water resource managers will face significant challenges as storm intensity increases:

- although there is some uncertainty with respect to climate models addressing storm intensity and frequency, emergency plans for drinking water and wastewater infrastructure need to recognize long-term increases in high flow and high velocity events due to intense storms as well as potential low flow periods;

- damage from intense storms may increase the demand for public infrastructure funding and may require re-prioritizing of infrastructure projects;
- floodplains may expand along major rivers requiring relocation of some water infrastructure facilities and coordination with local planning efforts;
- in urban areas, stormwater collection and management systems may need to be redesigned to increase capacity;
- combined storm and sanitary sewer systems may need to be redesigned;
- the aquatic system impacts of higher velocities from more intense storms will require expanded use of biological monitoring and assessment techniques;
- the demand for watershed management techniques that mitigate the impacts of intense storms and build resilience into water management through increased water retention (e.g., green roofs, smart growth) is likely to increase; and
- the management of wetlands for stormwater control purposes and to buffer the impacts of intense storms will be increasingly important.



Storm Intensity: Effects on Water Programs
(Shaded areas reflect programs most affected by storm intensity)

Drinking Water Standards	Surface Water Standards	Technology Based Standards	Emergency Planning
Drinking Water Planning	Clean Water Planning	Water Monitoring	Water Restoration/TMDLs
Underground Injection Control Permits	Discharge Permits	Storm Water Permits	Wetlands Permits
Source Water Protection	Nonpoint Pollution Control	Coastal Zone	National Estuaries Program
Drinking Water SRF	Clean Water SRF	Ocean Protection	Combined Sewer Overflow Plans

5. Sea Level Rise

“Global mean sea level has been rising”, according to the IPCC. “From 1961 to 2003, the average rate of sea level rise was 1.8 ± 0.5 mm [per year]. For the 20th century, the average rate was 1.7 ± 0.5 mm [per year]. There is high confidence that the rate of sea level rise has increased between the mid-19th and the mid-20th centuries” (Bindoff et al. 2007, p. 387). Further, “[t]here are uncertainties in the estimates of the contributions to sea level change but understanding has significantly improved for recent periods

(Bindoff et al. 2007, p. 387).” For example, “... for the period 1993 to 2003, ... the contributions from thermal expansion (1.6 ± 0.5 mm [per year]) and loss of mass from glaciers, ice caps and the Greenland and Antarctic Ice Sheets together give 2.8 ± 0.7 mm [per year]” (Bindoff et al. 2007, p. 387).

A. Background

The IPCC states that the primary factors driving current sea level rise include the expansion of ocean water caused by warmer ocean temperatures, melting of mountain glaciers and small ice caps, and (to a lesser extent) melting of the Greenland Ice Sheet and the Antarctic Ice Sheet (EPA 2007f).

Other factors may also be responsible for part of the historic rise in sea level, including the pumping of ground water for human use, impoundment in reservoirs, wetland drainage, deforestation, and the melting of polar ice sheets in response to the warming that has occurred since the last ice age (EPA 2007f). Considering all of these factors, scientists still cannot account for the last century's sea level rise in its entirety. It is

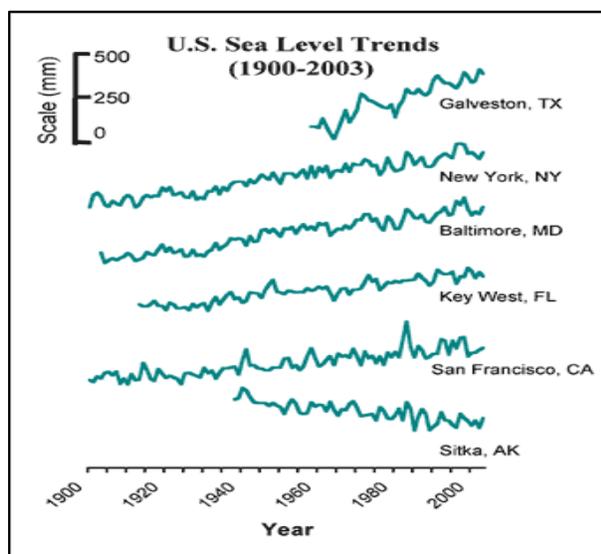


Figure 6: Sea level trends in selected U.S. cities. Source: Proudman Oceanographic Laboratory's Permanent Service for Mean Sea Level (PSMSL), as found in EPA 2007f.

possible that some contributors to sea level rise have not been documented or well-quantified (EPA 2007f).

According to the IPCC, current model projections indicate substantial variability in future sea level rise between different locations. Some locations could experience sea level rise higher than the global average projections, while others could have a fall in sea level (EPA 2007g). In the United States, sea level has been rising 0.08 to 0.12 inches (2.0 to 3.0 mm) per year along most of the U.S. Atlantic and Gulf coasts (EPA 2007f). The rate of sea level rise varies from about 0.36 inches per year (10 mm per year) along the Louisiana Coast (due to land sinking), to a drop of a few inches per decade in parts of Alaska (because land is rising) (EPA 2007f, and for

more information see also the NOAA 2001 technical report in the Further Reading section at the end of this document). (See Figure 6 for sea level trends in selected cities.)

IPCC forecasts global average sea level rise of between 0.18 and 0.59 m by the end of the 21st century (2090 to 2099) relative to the years 1980 to 1999 under a range of scenarios (IPCC 2007a, see Working Group I *Summary for Policymakers*, p. 13). Note that these estimates assume that ice flow from Greenland and Antarctica will continue

at the same rates as observed from 1993-2003. The IPCC cautions that these rates could increase or decrease in the future. For example, if ice flow were to increase linearly, in step with global average temperature, the upper range of projected sea level rise by the year 2100 would be 19.2 to 31.6 inches (48-79 cm or 0.48-0.79 m). But current understanding of ice sheet dynamics is too limited to estimate such changes or to provide an upper limit to the amount by which sea level is likely to rise over this century (IPCC 2007a, see Working Group I *Summary for Policymakers*, pp. 13-14; as found in EPA 2007g).

B. Impacts on Water Resources

The primary impact of sea level rise on water resources is the gradual inundation of natural systems and human infrastructure in coastal and estuarine areas. Inundation impacts include:

- wetland displacement (Burkett et al. 2001, p. 348);
- accelerated coastal erosion (Burkett et al. 2001, p. 345);
- water quality modifications may also be observed in the future as a result of storm water drainage operation and sewage disposal disturbances in coastal areas due to sea-level rise (Kundzewicz et al. 2007, p. 189);
- "... low-lying coastal areas such as deltas, coastal plains, and atoll islands are regarded as particularly vulnerable to small shifts in sea level" (Burkett et al. 2001, p. 348). "Coastal areas also include complex ecosystems such as coral reefs, mangrove forests, and salt marshes. In such environments, the impact of accelerated sea-level rise will depend on vertical accretion rates and space for horizontal migration, which may be limited by the presence of infrastructure" (Burkett et al. 2001, p. 345); and
- sea level rise increases the vulnerability of coastal areas to flooding during storms (EPA 2007I).

Impacts of sea level rise other than inundation include:

- rising sea level increases the salinity of both surface water and ground water through salt water intrusion (EPA 2007I);
- if sea level rise pushes salty water upstream, then the existing water intakes might draw on salty water during dry periods (EPA 2007I); and
- salinity increases in estuaries can harm aquatic plants and animals that do not tolerate high salinity (EPA 2007I).

C. Impacts on Water Programs

Sea level rise will affect a range of water programs and pose significant challenges for water program managers.

- emergency plans for drinking water and wastewater infrastructure need to recognize long-term projections for rising sea levels;
- drinking water systems will need to consider relocating facilities or intakes as sea levels rise and salt water intrudes into freshwater aquifers used for drinking water supply;
- sewage treatment plants will need to consider relocation of some treatment facilities and discharge outfalls; and
- watershed-level planning will need to incorporate an integrated approach to coastal management in light of sea level rise including land use planning, building codes, land acquisition and easements, shoreline protection structures (e.g., seawalls and channels), beach nourishment, wetlands management and related programs.

Sea Level Rise: Effects on Water Programs
(Shaded areas reflect programs most affected by sea level rise)

Drinking Water Standards	Surface Water Standards	Technology Based Standards	Emergency Planning
Drinking Water Planning	Clean Water Planning	Water Monitoring	Water Restoration/ TMDLs
Underground Injection Control Permits	Discharge Permits	Storm Water Permits	Wetlands Permits
Source Water Protection	Nonpoint Pollution Control	Coastal Zone	National Estuaries Program
Drinking Water SRF	Clean Water SRF	Ocean Protection	Combined Sewer Overflow Plans

6. Coastal/Ocean Characteristics

The IPCC states that the oceans are warming, ocean biogeochemistry is changing, and global mean sea level has been rising (Bindoff et al. 2007, p. 387). “The increase in atmospheric CO₂ causes additional CO₂ to dissolve in the ocean.... The increase in surface ocean CO₂ has consequences for the chemical equilibrium of the ocean. As CO₂ increases, surface waters become more acidic ...; [h]owever, the response of marine organisms to ocean acidification is poorly known and could cause further changes in the marine carbon cycle with consequences that are difficult to estimate” (Bindoff et al. 2007, p. 403). Further, as mentioned in the previous section, rising sea level increases the salinity of waters, and salinity increases in estuaries can harm aquatic plants and animals that do not tolerate high salinity (EPA 2007I).

A. Background

According to the IPCC, “[t]he total inorganic carbon content of the oceans has increased by 118 ± 19 GtC between the end of the pre-industrial period (about 1750) and 1994 and continues to increase (Bindoff et al. 2007, p. 387). “Ocean CO₂ uptake has lowered the average ocean pH (increased acidity) by approximately 0.1 since 1750. Ocean acidification will continue and is directly and inescapably coupled to the uptake of anthropogenic CO₂ by the ocean” (Denman et al. 2007, p. 533). “It is important to note that ocean acidification is not a direct consequence of climate change but a consequence of fossil fuel CO₂ emissions, which are the main driver of the anticipated climate change” (Denman et al. 2007, p. 529).

“As CO₂ increases, surface waters become more acidic and the concentration of carbonate ions decreases” (Bindoff et al. 2007, 403). “The availability of carbonate is particularly important because it controls the maximum amount of CO₂ that the ocean is able to absorb. Marine organisms use carbonate to produce shells of calcite and aragonite (both consisting of calcium carbonate (CaCO₃))” (Bindoff et al. 2007, p. 406).

“... [O]cean acidification is leading to a decrease in the saturation of CaCO₃ in the ocean. Two primary effects are expected: (1) the biological production of corals as well as calcifying photoplankton and zooplankton within the water column may be inhibited or slowed down ..., and (2) the dissolution of CaCO₃ at the ocean floor will be enhanced. Aragonite, the meta-stable form of CaCO₃ produced by corals and pteropods (planktonic snails ...), will be particularly susceptible to a pH reduction.... According to a model experiment ..., bio-calcification [a process in which organisms use CaCO₃ to create their shells] will be reduced by 2100, in particular within the Southern Ocean ..., and by 2050 for aragonite-producing organisms.... ” (Denman et al. 2007, p. 529).

“The overall reaction of marine biological carbon cycling (including processes such as nutrient cycling as well as ecosystem changes including the role of bacteria and viruses) to a warm and high-CO₂ world is not yet well understood. Several small feedback mechanisms may add up to a significant one. The response of marine biota to ocean acidification is not yet clear, both for the physiology of individual organisms and for ecosystem functioning as a whole. Potential impacts are expected especially for organisms that build CaCO₃ shell material.... Extinction thresholds will likely be crossed for some organisms in some regions in the coming century” (Denman et al. 2007, p. 533).

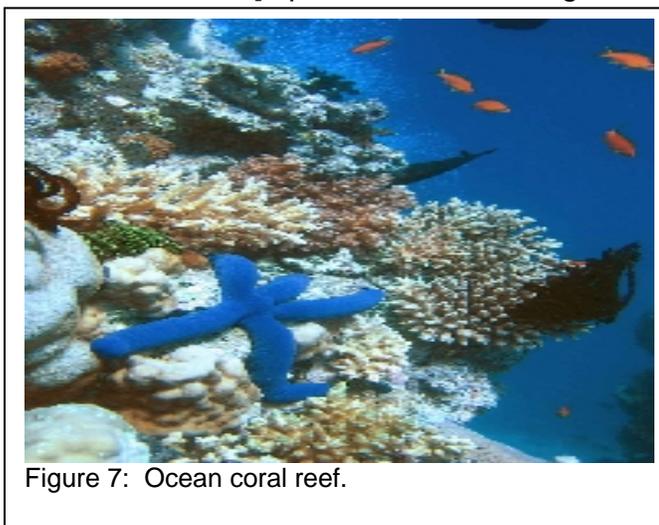


Figure 7: Ocean coral reef.

B. Impacts on Water Resources

Changes in ocean characteristics are expected to have several impacts on coastal and ocean resources including:

- “... the biological production of corals, as well as calcifying photoplankton and zooplankton within the water column, may be inhibited or slowed down” as a result of ocean acidification (Denman et al. 2007, p. 529);
- “[e]cological changes due to expected ocean acidification may be severe for corals in tropical and cold waters ... and for pelagic [or oceanic] ecosystems” (Denman et al. 2007, p. 529);
- “[a]cidification can influence the marine food web at higher trophic levels” (Denman et al. 2007, p. 529); and
- salinity increases in estuaries can harm aquatic plants and animals that do not tolerate high salinity (EPA 2007I).

C. Impacts on Water Programs

Changes in ocean characteristics pose several challenges for water program managers including:

- watershed level protection programs, such as the National Estuary Program, may need to be revised to account for changes in natural systems as salinity and pH levels change;
- programs to protect coral reefs from land-based pollution and impacts may need to be reassessed to provide enhanced protection; and
- wetlands programs may need to be adjusted to account for changing salinity levels and impacts on wetlands health.

Changing Ocean Characteristics: Effects on Water Programs

(Shaded areas reflect programs most affected by changing ocean characteristics)

Drinking Water Standards	Surface Water Standards	Technology Based Standards	Emergency Planning
Drinking Water Planning	Clean Water Planning	Water Monitoring	Water Restoration/TMDLs
Underground Injection Control Permits	Discharge Permits	Storm Water Permits	Wetlands Permits
Source Water Protection	Nonpoint Pollution Control	Coastal Zone	National Estuaries Program
Drinking Water SRF	Clean Water SRF	Ocean Protection	Combined Sewer Overflow Plans

7. Changes in Energy Generation

Likely responses to climate change include development of alternative methods of energy production that reduce emissions of greenhouse gases and “sequester” carbon generated by energy production. Alternative methods of energy generation can have impacts on water resources, as can the sequestering of carbon from conventional energy generation processes.

A. Background

The IPCC lists biofuels and early applications of carbon capture and storage (CCS, e.g., storage of removed CO₂ from natural gas) as key mitigation technologies and practices currently available (IPCC 2007c, Working Group III *Summary for Policymakers*, p. 10). “Biomass energy is primarily used for industrial process heating, with substantially increasing use for transportation fuels and additional use for electricity generation” (U.S. CCSP 2007, p. 64). “Liquid fuel production from biomass is highly visible as a key renewable alternative to imported oil. Current U.S. production is based largely on corn for ethanol and, to a lesser extent, soybeans for biodiesel” (U.S. CCSP 2007, p. 69). “Sustainable biomass production and use imply the resolution of issues relating to competition for land and food, water resources, biodiversity and socio-economic impact” (Barker et al. 2007, p. 621).

“CCS in underground geological formations is a new technology with the potential to make an important contribution to mitigation by 2030. Technical, economic and regulatory developments will affect the actual contribution” (IPCC 2007c, Working Group III *Summary for Policymakers*, p. 13). Other types of carbon sequestration include injection of carbon into the deep ocean, as well as storage in biological forms (e.g., forests).

B. Impacts on Water Resources

“While providing the United States with a majority of its annual energy needs, fossil fuels also place a high demand on the Nation’s water resources in terms of both use and quality impacts” (U.S. CCSP 2007, p. 51). “As currently designed, [thermoelectric] power plants [that generate electricity using fossil or nuclear power] require significant amounts of water, and they will be vulnerable to fluctuations in water supply” (U.S. CCSP 2007, p. 49).

Regarding the geologic storage of carbon, according to the IPCC, “[i]mpacts of elevated CO₂ concentrations in the shallow subsurface could include lethal effects on plants and subsoil animals and the contamination of groundwater” (IPCC 2005, p. 12)”. “Groundwater can be affected both by CO₂ leaking directly into an aquifer and by brines

that enter the aquifer as a result of being displaced by CO₂ during the injection process” (IPCC 2005, p. 31).

Another “... potential CO₂ storage option is to inject captured CO₂ directly into the deep ocean (at depths greater than 1,000 m), where most of it would be isolated from the atmosphere for centuries. This can be achieved by transporting CO₂ via pipelines or ships to an ocean storage site, where it is injected into the water column of the ocean or at the sea floor. The dissolved and dispersed CO₂ would subsequently become part of the global carbon cycle.... Ocean storage has not yet been deployed or demonstrated at a pilot scale, and is still in the research phase” (IPCC 2005, p. 34). IPCC also states that “[e]xperiments show that adding CO₂ can harm marine organisms” (IPCC 2005, p. 35) and that “[s]tudies are needed of the response of biological systems in the deep sea to added CO₂, including studies that are longer in duration and larger in scale than those that have been performed until now” (IPCC 2005, p. 45).

At the same time, sequestration of carbon in “biological” forms, (i.e., preserving forests, no-till agriculture and related land management practices) may have water quality benefits by encouraging practices that reduce the amount of stormwater runoff and the pollution levels in the runoff. “Stopping or slowing deforestation and forest degradation (loss of carbon density) and sustainable forest management may significantly contribute to avoided emissions, conserve water resources and prevent flooding, reduce run-off, control erosion, reduce river siltation, and protect fisheries and investments in hydroelectric power facilities; and at the same time, preserve biodiversity” (Nabuurs et al. 2007, p. 574). On the subject of agriculture, according to the IPCC, “[a] mix of horticulture with optimal crop rotations would promote carbon sequestration and could also improve agro-ecosystem function” (Smith et al. 2007, p. 521). However, “[w]hile the environmental benefits of tillage/residue management are clear, other impacts are less certain. Land restoration will have positive environmental impacts, but conversion of floodplains and wetlands to agriculture could hamper ecological function (reduced water recharge, bioremediation, nutrient cycling, etc.) and therefore, could have an adverse impact on sustainable development goals” (Smith et al. 2007, p. 522).

Demand for biofuels is also likely to have impacts on water including increasing land in agricultural production, resulting in increased risk of runoff of sediments, nutrients, and pesticides. Production of biofuels also uses significant amounts of water.

C. Impacts on Water Programs

Changing energy generation methods poses several challenges for water program managers including:

- increased water use and withdrawals will require expanded efforts to assure water supply availability;
- increased attention to potential nonpoint pollution impacts of expanded agricultural production may be needed;

- increased attention to discharge permit conditions may be needed to address issues related to increased temperature and concentration of pollutants due to low flows;
- new capability to assess complex effects of ocean sequestration activities may be needed; and
- effective market-based practices that have water quality benefits could be a source of revenue for these practices.

Energy Generation Shifts: Effects on Water Programs
(Shaded areas reflect programs most affected by energy generation shifts)

Drinking Water Standards	Surface Water Standards	Technology Based Standards	Emergency Planning
Drinking Water Planning	Clean Water Planning	Water Monitoring	Water Restoration/ TMDLs
Underground Injection Control Permits	Discharge Permits	Storm Water Permits	Wetlands Permits
Source Water Protection	Nonpoint Pollution Control	Coastal Zone	National Estuaries Program
Drinking Water SRF	Clean Water SRF	Ocean Protection	Combined Sewer Overflow Plans

III. National Water Program: Climate Change Response Actions

Climate change will result in significant impacts on water resources. Water program managers need to define goals for responding to climate change and identify key response actions to be implemented to accomplish these goals over the coming years.

Five major goals for the National Water Program Response to Climate change are:

Goal 1: Water Program Mitigation of Greenhouse Gases: use water programs to contribute to greenhouse gas mitigation;

Goal 2: Water Program Adaptation to Climate Change: adapt implementation of core water programs to maintain and improve program effectiveness in the context of a changing climate;

Goal 3: Climate Change Research Related to Water: strengthen the link between EPA water programs and climate change research;

Goal 4: Water Program Education on Climate Change: educate water program professionals and stakeholders on climate change impacts on water resources and programs; and

Goal 5: Water Program Management of Climate Change: establish the management capability within the National Water Program to engage climate change challenges on a sustained basis.

These five major goals are supported by more specific objectives and “Key Actions” to be implemented by the National Water Program. The Key Actions are highlighted in text boxes throughout this section. Some Key Actions would expand existing efforts to better address climate change while others are new actions specifically focused on climate change issues. All the actions in this Strategy are to be initiated within the next two years (i.e., FY 2008 or 2009). Appendix 2 includes a summary of Key Actions and supporting information, including the water program office responsible for implementing the action.

The Key Actions described throughout this document were selected with several general principles in mind.

1. **Define Areas of Uncertainty:** Key Actions included in this document draw on the best available science and every effort has been made to understand uncertainty related to the action and to defer actions not supported by sound science. Given the uncertainty associated with some climate change impacts on water resources, it will be important for water programs to be able to clearly measure water-related climate impacts, to adapt program management based on new information, and to conduct research needed to address issues.
2. **Evaluate Proactive and Reactive Actions:** Some actions seek to proactively avoid the consequences of climate change (e.g., protecting wetlands) while others react to these consequences (e.g., protecting infrastructure facilities against flooding). Given

uncertainty, proactive policies can result in needless costs while reactive policies can be much more expensive than avoiding the problem in the first place. Careful balancing of these concerns is needed.

3. **Guard Against Unintended Consequences:** Actions to address climate change can have unintended consequences that need to be understood (e.g., hardening of sea defenses around a water infrastructure facility can shift rising sea levels to inundate wetlands or other infrastructure) and should be weighed in implementation plans.

1. Greenhouse Gas Mitigation Related to Water

The largest sources of emissions and of potential reductions of greenhouse gases are from the electricity generation, transportation and industry sectors. However, reductions of greenhouse gases associated with water programs can play a role in America's efforts to reduce greenhouse gases, and such reductions would contribute to meeting the President's goal of an 18% reduction in greenhouse gas intensity by 2012.

Goal 1: Water Program Mitigation of Greenhouse Gases: use water programs to contribute to greenhouse gas mitigation.

Many of the actions that can help reduce greenhouse gas releases also help conserve scarce water supplies and help improve water quality. Water conservation is a win-win situation—in many cases a single program investment will have greenhouse gas, water supply, and water quality benefits, and will lead to economic savings and greater sustainability of water infrastructure.

A range of Key Actions related to water programs that lead to mitigation of greenhouse gases are described in the following sections:

- water-related energy conservation/production;
- water conservation;
- “green building” design and “smart growth;” and
- direct greenhouse gas emissions mitigation from agriculture.

In addition, EPA recognizes that water pollution control processes can be energy intensive and, where authorized by statute, will consider the energy and potential climate change implications of clean water and drinking water regulations.

If creation of greenhouse gases cannot be avoided, these gases can be “sequestered” so that they are not released to the atmosphere. Carbon dioxide sequestration refers to the process of removing carbon dioxide from the atmosphere and sequestering or

capturing the carbon dioxide to prevent release to the atmosphere. Sequestration activities related to water programs include:

- geologic sequestration of carbon through underground injection; and
- “biological” carbon sequestration through forestry and agricultural practices, many of which benefit water resources.

A. Water- Related Energy Conservation/Production

Drinking water and wastewater facilities, both public and private, spend billions of dollars a year on energy to collect, treat,

OBJECTIVE: promote water-related energy conservation.

and deliver clean water – with much of this cost borne by ratepayers. Pumping water, including pumping and conveyance of wastewater to treatment plants, and distribution of treated water to customers, are generally the most energy intensive components of water and wastewater systems. Energy is also required to treat wastewater and to treat water to drinking water standards, and for collection and distribution. Nationwide, drinking water and wastewater utilities use 75 billion kilowatt hours (Reardon 1994)—resulting in the emissions of approximately 116 billion pounds of CO₂—per year.

Energy use by drinking water and wastewater facilities accounts for approximately three percent of the United States' energy consumption (Reardon 1994). Drinking water and wastewater treatment facilities have the potential to achieve 15–30 percent energy savings (CEE 2007, p.1) by implementing energy conservation measures alone, and even more with on-site energy generation. Drinking water and wastewater treatment facilities have the capacity to generate and use energy from low-head hydroelectric, solar and/or wind power, while wastewater treatment facilities also have the capacity to generate energy from capture and use of methane.

Pumping is typically the major use of energy in the treatment stage, although the amount of energy used by drinking water facilities is also affected by the quality of the source water. Most energy consumed by wastewater facilities is for aeration, pumping, and solids processing. Energy requirements for biosolids processing vary according to the method used. Pump and blower motors can account for more than 80 percent of a wastewater utility's energy use (EPA 2006). Although lagoons use little energy, trickling filters used in attached growth processes and aeration in activated sludge systems require large amounts of energy. Advanced treatment also requires a great deal of energy, particularly denitrification and membrane filtration processes. The energy required for the handling, transport, and beneficial use of treated residuals increases as the distance from the treatment site to the disposal/application sites increases.

Energy consumption by drinking water and wastewater treatment facilities is likely to continue increasing. New or revised drinking water treatment requirements could also heighten energy consumption. Further, reduced supplies and increased demand will require pumping water greater distances. Climate change will lead to higher

temperatures that will likely result in buildings and unit processes needing more cooling. Changes in rain patterns in some areas may increase CSO and SSO events while in other areas declining in-stream flows will cause reduced assimilative capacity for wastewater effluent, both of which may require greater treatment for sediments, pathogens, and nutrients.

To improve water and wastewater energy efficiency, EPA's ENERGY STAR program has developed a Focus in the water and wastewater industries. An ENERGY STAR Focus is a targeted effort to improve the energy efficiency within a specific industry or combination of industries. A Focus creates momentum for continuous improvement in energy performance, provides the industry's managers with the tools they need to achieve greater success in their energy management programs, and creates a supportive environment where energy efficiency ideas and opportunities are shared. The National Water Program will continue working with the ENERGY STAR program to promote energy efficiency in this sector.

Several provisions of the Clean Water Act speak directly or indirectly to the question of energy efficiency in wastewater treatment. For example:

- section 313(b) of the Act encourages demonstration of innovative processes and techniques for more efficient use of energy at Federal wastewater treatment facilities;
- section 304(d)(3) of the Act encourages development of innovative processes and techniques for publicly owned (wastewater) treatment works (POTWs), including those processes described under section 201(g)(5), that take into account the more efficient use of energy (e.g., variable frequency drive motors reduce energy use of pumps by up to 50 percent); and
- under sections 304(b)(1)(B), 306, and 307 of the Clean Water Act, the National Water Program develops effluent limitations guidelines (ELGs) for industrial (non-POTW) facilities and the use of energy in these processes is one consideration in the development of the guidelines.

Significant progress is being made in the development of new tools for benchmarking energy performance among public water and wastewater utilities. For example, the ENERGY STAR program is expanding the capability of its Energy Performance Rating System (EPRS) to enable drinking water and wastewater utilities to assess their energy use over time and compare it to other utilities—normalized for weather and facility characteristics. As of October 2007, wastewater treatment plant energy performance can be rated using the ENERGY STAR program's on-line tool, Portfolio Manager. Portfolio Manager can be used to establish baseline energy use, prioritize investments, set goals, and track energy use and carbon emissions reductions over time. The ability to rate the energy performance of drinking water treatment and distribution facilities is still under development.

A related effort is the development of audit and tracking systems. For example, a Supervisory Control and Data Acquisition (SCADA) system monitors the operation of water-system control points such as pumps, reservoirs, and metering stations, and keeps track of energy usage. Other types of databases, such as the Washington D.C. Blue Plains wastewater treatment facility's Energy Information System, keep track of energy use and cost, broken down by the facility's processes.

In addition to saving energy, public and private drinking water and wastewater facilities can produce energy to offset what they would otherwise need to buy from local power utilities. The National Water Program could also work with the Office of Air and Radiation to promote these practices. Many facilities have already installed alternative energy power production facilities, including solar, wind, and hydro, for heating and electricity generation. For example, Calera Creek Water Recycling Plant in Pacifica, CA is using solar panels that provide 10–15 percent of its energy needs, resulting in an estimated \$100,000 savings annually in energy costs (EPA 2006).

Wastewater facilities can also generate energy from the capture and use of methane. Combined Heat and Power (CHP) systems can recover biogas (a mixture of methane, carbon dioxide, water vapor and other gases) from anaerobic digesters to heat buildings or to generate electricity. For example, San Francisco's East Bay Municipal Utility District (EBMUD) captures and uses biogas to generate enough energy to cover 50 percent of its energy need. If all 544 large sewage treatment plants in the U.S. operating anaerobic digesters were to install combined heat and power, about 340 megawatts of clean energy could be generated, offsetting 2.3 million metric tons of carbon dioxide emissions annually (i.e., equivalent to planting about 640,000 acres of forest, or the emissions of about 430,000 cars) (EPA 2007n).

This power is also marketable as "green power" to power utilities that are now required by State laws to have alternative or "green" power as a part of their overall production. Additional energy savings can be achieved by installing adequate insulation in buildings and replacing conventional lighting with energy-efficient options.

KEY ACTION #1: Improve Energy Efficiency at Water and Wastewater Utilities.

The National Water Program will continue to work with the Office of Air and Radiation to promote energy performance benchmarking programs, use of energy audits and energy tracking systems, use of alternative energy sources within plants (e.g., solar, wind, hydro), installation of Combined Heat and Power systems for heat and energy generation in facilities that use anaerobic digesters, and will provide State and local governments information on available and emerging treatment technology.

B. Water Conservation

OBJECTIVE: promote water conservation to reduce energy use.

Water quantity and water quality are inextricably linked. Impacts on water resources due to climate change will make this connection more visible. For example, discharge of treated effluent assumes adequate flow for dilution and low flows require higher treatment to avoid impairments; shortages of precipitation and reduced snow melt result in increased competition between human uses and aquatic uses of in-stream flows; and shortages of surface water drive increases in groundwater pumping, which in turn affect recharge.

Water conservation through water use efficiency will be important not just to extend water supply, but also to reduce greenhouse gases. Reduced water consumption saves energy because less water is needed to be pumped and treated. On the other side of the water/energy equation, when energy use is reduced, water is saved because less is needed to operate power plants. About half of the water gathered in the United States from surface and groundwater sources is used for power plant cooling (although most is returned) compared to 34 percent for irrigation and 11 percent for residential and commercial purposes (USGS 2004, pp. 6-7). On average, each kilowatt generated consumes approximately 0.2 to 0.3 gallons of water (EPA 2007o), which is based on cooling water consumption and annual electricity generation estimates from the Electric Power Research Institute (EPRI 2002, p. 6-3) and the Energy Information Administration (EIA 2004), respectively.

There are many opportunities for energy savings on the supply side, realized through better planning, maintenance, and operation of water delivery systems, as well as through the development of new technologies and processes. What is often overlooked is how demand-side management or conservation programs can effectively increase water and energy savings. For example, California's State Water Plan (California Department of Water Resources 2005) concluded in 2005 that the largest single new water supply available to meet their expected growth over the next 25 years will be water-use efficiency—made more critical in light of projected water shortages due to climate-related decreases in snow pack.

Residential and business customers use more energy to heat, cool, and otherwise use water than utilities spend treating and distributing it. For example, running a hot water faucet for five minutes is equivalent to running a 60-watt light bulb for 14 hours (Grumbles 2007 and EPA 2007o). By conserving water, less energy is used for these purposes.

For residential consumers, the opportunity to save both water and energy comes primarily from using water-efficient fixtures and appliances, including toilets, showerheads, faucets, clothes washers, dishwashers, and irrigation equipment. If every American home installed water-efficient showerheads, the United States could save more than 160 billion gallons of water per year and save about \$2 billion in energy costs for heating that water. An additional 60 billion gallons and \$650 million in energy costs

(Grumbles 2007 and EPA 2007o) could be saved if every household also installed high-efficiency faucets or faucet aerators.

To promote water-efficiency and protect the future of our Nation's water supply, EPA launched the WaterSense program last year. The WaterSense label will help consumers and businesses identify products that meet the program's water-efficiency and performance criteria. The WaterSense program sets specifications for the labeling of products that are at least 20 percent more efficient than the current standards while performing as well or better than their less-efficient counterparts. Once manufacturers demonstrate that their products meet EPA criteria, they can use the label on their products. The WaterSense product specifications do not currently address energy consumption directly. However, all water savings realized through the use of WaterSense labeled products and services have a corresponding reduction in energy consumption. Both commercial and residential products and services will be addressed by WaterSense labeling efforts.

KEY ACTION #2: Implement the WaterSense Program. EPA will continue its current efforts to implement the WaterSense program and will incorporate educational information about related reductions in energy use.

As noted above, water conservation offers climate change mitigation opportunities through energy savings and in addition may serve adaptive needs that arise as a result of changes in water availability and/or overall demand. Adaptation is supported particularly when water conservation is carried out in a broader context of water resources management.

KEY ACTION #3: Water Conservation and Management for Drinking Water Systems. The National Water Program will explore opportunities with States and drinking water systems to better address expected impacts of climate change on water supply and water usage rates through water conservation and water resources management.

A major opportunity for water conservation is the repair of leaking distribution systems. Such leaks commonly result in the loss of ten percent of a city's water. Significant amounts of water can be saved by timely investments in leak correction and more active implementation of leak detection technologies. In addition, infiltration and inflow in wastewater collection systems can significantly increase the volume of wastewater required to be treated resulting in increased energy and chemical demand.

KEY ACTION #4: Water Conveyance Leak Detection and Remediation. The National Water Program will promote technologies to identify and address leakage from water pipes and other conveyances.

Industry is also a significant user of water and is becoming aware of the importance of measuring, managing, and controlling water use. In particular, energy-intensive industries are finding water scarcity to be a limit to growth. In general, there is an economic incentive for facilities to use as little water as possible in their industrial operations. Reducing water use will also reduce costs (and energy requirements) associated with water use. In addition to increasing its water efficiency, industry has substantially increased its application of water re-use in the past 15 years through the practice of potable substitution, where reclaimed industrial wastewater is used for non-potable applications. The cost savings of implementing water re-use and reduction technologies and pollution prevention practices can be significant. Often the monetary savings of implementing water conservation and efficiency measures can be significant with payback periods often measured within a few months or years.

KEY ACTION #5: Industrial Water Conservation, Reuse, and Recycling Technology Transfer. The National Water Program will identify industries and facilities that best maximize their water efficiency and develop a technical guide for control authorities and industry for promoting water minimization, re-use, and recycling.

Finally, Executive Order 13423, Section 2 (c), requires that beginning in 2008, Federal agencies reduce water consumption intensity, relative to the baseline of the agency's water consumption in fiscal year 2007, through life-cycle cost-effective measures, by 2 percent annually through the end of fiscal year 2015, or 16 percent by the end of fiscal year 2015. The Office of Water is responsible for developing Water Efficiency Implementation Guidance for all agencies covering the three elements of compliance: baseline development, efficiency opportunity identification/implementation, and reporting. Federal agencies are also encouraged to include WaterSense products and services in their implementation strategies.

KEY ACTION #6: Federal Agency Water Conservation Guidance. The National Water Program will develop Water Efficiency Implementation Guidance for all Federal agencies under Executive Order 13423.

C. Promote “Green Building” Design and “Smart Growth”

Increasing the water and energy efficiency of water utilities has value from a greenhouse gas mitigation point of view, but sustaining these efficiencies over the long-term will

OBJECTIVE: promote “green buildings” and “smart growth” to reduce energy and water needs.

require extending the commitment to water and energy efficiency into the building stock and the design of communities. By applying “green building” principals and “smart growth” policies, energy and water efficiencies at utilities can be multiplied. The

National Water Program plays a role in this process because it regulates the storm water associated with buildings and municipalities.

Several organizations, such as the U.S. Green Building Council's Leadership for Energy and Environmental Design (LEED) program and the American National Standards Institute (ANSI), are working with State and local governments and the private sector in promoting the "green buildings" concept and rating systems. These rating systems document the commitment made by a developer to "green" building practices, such as reduced use of energy and water, on-site (decentralized) energy generation (e.g., solar power, geothermal), and water retention (e.g., green roofs).

Recent developments are expanding this concept to integrate "smart growth," "low impact design," and green building practices. For example, the new LEED for Neighborhood Development (LEED-ND) pilot Rating System reaches beyond the building envelope to include site selection and design, infrastructure linkages (e.g., mass transit), and credits for onsite stormwater management practices such as green roofs, rain gardens, and vegetated swales. The National Water Program is working with other offices in EPA to promote low impact development and smart growth concepts.

The National Pollutant Discharge Elimination System (NPDES) permit program requires that industrial facilities, construction sites, and municipalities have permits for discharges of stormwater. These permits are a key regulatory tool for managing stormwater. As "green building" standards and "green infrastructure" practices gain wider acceptance, there will be a growing demand for recognition of these standards and practices within stormwater permits. In some cases, this may require greater flexibility in permitting to allow the use of such standards and practices. Recognition of "green building" standards and "green infrastructure" practices as an allowable element of stormwater permits would encourage their adoption.

KEY ACTION #7: Promote Energy Saving/Generating "Green Buildings" and "Green Infrastructure" Including Provisions Allowing Such Practices in Stormwater Permits: The National Water Program will work with other EPA offices to support States, Tribes, and local governments and the private sector in promoting the "green buildings" rating systems, with a focus on saving water and energy and will work to integrate provisions allowing "green infrastructure" practices into stormwater permits.

D. Promote Water Quality/Climate-Friendly Agricultural Practices

Climate change can potentially be mitigated not only by the energy and water conservation efforts described above that reduce carbon emissions from fossil-fuel based energy production, but also through reductions in direct greenhouse gas releases, such as

OBJECTIVE: reduce greenhouse gas emissions from agricultural sources.

methane and nitrous oxide releases associated with agriculture and wastewater treatment.

Agriculture accounts for more than 8 percent of total greenhouse gas emissions, more than 30 percent of methane releases and 80 percent of nitrous oxide releases. Agricultural producers have the potential to reduce nitrous oxide releases by expanding use of manure, biosolids or other organic residuals. The impacts of such practices with regard to climate change are of interest because soil management and fertilizer use are the source of 79 percent of releases of nitrous oxide, which is 300 times more heat trapping than CO₂. Agricultural animal producers have the potential to reduce methane releases from livestock and its manure by considering feed alternatives and utilizing methane capture for combined heat and power production (EPA 2007m).

The National Water Program supports the U.S. Department of Agriculture in promoting sound agricultural management practices and works with the EPA Office of Air and Radiation to promote agricultural practices that benefit air quality and reduce greenhouse gas emissions. In this supporting role, the National Water Program will:

- identify and promote through nonpoint pollution control programs, agricultural management practices that have both water quality and greenhouse gas reducing benefits (e.g., no till agriculture);
- encourage the use of organic residuals in row-crop and animal agriculture operations; and
- support programs, such as the AgStar program, that encourage the development of animal waste management practices that both protect water quality and reduce releases of methane while generating electric power.

E. Carbon Sequestration through Underground Injection

Geologic sequestration is one technology in a portfolio of options that could be effective in reducing CO₂ emissions to the atmosphere and stabilizing atmospheric concentrations of CO₂.

OBJECTIVE: assure that commercial scale geologic sequestration of carbon safeguards drinking water and the ocean environment.

Available evidence suggests that geologic storage capacity in the United States could be as high as 3,900 gigatons (Gts or a billion metric tons) of CO₂ in some 230 candidate sites. The 1,715 largest sources of CO₂ in the United States release about 2.9 GtCO₂ per year (Dooley et al. 2006, and for more information see also DOE's 2007 *Carbon Sequestration Atlas of the United States and Canada* in the Further Reading section at the end of this document).

The Underground Injection Control (UIC) Program under the Safe Drinking Water Act regulates injection of fluids, including solids, semi-solids, liquids, and gases such as

CO₂, to protect underground sources of drinking water. UIC regulations address the siting, construction, operation, and closure of wells that inject a wide variety of fluids, including those that are considered commodities or wastes. Proper operation of injection wells for sequestration projects is required under the Safe Drinking Water Act to safeguard underground sources of drinking water and protect public health.

Injection of fluids, including CO₂, into the subsurface for enhanced oil recovery and enhanced gas recovery is a long-standing practice within the UIC program; however, there are key differences anticipated for geologic sequestration. CO₂ injection for geologic sequestration will eventually involve much greater volumes of CO₂, which will be stored for very long periods of time.

The Department of Energy's (DOE) National Energy Technology Lab and DOE's Regional Carbon Sequestration Partnerships are conducting research on geological sequestration of CO₂ to provide information about the capabilities, impacts, and best practices related to geologic sequestration (GS). On October 9, 2007, DOE announced awards for three demonstration projects that will test large-scale geologic sequestration of CO₂ (<http://www.doe.gov/news/5597.htm>).

EPA's Office of Ground Water and Drinking Water and Office of Atmospheric Programs issued UIC Program guidance in March 2007 (*Using Class V Experimental Technology Well Classification for Pilot Geologic Sequestration Projects – UIC Program Guidance* (UICPG # 83)) to assist States and EPA Regional UIC program managers in evaluating permit applications for GS pilot projects and setting appropriate permit conditions for these projects to protect underground sources of drinking water and public health. (See EPA 2007 in the Further Reading section at the end of this document.)

EPA is also preparing to assist States and Regions in addressing permitting of commercial scale GS projects, which are important in addressing climate change. EPA will use an adaptive management approach, which includes establishing minimum federal requirements for States to protect underground sources of drinking water, providing technical assistance to States and Regions, and coordinating with a range of other Federal agencies. Through workshops and other outreach, stakeholders and the public will have an opportunity to participate in this process. EPA will propose revisions to the UIC Program regulations authorized under the Safe Drinking Water Act in summer 2008.

KEY ACTION #8: Develop Geologic Sequestration Regulations. EPA will propose regulations to address permitting of commercial scale geologic sequestration (GS) projects in 2008.

EPA has held several technical workshops to better define research gaps and needs and will continue this effort.

Topics of past and future workshops may include:

- potential impacts on ground water and underground sources of drinking water;
- potential impacts on human health and the environment;
- integrity of CO₂ injection wells and other wells in the area of review;
- fluid displacement and pressure impacts;
- potential for large-scale CO₂ releases;
- measurement, monitoring, and verification tools applicable to sequestration of CO₂;
- potential impacts of CO₂ injection on geologic media (reservoir and seals); and
- geochemical and geomechanical effects.

EPA strongly encourages gathering and sharing of data through the permitting process for pilot projects and other efforts.

KEY ACTION #9: Continue Technical Sequestration Workshops. The National Water Program will continue to conduct and sponsor workshops to explore the technical aspects of CO₂ sequestration and share ideas with experts and stakeholders.

Finally, carbon can be sequestered in geologic formations under the seabed as well as on land. The 1996 Protocol to the London Convention on ocean dumping (“London Protocol”) regulates sub-seabed sequestration of carbon dioxide streams from carbon dioxide capture processes for sequestration. Parties to the London Convention and London Protocol are developing guidance for sub-seabed carbon sequestration. The National Water Program and the Office of Air and Radiation are participating in this effort.

The United States is working toward ratification of the London Protocol, including the proposal of amendments to the Marine Protection, Research, and Sanctuaries Act (MPRSA), to implement the treaty. One proposed change to the Act would require a permit for sub-seabed carbon sequestration. In addition, under the Safe Drinking Water Act, sub-seabed sequestration beneath ocean waters within a State’s territorial waters must comply with any applicable requirements under EPA’s Underground Injection Control program regarding the design, operation, and closure of underground injection wells.

KEY ACTION #10: Support Evaluation of Sub-seabed and Ocean Sequestration of CO₂. EPA will work with other interested agencies and the international community to develop guidance on sub-seabed carbon sequestration and will address any requests for carbon sequestration in the sub-seabed or “fertilization” of the ocean, including any permitting under the Marine Protection, Research, and Sanctuaries Act or the Underground Injection Control program that may be required.

F. Water Related “Biological” Sequestration of Carbon

Carbon can be sequestered in biological as well as geologic structures. Some of the practices that result in the “biological sequestration” of carbon, and estimated tons of carbon sequestered per year/per acre of each practice, are described in Figure 8.

OBJECTIVE: support “biological sequestration” of carbon through agricultural and forestry practices.

Biological Sequestration Practices Related to Water

Agriculture/Forest Practice	Estimated Tonnes of CO ₂ Sequestered/Acre/Year
• Reduce cropland tillage	0.6 – 1.1
• Cropland conversion to grassland	0.9 – 1.9
• Riparian buffers	0.4 – 1.0
• Afforestation	2.2 – 9.5
• Reforestation	1.1 – 7.7
• Changes in forest management	2.1 – 3.1

Figure 8: Source: Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture (EPA 2005, p. 2-3).

As a result of the world-wide effort to reduce carbon, a market has developed for the sequestration of carbon, and there is a worldwide price per ton sequestered. Although the price per ton is now low, this price is expected to increase as the demand for carbon sequestration rises. EPA has estimated that the biological sequestration resulting from forest and agriculture practices in the United States could reach close to 100,000 Tg (teragrams or million tonnes⁵) by 2095 if prices were to rise to \$50 per ton/per acre (EPA 2005).

The National Water Program is now promoting practices to protect water quality and reduce nonpoint pollution that include some of the practices that also sequester carbon. By continuing to promote these practices, water programs are contributing to carbon sequestration. Perhaps more important, as the price of a ton of carbon rises, land owners will change land uses in response to this price signal, adopting some additional practices with both carbon and water quality benefits.

EPA has estimated that the water quality benefits of carbon sequestration practices may be significant, depending on the price and the region of the country. Nationally, EPA estimates that, at a price of \$6.80 per tonne of CO₂ equivalent, nitrogen loadings are reduced by 3.1% and phosphorous loadings reduced by 2% for a representative year

⁵ A tonne is a metric ton, equal to 1 megagram (Mg); and 1 gigatonne (Gt) equals 1,000 Tg (therefore, 100,000 Tg = 100 Gt).

(i.e., 2020). The overall impact on a 100-point water quality index is an improvement of about 2%. The biggest benefit would be in corn growing States. In 2020, at higher prices of \$15 per tonne of CO₂ equivalent, phosphorous reductions approach a 40% decrease from baseline conditions, and nitrogen reductions are slightly more than 10% below baseline conditions. These water quality benefits would be greater in twenty to thirty years (see Figure 9). These benefits would diminish or disappear in later years (e.g., 2060) as alternative sequestration practices are implemented (EPA 2005). In addition, more work is needed to understand how new incentives for agricultural production related to biofuels will impact these practices.

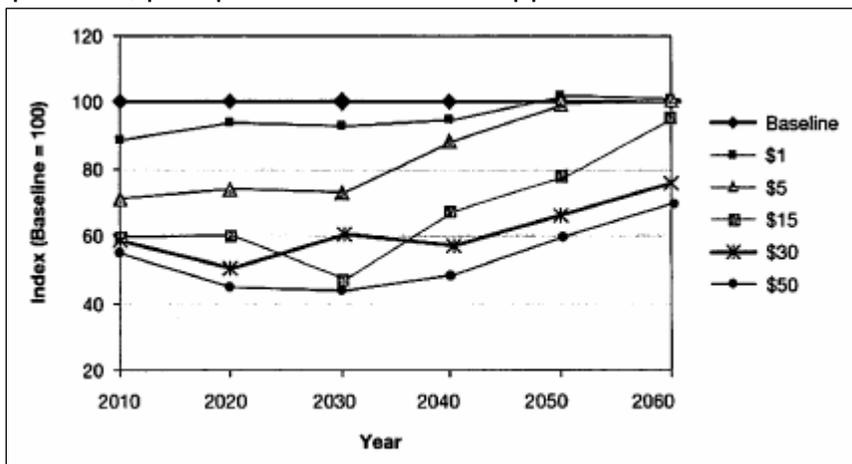


Figure 9: Phosphorus loading index over time by (constant) greenhouse gas price scenario (baseline = 100). This figure shows that estimated phosphorus loadings decline with the introduction of greenhouse gas prices (\$ per tonne of CO₂ equivalent). Source: EPA 2005.

In recognition of the emerging market in biological methods of sequestering carbon, the National Water Program needs to learn how to identify which pollution control practices can also be marketed for their carbon sequestration value and to help realize this value. In addition, the program intends to support the efforts of the EPA Office of Air and Radiation and others to develop the documentation and data systems to effectively verify that the tons of carbon sequestered by these projects is accounted for and recognized as a contribution to mitigation of greenhouse gases.

KEY ACTION #11: Study Pilot Projects for Marketing of Nonpoint Source Biological Sequestration. The National Water Program will study options for supporting nonpoint source control practices that have water quality and carbon sequestration benefits and support cooperative pilot projects between selected State section 319 nonpoint pollution control programs that demonstrate the potential for the cumulative results of 319 programs to provide carbon sequestration benefits.

2. Adapting Water Programs to Climate Change

As the climate changes, the National Water Program has an obligation to continue to ensure that water is safe to drink and that the health of aquatic ecosystems is protected. To meet this challenge, Federal, State and Tribal managers of clean water and drinking water programs will need to adapt the implementation of the programs in light of the changing climate.

Adaptation of water programs to climate change will be a long and iterative process. The understanding of the impacts of climate change on water that is now emerging from scientific studies, however, provides a sufficient basis for defining an initial set of preliminary steps to adapt water programs to climate change.

Goal 2: Water Program Adaptation to Climate Change: adapt implementation of core water programs to maintain and improve program effectiveness in the context of a changing climate.

Key actions that National Water Program managers will take in response to climate change are discussed in the following five sections representing core water programs:

- Drinking Water, Water Quality and Effluent Standards;
- Watershed Protection;
- NPDES Permits;
- Water Infrastructure; and
- Wetlands Protection.

The National Water Program is implemented through many individual programs established under the Clean Water Act, Safe Drinking Water Act, and other laws. Most of these programs fit within several core program areas (e.g., standards, watershed protection, NPDES permits, infrastructure protection, and wetlands protection). These core programs provide the organizing structure for most State and Federal water quality agencies and provide the organizing structure for the Key Actions in the "adaptation" goal of this **Strategy**.

The challenges posed by climate change, however, do not always fit neatly into existing programs and it is important to think about themes that define the critical elements of an effectively adapting core water program in response to climate change. Some of these climate change crosscutting themes are:

- **Develop Data to Adapt to Climate Change:** Water managers need baseline data and information to understand how climate change is altering the environment and inform long-term planning. Better information concerning the spatial location of waterbodies and wetlands is needed. In order to improve or maintain water quality and to protect public health, program managers need to understand the changes that might affect standards, permits, implementation

strategies, etc. Further, in the event that a baseline ecological condition has permanently shifted, managers need to be able to identify that point and adapt program expectations and requirements.

- **Develop Analytic Tools:** In virtually every water program, the analytic and decision support tools that water managers rely on to process environmental data need to be expanded to address the more complex conditions that will arise from a changing climate.
- **Plan for Extreme Water Events:** Better data and analytic tools are of little value unless water managers recognize that climate change will change long-held assumptions about the norms of water events, including storms, an excess of water, and a lack of water. Recognition of the increased frequency of extreme water events is important to water program managers responsible for controlling nonpoint pollution, protecting wetlands, restoring impaired waters, and protecting the quality of drinking water. Perhaps most important, local water infrastructure managers need to adapt emergency plans to reflect the most extreme water events.
- **Increase Watershed Sustainability and Resilience:** Individual water programs, such as standards, permits, and wetlands protection, need to adjust to the extremes of climate change. The demands of a changing climate, however, make it more important than ever that these programs be integrated and well coordinated on a watershed basis. From this more holistic perspective, managing stormwater, protecting wetlands, building water infrastructure, and sustaining drinking water supply all support an overarching goal of making an aquatic system more sustainable and resilient to the stresses of a changing climate.
- **Strengthen Partnerships and Collaboration:** A hallmark of water programs is that Federal, State, Tribal and local government share responsibility for program implementation. Although many of the Key Actions in this **Strategy** address steps that EPA will take, the success of the National Water Program response to climate change will depend on strengthening partnerships with State, Tribal, and local governments, the research community, and stakeholders representing agriculture, industry, and the environmental community..

A. Drinking Water, Water Quality, and Effluent Standards

Under the Safe Drinking Water Act and the Clean Water Act, EPA establishes standards that define when water is safe to drink and when surface water is clean enough to support uses such as fishing and recreation. EPA also sets

OBJECTIVE: water standards continue to protect human health and the environment as the climate changes.

standards that must be met by all dischargers in an industry (e.g., paper mills) called “effluent guidelines.” Each of these three types of standards will be affected by climate change.

Drinking Water Standards

The Safe Drinking Water Act provides for a comprehensive process to assess public drinking waters for contaminants and to develop drinking water standards for contaminants posing the greatest risk. The changes to water resources resulting from climate change, including warmer waters and higher levels of organic materials in water, suggest that drinking water contaminants may increase as the climate changes. EPA intends to assess these risks as part of its regular review of drinking water regulations, giving special attention to the risks of waterborne disease.

There are two key processes to identify and evaluate the potential impact of contaminants on public water systems. Under the Six Year Review process, the Agency reviews existing drinking water standards for more than 90 contaminants to determine whether it is appropriate to revise any of these regulations to maintain or provide for greater health protection. Under the Contaminant Candidate List (CCL) process, EPA identifies new, unregulated contaminants that are known or likely to occur in public water systems and may need a national drinking water regulation. Because climate change could impact weather patterns and result in increased rain events, the runoff from these events could increase the occurrence of regulated and unregulated contaminants in public drinking water sources and supplies. Under both the Six Year Review and CCL processes, the Agency evaluates the occurrence of contaminants in drinking water to determine potential impacts on public health.

KEY ACTION #12: Address Impacts of Climate Change on Potential Contamination of Drinking Water Sources.

The National Water Program will evaluate, as part of the contaminant occurrence analyses supporting the EPA 6 year review of drinking water standards and the contaminant candidate list, the potential for projected climate change to increase the nature and extent of contaminants in drinking water supplies and systems.

In addition to recognizing the need to adapt standards established under the Safe Drinking Water Act to changing climatic conditions, the condition of surface water providing the supply for drinking water systems may also need attention. To better understand this potential problem, EPA will assess implications of climate change for biological contaminants and pathogens in surface waters and evaluate needed response actions, including revision of criteria under the Clean Water Act.

KEY ACTION #13: Assess Clean Water Microbial Criteria and Risks of Waterborne Disease. The National Water Program will assess the potential for increases in waterborne disease and other water-related disease vectors as a result of climate change, including recommendations for appropriate responses (e.g., revision of biological/pathogen criteria for surface waters).

Water Quality Standards

Climate change is likely to have significant effects on water quality standards for surface waters in several areas:

- higher/lower flows;
- water temperature;
- modified habitat; and
- salinity changes.

Changes in precipitation are expected to result in higher flows in some regions, lower flows in other regions, and more variability of flows. Higher flows could increase available dilution, but could also increase erosion and sedimentation (especially combined with greater peak velocity). Lower flows could substantially reduce available dilution, concentrate salts and other pollutants, and indirectly reduce dissolved oxygen (by increasing temperature and increasing metabolism). As a result, it may become more difficult to meet current water quality or drinking water standards.

Increases in water temperature can also make some contaminants, such as ammonia (EPA 1999) and pentachlorophenol (EPA 1986), more toxic for some species and foster the growth of microbial pathogens in sources of drinking water. Warmer temperatures often result in less water which in turn results in increased contaminant concentration levels. Perhaps most significantly, warmer waters hold lower levels of dissolved oxygen, the availability of which is critical to the health of aquatic species. Depending on the severity of such effects, States may need to consider them in their triennial review of water quality standards.

Changes in climate could change the range and distribution of aquatic species with, for example, warm water species expanding their habitat range and increasing in number and cold water species reducing their range and being eliminated in some waters. The timing and duration of various life stages could also become altered, which may produce subtle or possibly dramatic shifts in community structure. As a result, the appropriate target for some water quality standards (particularly numeric and narrative criteria based on biological assessment) may change. With a changing “natural reference”, water quality standards for temperature and biological expectations may need to change to reflect these dynamic conditions.

Changes in sea level and fresh water flow could increase saltwater intrusions and affect the position of the salt front in estuaries and tidal rivers. As a result, there may be increased pressure to manage freshwater reservoirs to increase flows and attempt to maintain salinity regimes to protect estuarine productivity and drinking water supplies. Water quality standards in watersheds experiencing reservoir depletion may need to reflect these conditions. In the case of saltwater intrusions, biological expectations again may need to be adjusted.

There are three principle responses to climate change with respect to water quality standards:

- expanded efforts to meet current standards;
- modifying criteria to protect uses; and
- modifying designated uses.

Dischargers and watershed activities may need to change to reflect the increased degree of difficulty in meeting current standards, where those standards remain the appropriate targets and where they remain attainable. In these cases, program efforts will concentrate on ways to better implement actions to meet standards in an altered or changing climate.

Some standards (i.e., pollutant-specific goals) may need to change to reflect more sensitive environmental conditions. In these cases, program efforts will concentrate on providing better recommendations that reflect necessary levels of protection in an altered or changing climate. For example, expected increases in sediment loads could be addressed with development of sediment criteria. Program efforts will also focus on ways to implement and meet these new recommendations.

Some designated uses and associated criteria may need to be removed and replaced with alternative uses and criteria where conditions have changed, or are anticipated to change, to the point that the current water quality standards are not appropriate or are not attainable. In these cases, program efforts will concentrate on providing the means to discern these situations and providing options and approaches for developing revised standards in an altered or changing climate.

KEY ACTION #14: Clean Water Criteria for Sedimentation/Velocity. In anticipation of increased flow and velocity and sediment loadings in some streams, rivers, and estuaries, the National Water Program will review the potential for development of criteria for sediment and velocity in streams that are appropriate to these changing conditions.

In response to these problems, the following tools and procedures will need to be fully developed and implemented:

- measurement of biological condition and detection of changes;
- models to forecast hydrologic and water quality changes; and
- partnerships with land use managers.

The program will need the ability to measure and detect modifications in biological conditions as a result of climate change impacts. This may involve more extensive biological monitoring, development of indices and indicators that are sensitive to climate change impacts, and methods to link monitoring results with the effects of other stressors. This biological information base will be crucial to managing adaptation and deciding when compensation is appropriate (e.g., change activity in the watershed to maintain biology) and when revised goal setting is appropriate (i.e., to reflect reality). An example of this work is the development of guidance on coral reef bioassessments and biological criteria as part of EPA’s participation in the U.S. Coral Reef Task Force.

KEY ACTION #15: Develop Biological Indicators and Methods. The National Water Program will improve the biological information base to better manage water resources in a changing climate, including developing guidance on coral reef bioassessments and biological criteria.

The program will need the ability to link ecological process models with landscape hydrology models to meet the forecasting need. This may involve predicting the effects of new temperature and precipitation patterns and discerning the effects of long-term climate change from the effects of normal short-term variability. As “natural conditions” become more dynamic, current empirical modeling approaches and characterization of current or past conditions may no longer be relevant or effective means of projecting to the future. Mechanistic modeling approaches and quantitative uncertainty analysis will become more important tools. The Office of Research and Development’s Global Change Research Program will support this effort by developing national maps depicting projected land use patterns, by decade, through 2040. ORD will also develop a downloadable and customizable ArcGIS tool that will enable local decision makers to develop their own land use scenarios.

KEY ACTION #16: Link Ecological and Landscape Models. The National Water Program will work with the Office of Research and Development and the Office of Air and Radiation to invest in refinement of models of ecological process and landscape hydrology.

Effluent Standards

Alternate energy source development may result in effluent sources that need to be controlled. For example, EPA intends to evaluate whether effluent limitation guidelines might be appropriate for alternative energy sources such as biofuels. In addition, EPA

intends to study whether new industries associated with climate change, will require permits as new sources and/or new dischargers.

KEY ACTION #17: Evaluate New Industry Sectors. The National Water Program will evaluate new industry sectors (including biofuels) and existing industrial categories to determine potential NPDES permitting needs and assess the need for new or revised technology-based performance standards.

Potential changes in effluent composition, such as changes in pollutants or the amount of pollutants due to new or different air emissions control technologies or the addition of carbon sequestration technologies, may also require modifications to existing industrial effluent guidelines or require changes in permit limitations for some existing industrial categories.

KEY ACTION #18: Review Existing Effluent Guidelines. Review the existing effluent guidelines to identify needed changes based on industrial production or treatment changes related to climate change.

B. A Watershed Approach

For some time, EPA has supported management of water resources using a watershed approach, which is a coordinating framework that focuses

OBJECTIVE: use a watershed approach to adapt core water programs to climate change challenges.

community efforts on priority problems within a watershed. Using the watershed approach, utilities, agricultural producers, and other stakeholders look holistically at infrastructure planning, water pollution control, waterbody restoration, and soft path technologies, such as low impact development, thereby protecting, maintaining or restoring the natural functions of the watershed. Many of the elements of a watershed approach lend themselves to adapting water programs to climate change including:

- water monitoring and data;
- watershed management tools;
- protecting estuaries;
- restoring impaired waters; and
- reducing pollution from nonpoint sources.

An important challenge the National Water Program will face in adapting these national programs to better address climate change needs will be managing the process of implementing the Key Actions described below and making the numerous small scale adaptations to core program management that are needed. In support of the prompt implementation of climate change adaptation actions related to watershed management, the Office of Wetlands, Oceans and Watersheds will develop a Climate

Change Policy Memo that directs the incorporation of responses to climate change into these core programs.

KEY ACTION #19: Watershed Climate Change Policy Memo. The Office of Wetlands, Oceans and Watersheds will develop a Climate Change Policy memo that promotes the incorporation of responses to climate change into these core programs.

Water Monitoring and Data

The Nation's waters are monitored by State, Federal, Tribal, and local agencies, universities, dischargers, and volunteers. Water quality data are used to characterize waters, identify trends over time, identify emerging problems, determine whether pollution control programs are working, help direct pollution control efforts to where they are most needed, and respond to emergencies such as floods and spills. As the climate changes, monitoring the condition of water resources will be increasingly important and increasingly challenging. At the same time, identifying and measuring environmental changes that result from a changing climate is both difficult and uncertain. In addition, assigning effects to "climate" as opposed to other causes is frequently challenging.

The National Water Program will include assessment of climate change impacts in water resources assessments at the national level, such as the recent wadeable stream assessment and the Coastal Condition Report. These national overviews will provide useful information on climate-related changes to water resources but will also form a foundation for assessment of trends over time. To support this work, EPA will work with States, Tribes and other Federal agencies to include climate change-related measurements in monitoring programs, including reports from States under section 305(b) and ocean monitoring conducted by the Ocean Survey Vessel (OSV) *Bold*.

KEY ACTION #20: Expand National Water Resource Surveys to Include Climate Change Indicators. The National Water Program will expand the national water resources surveys, such as the recent assessment of wadeable streams and the Coastal Condition Report, to address climate change issues and information.

While understanding the impacts of climate change on the quality of water resources, it will also be increasingly important over time to understand changes in the spatial characteristics of waterbodies. The National Water Program will work with the U.S. Geological Survey to assess the potential for change in the spatial characteristics of wetlands, freshwater lakes, rivers, and streams as a result of changes in flow, velocity, and other factors associated with climate change and issue a report describing findings.

KEY ACTION #21: Assess Fresh Waterbody Spatial Changes Due to Climate Change. In cooperation with USGS, develop an assessment of the potential for change in the spatial characteristics of waters due to climate change and issue a report describing findings.

Watershed Management Tools

One of the most useful tools for understanding climate change impacts on water resources, especially impaired waters, is the Climate Assessment Tool (CAT) element of the BASINS water modeling program. (For more information about CAT, see Johnson et al. 2006 in the Further Reading section at the end of this document or visit <http://www.epa.gov/waterscience/BASINS/>.) EPA intends to promote the use of the model and provide training to EPA, State and Tribal program staffs on how to use the model to support assessment of climate-related water resources impacts and program decisions.

KEY ACTION #22: BASINS Climate Assessment Tool. The Office of Water will develop training sessions in Washington, DC, and selected Regions to assist EPA, State, Tribal, and other government staffs in using the CAT element of the BASINS decision support tool.

Protecting Coastal Estuaries

The National Estuary Program (NEP) promotes technical transfer of information, expertise, and best management practices within 28 estuaries designated as nationally significant watersheds. The accomplishments within these watersheds also assist other coastal watersheds facing similar water pollution and water quality impairments. This approach has proven to be a success over the past 15 years and the NEP is seen as a model for other comprehensive watershed and community-based programs.

The National Water Program will work with individual estuary programs to promote climate change as a priority for NEPs' Comprehensive Conservation and Management Plan revisions. In addition, the National Water Program will work with the Office of Air and Radiation to establish a "Climate Ready Estuaries Program" (similar to the existing "Climate Friendly Parks" with the National Park Service) that would provide climate change outreach to estuaries and recognize efforts of coastal watersheds to adapt to climate change.

KEY ACTION #23: "Climate Ready Estuaries". The National Water Program will establish a Climate Ready Estuaries Program in partnership with the Office of Air and Radiation's Climate Change Division.

In a related effort, the National Water Program will continue participation in the U.S. Coral Reef Task Force. In this effort, EPA is supporting local action strategies to address threats to reefs, developing guidance on coral reef bioassessments and biological criteria, and working to reduce stress on reefs from other sources (e.g., water pollution, vessel discharges).

KEY ACTION #24: Continue Coral Reef Protections: The National Water Program will continue participation in the U.S. Coral Reef Task Force and support related efforts to protect coral reefs.

Restoring Impaired Waters

The Clean Water Act provides for listing of waters not meeting State water quality standards and the development of plans, called “Total Maximum Daily Loads” (TMDLs) for reducing pollutant loadings as needed to meet water quality standards. The National Water Program is encouraging States and others to look for opportunities to develop TMDLs on a watershed basis and to implement restoration at the watershed scale. The National Water Program will consider the long range implications for waterbody impairment associated with climate change and will make needed revisions to TMDL guidance.

Nonpoint Pollution Control

Nonpoint source pollution continues to be the largest remaining source of water quality impairments in the Nation. State nonpoint source programs, developed under the Clean Water Act (CWA) Section 319 Program, are working to meet this challenge.

Congress enacted the 319 Program in 1987, establishing a national program to address nonpoint sources of water pollution. Under section 319(a), all States have developed nonpoint source assessment reports that identify nonpoint source pollution problems and the sources responsible for those water quality problems. Under section 319(b), all States have also adopted management programs to control nonpoint source pollution. Since 1990, Congress has annually appropriated grant funds to States under Section 319(h) to help them to implement those management programs.

In cooperation with NOAA, EPA has developed guidelines and methods under section 304(f)(1) and (2) of the Clean Water Act and under Coastal Zone Act Reauthorization Amendments (CZARA) of 1990 section 6217 concerning estimates of the nature and extent of nonpoint sources of pollutants and methods to control pollution. EPA has further developed these guidelines into management measures for multiple stakeholder sectors. EPA will review the current guidelines and methods in light of information related to climate change impacts on the type and extent of pollutants associated with

nonpoint sources (e.g., greater storm intensity resulting in high rates of pollutant loads in runoff) and revise the guidelines and methods as needed.

KEY ACTION #25: Review/Revise Nonpoint Pollution Guidelines and Methods.

EPA will review nonpoint pollution guidelines and methods in light of climate change and revise them as needed.

As research develops and nonpoint pollution control methods are better tailored to climate change, EPA will work with States to make climate change a priority for funding under section 319 and consider asking States and Tribes to amend nonpoint pollution management programs as needed to reflect new information relating to climate change, including information developed under section 304(f) relating to water movement and flow and the value of wetlands in mitigating impacts of climate change.

C. NPDES Permits

The National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point source discharges of

OBJECTIVE: NPDES permits maintain protection of water quality as the climate changes.

pollutants into the waters of the United States. The NPDES permit program covers approximately 500,000 facilities and is administered by either EPA or authorized States.

At the national level, EPA establishes regulations and policies that set technology- and water quality-based standards and that provide a framework for implementing those standards in discharge permits. Permit authorities are required to reevaluate and renew NPDES permits every five years to ensure that permit requirements protect the quality of a waterbody.

Changes in the hydrologic cycle due to climate change will need to be taken into consideration throughout the permitting process in order to preserve water quality. The NPDES program will undertake the following actions to adapt program management in response to climate change impacts:

- coordinate with other parts of EPA's Surface Water Program and other agencies, such as USGS, to evaluate climate change impacts on water quality and to identify appropriate responses by EPA's water quality program;
- lay the groundwork to build EPA's ability to provide technical assistance to permit authorities and, in the long term, incorporate new information into permit writer training and stakeholder outreach; and
- build the capability of EPA's Wet Weather Permit Program to assist communities with adaptation to changes in hydrological cycles.

As discussed in the mitigation section of this **Strategy**, the NPDES program will also promote technologies and practices that will help mitigate emissions of greenhouse gases.

Adapting the NPDES Permit Program

The five-year permitting cycle, as well as other mechanisms, provide permit writers with a significant amount of flexibility to adapt to changing conditions. However, an awareness on behalf of the permit writers and other stakeholders of the impacts of climate change will be crucial for ensuring that the program is protective of water quality within a changing climate regime. As an integral part of the National Water Program, conditions written into NPDES permits depend upon other program inputs, such as water quality standards, effluent guidelines, and Total Maximum Daily Loads (TMDLs). Cross-program workgroups (e.g., pesticides, ground water, and air programs) may be useful to identify changes each program will need to make. The NPDES program will be directly impacted by a variety of inter-office and intra-Agency decisions; therefore, continuous and effective inter-office dialogue will ensure that permit authorities are aware of, and properly able to incorporate, any new or revised permit requirements responsive to climate change.

Technical Assistance

Education, outreach, and technical assistance efforts will be targeted to permit writers as well as municipal, industrial, and agricultural stakeholders to help them understand and respond to the potential impacts of climate change in their areas. For example, the NPDES program intends to provide technical support to permitting authorities and permit writers on how to assess the need for revised water quality–based effluent limitations (WQBELs) and other permit conditions, as well as other aspects of program implementation. This may include assistance on issues such as:

- how to address changing values for low flow conditions due to climate change, used in calculating permit limits (i.e., 7Q10—the 7-day average low flow occurring once in 10 years);
- how to make reasonable potential determinations as other flow conditions change (i.e., 1Q10, 7Q10, and 30Q5);
- how to determine whether existing mixing zones continue to be protective of water quality;
- evaluating appropriate upset and bypass emergency conditions; and
- how climate change might affect anti-backsliding provisions.

EPA also intends to provide training and outreach to permit writers that will focus on ensuring the latest information and tools are available. The Permit Writers Course is one opportunity for providing basic information on a broad range of issues that permit writers should consider when developing permits. An introduction to climate change

impacts can be incorporated into this training, but a more detailed forum for discussion will also be useful. Some of the climate change–related topics that may be suitable for more advanced training include:

- watershed–based permitting and the potential impacts that climate change can have on this process;
- use of best professional judgment (BPJ) to develop technology-based effluent limitations for pollutant discharges from new technologies that may be developed to adapt to climate change;
- ways to evaluate the need for new or revised permit conditions due to impacts caused by climate change.
- how existing data systems can be used as tools for collecting and querying information on facilities and water bodies; and
- trainings targeted to stakeholders on specific topics related to their areas of focus (e.g., CAFOs, POTWs, and wet weather)

KEY ACTION #26: Review and Adapt NPDES Permit Program Tools. Conduct an internal review of the flexibilities and tools in the NPDES program that can be used to respond to changing water quality/quantity conditions and new technologies; collaborate with programs within the Office of Water and across the Agency, modify and expand training to reflect climate change, and provide technical assistance to permit authorities and permit writers.

Wet Weather Permits

As discussed previously in this document, climate change is projected to cause increased intensity of wet weather events in some areas, while increasing intensity of drought in other areas, and in some cases both “wetter wet and drier dry” periods in the same region. This variability hits at the heart of one of the most challenging sources of water pollution—stormwater runoff and sewer overflows during “wet weather” events. Although overall precipitation may decline nationwide, precipitation is expected to fall in more intense downpours, challenging current wet weather controls.

Intensifying the Global Water Cycle:

”According to model predictions, the most significant manifestation of climate change for humans and the environment is an intensification of the global water cycle, leading to increased global precipitation, faster evaporation, and a general exacerbation of extreme hydrologic regimes, floods, and droughts” (Asrar et al. 2001, p. 1313). Further, the National Research Council stated that “Water is at the heart of both the causes and the effects of climate change” (NRC 1999).

The NPDES program is charged with controlling urban and industrial wet weather discharges. Urban discharges are those from a municipality's wastewater conveyance

infrastructure that are caused by precipitation events such as rainfall or heavy snowmelt. Wet weather discharges include stormwater runoff through municipal separate storm sewer systems (MS4s), combined sewer overflows (CSOs), and wet weather sanitary sewer overflows (SSOs). Stormwater runoff gathers pollutants such as oil and grease, chemicals, nutrients, metals, and bacteria as it travels across land and over surfaces. CSOs and wet weather SSOs contain a mixture of raw sewage, industrial wastewater and stormwater and have resulted in beach closings, shellfish bed closings, and aesthetic problems.

Installing infrastructure, such as pipes and wet weather storage and treatment systems, involves long-term planning and may take 15-20 years to fully implement, and these systems have projected lifetimes of 50 years or more. Existing systems and current planning to reduce or eliminate CSOs and SSOs are based on historical rainfall records. EPA and States will need to help communities understand the climate scenarios that they are facing and will need to take climate change into account in their long-term planning. EPA will evaluate its programs to identify optimal response strategies and will work with the research community to develop tools for assessing rainfall patterns and design considerations.

Controlling stormwater runoff begins where water hits the ground. Traditional building techniques have created urban landscapes dominated by impervious cover, forcing rainfall to run off into waterways and stormwater systems. High volume and velocity scours waterways, increases erosion, floods human settlements, and overwhelms treatment systems. Shifting practices can significantly reduce both the volume and speed of runoff and, in fact, can aid the natural ecosystem by retaining water in the watershed and filtering out pollutants before they reach waterways. In the future, this will become even more important in the face of increasing temperatures and low flow periods that cause water shortages.

In support of this education effort, the National Water Program's Green Infrastructure Initiative is working to identify and demonstrate improved and new methods and techniques for preserving green space, increasing the perviousness of various types of land cover, retaining stormwater, and otherwise reducing the impacts of stormwater discharges. This work is expected to include assessment of the role of "green building" design specifications and approaches in developing CSO, SSO, and MS4 controls, as well as in guidance for non-point source stormwater controls.

KEY ACTION #27: Evaluate Opportunities to Address Wet Weather/ Climate Impacts at Municipal and Industrial Operations. The National Water Program will evaluate the wet weather program to identify initiatives to effectively address increases in precipitation due to climate change. Actions will include identifying best practices for characterizing design storms that take climate change into account, incorporating climate change into outreach and training materials, and promoting Green Infrastructure and Sustainable Infrastructure.

Industrial activities are also subject to NPDES permit requirements for their storm water discharges. The NPDES program will evaluate appropriate steps to take to address climate change impacts.

In addition, EPA intends to work with USDA and the agricultural community to better understand how climate change may impact major agricultural communities where animal feeding operations (AFOs) and concentrated animal feeding operations (CAFOs) are located, especially with regard to how manure storage and management systems might take into account climatological and hydrological changes.

KEY ACTION #28: Assess Climate Impacts at Animal Feeding Operations.

The National Water Program will work with USDA to evaluate climate change impacts, such as increases in wet weather, on animal feeding operations.

D. Water Infrastructure

Impacts should be expected to vary regionally, but in general, climate change could result in increased demands on our infrastructure systems, both in terms of O&M costs and the need for capital expenditures. The suite of expected impacts can be grouped according to the type of change a system may face and fall roughly into the following categories:

- more water (through increased precipitation and storm intensity) and sea level rise;
- less water, with increased frequency and duration of drought;
- temperature change; and
- damage from more intense storms.

Changes will affect drinking water, wastewater, and stormwater systems and range in scope from physical damage, to changes in treatment costs and treatment infrastructure, to changes in drinking water supply. Some of the steps that the National Water Program can take to respond to the challenges that climate change poses for water infrastructure include:

- continue the Sustainable Infrastructure Initiative, a comprehensive strategy to change the way the nation views, values, and manages its water infrastructure—for more information, please visit <http://www.epa.gov/waterinfrastructure/>;
- support infrastructure planning tools;
- address issues related to use of the State Revolving Fund (SRF) loans; and
- improve emergency planning.

Sustainable Infrastructure Initiative

In attempts to move our systems and the sector as a whole towards greater sustainability, EPA initiated and is pursuing its Sustainable Water Infrastructure (SI) Initiative. The Initiative includes a suite of approaches that reduce the demands on our water and wastewater systems and, paired with innovations in financing, help to ensure that our infrastructure serves us for the long term. It is organized around four principles, or “pillars”:

- Better management,
- Water efficiency,
- Full cost pricing, and
- Watershed approaches to infrastructure.

As all of the work under the Initiative seeks to reduce the demands on infrastructure and lessen the gap, it also encompasses the adaptations that help address any additional costs and demands resulting from climate change.

Decision Support Tools

A number of tools and outreach efforts can be adapted or created to foster the consideration of climate change in planning for infrastructure sustainability. For example:

- Advanced Asset Management (AAM) is an approach that plans for the replacement and repair of all a utility’s infrastructure. Impacts from climate change will be included in EPA’s AAM training and messaging; and
- Environmental Management Systems (EMSs) provide a means through which utilities examine their environmental footprints and constantly work towards improvements. This self evaluation process can be used as a vehicle for evaluating, adapting to, and mitigating climate change, and discussion of climate change will be included in EPA’s outreach to promote EMSs.

KEY ACTION #29: Implement the Sustainable Water Infrastructure Initiative and Adapt Decision Support Tools to Include Climate Change. The National Water Program will continue the implementation of the Sustainable Infrastructure Initiative and incorporate climate change into its activities, including incorporating climate change considerations in a range of new and existing sustainable infrastructure tools and outreach efforts.

Adaptation requires that communities understand the potential consequences of climate change at the local level. While climate models are not scaled to project such local impacts, communities can use available science to understand the plausible range of

changes to climate and resulting impacts on water resources they could face. This information can then be considered in local decision making processes. Given the long lifespan of water and wastewater infrastructure, it is prudent that planning for new and existing facilities include climate considerations. EPA can work with the professional water and wastewater community to develop and disseminate such decision support tools.

KEY ACTION #30: Develop a Sustainability/Vulnerability Analysis Handbook for Climate Change Impacts. Work to publish a document describing a process through which utilities can conduct a self analysis of sustainability, including a climate change–specific vulnerability analysis.

State Revolving Funds and Climate Change

The Clean Water Act and Safe Drinking Water Act both provide for State Revolving Funds (SRFs) through which States make low interest loans to finance water infrastructure projects. The National Water Program works with States to assure the effective management of these funds. The Drinking Water SRF provides about \$1.6 billion in loans each year and the Clean Water SRF provides about \$5 billion in loans each year. Taken together, the SRFs are a vital tool for financing needed water infrastructure.

It will be important to clarify the SRF eligibility of projects that provide for mitigation of greenhouse gases (through energy or water efficiency or energy generation) or for the adaptation of treatment and distribution/collection systems to accommodate climate change.

KEY ACTION #31: Clarify Use of the Clean Water and Drinking Water SRFs to Support Adaptation to Climate Change. Work with State partners to clarify what types of climate change–related infrastructure expenditures are eligible for SRF assistance.

Emergency Planning for Water Facilities

The impacts of climate change present ongoing challenges for the Agency’s emergency response program. The possibility of more frequent and severe storms and flooding due to climate changes, along with the continued threat of terrorist attacks on our water and wastewater infrastructure, calls for a coordinated approach. To address this challenge, EPA has developed an agency-wide approach that identifies roles and responsibilities for Regions and Headquarters. The EPA approach incorporates an Incident Command System (ICS) that provides a set of core concepts, terminologies, and technologies common to all federal agencies.

Under the National Response Framework, EPA serves as an important support agency to the U.S. Army Corps of Engineers (the Corps) to enable the rapid restoration of critical water and wastewater services after a calamitous event. By Presidential Directive, EPA also is the federal lead for preparing water and wastewater systems to prevent, detect, respond to, and recover from terrorism and natural disasters.

In order to be prepared to respond to natural disasters such as hurricanes and floods, or possible terrorist attacks on our water and wastewater infrastructure, the National Water Program can take the following additional actions:

- **Provide Training:** Provide training (e.g., National Incident Management System and Incident Command System) and materials (e.g., best practices and table-top exercises) to improve the ability of drinking water and wastewater systems to prepare for and recover from all hazards, including natural disasters.
- **Develop Response Networks:** Coordinate with States, Tribes, and water sector associations to promote the adoption of mutual aid and assistance programs, known as Water and Wastewater Agency Response Networks (WARNs), so that utilities can exchange equipment and personnel to expedite the restoration of critical water services.
- **Participate in Emergency Response Exercises:** Integrate the water sector into national emergency response exercises such as Spill of National Significance (SONS) and TOPOFF (“TOP OFFICIALS”) to enhance awareness of the importance of the sector and to measure the effectiveness of a simulated response. Implement a national effort to measure risk reduction efforts against all hazards in the water sector.
- **Coordinate Incident Control:** In coordination with the Federal Emergency Management Agency (FEMA) and the Corps, EPA will work within the National Response Framework to improve the marshalling of aid for utilities. This work includes identifying Department of Homeland Security and other databases as resources for critical infrastructure information that could prove useful in preparing for or responding to an event on the State or Federal level, and for establishing key definitions across the Federal government to facilitate emergency assistance (e.g., credentialing, resource typing).
- **Streamline Permitting:** In order to address emergency response and climate change, the NPDES program intends to develop processes to streamline and expedite permits concerning natural disasters. It will be important to provide flexible mechanisms for dealing with emergencies, such as permitting for emergency package treatment systems to quickly reinstate the ability to treat wastewater.

Following unfortunate events that damage communities and ecosystems, EPA and its Federal partners intend to ensure that rebuilding efforts take advantage of the opportunity to re-think planning and development. It is appropriate that Federal funding promote use of water and energy efficient technologies, use of sustainable re-development principles such as smart growth and green buildings/green infrastructure, and re-evaluate how to rebuild and preserve wetlands to mitigate future storm damage.

KEY ACTION #32: Develop and Expand Emergency Response Planning. The National Water Program will implement a range of actions (see above) to ensure existing emergency response planning considers impacts from climate change, and will work with federal partners to promote adoption of sustainable practices during recovery and rebuilding.

E. Wetlands Management

Since 1989, the Federal government as a whole has embraced a policy goal of no net loss of wetlands under the Clean Water Act Section 404 regulatory program. In 2004, President Bush announced an additional national goal to protect, restore, and improve 3 million acres of wetlands by 2009. The Wetlands Program contributes to that goal through implementation of the section 404 regulatory permit program and by fostering effective wetlands management through strategic partnerships with States, Tribes, local governments, and other key partners.

OBJECTIVE: assure that development of wetlands protection guidelines and policies includes consideration of climate change.

In addition to protecting wetlands, the section 404 permit program regulates the discharge of dredged or fill material into all “Waters of the United States” (as defined in the Clean Water Act). Wetlands are also the focus of the voluntary State/Tribal portion of the Program, which builds the capacity of State, Tribal, and local governments to protect and manage wetlands through grants, by promoting wetlands monitoring and assessment, mapping, outreach, and through strategic partnerships.

The important functions and ecosystem services provided by the nation’s wetlands, streams and other aquatic resources will continue to grow in importance as the climate changes. Wetlands provide crucial functions in four areas related to climate change:

- **Coastal Protection:** Facing the certainty of sea level rise and the potential for increasing hurricane intensities, the ability of coastal wetlands to reduce wave energy and protect coastal settlements may become more important.
- **Protecting Water Supplies:** With increasing aridity in some regions of the United States, the protection of remaining wetlands and streams that provide

groundwater recharge and maintain minimum stream flows is important for maintaining water supplies.

- **Flood Mitigation:** With the projected increase in precipitation and storm frequency in other parts of the United States, the capacity of wetlands and headwater streams to reduce flood peaks, detain stormwater, and filter pollutants, is important to the protection of life, property, and water quality.
- **Carbon Sequestration:** Lastly, the high primary productivity of coastal wetlands may make these systems attractive components of existing and future carbon sequestration efforts.

In light of the important contributions wetlands can make to adapting to climate change, the National Water Program will evaluate strategies for enhanced wetlands protection and develop a new standard for wetlands mapping. Key themes of this assessment process are to consider a watershed approach to wetlands protection and to emphasize integration with other water programs.

Regulatory Framework

Section 404 of the Clean Water Act establishes a program to regulate the discharge of dredged or fill material into waters of the United States, including wetlands. Activities in waters of the United States regulated under this program include fill for development, water resource projects (such as dams and levees), infrastructure development (such as highways and airports) and mining projects. Section 404 requires a permit from the U.S. Army Corps of Engineers (the Corps) or a state with an EPA-approved program before dredged or fill material may be discharged into waters of the United States.

EPA developed the substantive environmental criteria used by the Corps to make its permitting decisions, known as the Section 404(b)(1) Guidelines (the Guidelines). As articulated in the Guidelines, the basic premise of the permitting program is that no discharge of dredged or fill material may be permitted if a practicable alternative exists that is less damaging to the aquatic environment or the nation's waters would be significantly degraded. Permit applicants must demonstrate that:

- impacts to wetlands and other waters of the U.S. have been **avoided** to the "maximum extent practicable";
- unavoidable impacts have been **minimized** "to the extent appropriate and practicable"; and
- remaining impacts have been **compensated** for "to the extent appropriate and practicable."

Since protecting our Nation's existing aquatic resource base is critical to ensuring the country's ecological and economic resilience as climatic patterns shift, effective implementation of the Section 404 regulatory program and meeting the no net loss goal is an important part of maintaining the ability to adapt to climate change

The §404 Guidelines currently prohibit discharges that will cause or contribute to “significant degradation” of the waters of the United States. Significant degradation is broadly defined to include individual or cumulative impacts to human health and welfare; fish and wildlife; ecosystem diversity, productivity and stability; and recreational, aesthetic or economic values. In light of the growing concerns regarding the adverse effects of climate change and the recognition that protecting the Nation’s wetlands and other aquatic resources can help to mitigate these effects, EPA will explore how consideration of the effects of climate change should inform significant degradation determinations and publish additional guidance where appropriate.

The §404 permit review process also includes determining where there would be an “unacceptable adverse impact” resulting from the proposed activity, as described under §404(c), as well as “substantial and unacceptable” impacts to Aquatic Resources of National Importance, pertaining to §404(q), often called permit elevations. Criteria used for these determinations should take into account the chemical, physical and biological importance of an aquatic resource in light of climate change. The program will consider developing guidance describing any impacts determined to be “unacceptable” in consideration of the potential effects of climate change (e.g., where discharges would result in harm to wetlands critical to storm surge reduction).

General permits under section 404 authorize categories of activities that are expected to have minor impacts, without the need for completion of an individual permit application, as long as specified procedures and conditions for minimizing impacts are followed. Since almost 90% of §404 permits each year are general permits, effective implementation of the general permit program is an important component of the broader regulatory program role in addressing the potential impacts of climate change. For example, conditions in general permits may identify key resource types (e.g., playa lakes) or specific locations (e.g., coastal Louisiana) that are protected on a regional or State basis.

In order to offset permitted impacts, the Corps typically requires between 40,000 – 50,000 acres of compensatory mitigation annually. This compensation takes the form of restored, created, enhanced and/or preserved complexes of wetlands and streams. EPA, in conjunction with the Corps, will evaluate how these wetland and stream compensation projects could be selected, designed and sited to also aid in mitigating the effects of climate change. For example, certain types of restoration projects could be encouraged because of their relative carbon sequestration benefits or because they would facilitate more effective wetland migration as sea level rises.

KEY ACTION #33: Effective Implementation of the 404 Regulatory Framework:

The National Water Program will work with the Army Corps of Engineers to ensure effective implementation of the regulatory framework under section 404 of the Clean Water Act in a way that considers the effects of climate change and will explore the need for additional guidance on avoiding or minimizing impacts, defining “significant degradation” and “unacceptable adverse impact”, and/or implementing compensatory mitigation.

National Wetlands Mapping Standard

Baseline information on the location and condition of wetlands and aquatic resources is necessary to manage the wetlands program and develop the models and plans needed to adapt to climate change. The existing National Wetland Inventory (NWI) mapping, managed by the Fish and Wildlife Service, is used extensively for those efforts and is already used to address the effects of climate change (e.g., modeling sea level rise).

The NWI maps were innovative when first produced, but additional work is now needed to better satisfy the demands for sophisticated analysis that supports effective environmental planning. Hardcopy maps are available for 81% of the Nation, and 53% of the NWI is available online for use in GIS applications. However, a significant portion of the arid West has not yet been mapped.

Stakeholder agencies and organizations have started an initiative to develop and implement a modernized Wetland Mapping Standard to update and improve the quality of the data. The goal of this effort is twofold: to accelerate the rate at which the national wetlands mapping is completed and to enable real-time updates of the national wetlands data layer in the future. Using the new Standard, other groups, such as States, local governments, and non-governmental organizations, will be able to collect and upload digitally mapped data to the NWI. EPA and other Federal agencies will be supporting a range of organizations to complete the national map. The Standard was published for public comment in August 2007.

KEY ACTION #34: Finalize National Wetlands Mapping Standard: Work with other Federal agencies to finalize the National Wetlands Mapping Standard and work with Federal partners to fund updates of arid west maps.

3. Climate Change Research Related to Water

Research on climate change issues related to water is occurring both internationally and in the United States. Much of this research is being managed by Federal agencies, including EPA. The National Water Program will benefit from much of the research now underway and this **Response to Climate Change** document will be revised periodically to reflect emerging research. At the same time, the National Water Program will begin to play a larger role in defining research priorities and working with the research community to make research results as useful as possible. Three key research topics are addressed below:

- research projects related to water now underway as part of the Federal government interagency U.S. Climate Change Science Program (CCSP);
- research projects underway within the EPA Office of Research and Development (ORD) related to water quality, drinking water and ecosystems that relate to climate change; and
- elements of the ORD Global Change Research Program that relate to water (all of which are consistent with the CCSP Strategic Plan).

Goal 3: Climate Change Research Related to Water: strengthen the link between EPA water programs and climate change research.

Additional research topics were identified by the National Water Program Climate Change Workgroup during the development of this **Strategy** (noted in Appendix 5) and will be considered in future research planning.

Although not addressed below, it is important to note the vital and continuing research sponsored by the Intergovernmental Panel on Climate Change (IPCC). ORD scientists and grantees make a significant contribution to the IPCC as authors, and through research cited by the IPCC. The IPCC is now completing its Fourth Climate Change Assessment and is publishing a series of reports summarizing worldwide research on climate change. Much of the work is related to water resource impacts of climate change and a significant portion addresses water issues in North America.

A. U.S. Interagency Research: CCSP Projects Underway

The interagency U.S. Climate Change Science Program (CCSP) coordinates and integrates scientific research on global change and climate change, including research related to water, sponsored by 13 participating departments and agencies of the U.S. Government. The planning and implementation of ORD's Global Change Research Program is integrated by the CCSP with other participating Federal departments and agencies to reduce overlaps, identify and fill programmatic gaps, and add integrative value to products and deliverables produced under the CCSP's auspices. ORD coordinates with other CCSP agencies to develop and provide timely, useful, and scientifically sound information to decision makers.

A major activity called for in the 2003 CCSP Strategic Plan is the production of 21 Synthesis and Assessment Products (SAPs) by 2008 that respond to the CCSP highest priority research, observation, and decision support needs. A full list of the 21 CCSP SAPs is available at

<http://www.climatescience.gov>. The following SAPs relate to water resources:

OBJECTIVE: monitor and make good use of Federal interagency climate change research.

- **Weather and Climate Extremes in a Changing Climate: Focus North America, Hawaii, Caribbean, and the U.S. Pacific Islands (SAP 3-3):** Report to be published 6/08; NOAA lead with NASA, USGS, DOE.
- **Coastal Elevation and Sea Level Rise (SAP 4-1):** Report to be published 6/08; EPA lead with USGS and NOAA.
- **Thresholds of Change in Ecosystems (SAP 4-2):** Report to be published 6/08; USGS lead with EPA, NOAA, DOE and NSF.
- **Effect of Climate Change on Agriculture, Biodiversity, Land, and Water Resources (SAP 4-3):** Report to be published by 5/08; USDA lead with many other agencies.
- **Review of Adaptation Options for Climate Sensitive Ecosystems and Resources (SAP 4-4):** Report to be published by 5/08; EPA lead with other contributing agencies.
- **Effect of Climate Change on Energy Production and Use (SAP 4-5):** Report completed in 10/07; DOE lead.
- **Analyses of the Effects of Global Climate Change on Human Health and Welfare and Human Systems (SAP 4-6):** Report to be published 5/08; EPA lead with other agencies.
- **Effect of Climate Change on Transportation and Infrastructure: Gulf Coast Study (SAP 4-7):** Report to be published by 5/08; DOT lead with USGS, DOE, NASA.

The National Water Program intends to monitor the development of these key CCSP products and use these reports to refine and improve responses to climate change. As this **Response to Climate Change** is revised over time, findings from these reports will be considered.

In addition to the Synthesis and Assessment Products, the CCSP also has detailed implementation plans for each of its priority program elements. This includes a plan for its Carbon Cycle Workgroup’s research activities related to carbon sequestration. The National Water Program will work with ORD to integrate information from these activities into the management framework.

KEY ACTION #35: Monitoring of Water Related CCSP Reports. The National Water Program will monitor the development of reports by the Climate Change Science Program and name a representative to join an ORD representative on the CCSP Water Cycle Working Group.

B. EPA/ORD Water Research Related to Climate

The National Water Program works closely with the EPA Office of Research and Development (ORD) on a wide range of water related research focusing on the Multi-Year Plans and Strategies for:

OBJECTIVE: EPA research on water issues will address climate change

- Ecosystem Research;
- Clean Water Research; and
- Drinking Water Research.

Some of this research applies to issues related to climate change.

Ecological Research Program

The Ecological Research Program is undergoing a major shift in direction. The new focus is on “ecosystems services, their value, and their relationship to human well being, for consistent incorporation into environmental decision making” (Ecological Research Program; Multi-Year Plan; draft 4/07). It is clear that in adapting to climate change, risk managers make choices involving land use, benefit vs. cost of ecosystem maintenance or restoration, value of preserving endangered species in a particular location and so forth. Research in ecosystems services will provide direct support in these decisions.

The draft Multi-Year Plan for Ecological Research specifies several outputs that will be of use in managing climate change impacts on water programs:

- measures and dynamic maps of ecosystems services;
- predictive models relating to the response of stressors;

- management options, based on alternative future scenarios; and
- decision support platforms.

Some specific areas of research that are particularly germane to climate change are also described including a focus on nitrogen, concentrated work on evaluating ecosystem services of wetlands, and place-based research—for which the Willamette River basin and adjacent areas and the Tampa Bay ecosystem have been selected for near term studies.

Clean Water Research Program

The Water Quality Multi-Year Plan includes many areas that will directly support decision making related to climate change impacts including:

- **Multiple Stressors:** Assessment of multiple stressors (i.e., changes in temperature, salinity, water flow, pH and other parameters) on the health of waters.
- **Bioassessment/Biocriteria:** In developing permits and standards to address climate change, the National Water Program will need a greater concentration on bioassessment and biocriteria.
- **Nutrients:** Increased water flow will mean changes in nutrient status of water bodies in some areas of the country and research theme 1.3 is dedicated to nutrients research.
- **Flooding Impacts on Infrastructure:** To the extent that extreme weather events increase, flooding events may increase in magnitude and the Multi-year Plan addresses research needs in this area in the Aging Infrastructure research theme.
- **Pathogens:** Climate change may result in changes in the range of existing pathogens and a need to revise traditional indicators of pathogens. New means of testing for the presence of microbial pathogens are being developed, including rapid indicators based on genomic and other state-of-the-art techniques. These methods will be relevant not only to recreational waters, but also to shellfish beds and drinking water uses.

Drinking Water Research Program

The Drinking Water Multi-year Plan also describes research on microbial contaminants, including rapid detection methods and evaluation of emerging pathogens. One area addressed in the Plan that is particularly important is improved and rapid detection methods for algal toxins so that we can better address harmful algal blooms in both freshwater and marine environments.

Underground injection wells figure prominently in some climate mitigation strategies, and the Drinking Water Multi-Year Plan identified several projects in this area under Source Water Protection including:

- a report on CO₂ transport, modeling and risk assessment (2008);
- a report on impacts on drinking water sources of carbon capture and storage (2010); and
- a report on mechanical integrity test methods for CO₂ injection (2011).

KEY ACTION #36: Climate Research in Water Related ORD Research. The National Water Program will work with the EPA Office of Research and Development in development of water research related to climate change.

C. ORD Global Change Research Program

The EPA ORD also develops a Multi-Year Plan for Global Change Research. This Plan provides an implementation plan for the 2001 Research Strategy for ORD's Global Change Research

OBJECTIVE: The EPA Global Change Research Program will address water program research needs.

Program, which was externally peer-reviewed. Although the National Water Program has had limited participation in development of this Plan in the past, the current Plan includes a number of important research projects related to the impacts of climate change on water resources.

ORD's Global Change Research Program is stakeholder-oriented, with emphasis on assessing the potential consequences of global change on air quality, water quality, aquatic ecosystems, human health, and socioeconomic systems. ORD uses the results of these studies to investigate adaptation options to improve society's ability to respond to the risks and opportunities presented by global change, and to develop decision tools for resource managers coping with a changing climate.

KEY ACTION #37: Revision of ORD Global Change Multi-Year Plan. The Office of Water will appoint a representative to participate in the ORD revision of the Global Change Multi-Year Plan.

The most significant major study called for in the current Multi-Year Global Change Research Plan calls for ORD and the National Water Program to cooperate in the development of an assessment of the sensitivity to climate change of the goals articulated by the Clean Water Act and Safe Drinking Water Act and the opportunities available within the provisions of these laws to address the anticipated impacts of climate change. The assessment will also develop an atlas of vulnerabilities of water resources and aquatic ecosystems in the United States to climate change.

ORD's Global Change Research Program recognizes that there is a lack of empirical data about the importance and prevalence of climate-related decisions, including those related to water resources.

To fill this information gap, the ORD Global Change Research Program will develop a new "decision assessment" process to help prioritize future climate change/water research needs. This process will provide a foundation for future research. ORD will develop a dynamic "decision inventory" to identify different classes of climate-sensitive decisions related to water resources in different regions of the country, and to evaluate the returns from providing better scientific information to inform those decisions.

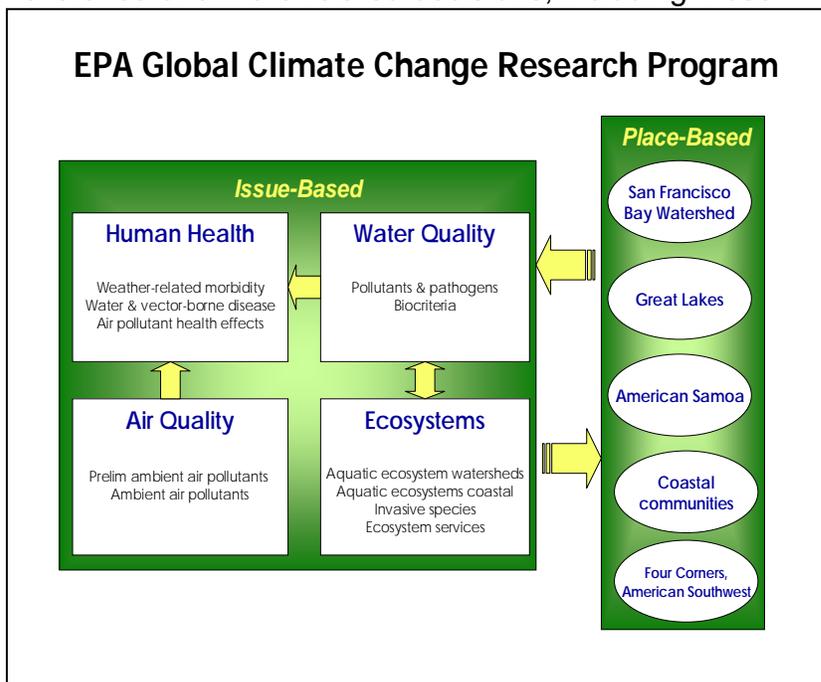


Figure 10: Source: EPA ORD Global Change Research Program.

Other major research projects in ORD's Global Change Research Program related to the water resource impacts of climate change are described in Appendix 4. ORD will also work with the National Water Program to complement research on geologic sequestration. The Office of Water will monitor the development of ORD reports on climate change impacts on water resources, distribute the reports to water program managers, and apply the findings of the reports to program implementation.

4. Water Program Education on Climate Change

Climate change science and policy is evolving rapidly and today's understanding of climate change impacts on water resources, and conclusions about needed response actions, may change over time. In order for the National Water Program to stay current with climate change issues, new practices are needed to strengthen outreach to partners and stakeholders on climate change-related water program issues and educate water program professionals on climate change generally.

Goal 4: Water Program Education on Climate Change: educate water program professionals and stakeholders on climate change impacts on water resources and programs.

This communication needs to involve both EPA informing others about new issues and activities and EPA listening to and learning from the suggestions of others.

A key first step toward establishing the strong communication linkages that will support successful implementation of water program climate change adaptations is the operation of a water and climate change website and “listserve”. These web tools will provide basic information about the impacts of climate change on water programs including copies of related materials and links to the EPA climate change website and other related sites. The “listserve” will provide periodic email updates on climate change–related issues to subscribers.

KEY ACTION #38: Clearinghouse Website/Listserve. The Office of Water will work with other EPA offices to establish a website to provide documents related to water and climate change, including research products, and offer as part of this site, a “listserve” to send update emails to interested parties.

Keeping partners and stakeholders informed of progress in implementing the Key Actions identified in this document will be a continuing task. For many interested parties, however, a single, annual report on progress and new or emerging issues will best serve their needs. We expect the reports will identify progress toward key goals identified in the **Strategy** and identify “best practices” addressing the water impacts of climate change.

KEY ACTION #39: Annual Public Reports on Strategy Implementation. The Office of Water will publish annual reports describing progress in implementing this **Strategy**.

As water program partners and stakeholders become more involved in activities related to climate change, issues and priorities will become clearer and requests for information and analysis will increase. In anticipation of these requests, the National Water Program intends to take the initiative to provide existing advisory groups and related organizations with information on climate change activities.

State and Tribal organizations are also an effective vehicle for providing basic information about climate change to water program professionals. For example, EPA relies on the National Drinking Water Advisory Council to provide guidance on a range of safe drinking water program implementation issues. Some of these other organizations include:

Stakeholder Meetings to Date:

The National Water Program Climate Change Workgroup has held five listening sessions with stakeholders:

May 24:	Environmental Community
June 6:	Agriculture Community
June 13:	Industry Organizations
June 14:	State and Local Government Organizations
August 10:	Tribal Officials

- Association of State and Interstate Water Pollution Control Administrators;
- Association of State Drinking Water Administrators;
- Ground Water Protection Council;
- Association of State Wetland Managers;
- Coastal States Organization; and
- National Tribal Water Council.

KEY ACTION #40: Outreach to Partners. The Office of Water will provide material and briefings on the National Water Program climate change response actions periodically to a wide variety of EPA advisory groups, State and Tribal organizations, and stakeholder organizations.

The National Water Program intends to work with these organizations to identify meetings, seminars and other opportunities to provide information about climate change and to identify and address climate change issues related to water programs.

Among the most important steps that the National Water Program can take to respond to the many challenges of climate change is to inform and educate the tens of thousands of water program professionals in Federal, State, Tribal, and local governments and in the private sector concerning climate change issues and potential impacts on water resources. With access to basic information about climate change, professionals can apply this knowledge to numerous specific cases and make countless valuable program adaptations.

As a first step in building understanding of climate change issues among water program professionals, the Office of Water intends to make basic information about climate change available to a wide range of water program managers. By publishing a basic reference document that focuses on water resource impacts of climate change, the National Water Program can encourage individual program managers to recognize climate change issues and impacts and to address these problems effectively.

KEY ACTION #41: Climate Change Background Papers. The Office of Water will publish “*Background Papers: A Climate Change Primer for Water Professionals*” (hard copy and online) to provide a basic reference for water program professionals describing the potential impacts of climate change on water programs.

The National Water Program is now making a significant investment in training for water program professionals in the management, policy, and technical challenges arising from the management of core clean water and safe drinking water programs. The Water Quality Standards Academy, the Watershed Academy, and the Drinking Water Academy are just a few examples. By including basic information about climate change in these training programs, the National Water Program can build understanding

of climate change issues among water program staff and strengthen the ability of the program to address climate change problems. In addition, short, focused training on climate change issues related to water would be a benefit to water program staff in national and Regional offices.

KEY ACTION #42: Expand Water Training on Climate Change. EPA will revise existing training programs to include attention to the impacts of climate change on water programs and will offer training on water-related climate change impacts to national and Regional offices.

5. Water Program Management of Climate Change

Climate change poses significant and long-term challenges for the National Water Program. The development of this ***National Water Program Strategy: Response to Climate Change*** is a key first step in understanding climate change impacts on water programs and the beginning of the process of implementing response actions. To sustain this focus on climate change, the National Water Program will need to establish management practices to build on this initial assessment of climate change impacts.

Goal 5: Water Program Management of Climate Change: establish the management capability within the National Water Program to address climate change challenges on a sustained basis.

A first key step in this process is to continue the operation of the National Water Program Climate Change Workgroup. This group is chaired by the Deputy Assistant Administrator for Water and includes senior managers from national and EPA Regional offices as well as representatives of the Office of Air and Radiation and the Office of Research and Development and helps maintain good communication among these offices on climate change issues. For the next several years, we expect the Workgroup will oversee implementation of this ***Strategy***, oversee water program coordination with other EPA offices and other Federal agencies on climate-related issues, and make needed revisions to the ***Response to Climate Change*** document on a periodic basis.

KEY ACTION #43: Maintain Office of Water Climate Change Workgroup. The Office of Water will maintain the National Water Program Climate Change workgroup.

As the water program begins implementation of the ***Response to Climate Change***, it is likely that issues with respect to coordination of this work with other program implementation work will arise. To address these issues, the National Water Program will integrate climate-related Key Actions with the established water program management tools, including the EPA ***Strategic Plan*** and the annual water program

guidance. The FY 2009 annual National Water Program guidance will be developed in early 2008 and published in April 2008 and we expect it will reflect Key Actions included in this document.

KEY ACTION #44: Agency *Strategic Plan* and Water Program Annual

Guidance. The Office of Water will include Key Actions from this *Strategy* in the FY 2009 annual National Water Program guidance, and when appropriate, make needed changes to the water elements of the EPA *Strategic Plan*.

EPA Regional water programs will play a central role in responding to climate change by implementing Key Actions identified in this document. While this national strategy describes actions to be implemented at the national level and in each of the ten EPA Regions, there is likely to be significant variation in the nature and extent of climate impacts in each Region. For example, drought and water supply issues may be a top priority in western Regions while sea level rise may be more critical in other Regions. Some Regions may want to supplement this national strategy with Key Actions designed to more specifically address the specific needs in the Region.

KEY ACTION #45: Regional Additions to National Water Climate Strategy.

Each EPA Regional Water Division will review climate change potential impacts in the Region, identify impacts of special concern to that Region, and develop Region-specific additions to this national *Strategy* as needed.

This *Response to Climate Change* document is the product of an internal, EPA review of opportunities to better adapt water programs to climate change. Water program staff have discussed this work with staff from other Federal agencies, but have not asked other Federal agencies to endorse the document. It is clear that there are numerous opportunities to coordinate the climate change-related work of the National Water Program with the activities of other Federal agencies. Some of the other Federal agencies with an interest in water-related climate change issues include:

- the Army Corps of Engineers;
- National Oceanic and Atmospheric Administration;
- U.S. Department of Energy;
- Federal Emergency Management Agency;
- U.S. Department of Interior (Bureau of Reclamation, Geologic Survey, and Fish and Wildlife Service);
- U.S. Department of Agriculture; and
- National Science Foundation.

As a first step in strengthening water-related communication among these agencies, EPA will convene a staff level coordination group to exchange information, report on best practices, and improve program efficiency.

KEY ACTION #46: Federal Agency Water Climate Coordination Group. The Office of Water will work with other Federal agencies with a significant interest in the water-related impacts of climate change through creation of a staff level coordination group.

APPENDICES

1. Climate Change Impacts on Water in Regions of the United States
2. Summary List of Climate Change Actions (including responsible offices)
3. Adaptations for Alaska Water Infrastructure
4. EPA Global Climate Change Research Program Projects Related to Water
5. Potential Climate Change/Water Research Needs
6. Glossary of Water Program and Climate Change Terms
7. Water Program and Climate Change Acronyms
8. References and Further Reading

APPENDIX 1:

Climate Change Impacts on Water in Regions of the United States

In addition to the general impacts of climate change on water resources described in Section II of this document, the following list provides examples of some effects of climate change on water resources in different parts of the United States that have been projected by various researchers. More information is available at the EPA Climate Change website at: <http://www.epa.gov/climatechange/effects/usregions.html>

In the East:

- “streamflow in the eastern U.S. has increased 25% in the last 60 years ...” (Field et al. 2007, p. 621)
- “[s]ea-level rise has accelerated in eastern North America since the late 19th century ... and further acceleration is expected ...” (Field et al. 2007, p. 630); and
- “[u]p to 21% of the remaining coastal wetlands in the U.S. mid-Atlantic region are potentially at risk of inundation between 2000 and 2100” (Field et al. 2007, p. 630).

In the Northeast:

- coastal erosion, loss of wetland habitat, increased risk from storm surges from sea level rise (IPCC 2007b, as found in EPA 2007j).

In the Southeast and Gulf Coast:

- increased coastal erosion including loss of barrier islands and wetlands (IPCC 2007b, as found in EPA 2007j);
- intense coastal zone development places coastal floodplains at risk to flooding from sea level rise, storm surge, and extreme precipitation events (IPCC 2007b, as found in EPA 2007j); and
- “[s]torm impacts are likely to be more severe, especially along the Gulf and Atlantic coasts” (Field et al. 2007, p. 619).

In the Midwest and Great Lakes:

- lowered lake and river levels, resulting from warmer temperatures and increased evaporation (IPCC 2007b, as found in EPA 2007j);
- increased agricultural productivity in many regions resulting from increased carbon dioxide and warmer temperatures (IPCC 2007b, as found in EPA 2007j);
- “[i]n the Great Lakes, both extremely high and extremely low water levels have been damaging and disruptive” (Field et al. p. 622);
- “[i]n the Great Lakes and major river systems, lower [water] levels are likely to exacerbate challenges relating to water quality, navigation, recreation,

hydropower generation, water transfers, and bi-national relationships” (Field et al. 2007, p. 619);

- “[r]ecent winters with less ice in the Great Lakes and Gulf of St. Lawrence have increased coastal exposure to damage from winter storms” (Field et al. 2007, p. 623); and
- “[r]estoration of beneficial uses (e.g., to address habitat loss, eutrophication, beach closures) under the Great Lakes Water Quality Agreement will likely be vulnerable to declines in water levels, warmer water temperatures, and more intense precipitation” (Field et al. 2007, p. 629).

In the West:

- earlier runoff of snowmelt, stressing some reservoir systems (IPCC 2007b, as found in EPA 2007j);
- “[s]pring and summer snow cover has decreased in the U.S. west” (Field et al. 2007, p. 622), and “[t]he fraction of annual precipitation falling as rain (rather than snow) increased at 74% of the weather stations studied in the western mountains of the U.S. from 1949 to 2004” (Field et al. 2007, p. 622);
- “[t]hreats to reliable supply are complicated by the high population growth rates in western states where many water resources are at or approaching full utilization” (Field et al. 2007, p. 633);
- increased wildfire potential (IPCC 2007, as found in EPA 2007j); and
- streamflow has decreased by about 2% per decade in the central Rocky Mountain region over the last century (Field et al. 2007, p. 621).

In the Southwest:

- annual precipitation has decreased (Field et al. 2007, p. 621); and
- “[h]eavily utilized groundwater-based systems in the southwest U.S. are likely to experience additional stress from climate change that leads to decreased recharge ...” (Field et al. 2007, p. 629).

In Alaska:

- damage to infrastructure resulting from permafrost melting (IPCC 2007b, as found in EPA 2007j);
- retreating sea ice and earlier snowmelt alter native people's traditional life styles (IPCC 2007b, as found in EPA 2007j);
- general increase in biological production from warming, but reduced sea ice and warming disrupts polar bears, marine mammals, and other wildlife (IPCC 2007b, as found in EPA 2007j);
- “[m]any indigenous communities in northern Canada and Alaska are already experiencing constraints on lifestyles and economic activity from less reliable sea and lake ice (for travelling, hunting, fishing, and whaling) ... and more exposed coastal infrastructure from diminishing sea ice (Field et al. 2007, p. 625); and

- “[s]ome Alaskan villages are threatened and require protection or relocation at projected costs up to US\$54 million (Field et al. 2007, p. 623).

In Hawaii and the Pacific Islands:

- “[s]ea-level rise will exacerbate inundation, erosion and other coastal hazards, threaten vital infrastructure, settlements and facilities, and thus compromise the socio-economic well-being of island communities and states” (Mimura et al. 2007, p. 689);
- for small islands in the Pacific, changes in temperature, rainfall, and sea level rise are projected to result in “accelerated coastal erosion, saline intrusion into freshwater lenses, and increased flooding from the sea ...” (Mimura et al. 2007, p. 696); and
- the projected sea level rise is expected to result in a 50% loss of mangrove area in American Samoa, and a 12% reduction in the mangrove area within 15 other Pacific islands (Mimura et al. 2007, p. 696).

For More Information:

For more information on how climate change may affect different regions and States within the U.S., see:

<http://www.epa.gov/climatechange/effects/usregions.html>

APPENDIX 2: Summary List of Climate Change Actions

The following 46 key actions appear in the draft strategy, and this table indicates the lead and supporting offices for each action.

Key Actions		Office of Water Lead with Supporting Offices	Comments
1) Greenhouse Gas Mitigation			
Energy Conservation/Production			
1	Improve Energy Efficiency at Water and Wastewater Utilities	OWM (Note that OAR leads this work for the Agency)	
Water Conservation			
2	Implement Water Sense Program	OWM	
3	Water Conservation at Drinking Water Facilities	OGWDW	
4	Water Conveyance and Leak Detection Remedies	OGWDW with OWM	
5	Industrial Water Conservation and Reuse	OST	
6	Federal Agency Water Conservation Guidance	OWM	
Green Building Design and Smart Growth			
7	Promote Green Buildings	OWOW with OWM	
Agriculture Related Mitigation			
Carbon Sequestration/Injection			
8	Develop Geologic Sequestration Regulations	OGWDW	
9	Continue Technical Workshops	OGWDW	
10	Evaluate Ocean and Subseabed Sequestration	OWOW	
Biological Sequestration			
11	Pilot Projects for Marketing NPS Biological Sequestration	OWOW	
2) Water Program Adaptation to Climate Change			
Water Quality and Technology-Based Standards			
12	Address Impacts of Climate Change on Potential Contamination of Drinking	OGWDW	

Key Actions		Office of Water Lead with Supporting Offices	Comments
	Water Sources		
13	Assess Clean Water Microbial Criteria and Risks of Waterborne Disease	OST	
14	Consider Criteria for Sedimentation/Velocity	OST	
15	Develop Biological Indicators and Methods	OST	
16	Link Ecological and Landscape Models	OST	
17	Evaluate New Industry Sectors	OST with OWM	
18	Review Existing Effluent Guidelines	OST	
Watershed Approach			
19	Watershed Climate Change Policy Memo	OWOW	
20	Expand National Water Resource Surveys to Address Climate Change	OWOW	
21	Assess Fresh Waterbody Spatial Changes Due to Climate Change	OWOW	
22	Promote BASINS Climate Assessment Tool	OST	
23	Climate Ready Estuaries	OWOW	
24	Continue Coral Reef Protections	OWOW	
25	Review/Revise NPS Guidelines	OWOW	
NPDES Program			
26	Review Permit Program Tools	OWM	
27	Evaluate Climate Impacts on Wet Weather Program	OWM	
28	Assess Climate Impacts at Animal Feeding Operation	OWM with OWOW	
Water Infrastructure			
29	Continue Implementing Sustainable Infrastructure Initiative	OWM with OGWDW and OWOW	
30	Sustainability Handbook with Climate Impacts	OWM with OGWDW	
31	Clarify Use of SRFs for Climate Change Related Projects	OWM with OGWDW	
32	Expand Emergency Response Planning	OGWDW with OWM	

Key Actions		Office of Water Lead with Supporting Offices	Comments
Wetlands Protection			
33	Implementation of 404 Regulatory Framework	OWOW	
34	Complete National Wetlands Mapping Standard	OWOW	
3) Water/Climate Related Research			
35	Monitoring of Water Related CCSP Reports	OST	
36	Add Climate Research in ORD Water Related Research Plans	OST	
37	OW Role in Revision of Global Climate Research Plan	OST	
4) Education on Climate Change			
38	Clearinghouse/Website	OW	
39	Annual Public Reports on Strategy Implementation	OW	
40	Outreach to Partners and Stakeholders	OW	
41	Climate Change Background Papers	OW	
42	Expand Existing Training Programs	OW	
5) Climate Change Management			
43	Maintain Office of Water Climate Change Workgroup	OW	
44	Strategic Plan and Annual Program Guidance	OW	
45	Regional Additions to National Strategy	Regions with OW	
46	Federal Agency Water Climate Coordination Group	OW	

EPA OFFICES:

OAR Office of Air and Radiation
OGWDW Office of Groundwater and Drinking Water (EPA's Office of Water)
OST Office of Science and Technology (EPA's Office of Water)
OW Office of Water
OWM Office of Wastewater Management (EPA's Office of Water)
OWOW Office of Wetlands, Oceans, and Watersheds (EPA's Office of Water)

APPENDIX 3:

Adaptations for Alaska Water Infrastructure

Alaska is particularly vulnerable to the effects of climate change. Changes in permafrost have created stability issues for buildings. Greater storm intensity has increased coastal erosion. Freeze-up is occurring later, increasing the risk of storm surges to inundate the numerous villages located in the large river deltas. The Government Accountability Office (GAO) identifies the communities of Kivalina, Koyukuk, Newtok, and Shishmaref as being “in imminent danger from flooding and erosion and are making plans to relocate” (GAO 2004, p. 3).

EPA, the Alaska Department of Environmental Conservation, and others are taking steps to address these concerns.

Existing actions include:

- use of thermal siphons to ensure the stability of buildings located on discontinuous permafrost; and
- avoid funding long-term improvements of water infrastructure where flooding or erosion is an imminent danger to the facility.

Likely future actions include:

- modify designs of buildings and related infrastructure to include hardening to address storm surges and/or sea level rise;
- prepare for extensive retrofitting to protect facilities from melting permafrost, flooding, and/or erosion; and
- refine maps to show climate change impacts on a more local level.

APPENDIX 4: EPA Global Climate Change Research Related to Water

The Global Change Research Program in the EPA Office of Research and Development (ORD) is developing important scientific information on the impacts of climate change on the nation's water resources. Research projects now underway are identified below.

- **Aquatic Ecosystems and Climate Change:** ORD will complete a report assessing the impact of climate change on aquatic ecosystems.
- **Uncertainty of Regional Impacts:** ORD is developing models to improve estimation of climate change impacts on regional and local scales.
- **Regional Climate Change and Invasive Species:** ORD will release an assessment of the effects of climate change and interacting stressors on the establishment and expansion of aquatic invasive species, and the implications for resource management.
- **Climate-Related Decisions in the Chesapeake Bay Program:** ORD will complete an assessment that inventories and prioritizes climate-related decisions related to water quality in the Chesapeake Bay Program.
- **Climate Change Consequences for Biocriteria:** ORD will complete an assessment of the consequences of global change for water quality related to biocriteria in 2008.
- **CSO Control and Impacts of Climate Change:** ORD will release a final report in 2008 on the implications of climate change for Combined Sewer Overflows in the Great Lakes and New England areas.
- **Water Quality–Based Effluent Limits at POTWs in the Great Lakes Region:** ORD will release a final report in 2008 on the implications of climate change for water quality–based effluent limits at POTWs in the Great Lakes region.
- **Water Erosion Prediction Model:** In response to anticipated increases in soil erosion as a result of climate change, ORD is incorporating a Climate Assessment Tool into USDA's Water Erosion Prediction Project Model (WEPP), expected to be available in 2008, to provide online capability for assessing climate change impacts on sediment in streams.
- **National Maps Depicting Land-Use Scenarios:** ORD will release national maps depicting land-use scenarios for the conterminous United States for use in assessments of where climate-land use interactions may exacerbate impacts or create adaptation opportunities.
- **Coral Reefs and Climate Change:** ORD will develop a report identifying adaptation options for protecting coral reefs from multiple stressors, including climate change, land-use practices, and other factors.
- **Geologic Sequestration of CO₂:** ORD will assess and provide decision support related to the behavior of injected CO₂ in the subsurface and impacts to drinking water sources.

APPENDIX 5: Potential Climate Change/Water Research Needs

Given the extensive range of likely impacts of climate change on water resources, the potential research topics in this field are almost limitless. The work now underway or planned by the IPCC, the CCSP and the EPA ORD will make important contributions to questions concerning water resources impacts of climate change, but additional research will be needed. The National Water Program expects to play an active role in identifying climate change/water resource research needs, both within the context of existing research programs as well as in other forums. A key goal of this process will be to identify from among the many potential research projects, those that are the most important and pressing.

During the development of this *Response to Climate Change*, members of the Climate Change Workgroup assessed climate change impacts on water resources and, as part of this effort, developed ideas for additional research projects to fill gaps in current knowledge. Although this is an initial list of research needs and is not yet complete or ranked in terms of relative priority, it suggests the range of research needs in this area.

Human Health

- **Better Predict Municipal Water Supply Impacts Associated with Temperature Increases/Snow to Rain Shifts:** Develop more complete estimates of water supply impacts of snow to rain shifts, the correlation of increased use of municipal water supplies, and water loss due to evapotranspiration.
- **Literature Review on Effects of Heat Stress:** It is likely that humans will continue to modify their environment to deal with rising temperature. Nevertheless, given the expected increase in frequency of extreme temperature events, people will be exposed to higher temperatures for at least short periods of time. Toxicological tests for all endpoints are done in animals kept at steady, standard temperatures. Thus, the extent to which temperature increases affects observations in these tests needs to be investigated.
- **Assess Population at Risk of Salt Water Intrusion to Drinking Water Wells:** Identify the population that relies on public and private drinking water wells that may be at risk to intrusion of salt water and the likely impacts on nearby community water systems.

Ecosystem Effects

- **Estimate Location of Loss of Shellfishing Areas:** Identify coastal waters used for shellfishing and assess the impact of expected sea level rise on the productivity and viability of these areas, including estimates of economic impacts.
- **Maintaining Water Retention Rates within Watersheds:** Develop methods to scale the rates of retention of watersheds and indices to compare retention rate

impacts of land use shifts, including retention rates of various practices (e.g., green roofs, impervious surfaces, retention basins, wetlands).

- **Increasing Resilience of Aquatic Ecosystems:** Identify the elements of aquatic ecosystems that foster increased resilience of the ecosystem and identify ways to strengthen and expand these elements.
- **Estimate Hypoxia/DO Events:** Identify coastal and fresh waters most at risk to decreased levels of oxygen in the water as a result of warmer air and water temperatures, the extent of increase of such events, and the environmental costs and economic impacts of the events.
- **NPS Management Models:** Develop models to forecast NPS loadings under variable climate change scenarios including changes in velocity of flows and pollutant concentrations and describe how these models can be used in design of NPS control plans and watershed plans.
- **Impacts of Salinity Changes on Health of Aquatic Systems:** Identify the waters most at risk of increasing levels of salinity and the likely impacts on fisheries and the health of aquatic systems.
- **Identify Flooding Impacts on Water Quality:** Identify the water pollutant increases and the hydrologic changes associated with flooding of varying types (e.g., inland, coastal).

Technology Studies

- **Stormwater Injection Wells:** Identify potential issues and benefits of injection of stormwater into underground geologic formations and recommend how this practice might best be managed in the future.
- **Biofuels Impacts on Water Quantity and Quality:** Evaluate the impact of increased biofuels production on water quality (e.g., increased land in crop production and increased use of fertilizer/pesticides) and use of water for production of biofuels.
- **Assess Drinking Water Treatment Complications Associated with Climate Change Impacts:** Assess the impacts of climate change (e.g., salt water intrusion, increased source water sediment and organic levels, and increased microorganism levels in water) for treatment of drinking water and for compliance with drinking water standards.
- **Energy Savings of Water Conservation:** Evaluate the potential for energy savings associated with different water conservation practices in areas of the country served by different power generation sources (e.g., coal-fired power plants vs. hydropower).
- **Identify Water Quality Issues Associated with Desalination:** In anticipation of increased demand for desalination, identify the water quality implications of this practice.
- **Effects of Water Conservation on Treatment Plant Operations:** Evaluate the impact of water conservation practices that reengineer water conveyance and reuse on the efficiency of conventional sewage treatment plant operations (i.e., dewatering of influent).

- **Methane Cleaning Technology:** Identify technologies to more cost effectively and reliably clean methane from sewage treatment plant digesters to allow for combustion of power of fuel cells.
- **Identify Energy Efficient Treatment Technologies:** Identify energy efficient treatment technologies for drinking water treatment, wastewater treatment, and industrial wastewater treatment.
- **Investigate Energy Conservation Measures:** Topics include assessing less energy intensive treatment methods, identifying opportunities for on-site combined heat and power production efforts such as utilizing biogas from anaerobic digesters and/or low head small hydroelectric, identifying more efficient processing of biosolids, and assessing the potential benefits of co-location of power plants and water utilities.

APPENDIX 6: Glossary of Water Program and Climate Change Terms

Key terms used in this **Strategy** related to water programs and climate change are defined below. Many of these terms are further defined on the EPA Office of Water website.

Adaptation (to climate change) – “Adjustment in natural or *human systems* in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.” <http://www.ipcc-wg2.org/index.html> (click on “glossary” of the Working Group II (WGII) contribution to the Fourth IPCC Assessment Report)

AgSTAR – The AgSTAR Program is a voluntary effort jointly sponsored by the EPA, USDA, and USDOE. The program encourages the use of methane recovery (biogas) technologies at concentrated animal feeding operations that manage manure as liquids or slurries. <http://www.epa.gov/agstar/>

Aquifer storage and recovery (ASR) – ASR is the process of injecting water at times of high supply with the intention to retrieve the stored water at a later date.

Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) – BASINS is a multi-purpose environmental analysis system that integrates a geographical information system (GIS), national watershed data, and state-of-the-art environmental assessment and modeling tools. The Climate Assessment Tool (CAT) is an element of the BASINS water modeling program that is useful for learning about climate change impacts on water resources, especially impaired waters. <http://www.epa.gov/waterscience/BASINS/>

Biofuels – A gaseous, liquid, or solid fuel that contains an energy content derived from a biological source. <http://www.epa.gov/trs/>

Carbon sequestration – Carbon sequestration refers to “[t]he process of increasing the carbon content of a reservoir/pool other than the atmosphere” <http://www.ipcc-wg2.org/index.html> (click on “glossary” of the WGII contribution to the Fourth IPCC Assessment Report). The draft strategy refers to several types of sequestration, including subseabed and ocean, geologic, and biological.

Climate Change Science Program (CCSP) – The interagency U.S. CCSP coordinates and integrates scientific research on global change and climate change, including research related to water, sponsored by 13 participating departments and agencies. The CCSP incorporates the U.S. Global Change Research Program (USGCRP) and the Climate Change Research Initiative (CCRI). <http://www.climate-science.gov/>, <http://www.usgcrp.gov>, <http://www.climate-science.gov/about/ccri.htm>

Combined heat and power (CHP) – CHP, also known as cogeneration, is an efficient, clean, and reliable approach to generating power and thermal energy from a single fuel source. <http://www.epa.gov/chp/>

Combined sewer overflow (CSO) – Combined sewer systems (CSSs) are sewers that are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe. During periods of heavy rainfall or snowmelt, the wastewater volume in a CSS can exceed the capacity of the sewer system or treatment plant. For this reason, CSSs are designed to overflow occasionally and discharge excess wastewater directly to nearby water bodies. These overflows are referred to as CSOs. <http://www.epa.gov/npdes/cso>

Contaminant Candidate List (CCL) – The SDWA includes a process to identify and list unregulated contaminants that may require a national drinking water regulation in the future. EPA must periodically publish this list of contaminants—called the CCL—and decide whether to regulate at least five or more contaminants on the list. <http://www.epa.gov/safewater/ccl/index.html>

Effluent limitations guidelines (ELGs) – Effluent guidelines are national standards for wastewater discharges to surface waters and publicly owned treatment works (municipal sewage treatment plants). <http://www.epa.gov/guide/>

ENERGY STAR – ENERGY STAR is a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy designed to help save money and protect the environment through energy efficient products and practices. <http://www.energystar.gov/>

Five Star Restoration Grant Program – The Five Star Restoration Program brings together students, conservation corps, other youth groups, citizen groups, corporations, landowners, and government agencies to provide environmental education and training through projects that restore wetlands and streams. The program provides challenge grants, technical support, and opportunities for information exchange to enable community-based restoration projects. <http://www.epa.gov/owow/wetlands/restore/5star/>

Green building – Green or sustainable building is the practice of creating healthier and more resource-efficient models of construction, renovation, operation, maintenance, and demolition. <http://www.epa.gov/greenbuilding/>

Greenhouse effect – Energy from the Sun drives the Earth's weather and climate. The Earth absorbs energy from the Sun and also radiates energy back into space. However, much of this energy going back to space is absorbed by “greenhouse gases” in the atmosphere. Because the atmosphere then radiates most of this energy back to the Earth's surface, the planet is warmer than it would be if the atmosphere did not contain these gases. Without this natural “greenhouse effect” temperatures would be

about 60°F lower than they are now, and life as we know it today would not be possible. <http://www.epa.gov/climatechange/science/index.html>

Greenhouse gas (GHG) – Gases that trap heat in the atmosphere are often called greenhouse gases. Some greenhouse gases such as carbon dioxide occur naturally and are emitted to the atmosphere through natural processes and human activities. Other greenhouse gases (e.g., fluorinated gases) are created and emitted solely through human activities. The principal greenhouse gases that enter the atmosphere because of human activities are: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and fluorinated gases (hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride).

<http://www.epa.gov/climatechange/emissions/index.html#ggo>

Green infrastructure – Green infrastructure represents a new approach to stormwater management that is cost-effective, sustainable, and environmentally friendly. Green infrastructure techniques utilize natural systems, or engineered systems that mimic natural landscapes, to capture, cleanse and reduce stormwater runoff using plants, soils and microbes. <http://www.epa.gov/npdes/greeninfrastructure>

Green power – Renewable energy resources such as solar, wind, geothermal, biogas, biomass and low-impact hydro generate green power. Not all sources of power generation share the same environmental benefits. As a result, green power is considered a subset of renewable energy.

<http://www.epa.gov/greenpower/whatis/index.htm>

Intergovernmental Panel on Climate Change (IPCC) – The IPCC was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess scientific, technical and socio-economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation. <http://www.ipcc.ch/>

Leadership for Energy and Environmental Design (LEED) – “The [LEED] Green Building Rating System™ is the nationally accepted benchmark for the design, construction, and operation of high performance green buildings.”

<http://www.usgbc.org/LEED/>

Low impact development (LID) – LID is development that results in low impacts on natural resources. This is done by using planning and designs that preserve green space and manage stormwater to minimize increases in flow and pollutants. LID techniques include conservation of forests and sensitive waters, water reuse, and stormwater controls that detain and retain rainfall throughout the development.

http://www.epa.gov/owow/nps/lid/stormwater_hq/pdf/qanda.pdf

Mitigation (of greenhouse gases) – “An anthropogenic intervention to reduce the anthropogenic forcing of the climate system, it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks.” <http://www.ipcc->

wg2.org/index.html (click on “glossary” of the WGII contribution to the Fourth IPCC Assessment Report)

National Dredging Team – The interagency U.S. National Dredging Team was established in 1995 to implement the recommendations in a 1994 report to the Secretary of Transportation on the dredging process, to promote national and regional consistency on dredging issues, and to provide a mechanism for issue resolution and information exchange among federal, state, and local agencies and stakeholders.
<http://www.epa.gov/owow/oceans/ndt/>

National Estuary Program (NEP) – EPA’s NEP was established by Congress in 1987 to improve the quality of estuaries of national importance. The NEP is a voluntary program that brings community members together to improve their estuary using a forum to establish working relationships and develop solutions.
<http://www.epa.gov/owow/estuaries/>

National Pollutant Discharge Elimination System (NPDES) – As authorized by the Clean Water Act, the NPDES permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States.
<http://cfpub.epa.gov/npdes/>

National Water Program – The National Water Program is a cooperative effort by Federal, State, Tribal, and local governments to implement core laws, including the Safe Drinking Water Act and the Clean Water Act, to protect and improve the quality of the Nation’s waters.

National Water Program Climate Change Workgroup – This EPA workgroup is chaired by the Deputy Assistant Administrator for Water and includes managers from the Office of Water, the Water Divisions within regional EPA offices, the Office of Air and Radiation, and the Office of Research and Development. The workgroup will oversee water program work related to climate change.

Nonpoint source (NPS) pollution – NPS pollution, unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even underground sources of drinking water. <http://www.epa.gov/owow/nps/qa.html>

Radiative forcing – “Radiative forcing is the change in the net, downward minus upward, irradiance (expressed in $W\ m^{-2}$) at the tropopause due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide or the output of the Sun.” http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_Annexes.pdf

Renewable energy – To be considered renewable energy, a resource must rely on naturally existing energy flows such as sunshine, wind and water flowing. The energy source, or “fuel”, must be replaced by natural processes at a rate that is equal to, or faster than, the rate at which the energy source is consumed.

<http://www.epa.gov/greenpower/whatis/renewableenergy.htm>

Separate Sewer Overflow (SSO) – Occasional unintentional discharges of raw sewage from municipal sanitary sewers occur in almost every system, which are referred to as SSOs. SSOs have a variety of causes, including but not limited to severe weather, improper system operation and maintenance, and vandalism.

<http://www.epa.gov/npdes/sso>

Smart growth – Smart growth covers a range of development and conservation strategies that help protect our natural environment and make our communities more attractive, economically stronger, and more socially diverse. <http://www.epa.gov/dced/>

State Revolving Fund (SRF) – There are two types of SRFs—the Clean Water SRF (CWSRF) and the Drinking Water SRF (DWSRF). CWSRF programs fund water quality protection projects for wastewater treatment, nonpoint source pollution control, and watershed and estuary management. CWSRF monies are loaned to communities and loan repayments are recycled back into the program to fund additional water quality protection projects. <http://www.epa.gov/owm/cwfinance/cwsrf/>

The DWSRF provides capitalization grants to states to develop drinking water revolving loan funds to help finance system infrastructure improvements, assure source water protection, enhance operation and management of drinking water systems, and otherwise promote local water system compliance and protection of public health.

<http://www.epa.gov/trs/> and <http://www.epa.gov/safewater/dwsrf/index.html>

Sustainable Infrastructure Initiative – The Sustainable Infrastructure Initiative for Water and Wastewater will guide EPA’s efforts in changing how the nation views, values, manages, and invests in its water infrastructure.

<http://www.epa.gov/waterinfrastructure/>

Total maximum daily load (TMDL) – A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that amount to the pollutant’s sources.

<http://www.epa.gov/owow/tmdl/intro.html#definition>

Underground Injection Control Program – EPA’s UIC Program works with State and local governments to oversee underground injection of fluids in order to prevent contamination of drinking water resources.

<http://www.epa.gov/safewater/uic/index.html>

Water infrastructure – Water infrastructure refers to the network of infrastructure that provides the public with access to water and sanitation and includes drinking water

treatment plants, sewer lines, drinking water distribution lines, and storage facilities.
<http://www.epa.gov/waterinfrastructure/>

Water quality standards (WQS) – WQS are the foundation of the water quality–based pollution control program mandated by the Clean Water Act. WQS define the goals for a waterbody by designating its uses, setting criteria to protect those uses, and establishing antidegradation policies. <http://www.epa.gov/waterscience/standards/>

Water reuse – Water reuse is the use of process wastewater or treatment facility effluent in a different manufacturing process. <http://www.epa.gov/trs/>

WaterSense – WaterSense is a voluntary partnership program that seeks to protect the future of the nation’s water supply by promoting water efficiency and enhancing the market for water-efficient products, programs, and practices. The WaterSense label will indicate that products and programs meet water efficiency and performance criteria.
<http://www.epa.gov/watersense/>

Watershed approach – The watershed approach is a coordinating framework for environmental management that focuses public and private sector efforts to address the highest priority problems within hydrologically defined geographic areas, taking into consideration both ground and surface water flow.
<http://www.epa.gov/owow/watershed/framework/ch2.html>

Wetland Program Development Grant (WPDG) – The Wetland Program Development Grants provide eligible applicants an opportunity to conduct projects that promote the coordination and acceleration of research, investigations, experiments, training, demonstrations, surveys, and studies relating to the causes, effects, extent, prevention, reduction, and elimination of water pollution.
<http://www.epa.gov/owow/wetlands/grantguidelines/>

7Q10 – 7Q10 refers to the 7-day average low flow occurring once in 10 years.
<http://www.epa.gov/trs/>

APPENDIX 7: Water Program and Climate Change Acronyms

Acronyms used in this **Strategy** related to water programs and climate change are defined below.

AAM	Advanced asset management
AFO	Animal feeding operation
ASR	Aquifer storage and recovery
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BMP	Best management practice
BPJ	Best professional judgment
CAA	Clean Air Act
CAFO	Concentrated animal feeding operation
CAT	Climate Assessment Tool (BASINS)
CCL	Contaminant Candidate List
CCSP	Climate Change Science Program
CHP	Combined heat and power
CSO	Combined sewer overflow
CWA	Clean Water Act
CWNS	Clean Watersheds Needs Survey
CWSRF	Clean Water State Revolving Fund
CZARA	Coastal Zone Act Reauthorization Amendments of 1990
DHS	Department of Homeland Security
DO	Dissolved oxygen
DWNS	Drinking Water Needs Survey
ELGs	Effluent limitations guidelines
EMS	Environmental management system
FEMA	Federal Emergency Management Agency
GS	Geologic sequestration
ICS	Incident Command System
IPCC	Intergovernmental Panel on Climate Change
LEED-NC	Leadership for Energy and Environmental Design for New Construction
LEED-ND	Leadership for Energy and Environmental Design for Neighborhood Development
MPRSA	Marine Protection, Research, and Sanctuaries Act
MS4	Municipal separate storm sewer system
MYP	Multi-year plan
NASA	National Aeronautics and Space Administration
NEP	National Estuary Program
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint source (pollution)
NWI	National Wetlands Inventory
OAR	Office of Air and Radiation (EPA)

OGWDW	Office of Groundwater and Drinking Water (EPA's Office of Water)
O&M	Operations and maintenance
ORD	Office of Research and Development (EPA)
OST	Office of Science and Technology (EPA's Office of Water)
OWM	Office of Wastewater Management (EPA's Office of Water)
OWOW	Office of Wetlands, Oceans and Watersheds (EPA's Office of Water)
POTWs	Publicly owned treatment works
SCADA	Supervisory Control and Data Acquisition
SDWA	Safe Drinking Water Act
SONS	Spill of National Significance
SRF	State Revolving Fund
SSO	Separate sewer overflow
TMDL	Total maximum daily load
UIC	Underground injection control
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USDOE	U.S. Department of Energy
USGBC	U.S. Green Building Council
USGS	U.S. Geological Survey
WEPP	Water Erosion Prediction Project (USDA model)
WPDG	Wetlands Program Development Grants
WQBELs	Water quality-based effluent limitations
WQS	Water quality standards

APPENDIX 8: References and Further Reading

References for works cited in this **Strategy** are provided below along with suggested further reading.

References

- Asrar, G., J.A. Kaye, and P. Morel. 2001. "NASA Research Strategy for Earth System Science: Climate Component." *Bulletin of the American Meteorological Society* 82, pp. 1309-1329. <http://www-nacip.ucsd.edu/BAMS8270701AsrarKayeMorel.pdf>
- Barker, T., I. Bashmakov, A. Alharthi, M. Amann, L. Cifuentes, J. Drexhage, M. Duan, O. Edenhofer, B. Flannery, M. Grubb, M. Hoogwijk, F. I. Ibitoye, C. J. Jepma, W. A. Pizer, K. Yamaji. 2007. Mitigation from a Cross-sectoral Perspective. In: IPCC. 2007. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [Metz, B., O. Davidson, P. Bosch, R. Dave, L. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. <http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter11.pdf>
- Bindoff, N.L., J. Willebrand, V. Artale, A. Cazenave, J.M. Gregory, S. Gulev, K. Hanawa, C. Le Quéré, S. Levitus, Y. Nojiri, C.K. Shum, L.D. Talley, and A.S. Unnikrishnan. 2007. Observations: Oceanic Climate Change and Sea Level. In: IPCC. 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. <http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter5.pdf>
- Burkett, V., J.O. Codignotto, D.L. Forbes, N. Mimura, R.J. Beamish, and V. Ittekkot. 2001. Coastal Zones and Marine Ecosystems. In: IPCC. 2001. *Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://www.grida.no/climate/ipcc_tar/wg2/index.htm
- California Department of Water Resources. 2005. Department of Water Resources Bulletin 160-05. *California Water Plan Update 2005: A Framework for Action*. Division of Planning and Local Assistance, California Department of Water Resources, Sacramento, California. <http://www.waterplan.water.ca.gov/previous/cwpu2005/index.cfm>

- Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton. 2007. Regional Climate Projections. In: IPCC. 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. <http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter11.pdf>
- Cohen, S., K. Miller, K. Duncan, E. Gregorich, P. Groffman, P. Kovacs, V. Magaña, D. McKnight, E. Mills, and D. Schimel. 2001. North America. In: IPCC. 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, K.S. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://www.grida.no/climate/ipcc_tar/wg2/548.htm
- Consortium for Energy Efficiency (CEE). 2007. "Initiative Description: CEE National Municipal Water and Wastewater Facility Initiative." <http://www.cee1.org/ind/mot-sys/ww/ww-init-des.pdf>
- Denman, K.L., G. Brasseur, A. Chidthaisong, P. Ciais, P. M. Cox, R. E. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S. Ramachandran, P. Leite da Silva Dias, S. C. Wofsy, and X. Zhang. 2007. Couplings Between Changes in the Climate System and Biogeochemistry. In: IPCC. 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. <http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter7.pdf>
- Dooley, J.J., R.T. Dahowski, C.L. Davidson, M.A. Wise, N. Gupta, S.H. Kim, and E.L. Malone. 2006. *Carbon Dioxide Capture and Geologic Storage: A Core Element of a Global Energy Technology Strategy to Address Climate Change*. A Technology Report from the Second Phase of the Global Energy Technology Strategy Program. PNNL-15296. Battelle, Joint Global Change Research Institute, Pacific Northwest National Laboratory, College Park, MD. http://www.pnl.gov/gtsp/docs/ccs_report.pdf
- Electric Power Research Institute (EPRI). 2002. *Water and Sustainability (Volume 3): U.S. Water Consumption for Power Production--The Next Half Century*. Report Number 1006786. Electric Power Research Institute, Palo Alto, California. <http://www.epri.com> (This report is downloadable from the EPRI website.)

Energy Information Administration (EIA). 2004. Table 1.1. Net Generation by Energy Source: Total (All Sectors), 1990 through January 2004. Energy Information Administration, Washington, DC.

http://www.eia.doe.gov/cneaf/electricity/epm/table1_1.html

EPA. 2007a. Climate Change Website. Climate Change—Science.

<http://www.epa.gov/climatechange/science/index.html>, accessed on February 8, 2008.

EPA. 2007b. Climate Change Website. Climate Change—Science: Temperature

Changes. <http://www.epa.gov/climatechange/science/recenttc.html>, accessed on February 8, 2008.

EPA. 2007c. Climate Change Website. Climate Change—Science: Future Temperature

Changes. <http://www.epa.gov/climatechange/science/futuretc.html>, accessed on February 8, 2008.

EPA. 2007d. Climate Change Website. Climate Change—Science: Precipitation and

Storm Changes. <http://www.epa.gov/climatechange/science/recentpsc.html>, accessed on February 8, 2008.

EPA. 2007e. Climate Change Website. Climate Change—Science: Future Precipitation

and Storm Changes. <http://www.epa.gov/climatechange/science/futurepsc.html>, accessed on February 8, 2008.

EPA. 2007f. Climate Change Website. Climate Change—Science: Sea Level Changes.

<http://www.epa.gov/climatechange/science/recentslc.html>, accessed on February 8, 2008.

EPA. 2007g. Climate Change Website. Climate Change—Science: Future Sea Level

Changes. <http://www.epa.gov/climatechange/science/futureslc.html>, accessed on February 8, 2008.

EPA. 2007h. Climate Change Website. Climate Change—Health and Environmental

Effects: Water Quality. <http://www.epa.gov/climatechange/effects/water/quality.html>, accessed on February 8, 2008.

EPA. 2007i. Climate Change Website. Climate Change—Health and Environmental

Effects: Water Availability. <http://www.epa.gov/climatechange/effects/water/availability.html>, accessed on February 8, 2008.

EPA. 2007j. Climate Change Website. Climate Change—Health and Environmental

Effects: Water Resources in North America.

<http://www.epa.gov/climatechange/effects/usregions.html>, accessed on February 8, 2008.

EPA. 2007k. Climate Change Website. Climate Change–Health and Environmental Effects: Coral Reefs.

http://www.epa.gov/climatechange/effects/eco_coral.html, accessed on February 8, 2008.

EPA. 2007l. Climate Change Website. Climate Change–Health and Environmental Effects: Coastal Zones and Sea Level Rise.

<http://www.epa.gov/climatechange/effects/coastal/index.html>, accessed on February 8, 2008.

EPA. 2007m. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005*. EPA 430-R-07-002. U.S. Environmental Protection Agency, Washington, DC.

<http://www.epa.gov/climatechange/emissions/usinventoryreport.html>.

EPA. 2007n. *Opportunities for and Benefits of Combined Heat and Power at Wastewater Treatment Facilities*. U.S. Environmental Protection Agency, Combined Heat and Power Partnership, Washington, DC.

http://www.epa.gov/chp/documents/wwtf_opportunities.pdf

EPA. 2007o. WaterSense Program Files. Cynthia Simbanin and Stephanie Tanner, WaterSense Program, U.S. Environmental Protection Agency, Washington, DC.

EPA. 2006. “Wastewater Management Fact Sheet: Energy Conservation.” U.S. Environmental Protection Agency, Office of Water, Washington, DC. EPA 832-F-06-024. http://www.epa.gov/owm/mtb/energycon_fasht_final.pdf

EPA. 2005. *Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture*. EPA 430-R-05-006. U.S. Environmental Protection Agency, Office of Atmospheric Programs, Washington, DC.

<http://www.epa.gov/sequestration/pdf/greenhousegas2005.pdf>

EPA. 2002. *Clean Water and Drinking Water Infrastructure Gap Analysis*. EPA-816-R-02-020. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

<http://www.epa.gov/waterinfrastructure/infrastructuregap.html>

EPA. 1999. *1999 Update of Ambient Water Quality Criteria for Ammonia*. EPA-822-R-99-014. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

<http://www.epa.gov/waterscience/criteria/ammonia/99update.pdf>

EPA. 1986. *Ambient Aquatic Life Water Quality Criteria for Pentachlorophenol*. EPA-440-5-86-009. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

<http://www.epa.gov/waterscience/criteria/1980docs.htm>

Field, C.B., L.D. Mortsch, M. Brklacich, D.L. Forbes, P. Kovacs, J.A. Patz, S.W. Running, and M.J. Scott. 2007. North America. In: IPCC. 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. <http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter14.pdf>

Government Accountability Office (GAO). 2004. *Alaska Native Villages: Villages Affected by Flooding and Erosion Have Difficulty Qualifying for Federal Assistance*. GAO-04-895T. GAO, Washington, DC. <http://www.gao.gov/cgi-bin/getrpt?GAO-04-895T>

Grumbles, B.H. July/August 2007. "Drops to Watts: Leveraging the Water and Energy Connection". *Water Efficiency: The Journal for Water Conservation Professionals*. Forester Communications. http://www.waterefficiency.net/we_0707_guesteditora.html

IPCC. 2007a. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp. <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>

IPCC. 2007b. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [Parry, M., O. Canziani, J. Palutikof, P. van der Linden, C. Hanson (eds.)] Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 976 pp. <http://www.ipcc-wg2.org/>

IPCC. 2007c. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [Metz, B., O. Davidson, P. Bosch, R. Dave, L. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://www.mnp.nl/ipcc/pages_media/AR4-chapters.html

IPCC. 2005. *IPCC Special Report on Carbon Dioxide Capture and Storage*. Prepared by Working Group III of the Intergovernmental Panel on Climate Change. [Metz, B., O. Davidson, H. de Coninck, M. Loos, L. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. <http://www.ipcc.ch/activity/srccs/index.htm>

Kundzewicz, Z.W., L.J. Mata, N.W. Arnell, P. Döll, P. Kabat, B. Jiménez, K.A. Miller, T. Oki, Z. Sen and I.A. Shiklomanov. 2007. *Freshwater Resources and Their*

Management. In: IPCC. 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 173-210.
<http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter3.pdf>

Mimura, N., L. Nurse, R. McLean, J. Agard, L. Briguglio, P. Lefale, R. Payet, G. Sem. 2007. Small Islands. In: IPCC. 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 173-210.
<http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter16.pdf>

Nabuurs, G. J., O. Masera, K. Andrasko, P. Benitez-Ponce, R. Boer, M. Dutschke, E. Elsiddig, J. Ford-Robertson, P. Frumhoff, T. Karjalainen, O. Krankina, W. A. Kurz, M. Matsumoto, W. Oyhantcabal, Ravindranath N.H., M. J. S. Sanchez, X. Zhang. 2007. Forestry. In: IPCC. 2007. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [Metz, B., O. Davidson, P. Bosch, R. Dave, L. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. <http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter9.pdf>

National Aeronautics and Space Administration (NASA). 2006. Goddard Institute for Space Studies (GISS) Surface Temperature Analysis.
<http://www.giss.nasa.gov/research/news/20070208/>

National Oceanic and Atmospheric Administration (NOAA)/National Environmental Satellite, Data, and Information Service (NESDIS)/National Climatic Data Center (NCDC). <http://www.ncdc.noaa.gov/oa/ncdc.html>

NOAA/NESDIS/NCDC. 2007. Climate of 2006—in Historical Perspective: Annual Report. <http://www.ncdc.noaa.gov/oa/climate/research/2006/ann/ann06.html>

National Research Council (NRC). 1999. *Global Environmental Change: Research Pathways for the Next Decade*. Committee on Global Change Research, Board on Sustainable Development, Policy Division, NRC. National Academy Press, Washington, DC.

Proudman Oceanographic Laboratory, Permanent Service for Mean Sea Level (PSMSL). Monthly and Annual Mean Sea Level Station Files.
http://www.pol.ac.uk/psmsl/psmsl_individual_stations.html and
<http://www.pol.ac.uk/psmsl/>

- Pulwarty, R.S., D.A. Wilhite, D.M. Diodato, and D.I. Nelson. May 2007. "Drought in Changing Environments: Creating a Roadmap, Vehicles, and Drivers." *Natural Hazards Observer* XXXI: 5. Natural Hazards Center, Institute of Behavioral Science, University of Colorado, Boulder, Colorado.
<http://www.colorado.edu/hazards/o/archives/2007/may07/may07.pdf>
- Reardon, D. 1994. *Energy Audit Manual for Water/Wastewater Facilities: A Guide for Electric Utilities to Understanding Specific Unit Processes and their Energy/Demand Relationships at Water and Wastewater Plants*. EPRI CR-104300. Electric Power Research Institute (EPRI), St. Louis, MO. <http://www.epri.com>
- Smith, P. D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko. 2007. Agriculture. In: IPCC. 2007. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [Metz, B., O. Davidson, P. Bosch, R. Dave, L. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
<http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter8.pdf>
- Smith, J.B. 2004. *A Synthesis of Potential Climate Change Impacts on the U.S.* Prepared for the Pew Center on Global Climate Change.
<http://www.pewclimate.org/docUploads/Pew-Synthesis.pdf>
- Trenberth, K.E., P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci, B. Soden and P. Zhai. 2007. Observations: Surface and Atmospheric Climate Change. In: IPCC. 2007. *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. <http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter3.pdf>
- U.S. Climate Change Science Program (CCSP). 2007. *Effects of Climate Change on Energy Production and Use in the United States*. Synthesis and Assessment Product (SAP) 4.5. <http://www.climatechange.gov/Library/sap/sap4-5/final-report/sap4-5-final-all.pdf>
- U.S. Geological Survey (USGS). 2004. *Estimated Use of Water in the United States in 2000*. Circular 1268. U.S. Geological Survey, U.S. Department of the Interior, Reston, Virginia. <http://pubs.usgs.gov/circ/2004/circ1268/>
- World Meteorological Organization (WMO). 2006. Summary Statement on Tropical Cyclones and Climate Change.
http://www.gfdl.gov/~tk/manuscripts/IWTC_Summary.pdf (see also http://www.wmo.ch/pages/prog/arep/tmrp/documents/iwtc_statement.pdf)

Further Reading

American Water Works Association Research Foundation (AwwaRF) and the University Corporation for Atmospheric Research. 2006. *Climate Change and Water Resources: A Primer for Municipal Water Providers*. AWWA Research Foundation, AWWA, and IWA Publishing.

http://www.isse.ucar.edu/water_conference/fulltext/ClimateChange_Final.pdf

California Department of Water Resources. 2006. *Progress on Incorporating Climate Change into Management of California's Water Resources*. Technical Memorandum Report. California Department of Water Resources, Sacramento, California. <http://baydeltaoffice.water.ca.gov/climatechange/reports.cfm>

Center for Science in the Earth System (The Climate Impacts Group), Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, and King County, Washington. 2007. *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments*. The Climate Impacts Group, King County, Washington, and ICLEI – Local Governments for Sustainability.

<http://www.cses.washington.edu/cig/fpt/guidebook.shtml>

Chesapeake Bay Foundation. 2007. *Climate Change and the Chesapeake Bay: Challenges, Impacts, and the Multiple Benefits of Agricultural Conservation Work*. http://www.cbf.org/site/PageServer?pagename=exp_sub_state_climatechange

Croley, T. E. II. 1991. "CCC GCM 2xCO₂ Hydrological Impacts on the Great Lakes". Task Group 2, Working Committee 3, International Joint Commission Water-Levels Reference Study (as found in EPA and Environment Canada 2000).

Department of Energy (DOE). 2007. *Carbon Sequestration Atlas of United States and Canada*. U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory.

http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlas/

Easterling III, W.E., B.H. Hurd, and J.B. Smith. 2004. *Coping with Global Climate Change: The Role of Adaptation in the United States*. Prepared for the Pew Center on Global Climate Change.

<http://www.pewclimate.org/docUploads/Adaptation.pdf>

Emanuel, K.A. 2005. "Increasing Destructiveness of Tropical Cyclones over the Past 30 Years". *Nature* 436:686-688.

<http://www.nature.com/nature/journal/v436/n7051/abs/nature03906.html>

- EPA and Environment Canada. 2000. *Lake Erie Lakewide Management Plan (LaMP)*. Prepared by the Lake Erie LaMP Workgroup.
<http://www.epa.gov/glnpo/lakeerie/lamp2000/index.html> and
<http://www.epa.gov/glnpo/lakeerie/lamp2000/Section11.pdf>
- EPA. 2007. *Using Class V Experimental Technology Well Classification for Pilot Geologic Sequestration Projects – UIC Program Guidance* (UICPG # 83).
http://www.epa.gov/safewater/uic/pdfs/guide_uic_carbonsequestration_final-03-07.pdf
- EPA. 2006. *A Screening Assessment of the Potential Impacts of Climate Change on Combined Sewer Overflow (CSO) Mitigation in the Great Lakes and New England Regions* (External Review Draft). EPA/600/R-07/033A. U.S. Environmental Protection Agency, Washington, DC.
<http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=166365>
- EPA. 2006. *A Screening Assessment of the Potential Impacts of Climate Change on the Costs of Implementing Water Quality-Based Effluent Limits at Publicly-Owned Treatment Works in the Great Lakes Region* (External Review Draft Report). EPA/600/R-07/034A. U.S. Environmental Protection Agency, Washington, DC.
<http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=166366>
- EPA. 1995. *Ecological Impacts from Climate Change: An Economic Analysis of Freshwater Recreational Fishing*. EPA 220-R-95-004. U.S. Environmental Protection Agency, Office of Policy, Economics and Innovation, Washington, DC.
- EPA. 1989. *The Potential Effects of Global Climate Change on the United States: Report to Congress*. EPA 230-05-89-052. U.S. Environmental Protection Agency, Washington, DC.
- Furlow J., J.D. Scheraga, R. Freed, and K. Rock. 2002. "The Vulnerability of Public Water Systems to Sea Level Rise." In: *Proceedings of the Coastal Water Resource Conference*. J.R. Lesnik (ed.). American Water Resources Association, Middleburg, Virginia, pp. 31-36. [http://scheraga.com/Furlow-Scheraga-Freed-Rock-\(FINAL\)%20published%20version.doc](http://scheraga.com/Furlow-Scheraga-Freed-Rock-(FINAL)%20published%20version.doc) (accessed on 8/13/07)
- Gleick, P.H. 2000. *Water: the Potential Consequences of Climate Variability and Change for the Water Resources of the United States*. The Report of the Water Sector Assessment Team of the National Assessment of the Potential Consequences of Climate Variability and Change for the U.S. Global Change Research Program. This report was prepared by the Pacific Institute for Studies in Development, Environment, and Security and supported by the U.S. Department of the Interior through the U.S. Geological Survey (grant# 98HQAG2118).
<http://www.gcrio.org/NationalAssessment/water/water.pdf>

International Joint Commission. 2003. *Climate Change and Water Quality in the Great Lakes Basin*. Report of the Great Lakes Water Quality Board to the International Joint Commission. ISBN 1-894280-42-3.

<http://www.ijc.org/php/publications/html/climate/index.html>

Johnson, T., C. Pyke, J. Kittle, J. Imhoff, and M. Gray. 2006. "The Climate Assessment Tool for the BASINS Modeling System: New Capabilities for Evaluating the Vulnerability of Hydrologic End Points to Climate Variability and Change". Summary of Presentation. Third Biennial Meeting of the International Environmental Modelling and Software Society, Burlington, VT.

http://www.iemss.org/summit/papers/s5/346_Pyke_0.pdf

Karl, T.R. and R.W. Knight; NOAA/NESDIS/National Climatic Data Center. 1998. "Secular Trends of Precipitation Amount, Frequency, and Intensity in the United States." *Bulletin of the American Meteorological Society* 79(2): 231-241.

<http://ams.allenpress.com/archive/1520-0477/79/2/pdf/i1520-0477-79-2-231.pdf>

Kleypas, J.A., R.A. Feely, V.J. Fabry, C. Langdon, C.L. Sabine, L.L. Robbins. 2006. *Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research*. Report of a workshop sponsored by the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS). Contribution no. 2897 from the NOAA/Pacific Marine Environmental Laboratory.

<http://www.isse.ucar.edu/florida/> and <http://www.fedworld.gov/onow>

Milly, Christopher (USGS). 6 June 2007. Statement of Christopher Milly, Research Hydrologist, U.S. Geological Survey, U.S. Department of the Interior, Before the Committee on Energy and Natural Resources, Subcommittee on Water and Power, United States Senate. Hearing on Impacts of Climate Change on Water Supply and Availability in the United States and Related Issues from a Water Use Perspective. http://energy.senate.gov/public/_files/MillyTestimony.doc (See also Milly et al. 2005 article in the Further Reading section below.)

Milly, P.C.D., K.A. Dunne, A.V. Vecchia. 2005. "Global Pattern of Trends in Streamflow and Water Availability in a Changing Climate." *Nature* 438: 347-350.

<http://www.nature.com/nature/journal/v438/n7066/full/nature04312.html>

Mortsch, L. and F.H. Quinn. 1996. "Climate Change Scenarios for Great Lakes Basin Ecosystem Studies." *Limnology and Oceanography* 41(5):903-911 (as found in U.S. EPA and Environment Canada 2000).

National Oceanic and Atmospheric Administration (NOAA). 2001. *Sea Level Variations of the United States 1854-1999*. NOAA Technical Report NOS CO-OPS 36. NOAA, Silver Spring, MD.

<http://tidesandcurrents.noaa.gov/publications/techrpt36doc.pdf>

- National Research Council. 2001. *Climate Change Science: An Analysis of Some Key Questions*. National Academy Press, Washington, DC.
<http://books.nap.edu/html/climatechange/>
- Rosenzweig, C., D.C. Major, K. DeMong, C. Stanton, R. Horton, and M. Stults. 2007. "Managing Climate Change Risks in New York City's Water System: Assessment and Adaptation Planning." *Mitigation and Adaptation Strategies for Global Change* 12(8).
- The Royal Society. 2005. *Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide*. Policy Document 12/05. ISBN 0854036172. The Royal Society, London.
<http://www.royalsoc.ac.uk/displaypagedoc.asp?id=13539>
- San Francisco Public Utilities Commission. Water Utility Climate Change Summit 2007. *Summary of Proceedings*. 31 January to 2 February 2007.
- Santer, B.D., T.M.L. Wigley, P.J. Gleckler, C. Bonfils, M.F. Wehner, K. AchutaRao, T.P. Barnett, J.S. Boyle, W. Brüggemann, M. Fiorino, N. Gillett, J.E. Hansen, P.D. Jones, S.A. Klein, G.A. Meehl, S.C.B. Raper, R.W. Reynolds, K.E. Taylor, and W.M. Washington. 12 September 2006. "Forced and Unforced Ocean Temperature Changes in Atlantic and Pacific Tropical Cyclogenesis Regions". *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*. 10.1073/pnas.0602861103.
<http://www.pnas.org/cgi/content/abstract/0602861103v1>
- Snover, A.K., P.W. Mote, L. Whitely Binder, A.F. Hamlet, and N.J. Mantua. 2005. *Uncertain Future: Climate Change and Its Effects on Puget Sound*. A report for the Puget Sound Action Team by the Climate Impacts Group (Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Seattle).
http://www.psat.wa.gov/Publications/climate_change2005/climate_home.htm
- Titus, J.G. and V. K. Narayanan. 1995. *The Probability of Sea Level Rise*. EPA 230-R95-008. U.S. Environmental Protection Agency. Washington, DC.
<http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsProbability.html>
- Twilley, R.R., E.J. Barron, H.L. Gholz, M.A. Harwell, R.L. Miller, D.J. Reed, J.B. Rose, E.H. Siemann, R.G. Wetzel, R.J. Zimmerman. 2001. *Confronting Climate Change in the Gulf Coast Region: Prospects for Sustaining Our Ecological Heritage*. A Report of the Union of Concerned Scientists and the Ecological Society of America. <http://www.ucsusa.org/gulf/gcchallengereport.html>
- U.S. Global Change Research Program. 2000. *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change: Overview*. A Report of the National Assessment Synthesis Team of the Potential

Consequences of Climate Variability.

<http://www.gcrio.org/NationalAssessment/overpdf/overview.html>

World Meteorological Organization. *The World Meteorological Organization's Contribution to Improved Decision Making for Climate Adaptation*. Position Paper Prepared for United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) 13. Bali, Indonesia, 3-14 December 2007.

<http://www.wmo.ch/pages/cop13/documents/COP13-1.pdf>