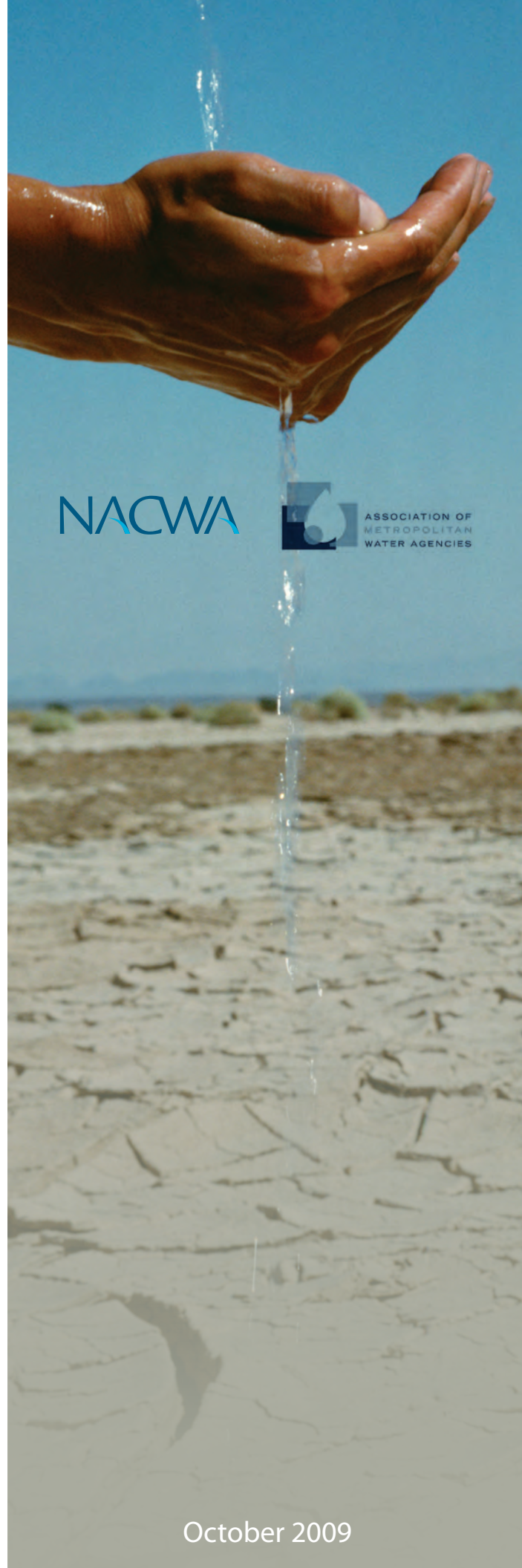


CONFRONTING CLIMATE CHANGE:

An Early Analysis of Water and Wastewater Adaptation Costs



NACWA



ASSOCIATION OF METROPOLITAN WATER AGENCIES

October 2009

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Executive Summary and Introduction





Executive Summary and Introduction

Climate change is here, and in the years ahead, it is expected to alter the water cycle, affecting where, when, and how much water is available.

The effects of climate change are already impacting our water and wastewater utilities—those entities entrusted with supplying our communities, our industries, and our natural environment with essential water management services.

Water is the most important natural resource necessary for stable economic growth, as well as for human and environmental health. Our nation's water and wastewater infrastructure enables our prosperity by delivering clean water to our homes and industries and by transporting wastewater for treatment. Our increasing understanding of climate change impacts on water and wastewater suggests that significant adaptation measures will be required for our infrastructure to continue protecting public health and the environment.

"Climate change must be considered in all short-term and long-term infrastructure and policy planning initiatives"

New York City Department of Environmental Protection
Assessment and Action Plan
(May 2008)

Climate Change Adaptation Needs and Costs through 2050: Why this Assessment?

This assessment has three objectives:

- To characterize the impacts of climate change on drinking water and wastewater services in the United States through 2050, based on greenhouse gas (GHG) scenarios and regional projections of climate change effects;
- To help policy makers and the water and wastewater sector begin to understand the challenges of ensuring that reliable water and wastewater services continue to be available in the face of a changing climate; and
- To provide early cost estimates so that policies can be developed that address these challenges and planning by utilities can begin.

This report is an early cost assessment of adaptations to address some of the likely impacts of climate change on our nation's drinking water and wastewater utilities through 2050. This time period is selected because it represents the timeframe within which we best understand climate change effects and their impacts on drinking water and wastewater utilities, and it is consistent with the typical planning horizon of many utilities. **The assessment indicates that the cost to utilities could range from \$448 billion to \$944 billion.**



Assessment Contents

The assessment provides a range of costs based on GHG emission scenarios, regional projections of climate change effects, sea level rise projections, and mixes of potential adaptations. (A detailed explanation of the methods for determining the range of costs is included in Appendix Sections C-1 through C-7). It relies on reports from utilities and other agencies, engineering experts, and available cost databases for many of the anticipated adaptation options.

We consider innovative and emerging technologies such as green infrastructure as potential options for managing localized temperature and precipitation impacts and building the resiliency of communities. However, only limited information exists to assess these costs and benefits; therefore, the discussions are qualitative. Databases with this type of information are expected to become more available in the future with the implementation and testing of these emerging technologies.

Not included in the assessment are the larger societal costs associated with disruptions to water and wastewater services such as adverse impacts to the natural environment and public health when extreme weather events cause sewage to overflow in rivers, streams, and coastal areas.

While the assessment is based on the most comprehensive water and wastewater utility databases available (as well as publicly available climate change projections), the inherent uncertainty of climate change projections, combined with incomplete cost databases, means that estimates could change as additional information becomes available.

Metropolitan Water District of Southern California

- Adopted a regional approach for planning and investments to increase resource diversity and environmentally-friendly imported water supply reliability
- Leveraging knowledge sharing and research support by collaborating with other utilities, NGOs, and legislators
- Quantifying current research to develop water supply and quality solutions that are economically and technologically feasible
- Implementing programs and policies for Integrated Resource Plans, GHG mitigation, energy efficiency, flood preparedness, and conservation, storage, and recycling incentives

NACWA_121_5

Multiple climate models agree that the impacts discussed in this report are likely to occur through 2050. Additional impacts not yet detected or measured may occur, with the potential to increase costs beyond the estimates included here. The same models indicate that, as a result of the longevity of GHG emissions in the Earth's atmosphere, existing emission concentrations will continue to drive climate change effects through 2050. Beyond 2050, climate change effects become more uncertain; however, model projections agree that effects will become more extreme unless GHG emissions are substantially reduced in the interim. Depending on how quickly the world is able to reduce emissions, climate change adaptation strategies that could be required after 2050 may involve more drastic measures to ensure clean and safe water supplies.

While the report focuses on the impacts and costs of climate change adaptation to water and wastewater utilities, it acknowledges that our water and wastewater sectors influence, are influenced by, and sometimes overlap with ecosystems, health, agricultural water use, and stormwater management, all of which are subject to climate change impacts (Exhibit ES-1). However, while they are related (for example, wastewater utilities provide ecosystem flows through treated wastewater discharge and nonpotable water for agriculture), costs for these sectors are not broken out in this assessment.



EXHIBIT ES-1
Climate Change Effects and the Resulting Impacts on Water and Wastewater



Summary of Climate Change Impacts by Region

The U.S. Global Change Research Program (USGCRP)(which includes 13 federal agencies) recognizes six regions in the continental United States that characterize geographic distinctions in climate based on projected temperature and precipitation changes. This report uses those six regions but modifies them slightly to correspond with state boundaries, consistent with water and wastewater utility databases. The report also includes Alaska, Hawaii, and Puerto Rico.

The climate change effects illustrated in Exhibit ES-1 result in general climate change impacts to water and wastewater services. Utilities in all six regions and Alaska, Hawaii, and Puerto Rico are expected to experience several common impacts associated with climate change effects.

Impacts common to all regions:

- Sea level rise and storm surge impacts (except in the Midwest)
- Increased extreme precipitation events
- Anticipated increased regulation for wet weather management
- Increased disrupted service from flooding
- Declining water quality
- Increased demand for emergency response and recovery (ER&R)
- Increased treatment requirements
- Higher energy demand



Additionally, most regions are expected to have geographically specific impacts:

Northeast

Drinking Water Utilities - Increased storage needs resulting from earlier snowmelt and increased extreme precipitation events

Wastewater Utilities - Increased demand for maintaining quality and quantity of discharges to rivers and streams for environmental purposes

Southeast

Drinking Water Utilities - Greater uncertainty in water supply

Wastewater Utilities- Increased demand for maintaining quality and quantity of discharges to rivers and streams for environmental purposes

Midwest

Drinking Water Utilities - Greater uncertainty in water supply

Wastewater Utilities – Impacts common to all regions

Central Plains

Drinking Water Utilities - Greater uncertainty in water supply

Wastewater Utilities - Impacts common to all regions

Northwest

Drinking Water Utilities - Greater uncertainty in water supply

Wastewater Utilities - Increased demand for maintaining quality and quantity of discharges to rivers and streams for environmental purposes.

Southwest

Drinking Water Utilities - Significant reductions in and increased uncertainty in water supply; increased need to optimize water use, conservation, reuse, operations, and storage

Wastewater Utilities - Anticipated increased regulation for many treatment components; increased issues with results of increased concentration of sewage, creating odor and treatment process problems; increased demand for maintaining quality and quantity of discharges to rivers and streams for environmental purposes

Alaska

Drinking Water Utilities - Increased storage needs resulting from earlier snowmelt and increased extreme precipitation events

Wastewater Utilities - Impacts common to all regions



Hawaii

Drinking Water Utilities and Wastewater Utilities - Impacts common to all regions

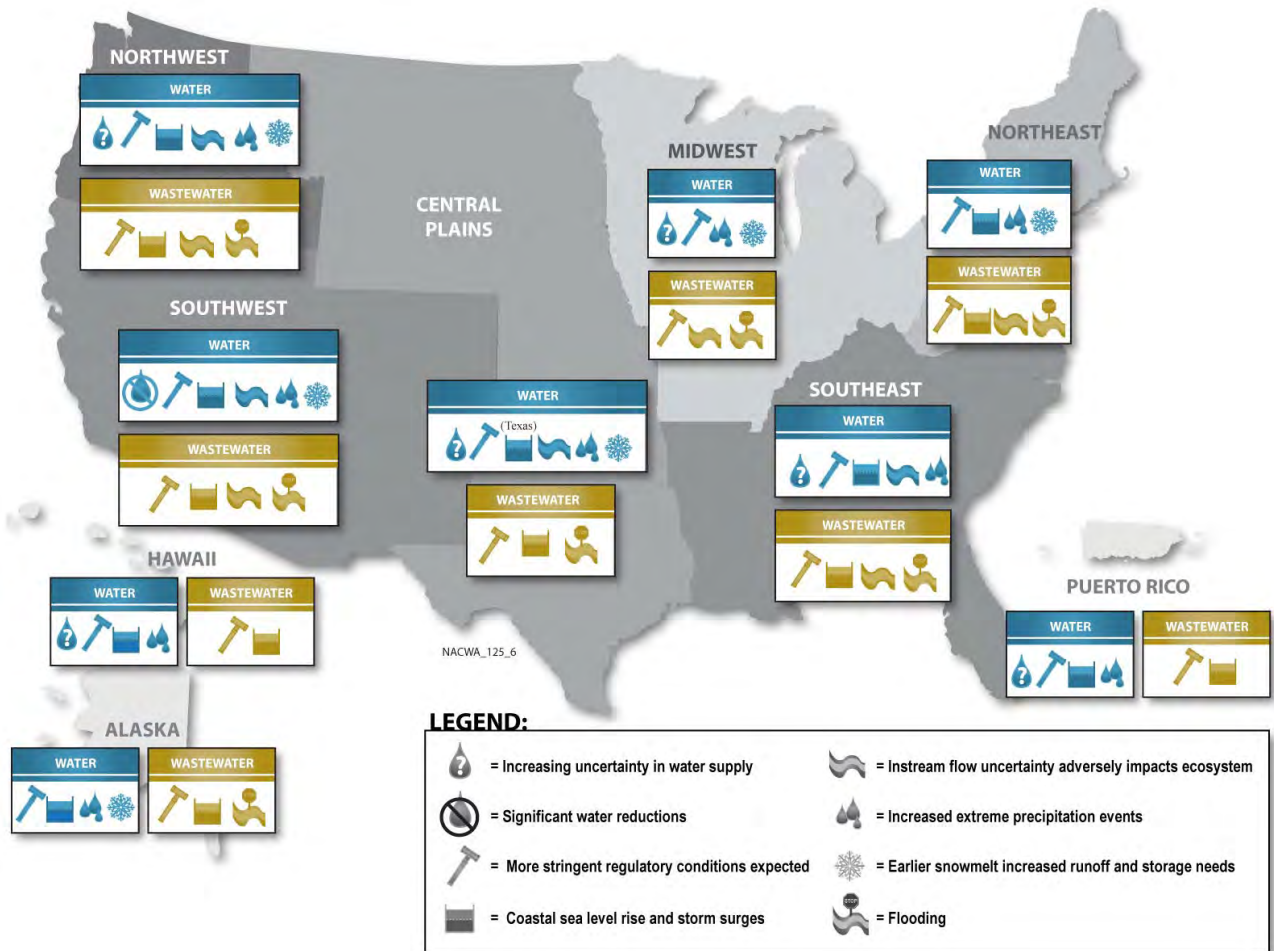
Puerto Rico

Drinking Water Utilities - Significant reductions in and increased uncertainty in water supply

Wastewater Utilities - Impacts common to all regions

Impacts for all regions are shown in Exhibit ES-2.

EXHIBIT ES-2
Climate Change Impacts to Drinking Water and Wastewater Services by Region



Summary of Climate Change Adaptation Strategies – Drinking Water

Drinking water utilities will likely use some of the following actions and adaptation strategies to address climate-related impacts that cause water supply shortfall and reduced water quality:

- Increasing focus on conservation to extend existing source water supplies
- Using new water sources including seawater desalination, lower quality groundwater, and wastewater reuse



- Increasing storage and conveyance to manage new water sources and accommodate changes in the intensity and timing of precipitation and runoff
- Increasing treatment in locations where increased precipitation causes increased turbidity, increased temperature results in reduced water quality, and lower quality source water requires greater levels of treatment. Additionally, wastewater reuse and recycling for water supply augmentation will require advanced treatment and in most locations, additional distribution system infrastructure.
- Adapting to address plant or conveyance flooding damage (as a result of sea level rise or storm surge) that may affect some drinking water facilities in coastal locations. Adapting to address inland flooding associated with extreme precipitation events including levee and related structural protection. Flooding tends to be more problematic for wastewater treatment plants because water treatment plants tend to be located at higher elevations; however, water intake facilities, treatment plants, and distribution systems have recently experienced flood damage during extreme precipitation events.
- Creating water management portfolios that combine and integrate these various water supply and treatment components to add flexibility and support sustainable water supply.

Summary of Climate Change Adaptation Strategies – Wastewater

Wastewater utilities will likely use some of the following actions and adaptation strategies to address climate-related challenges:

- Greater use of both green and gray infrastructure to manage wet weather flow, as well as more rapid treatment technologies. Though green infrastructure technologies can help manage larger volumes of stormwater to some degree, these approaches alone are not sufficient. As witnessed by the recent Georgia flooding, wastewater plants can quickly become overwhelmed and discharge partially-treated or raw sewage during extreme storm events unless there is sufficient capacity to handle the extra volume.
- Implementing increased effluent treatment (including cooling) to address probable increasing surface water temperatures of receiving water bodies, whose long-term ecological health will be compromised under climate change.
- Encouraging greater use of recycling and reuse technologies so wastewater can be used to compensate for the decrease in water availability and supplies.
- Raising pump stations, building levees, and, in some circumstances, relocating treatment plants to avoid rising sea levels from rendering the plants inoperable.

Uncertainty and Models

While we understand the general impacts of climate change on the United States, and on our water and wastewater services (Exhibit ES-1), we lack precise information on the magnitude, geographic distribution, and timing of these impacts. Multiple utilities have called for increased applied research to more precisely understand the climate change impacts on their service areas.



For this assessment, we rely on the models and projections developed for the Fourth Assessment Report released by the Intergovernmental Panel on Climate Change (IPCC) in 2007. A Fifth Assessment Report from the IPCC is due in 2013. This Fifth Assessment Report has the potential to lead to improved understanding of climate change impacts. Still, the uncertainty associated with the specific magnitude, geographic distribution, and timing of climate change likely will remain an issue.

Despite some uncertainty, extensive research, data collection, and modeling by a host of international and U.S. government agencies, academic, and other entities provides us with a good understanding of the overall and increasing effects of climate change. This understanding provides us with the ability to project how those effects will likely impact our water and wastewater services. This understanding also allows us to begin to plan and implement adaptation strategies to prepare ourselves for these impacts.

Using this information, this assessment captures some of the climate change impacts on water and wastewater services across the country, as well as the region-by-region impacts that utilities that provide these services will likely face as they strive to continue to provide sustainable water quantity and quality for our people and economy.

Water managers should take the initiative to clearly communicate their needs for applied science to the climate research community, and must seek opportunities to guide hydroclimate research in directions that will support real-world problem solving.

Western Governor's Association, 2008

What Does Congress Need To Know?

- Climate change is occurring and is impacting our critical drinking water and wastewater services at an ever-increasing rate.
- Now is the time to establish policies, invest in research, and provide support so that water and wastewater utilities can begin to plan for the necessary adaptation strategies needed to confront the inevitable impacts of climate change. Timely action is critical—water and wastewater infrastructure planning and implementation operates within a 20- to 40-year timeframe.
- The costs for drinking water and wastewater services to adapt to climate change are significant. Our early estimates using existing databases suggest a total cost of **\$448 billion to \$944 billion** for infrastructure and operations and maintenance (O&M) to adapt to climate change impacts through 2050 (Exhibit ES-3). *This does not include costs for ER&R from extreme storm events and drought, nor the costs associated with uncertain future regulatory controls.*
- Failure to provide a timely response to needed planning for climate change adaptation will have serious consequences for the nation. Examples include the high costs of ER&R, and more dire disruption or long-term loss of water and sanitation services to homes, municipalities, and industry—with the resultant short- and long-term impacts to human health, and the economy.



EXHIBIT ES-3

Drinking Water and Wastewater—Early Estimated Range of Net Present Value Capital and O&M Costs to Address Climate Change Needs Through 2050

SUMMARY
Drinking Water = \$325 - \$692 billion
Wastewater = \$123 - \$252 billion

GRAND TOTAL
Drinking Water and Wastewater = \$448 - \$944 billion





Report Organization

This report includes four Chapters:

Chapter 1 defines the challenges of climate change adaptation for our nation’s drinking water and wastewater services through 2050 and the role of utilities to address them.

Chapter 2 includes expected climate change effects and impacts projected through 2050 in six regions of the continental U.S. and Alaska, Hawaii, and Puerto Rico.

Chapter 3 identifies the adaptations that can be employed by drinking water and wastewater utilities for types of impacts, and presents early capital and O&M cost estimates associated with the implementation of those adaptations through 2050. Additionally, Chapter 3 discusses potential costs (for which data are not yet fully available) for ER&R actions, future regulatory controls, and other sources of uncertainty for utility climate change adaptation costs.

Chapter 4 provides summary conclusions for the assessment.

Appendices (A through D) include references consulted for the report content, the detailed assumptions that are the basis of our cost estimates, the methods by which we have developed the cost estimates, and a list of research and information needs identified while conducting the assessment.

Throughout the document are short case studies of utilities that have included climate change adaptation in their planning and their communities, as well as case studies of those that have experienced events projected to occur with climate change and the associated costs—in human health, loss of property, and the critical water and wastewater services necessary for our way of life.



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CHAPTER 1

Climate Change and Role of Water and Wastewater Utilities





Chapter 1: Climate Change and Role of Water and Wastewater Utilities

Climate Change Is Here. How Do We Adapt?

In common terms, we think of ‘climate’ as average weather conditions over an extended period. ‘Climate change’ is the shift in the average weather, or weather trends that are experienced over decades or longer. Climate change is not demonstrated by a single event, but by a series of events, like floods or warm years that change the average precipitation or temperature over time.

The Earth’s climate has long exhibited variability. The extremes of the 100,000-year ice-age cycles and ‘mega-droughts’ are well documented. The climate has been warm and stable through the last 10,000 years. In fact, the last millennium, during which current societies developed, has been one of the most stable climate periods known until recently.

Observations in the 20th century indicate rapid climatic change. A growing body of evidence indicates that the Earth’s atmosphere is warming in a trend consistent with a changing climate. Records show that average surface temperatures have risen about 1.5°F since the early 20th century, with most of this increase occurring since 1978. Changes in oceans, snow and ice cover, and ecosystems are consistent with this warming trend.

Warming over this century is projected to be considerably greater than over the last century. The global average temperature since 1900 has risen by about 1.5°F.

U.S. Global Change Research Program (2009)

Climate Change Seriously Impacts Water and Wastewater Services

Water is the most important natural resource necessary for stable economic growth, as well as for human and environmental health. Throughout our nation’s history, our water infrastructure has enabled our prosperity and development by delivering clean water for our homes and industry. However, our increasing understanding of climate change threats to our nation’s water supply suggests that our infrastructure is in grave danger without focused action.

Climate change affects water more than any other resource. Effects associated with climate change include:

- Increased temperature
- Greater evaporation rates
- Earlier snowmelt
- Reduced total precipitation in some parts of the country (but an increased number of days with very heavy precipitation)



- Significantly increased total precipitation in other regions (also with an increased number of days with very heavy precipitation)
- Sea level rise

The resulting impacts on our water and wastewater systems are significant:

- Extended and extreme drought
- Water scarcity and the need to develop new supplies
- Extreme flooding and sea level rise and the related loss of function at treatment plants
- Costly ER&R actions
- Water quality degradation and increased treatment requirements
- The need to provide environmental flows as natural sources are reduced and appropriated for other uses

More extreme precipitation events that result in flooding, as recently experienced in the Midwest, illustrate the tremendous infrastructure, economic, and social costs of not preparing for climate change.



In response to these challenges, our water and wastewater leaders will need to look for new approaches to assess system vulnerabilities, plan and develop more resilient and robust systems, and understand the costs to ensure that we have sustainable water and wastewater infrastructure and operations in a future strongly influenced by climate change.

Adaptation Costs are Significant

Now is the time to act to minimize costs and protect our water and wastewater services.

In light of these impacts and the critical role of providing the nation with reliable drinking water and sanitation, water and wastewater utilities should consider climate change impacts in their planning for facilities, and operations sooner—rather than waiting for additional impacts and higher costs. While the year 2050 (this cost report’s time horizon) may seem like a long way off, utilities typically engage in a 20-to 40-year planning cycle for infrastructure and some operations.

This assessment report has been commissioned by two organizations that represent some of the largest drinking water and wastewater utilities in the country—the National Association of Clean Water Agencies (NACWA) and the Association of Metropolitan Water Agencies (AMWA). It describes an early cost estimate to adapt to climate change through 2050 so that these utilities can continue to provide safe and secure water supplies and wastewater services.

CHAPTER 2

Climate Change Impacts





Chapter 2: Climate Change Impacts

Efforts to characterize climate change impacts and water and wastewater service costs must recognize that climate change effects, to some degree, differ across geographies. Different databases and information sources confound precise characterization of region differences in impacts, but some distinctions can be made.

The Climate Change Research Program, which is part of the USGCRP that comprises 13 federal agencies, uses six regions to characterize geographic distinctions in climate data, based on precipitation and temperature characteristics across the continental United States. Their 2009 report (USGCRP, 2009), also includes limited projections for Alaska, Hawaii, and Puerto Rico. This assessment addresses the six continental regions, as well as Alaska, Hawaii, and Puerto Rico, consistent with available data.

The USGCRP source map of climate change regions is modified slightly for this report to align with water and wastewater facility data that are only available by state (Exhibit 2-1).

EXHIBIT 2-1
Climate Change Regions



Exhibit 2-2 summarizes anticipated climate change effects in the six continental regions, and Alaska, Hawaii, and Puerto Rico. Exhibit 2-3 graphically illustrates the major impacts across the various regions.



EXHIBIT 2-2
Summary of Climate Change Effects by Region

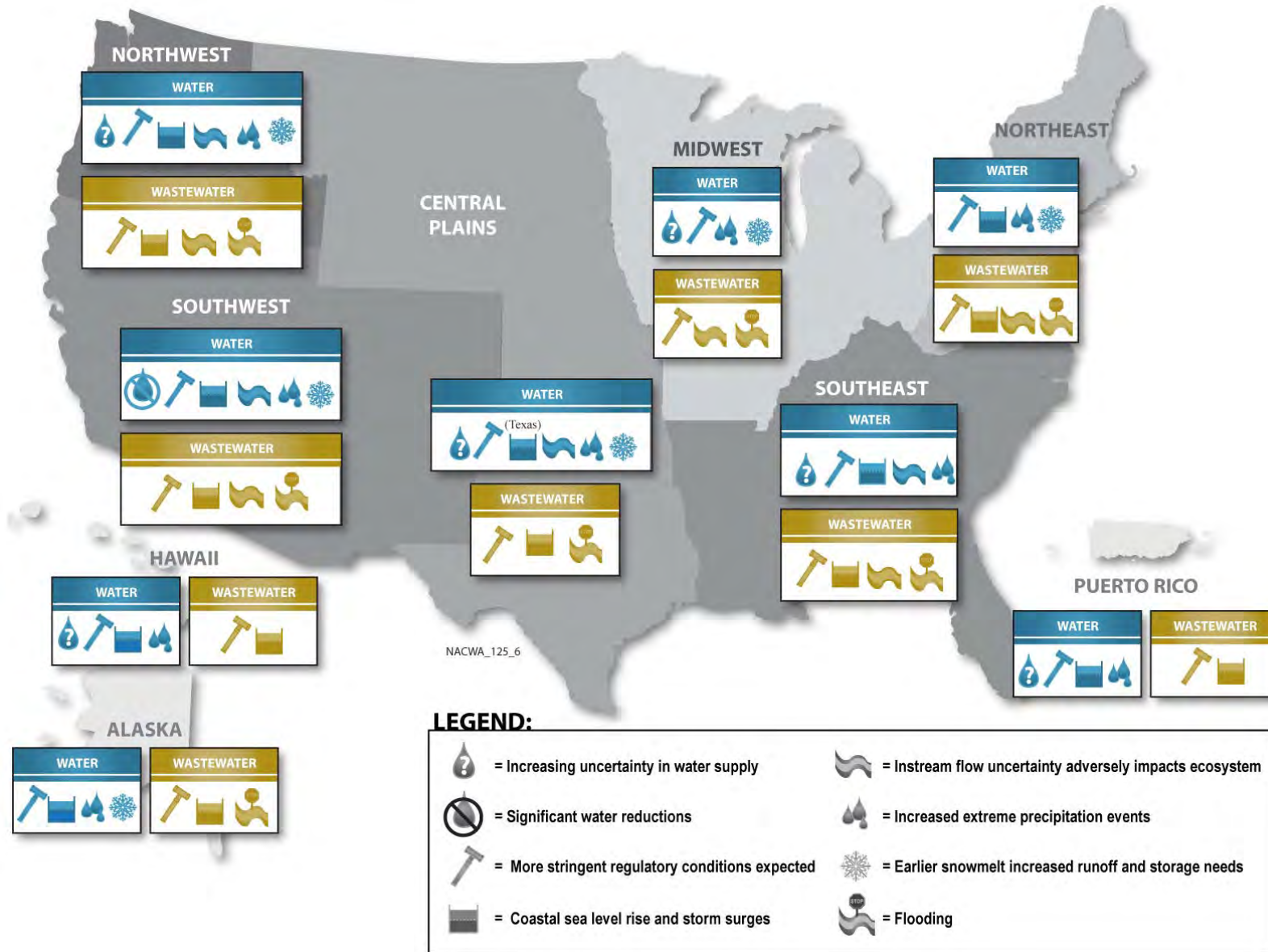
Region	Climate Change Effects				Climate Change Impacts	
	Approximate Temperature Increase (°F)	Approximate Precipitation Change (%)	Sea Level Rise (inches)	Annual Runoff Change (%)	Water	Wastewater
All					Climate Change Impacts Common to All Regions -Sea level rise and storm surge impacts (all regions except Midwest) -Increased extreme precipitation events -Increased treatment requirements -Anticipated increase in regulations for wet weather management -Higher energy demand -Increased disrupted service from flood -Increased emergency response and recovery -Declining water quality (water only)	
Northeast	4-6	+8	10-11	+2 to +5	-Increased storage needs resulting from earlier snowmelt and increased extreme precipitation events	-Increased demand for maintaining water quality and quantity of discharges to rivers and streams
Southeast	4-5	0 to +2	9-16	-10 to +5	-Greater uncertainty in water supply	-Increased demand for maintaining water quality and quantity of discharges to rivers and streams
Midwest	5-7	+3 to +5	N/A	+2 to +20	-Greater uncertainty in water supply	-No impacts in addition to those common to all regions
Central Plains	5-6	+1 to +2	14-30	-25 to -2	-Greater uncertainty in water supply	-No impacts in addition to those common to all regions
Northwest	5-6	+3 to +4	7-10	-2 to +3	-Greater uncertainty in water supply	-Increased demand for maintaining water quality and quantity of discharges to rivers and streams
Southwest	5-6	-6 to -4	7	-20 to -5	-Significant reductions and increased uncertainty in water supply -Increased need to optimize water use: conservation, reuse, operations, and storage	-Increased regulatory impacts for many treatment components -Increased potential issues with increased sewage concentration -Increased demand for maintaining water quality and quantity of discharges to rivers and streams
Alaska	7-9	+13 to +24	8-14	+20 to +40	-Increased storage needs resulting from earlier snowmelt and increased extreme precipitation events	-No impacts in addition to those common all regions
Hawaii	3-5	+3 to +10	8-14	-15 to -5	-No impacts in addition to those common to all regions	-No impacts in addition to those common to all regions
Puerto Rico	3-4	-19 to -3	8-14	-15 to -5	-Significant reductions and increased uncertainty in water supply	-No impacts in addition to those common to all regions

NOTE: Research shows a relationship between annual precipitation and intensity (see page 44 in "Global Climate Change Impacts in the US," U.S.GCRP (2009). However, no national database is available for regional projections of storm frequency, intensity and duration. Therefore, total annual precipitation data were taken as a measure of the change in expected annual frequency and intensity of precipitation. The exception was the southwest, where decreases in annual rainfall is expected to be associated with less frequent, but more intense storm events.



Chapter 2: Climate Change Impacts

EXHIBIT 2-3
Climate Change Impacts by Region





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CHAPTER 3

Adaptation Needs and Costs





Chapter 3: Adaptation Needs and Costs

Basis for Needs and Costs Assessment Through 2050

Climate change will result in multiple adverse impacts on the nation's water and wastewater systems.

Adaptations necessary to address these impacts are varied, as are their associated costs. This assessment of water and wastewater utility needs and costs associated with climate change recognizes that technologies are evolving and that responses must include innovative approaches and cooperation among water-related organizations.

This assessment is based on available information and includes costs for infrastructure for which water and wastewater utilities are directly responsible and for which cost estimation data are available. It relies on 2009 technologies and cost assumptions related to implementing climate change adaptations. Also contained in this assessment is a discussion of changing conditions, emerging options, and solutions for adaptation such as green infrastructure, and regulatory shifts. Unfortunately, cost assessment data for these opportunities and issues are limited and insufficient to perform robust calculations.

Exhibit 3-1 summarizes the overall estimated range of net present value (NPV) capital and O&M costs to address climate change needs through 2050.

Water and wastewater systems will require different adaptation strategies. This assessment recognizes that responses must include innovative approaches and cooperation among water-related organizations.



EXHIBIT 3-1

Water and Wastewater Sectors—Early Estimated Range of Net Present Value Capital and O&M Costs to Address Climate Change Needs Through 2050

SUMMARY

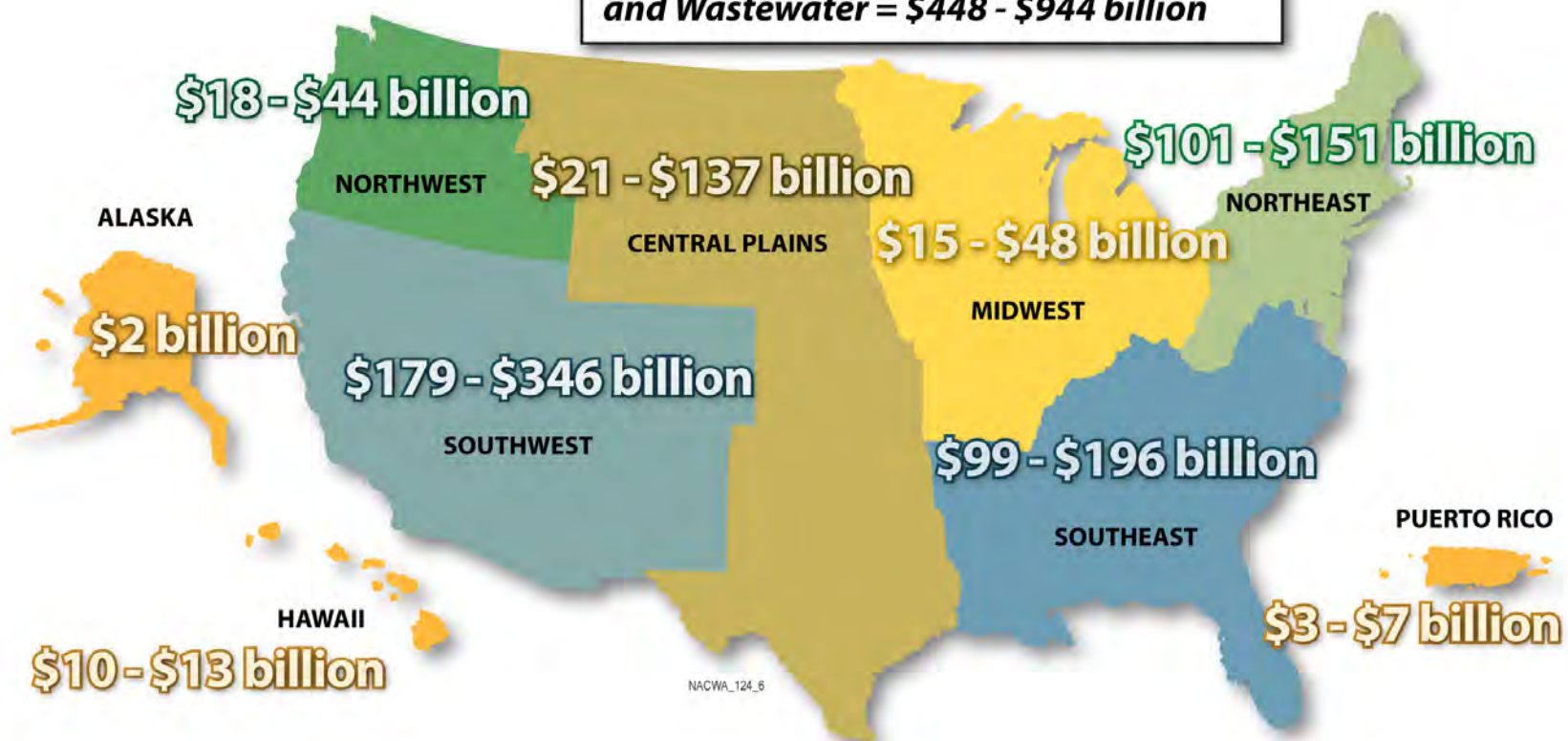
Drinking Water = \$325 - \$692 billion

Wastewater = \$123 - \$252 billion

GRAND TOTAL

Drinking Water

and Wastewater = \$448 - \$944 billion





Adaptation Portfolios for Sustainable Water Management

Integrating components of the built and natural water cycle through ‘water portfolio management’ or ‘total water management’ affords the greatest flexibility for sustainable water management and is an effective approach to adapt to climate change risks. This includes looking holistically at source water and water treatment options, stormwater/wastewater alternatives, and environmental flows.

Reduced supply often leads to integrated solutions, but integration across water cycle components usually takes time and is done in a stepwise fashion. Water scarcity—whether a result of population growth, short-term drought, or more pervasive influences such as climate change—triggers water conservation as the first step for utilities to address supply constraints. Utilities across the country are implementing aggressive conservation programs to improve water use efficiency and stretch their supplies. These programs will likely continue and expand as utilities adapt to increasing regional scarcity. However, conservation alone will not compensate for the projected shortfall in water supplies associated with climate change, nor will it alone provide the sustainable value of integrated water cycle management.

Adaptation portfolios feature many components ranging from conservation to new water conveyance and storage, desalination, and wastewater reuse. They also include green infrastructure solutions such as natural treatment systems that recharge aquifers and enhance water quality, as well as riparian restoration that can reduce water temperatures and protect or improve habitat for many terrestrial and aquatic species. These adaptation portfolios can be employed to make water and wastewater management more robust in the face of climate change.

Utility responses and adaptation portfolios will vary depending on climate-related risks to each system, utility management goals, changing regulatory environments, alternative local and regional water and wastewater management options, and who bears the implementation costs.

The Role of Green Infrastructure

Flood management and extreme precipitation events that will become more common with climate change may be addressed by traditional ‘gray’ infrastructure, such as levees and combined sewer overflow (CSO) tunnels and rapid disinfection processes. In addition, many agencies are incorporating ‘green infrastructure’ as part of their management portfolios. These technologies include permeable pavement, rain gardens, wetlands and swales, and green roofs, and others that enhance or mimic natural processes. Any or a combination of these technologies can reduce the load on drainage systems, recharge aquifers and, ultimately reduce loadings on wastewater collection systems. Increasingly, wastewater utilities are relying on green infrastructure to help manage wet weather challenges. These technologies also enhance neighborhood aesthetics and stimulate community engagement and pride in the urban environment.

While green infrastructure can provide multiple community benefits and help manage wet weather flows and recharge, runoff amounts associated with record-setting events (for example, high-intensity, short-duration events like in Louisville, Kentucky in August 2009 when six inches of rain fell in 75 minutes, and back-to-back events such as those in September 2009 in



Atlanta, Georgia where an unusual eight days of slow-moving back-to-back storms saturated the area, resulting in extreme flooding) are likely to be more than can be managed through green infrastructure alone.

For these types of extreme events, wastewater utilities must meet regulatory mandates to control sewer overflows that cause environmental and human health problems. These regulations will likely continue to require gray infrastructure solutions (and sometimes treatment) to handle very large volumes of runoff.

Addressing Uncertainty—Regulations, Emergency Response and Recovery, and Other Costs

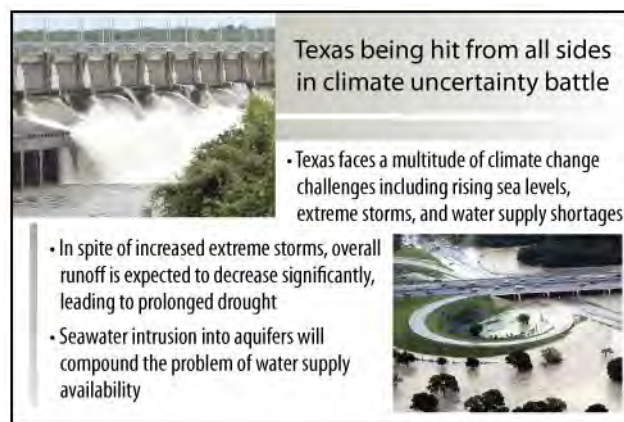
Among the more confounding challenges associated with climate change are the uncertainties of the magnitude, distribution, and timing of impacts; as well as the uncertainties associated with regulations intended to reduce the direct and indirect impacts of climate change and related environmental impacts.

While by no means easy to manage, physical impact uncertainty can be approached with existing forms of risk assessment already known to many utilities. However, future regulations regarding climate change for water and wastewater utilities also create uncertainty related to response costs.

Regulations have been, and are expected to continue to be a source of uncertainty for drinking water and wastewater utilities as they address the physical and institutional challenges to provide sustainable water and wastewater services. For example, California is often viewed as the bellwether for trends in water management and regulations. The California Global Warming Solutions Act of 2006 (AB32) establishes reduction measures and reporting requirements aimed at reducing the state's greenhouse gas emissions. Associated regulation specifics and implementation costs impact drinking water and wastewater utilities and will continue to evolve for the next several years, even as other regulations with which utilities must comply related to the protection of fisheries and other environmental resources also continue to evolve.

Other costs, such as cooling treated effluent prior to discharge to protect aquatic life that is exposed to increased surface water temperatures and reduced flows, accrue to utilities, as do the costs of complying with many other environmental quality conditions. By its nature, uncertainty in the cost of regulatory direction is neither easily understood, nor are these costs documented sufficiently to be included in this report. Costs associated with possible future regulatory controls are therefore not captured in this assessment.

In addition to regulatory uncertainty, unexpected costs associated with ER&R to restore wastewater services following extreme events, such as the flooding experienced in much of the



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Northeast, Southeast, Midwest, and Central Plains of the U.S. in 2008 and 2009 (Iowa, North and South Dakota, Minnesota, Kentucky, Georgia, Texas, and other states) can be devastating to municipalities and utilities.

Emergency response and recovery costs associated with these specific events are not included in databases at this time. In general, ER&R costs related to extreme precipitation events (consistent with, if not necessarily attributable to climate change) are in addition to climate change adaptation costs. Each of these events results in lost jobs, erodes local economies, threatens human and environmental health and property, and compromises the reliability of our nation's water and wastewater services.

While the frequency of these kinds of events is uncertain, little doubt exists that planning and preparation will be more cost-effective than recovery, retrofitting, and rebuilding as projected climate change impacts are more fully realized.

Drinking Water Sources and Treatment Systems

Projected Impacts and Adaptation Strategies

Climate change will impact drinking water systems by altering the quantity and timing of water availability, changing water quality, and inundating systems through sea level rise, storm surge, and flooding related to extreme events. Impacts on drinking water systems are considered in three categories for this assessment—source water availability, water treatment associated with water quality changes, and flood protection.

Source Water Availability

- **Changes in quantity of annual runoff.** Decreases in precipitation and/or increases in temperature, and therefore evapotranspiration, are projected to lead to runoff decreases in some regions. This is expected to reduce supplies in those geographies, *causing drinking water utilities to seek additional water supply and management options* to fill the gap between supply and demand.
- **Changes in runoff timing.** Not only will runoff quantity change in some regions, but the timing will also shift as a result of changes in precipitation timing and the melting of snowpack. These shifts *will affect the amount of water that utilities can capture in current reservoir and conveyance systems.*

New York City Department of Environmental Protection

- Developed Climate Change Assessment and Action Plan to identify vulnerabilities on the City's drinking water and wastewater infrastructure
- Evaluating effects of increased temperatures on reservoirs, including potential for increased algae growth and eutrophication
- Evaluating effects of increased precipitation on water supply and wastewater
- Collaborating with universities to develop future projections and trigger points for action plans
- Developing stormwater green infrastructure with NYC
- Evaluating computer-based tools for managing reservoir operations
- Undertaking capital projects that add redundancy and flexibility

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- **Seawater intrusion.** Sea level increases are likely to cause intrusion into coastal groundwater systems. In many cases, coastal systems are already challenged to provide sufficient freshwater to offset seawater intrusion. *Seawater intrusion into the coastal systems will affect the availability of drinking water supply* in some regions.

Adaptation Strategies. Responses will vary depending on water utility management goals, access to alternative supplies, and the degree of demand management already in place. Adaptation strategies to make up a source water shortfall include a portfolio of supply options such as water conservation, wastewater reuse, seawater desalination, and new groundwater sources. Additionally, as the timing and intensity of runoff shifts, additional storage and conveyance likely will be necessary to capture supplies. This assessment considers a range of response mixes based on current water management trends of small to large drinking water utilities.

Drinking Water Treatment

- **Changes in maximum temperature.** Temperature increases may lead to increases in disinfection by-products (DBPs) and the incidence of algal blooms, leading to *toxicity and taste and odor problems*.

Adaptation Strategies. Strategies to adapt to the changing quality of source water range from improvements and expansion of treatment processes to improvements and protection of source water watersheds. Reuse and recycling of wastewater effluent will also become a more common approach to address reduced water availability. Reuse and recycling for water supply augmentation will also require advanced treatment technologies and in many cases new distribution systems.

For this assessment, the adaptation measure likely to be used to address drinking water quality impacts resulting from changes in maximum temperature is *additional drinking water treatment*.

In addition, precipitation changes will influence turbidity, *driving large utilities that currently have waivers from filtration requirements to install filters as an adaptation measure*. As we tap more marginal sources of water to make up supply shortfalls, *microfiltration and reverse osmosis (MF/RO) may be required for some utilities to adapt to the changing source water quality*.

Southern Nevada Water Authority

SOUTHERN NEVADA WATER AUTHORITY

- Developing a water supply that is hydrologically independent of the Colorado River
- Adopted an aggressive water conservation program that has reduced water use by 22 billion gallons despite a population increase of 400,000
- Planned implementation of \$2.31 billion in water supply projects to mitigate the negative impacts of climate change impacts
- Estimated average Total Operating Cost increase related to reduced Lake Mead levels and resulting loss of hydropower: \$1.25 million per year

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Drinking Water Infrastructure Flood Protection

- **Increased sea levels.** Some drinking water treatment and distribution systems are in coastal areas or tidal estuaries that are affected by sea level rise, thereby causing inundation of facilities. *Storm surge, combined with increased sea levels, will put many of these facilities at risk*.



- **Increased flood events.** Some drinking water intake, treatment, and distribution systems are located in areas prone to flooding during extreme precipitation events. *Increases in the frequency or magnitude of these events may put critical infrastructure at risk.*

Adaptation Strategies. Sea level rise adaptation strategies include *installing levees and sea walls around treatment plants and key infrastructure*, such as pump stations. Protection of non-coastal infrastructure may also necessitate “hardening” of these structures or *investment in other flood protection measures*. Identifying critical versus non-critical infrastructure and relative risk to flooding will result in a range of adaptation strategies for each utility and system.

Estimated Cost of Implementation

Exhibit 3-3 shows the range of total early estimated NPV costs of climate change adaptation for drinking water systems through 2050, based on the climate effects described above—decreased runoff and seawater intrusion leading to new source water needs and associated treatment, and increased temperature leading to additional treatment.

EXHIBIT 3-3

Drinking Water: Early Estimated Range of NPV Capital and O&M Costs to Address Climate Change Adaptation Needs Through 2050



The total early estimated NPV cost of drinking water system adaptation in the U.S. through 2050 is between \$325 and \$692 billion above and beyond existing drinking water system infrastructure upgrade, renewal, and replacement programs that EPA estimates to be between \$300 billion and \$500 billion for combined drinking water and wastewater for the 2007–2027 period. This early estimate for adaptation costs includes both capital and O&M cost estimates. Please see the explanation of the cost development assumptions and methods in Appendices B and C, respectively, for more detail on the basis of this early estimate.



Wastewater Collection and Treatment Systems

Projected Impacts and Adaptation Strategies

Climate change will impact wastewater utilities on a number of fronts. Extreme storm events and overall precipitation increases will drive the need for wet weather program enhancements. Effluent quality considerations such as temperature will lead to investments at treatment plants. Flood protection adaptation measures such as levees and seawalls will be needed to address rising seas and floods associated with increased and extreme precipitation and runoff. In addition, as we integrate water cycle management, the wastewater industry will contribute to addressing drinking water supply challenges through wastewater reuse, requiring advanced treatment.

Wet Weather Programs

- **Changes in precipitation quantity and timing.** Changes in the frequency and intensity of precipitation events are assumed to correlate with changes in wet weather program capital costs related to wastewater collection and treatment systems. Wet weather programs aim to reduce the volume and frequency of untreated sewer overflows, including combined sewer systems and separate sanitary sewer systems. Note that in the Southwest, despite the projected decrease in annual precipitation, the intensity of storm events is expected to increase. The higher intensity is assumed to require *higher costs to reduce infiltration and inflow into sewers and other flooding issues*. Stormwater system costs are not included in this assessment's wet weather programs cost estimates.

Adaptation Strategies. Adaptation for wet weather management challenges can include a combination of green infrastructure applications that manage site specific runoff before it enters a stormwater or combined collection system, and gray infrastructure solutions, such as diversion and peak wet weather flow storage in tunnels, and rapid treatment technologies.

Wastewater Effluent Water Quality

- **Changes in maximum temperature and other environmental variables.** In many areas, wastewater treatment plant discharges can make up the majority of flow in streams and rivers, especially during droughts. Along the Pacific Coast and in the Northwest, where waterways support cold water fisheries, higher temperature effluent from wastewater treatment may have *detrimental effects on aquatic life fisheries, requiring cooling and additional treatment of wastewater discharge*. In addition, reduced summer river flows in many regions will increase the proportion of wastewater flow in a stream and may lead to *stricter effluent water quality requirements* for constituents such as dissolved oxygen, total dissolved solids, and nutrients. Strategies to deal with

Miami-Dade Water and Sewer Department

- Planning \$30 billion in capital improvements including \$2 billion in alternative water supply initiatives, \$10 billion in water/wastewater system improvements, and \$1 billion to protect against sea level rise impacts
- Established Climate Change Advisory Task Force for GHG reductions and adaptation recommendations
- Began serious reevaluation of laws and approaches to development, infrastructure, waste disposal and pollution, adaptation, and natural area preservation to reduce GHG emissions and defend against sea level rise
- GHG reduction efforts have yielded an annual average reduction of 2,532,732 tons of CO₂

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increased degradation of receiving water quality are likely be greater treatment of effluent prior to discharge.

Adaptation Strategies. Strategies to prevent high temperatures from affecting cold water fisheries include cooling by various methods like wetland treatment, shading through riparian restoration, mechanical cooling, evaporative cooling, and blending with cooler waste streams.

Wastewater Infrastructure Operation and Flood Protection

- **Increased sea levels.** Many wastewater collection and treatment systems are in coastal areas or in tidal estuaries that are affected by sea level rise and storm surge. Possible effects of sea level rise include *inundation that causes more inflow of brackish or salty water that requires higher volumes or treatment levels*; and *infrastructure system failure* that result from higher groundwater levels or high storm surge levels. In addition, many wastewater systems are designed to allow flow by gravity out to the discharge point. Rising downstream water levels *may require pumping to discharge through outfalls, thereby increasing energy demand*. Some utilities already pump effluent against ocean tides as a result of their plant locations. Sea level rise will increase the infrastructure and energy requirements to do so.
- **Increased flood events.** To enable flow by gravity, many wastewater treatment plants and collection systems are in areas prone to flooding during extreme precipitation events. *Increases in the frequency or magnitude of these events may put critical infrastructure at risk.*

Adaptation Strategies. Possible sea level rise strategies include *installing levees and sea walls around wastewater treatment plants and key infrastructure* such as pump stations. Another operational strategy is pumping effluent to raise the water level passing through or out of a wastewater plant. Hardening of sewer collection systems to reduce infiltration and inflow due to rising sea levels and groundwater levels is a third potential adaptation strategy. This assessment assumes that this last strategy is covered in the costs associated with reinforcing wet weather control programs (described above).

Protection of non-coastal infrastructure also may necessitate “hardening” of these structures or investment in other flood protection measures. Identification of critical versus non-critical infrastructure and relative risk to flooding will result in a range of adaptation strategies for each utility and system.

Not all wastewater plants will require all the measures identified above. Actual needs will be site specific, based on different climate effects and the relative elevation of individual plants.

Source Water Availability

As discussed above, one of the primary impacts on the drinking water sector will be a reduction in available water supplies in many regions. As part of the portfolio of water supply adaptations, many areas will turn to wastewater reuse. Reuse projects, by definition, involve collaboration between drinking water and wastewater utilities.

While cost allocations will vary considerably in different areas depending on water supply needs, water and wastewater governance structures, and other factors, this assessment assumes that wastewater reuse costs are split evenly between the drinking water and wastewater utilities.



Adaptation strategies. Adaptations that use treated wastewater for source water supply include non-potable reuse, where treated wastewater is distributed through separate reuse distribution infrastructure for uses such as irrigation and industrial process supply, as well as indirect potable reuse where treated wastewater is returned to storage facilities or groundwater aquifers and is available to supplement the drinking water supply. As additional pressure is placed on drinking water supplies, we expect reuse to become a critical part of utilities’ water portfolios.

Estimated Cost of Implementation

Exhibit 3-4 shows the range of total early estimated NPV costs of climate change adaptation for wastewater systems through 2050, based on the four climate effects described above—increased wet weather programs, need for system cooling, and need to adapt to sea level rise, and the need to provide source water through reuse and recycling to provide potable and non-potable water. **The total estimated NPV cost of wastewater system climate change adaptation in the U.S. is between \$123 billion and \$252 billion** above and beyond existing wastewater system infrastructure upgrade, renewal, and replacement programs that U.S. EPA estimates to be between \$300 billion and \$500 billion for combined drinking water and wastewater for the 2007-2027 period.

The NPV early estimate includes both capital and O&M cost estimates. Please see the explanation of the cost development assumptions and methods in Appendices B and C, respectively, for more detail on the basis of this estimate.

EXHIBIT 3-4
Wastewater Sector: Early Estimated Range of NPV Capital and O&M Costs to Address Climate Change Adaptation Needs Through 2050



CHAPTER 4

Conclusions





Chapter 4: Conclusions

Climate change has brought us to a turning point for the future of water and wastewater services in the United States. The direction we take from here will influence human and environmental health, our future economic conditions, and the way of life we all treasure.

Focused planning and action to proactively address and implement climate change adaptation through a 2050 timeframe to protect these services is a most critical priority as we formulate climate change legislation.

This report offers initial information with which we can begin to move forward with planning and action. This includes information on climate change impacts, the necessary adaptations to mitigate these impacts, and the costs of implementing those adaptations.

The timeframe (through 2050) corresponds to the period over which we best understand climate change impacts, and includes the 20- to 40-year planning period employed by most utilities. Beyond 2050, climate change impacts are less clear, but they are expected to be more severe, and the costs to adapt to them to be significantly higher.

The early cost estimates to maintain water and wastewater services through 2050 included in this report range from **\$448 billion to \$944 billion**. As more communities and utilities experience the extreme consequences of our changing climate, the costs will continue to rise and our water and wastewater services will be increasingly at risk.

A new level of awareness of a future strongly influenced by climate change is emerging among water and wastewater utilities. The Association of Metropolitan Water Agencies (AMWA) and the National Association of Clean Water Agencies (NACWA) serve as a voice for these utilities that understand the need for additional climate change research, as well as up-to-date information on the planning and adaptations necessary to deal with climate change impacts. (See Appendix D for additional research and information needs.)

"Americans have a remarkable ability to overcome adversity. We in the water industry respectfully ask that you support our efforts to adapt to and surmount the challenge of our changing climate."

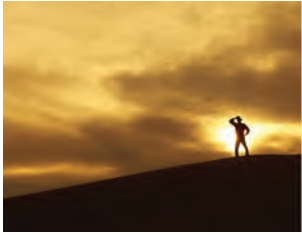
Patricia Mulroy, General Manager, Southern Nevada Water Authority. Testimony before the House Energy and Commerce Subcommittee on Energy and the Environment. Adapting to Climate Change April 2009



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Glossary



Glossary

AMWA – Association of Metropolitan Water Agencies
AOGCM – Atmosphere-Ocean General Circulation Model
AR4 – IPCC Fourth Assessment Report
B - Billion
BAC – Biologically Activated Carbon
CMIP3 - Coupled Model Intercomparison Project 3
CSO – Combined Sewer Overflow
DBP – Disinfection By-Product
ER&R – Emergency Response and Recovery
FEMA – Federal Emergency Management Agency
GAC – Granular Activated Carbon
GCM – General Circulation Model
GHG – Greenhouse Gas
gpd – gallons per day
IPCC – Intergovernmental Panel on Climate Change
M – million
MF/RO – Microfiltration and Reverse Osmosis
Mgd – million gallons per day
NACWA – National Association of Clean Water Agencies
NPV – Net Present Value
O&M – Operations and Maintenance
OMB – Office of Management and Budget
SRES – IPCC Special Report on Emissions Scenarios
TDS – Total Dissolved Solids
US EPA – U.S. Environmental Protection Agency
USACE – U.S. Army Corps of Engineers
USBC – U.S. Bureau of the Census
USBL – U.S. Bureau of Labor Statistics
USBRE – U.S. Bureau of Reclamation
USGCRP – U.S. Global Change Research Program
USGS – U.S. Geological Survey

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Appendices

- A. References
- B. Assumptions
- C. Methods
- D. Information Needs



Appendix A

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Appendix A. References

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Appendix B

Assumptions



Appendix B. Assumptions

Problem Definition

- The study timeframe is 2009–2050.
- 2009 technologies and facility capacities are in place at the outset of the analysis period.
- U.S. Climate Change Regions are based on *Global Climate Change Impacts in the United States—A State of Knowledge Report* from the U.S. Global Change Research Program, as modified to state boundaries to allow use of the Nature Conservancy ClimateWizard.
- Cost estimates include capital, operation, and maintenance costs.
- The general distribution and sizes of utilities remain constant over the period.
- The analysis considers only public utility systems in these early cost estimates.

Climate Analysis

The ClimateWizard Web site is the basis for estimates of temperature and precipitation changes. The General Circulation Model (GCM) ensemble data at the Web site are limited to MICROC3.2 (medres), Japan’s Model for Interdisciplinary Research on Climate GCM; CSIRO-Mk3.0, Australia’s Commonwealth Scientific and Industrial Research Organization GCM; and UKMO-HadCM3, the United Kingdom’s Hadley Centre for Climate Prediction and Research GCM. Additionally, the SimCLIM modeling tool is used for sea level rise assessments (see Appendix C).

Costs

B.1.1 Drinking Water

- The decrease in available withdrawals is equal to the percent decrease in runoff, plus the loss of supply due to changes in runoff patterns, plus the groundwater resources compromised by seawater intrusion.
- Calculations of the loss of supply due to changes in runoff patterns are based on the following considerations:
 - Approximately two-thirds of the annual runoff occurs in flood season.
 - The flood season is approximately 120 days.
 - The change in seasonal midpoint of runoff is equivalent to the shift in volume during the period that cannot be stored.
 - No changes to flood control operations occur.
 - No downstream facilities can capture this peak.
 - The loss in supply is annualized as a percent reduction in available source water.

- The estimated loss in supply defines the “make-up” amount that must be found elsewhere to meet future demand.
- In states affected by seawater intrusion into groundwater aquifers, intrusion continues and is exacerbated by climate change. New water sources are needed to replace the groundwater sources compromised by seawater intrusion — that is, the volume of compromised groundwater is added to the source water make-up needed for the region. Hydraulic barriers are not considered, because new water sources will be put to consumptive use rather than injected into groundwater.
- Total withdrawals for each region are derived from Table 5 of *Estimated Use of Water in the United States in 2000* (available at <http://pubs.usgs.gov/circ/2004/circ1268/hdocs/table01.html>). The withdrawal data used are for public water supplies only and from 2000.
- Total withdrawals for each size category of utility are proportional to population.
- Water demand and associated withdrawals escalate in proportion to population growth. Population growth projections for the period 2000–2025 are from the U.S. Census Bureau (Campbell, 1996; <http://www.census.gov/prod/2/pop/p25/p25-1131.pdf>). The 2025–2050 population growth rate is the same as for 2000–2025, and per capita water use remains constant. Demand increase for Puerto Rico escalates at a rate equal to the average increase for the other regions.
- Conservation constitutes 10 percent of make-up water, based on these studies: *Technical Memorandum No. 1: Water Demand Projections and Demand Management Water Resource Study*, Town of Purcellville, CH2M HILL 2007; and *Water Conservation Plan*, Town of Purcellville, CH2M HILL 2008x.
- Water conservation programs vary in cost based on system size, program type, a system’s starting level of user efficiency, and program implementation level. A cost range of \$0.12 to \$45 per 1,000 gallons is used, based on a CH2M HILL study for the Georgia Department of Natural Resources’ Environmental Protection Division, which covered basic programs only over a 20-year period. (http://www.conservewatergeorgia.net/documents/govt_tools.html#addTools)
- Reuse constitutes 25 percent of make-up water needed for all regions. In coastal areas, this number may be low, but it is high for inland areas in the West because of water rights limitations west of the Mississippi River, and demands from natural resources agencies for return flows. In the East, reuse is low but growing in response to water supply needs and requirements to reduce pollutant loadings to receiving waters. Within the range of current and future expected reliance on reuse, 25 percent represents a good mid-range number.
- Half of reuse costs are attributed to the drinking water sector and half to the wastewater sector because water and wastewater agencies both fund reuse programs and a detailed breakdown is unavailable. This split is considered reasonable.
- All reuse is indirect potable reuse, therefore requiring the highest level of treatment. In inland areas, the reuse process employs ozone and biologically activated carbon (BAC), which avoids brine disposal issues. In coastal areas, the reuse process employs microfiltration and reverse osmosis with brine discharged through the wastewater treatment plant outfall. Both processes include disinfection with ultraviolet light in combination with hydrogen peroxide

for advanced oxidation. The costs for both processes are similar. Direct reuse for potable use is not considered in this assessment.

- Reuse unit costs are based on *Groundwater Reliability Improvement Program (GRIP) for the Upper San Gabriel and Central Basins* (Jochem et al., 2009). These costs are for expansion of existing plants and include ultrafiltration, reverse osmosis, ultraviolet disinfection, advanced oxidation, decarbonation, and product water pumping. The costs reflect construction costs only and therefore do not include planning, engineering, pilot testing, land purchase, and site development. Therefore, \$3/gpd is added to the base cost for the additional project costs listed above and to include a contingency factor. The resulting capital costs do not include distribution, which are calculated separately (see below).
- Seawater desalination constitutes 40 percent of make-up water needed for large utilities in coastal regions, 20 percent for medium utilities in coastal regions, and zero for other utilities. The proportion of large utilities utilizing desalination is relatively high based a consideration that the majority of large utilities in a given region are located on the coast, and that medium utilities may partner with large utilities on desalination facilities.
- The cost of conveyance infrastructure for reuse and seawater desalination is the same. Conveyance costs are added to desalination and reuse source water costs to account for new distribution systems. CH2M HILL used its Parametric Cost Estimating System (CPES) to specify small, medium, and large distribution system models, generated cost estimates for the models, and assigned costs within the sector. The models are based on the following specifications:
 - There are 10 miles of conveyance lines with carrying capacities of 1.5, 15, or 150 mgd.
 - The 150-mgd case assumes two 78-inch pipes, each carrying 105 mgd (70 percent of the total capacity required).
 - Half of the pipes have cathodic protection.
 - Half of the pipes are for open country installation, the other half are for urban conditions.
 - Associated pump stations provide 150 psi discharge pressure and 5 feet per second.
- Costs for seawater desalination range from \$8 to \$16/gpd based on the U.S. Bureau of Reclamation's *USBR Desalting Handbook for Planners* (<http://www.usbr.gov/pmts/water/media/pdfs/report072.pdf>). These are capital costs and do not include distribution (see below for distribution costs).
- New developed supplies will contain the same proportion of surface water to groundwater now used by utilities in each region and size category (per the U.S. EPA Safe Drinking Water Information System (SDWIS)).
- All new source water acquired from surface and groundwater sources will need additional advanced treatment due to degraded quality. Additionally, the most common quality consideration is increased Total Dissolved Solids (TDS), from salinization of surface waters and accessing brackish groundwater sources. Therefore, the associated advanced treatment is microfiltration and reverse osmosis plus ultraviolet disinfection and advanced oxidation.
- Advanced treatment for compromised source waters is equivalent to that for desalination of brackish water. Process train costs for microfiltration and reverse osmosis are \$3 to \$6/gpd

per *USBR Desalting Handbook for Planners* (<http://www.usbr.gov/pmts/water/media/pdfs/report072.pdf>).

- The unit cost to treat the brine from the advanced treatment facilities is equivalent to the liquid process unit cost.
- Costs for development of new groundwater sources are based on the following range of experiences:
 - San Antonio Water System Carrizo Project: Phase 1 unit cost of \$0.88/gpd, based on a capital cost of \$5,300,000 for three 2-mgd wells; Phase 2 unit cost of \$0.74/gpd, based on a capital cost of \$5,900,000 for four 2-mgd wells.
 - Confidential Client: Unit cost of \$0.43/gpd, based on a capital cost of \$867,000 to provide 1,400 gpm.
 - Toho Water Authority: Unit cost range of \$2.11/gpd for 30 mgd to \$3.82/gpd for 10 mgd.
 - New Mexico Office of the State Engineer, Lower Pecos Project: Unit cost of \$0.43/gpd, based on a capital cost of \$500,000 to provide 800 gpm.
- Costs for conveying raw water very long distances, for example trans-continental pipelines, are not included in the cost estimates. Costs for agricultural to urban transfers associated with upgrading infrastructure in the agricultural sector are not included in the estimates.
- Major costs associated with filtration will be incurred by major utilities that now have filtration waivers: San Francisco Public Utilities Commission; New York Department of Environmental Protection; Portland Water Bureau; Seattle Public Utilities; and Massachusetts Water Resources Authority. The costs associated with adding clarification to facilities that have direct filtration are minimal.
- Costs for adding filtration are based on the following range of experiences:
 - Seattle, Washington: Unit cost of \$0.63/gpd.
 - Portland, Oregon: Unit cost of \$1.82/gpd, based on a capital cost of \$385,000,000 for 212 mgd.
 - Bend, Oregon: Unit cost of \$1.39, based on a capital cost of \$25,000,000 for 18 mgd.
 - Tacoma, Washington: Unit cost of \$1.20, based on a capital cost of \$180,000,000 for 150 mgd.
- In regions where the average summer temperature is below 21°C (69.8°F) and where temperature will exceed 21°C under climate change conditions, algal blooms are expected to increase (per David Austin, personal communication, 9/18/09). For cyanobacteria that cause algal blooms, the optimum temperature is 20 to 30°C (68 to 86°F.) A linear relationship exists between ambient temperature and water temperature. All utilities in these Regions will install post-filter GAC contactors to address concerns regarding taste, odor, and organics.
- Post-filter GAC contactor costs are based on the following information:
 - The unit cost for post-filter GAC contactors at a large WTP is \$1.00/gpd. This estimate is based on two data points, both taken from *Project Report: Design Engineering Services for Study of Alternative DBP Control Strategies* prepared for Southern Nevada Water Authority (CH2M HILL, August 2009).

- \$1.02/gpd estimated for the 600-mgd Alfred Merritt Smith Water Treatment Facility, Southern Nevada Water Authority: \$511,000,000 in construction costs, multiplied by 1.2 to account for other capital costs, yields \$613,000,000, divided by 600 mgd.
 - \$0.92/gpd estimated for the 400 mgd River Mountains Water Treatment Facility, Southern Nevada Water Authority: \$306,000,000 in construction costs multiplied by 1.2 to account for other capital costs, yields \$368,000,000, divided by 400 mgd.
- The unit cost for post-filter GAC contactors at a medium-sized WTP (15 to 44 mgd) is \$1.30/gpd. This cost is derived from arithmetic mean of three cost estimates from two reports:
- *Cobb-County Marietta Water Authority's Hugh A. Wyckoff Water Treatment Plant Regulatory and Operational Improvements Project, Basis of Design Report* (CH2M HILL in association with Jordan, Jones & Goulding and Engineering Strategies, Inc., September 2009).
 - *Northern Kentucky Water District's Basis of Design Report for Advanced Treatment Fort Thomas Treatment Plant/Memorial Parkway Treatment Plant* (CH2M HILL and HDR/Quest, January 2009).
- The unit cost for post-filter GAC contactors at a small WTP is \$2.50/gpd based on a typical relative relationship between costs at medium and small WTPs:
- Small facility cost = medium facility cost x (small mgd / medium mgd)^{0.71}.
 - Small facility \$/gpd is then small facility cost \$M / mgd.
- Flood protection costs for drinking water infrastructure are half of the flood protection costs for wastewater infrastructure, based on the fact that water treatment plants generally are sited at higher points in a community. (See below for more on such siting practices and rationale)
 - Costs associated with the impact of increased bed load or suspended sediment on intakes and pumps are not included. Adaptation measures that may be needed include sand sluices; sediment basins; relocation of intakes in river mouths associated with salt wedge; relocation or construction of new intakes related to reservoir elevation changes; and armoring intakes for intense wave action. These costs could not be reliably quantified and are therefore not factored into the baseline costs.
 - Flood management costs associated with inland water treatment facilities are half of those used for wastewater facilities, based on the following rationale. To take advantage of gravity, wastewater treatment plants tend to be low points in a watershed. Water treatment infrastructure tends to be at high points in a watershed for the same reason. Under these circumstances, in the aggregate, facilities sited at lower elevations in the watershed will have higher flood management costs than facilities sited at higher elevations in the watershed. The adaptation measures proposed for wastewater (levees) will be used to protect water facilities.
 - Costs associated with protecting drinking water facilities from sea level rise are 2 percent of the sea level rise protection costs associated with wastewater facilities, under the same rationale described above for flood management costs: water treatment infrastructure tends to be at high points in the watershed—very few are located on the coast relative to wastewater

facilities. The same adaptation measures proposed for wastewater (sea walls and levees) will be used to protect water facilities.

- Example and benchmark costs are accepted as current dollars unless otherwise indicated.

B.1.2 Wastewater

- The capital cost for wet-weather program adaptation, including separated sewer and combined sewer overflows, is 2 percent of the program costs estimated in the 2004 U.S. EPA Clean Watersheds Needs Survey—the same amount by which annual precipitation is projected to increase by 2050. Except in the southwest, where total annual rainfall and the frequency of rainfall events is projected to decrease but intensity of precipitation is expected to increase, the change in wet-weather program costs is proportional to the increase the top 1 percent of storms.
- All cost data are adjusted to 2009 dollars, as needed, using the *Engineering News-Record* Construction Cost Index (see ENRCCI at http://enr.construction.com/economics/current_costs/default.asp).
- U.S. EPA’s 2004 Clean Watersheds Needs Survey is the source for wastewater treatment capacity data.
- In California, Oregon, Washington, and Idaho summer high temperatures above 22.5°C (72.5°F) require cooling systems to satisfy temperature TMDLs.
- Sea level rise cost estimates are assigned to all coastal systems within 5 miles of the coast, including raising levees or installing new levees, plus effluent pumping.
- Estimates for levee construction costs are based on the California Climate Change Center report by Heberger et al. (2009).
- The length of levees is estimated according to a facility area of 1 acre/mgd of capacity, and specifying a facility square in shape.
- Costs for flood proofing wastewater systems on inland waterways are assigned to all plants in the 100- or 500-year floodplains, using the cost estimate for raising levees in the same manner as for coastal plant protection from sea level rise (see above).
- The cost of sealing wastewater collection systems to address sea level rise is included in the cost of infiltration/inflow system upgrades estimated for wet-weather system climate change adaptation.
- Wastewater utilities bear half the costs of new reuse facilities, as discussed under the assumptions for the water utilities.

B.1.3 Calculation of Total Costs in 2009 Dollars for Water and Wastewater

- Capital cost estimates are converted to annual debt service payments over the forecast period based on a financing term of 30 years at 4.5 percent interest, per the Office of Management and Budget’s (OMB) Circular A-94, Appendix C, *Discount Rates for Cost-Effectiveness, Lease Purchase, and Related Analyses* (rev. December 2008). This circular provides “a

forecast of nominal or market interest rates for 2009 based on the economic assumptions for the Fiscal Year 2010 December Budget Baseline.”

- Annual O&M costs in 2009 are 10.0 percent of the initial capital cost estimate (exclusive of financing costs). The 10 percent value reflects a doubling of currently observed O&M costs, generally 3 to 5 percent of capital costs, to account for escalating energy costs coupled with increasing use of energy-intensive technologies (per personal communication from Mike Matichich and Brock McEwen, CH2M HILL, September 18, 2009).
- The base 2009 O&M costs are subject to an annual inflation rate of 2.0 percent. The inflation rate estimate is the rounded average of estimates from two sources (1.75 and 2.3 percent).
 - One source is the OMB circular referenced above. One way to estimate an inflation rate is to divide $(1 + \text{nominal interest rate})$ by $(1 + \text{real interest rate})$. Following the values published in the OMB circular, $\text{inflation} = 1.045/1.027 = 1.0175$, for an estimated inflation rate of 1.75 percent. Because the water and wastewater industry generally experiences a higher cost inflation rate than the economy overall, another source was consulted to help better reflect this history.
 - The other source is a 10-year forward forecast of the U.S. Bureau of Labor Statistics’ index for “Installation, Maintenance, and Repair Occupation Group” prepared by IHS Global Insight economists (USBL 2001). <http://www.bls.gov/oes/2001/oes490000.htm> and IHS Global Insight at <http://globalinsight.com/>. The index is published by the Bureau under the Employment Cost Index (see <http://www.bls.gov/news.release/eci.toc.htm>).
 - The data are obtained through the National Compensation Survey, and the group is a part of the Standard Occupational Structure 49-00000. Among the available indices for which Global Insight provides forecasts, CH2M HILL cost estimators deem this the most appropriate single-index estimate of expected inflation of O&M costs in the water and wastewater sectors, which are predominantly driven by labor. CH2M HILL maintains a subscription service to Global Insight’s current data and projections, and pulled the forecast for this index on October 8, 2009, for the period 2009–2019. As of this date, the annual estimates range from 1.21 to 2.76 percent; the average inflation rate in these data is 2.3 percent.
- A nominal discount rate of 4.5 percent is used to discount future cash flows, per OMB guidance for similar evaluation periods: the nominal discount rate is equal to the nominal interest rate (see above).

Appendix C

Methods



Appendix C. Methods

C.1 Climate Data

C.1.1 Definition of Regions

The U.S. Global Change Research Program (USGCRP, 2009) uses six regions to define precipitation and temperature characteristics within the continental United States (Exhibit C1-1). The USGCRP also provides some projections for Alaska, Hawaii, and Puerto Rico. Those three geographies are treated separately from the six regions in the continental U.S.

EXHIBIT C1-1
Region Composition

Central Plains	Montana	Northeast	Vermont	Southeast	Tennessee
	North Dakota		Maine		Kentucky
	South Dakota		New Hampshire		Virginia
	Wyoming		Pennsylvania		Arkansas
	Nebraska		Massachusetts		North Carolina
	Kansas		Rhode Island		South Carolina
	Oklahoma		Connecticut		Georgia
	Texas		West Virginia		Mississippi
Midwest	Minnesota	Northwest	New York	Southwest	Alabama
	Wisconsin		New Jersey		Louisiana
	Iowa		District of Columbia		Florida
	Illinois		Delaware		Nevada
	Indiana		Maryland		Utah
	Michigan		Idaho		Colorado
	Ohio		Washington		Arizona
	Missouri		Oregon		New Mexico
				California	

C.1.2 Climate Data Source

The study and quantification of climate change impacts requires the assessment of temperature and precipitation data that characterize future climate scenarios. Climate projection data are available from ClimateWizard (Zganjar, 2009), an online tool for visualizing climate data developed jointly by the Nature Conservancy, the University of Washington, and the University of Southern Mississippi. ClimateWizard provides both historical and projected climate data for the continental United States. The historical dataset, which spans 1951–2006, was developed by the PRISM Group at Oregon State University (2009) (<http://www.prism.oregonstate.edu/>). The available climate projection data are a subset of the World Climate Research Programme’s (WCRP) Coupled Model Intercomparison Project (CMIP3) multi-model dataset (Meehl et al., 2007), which originally was produced by the Program for Climate Model Diagnosis and Intercomparison of Lawrence

Livermore National Laboratory. The base climate projections were downscaled by Ed Maurer of Santa Clara University (Maurer, et al., 2007).

C.1.3 Data Description

Projected climate data representative of conditions in 2050 were downloaded for two IPCC GHG emissions scenarios: high (A2) and medium (A1B). Emissions scenarios and GCMs are described later in this appendix. The data produced by GCMs were combined to create an ensemble result that captures a range of projected future climate conditions. Average temperature (°F) and precipitation (inches) were assessed annually and seasonally. Exhibit C1-2 summarizes the downloaded climate data. The climate data were downloaded in ASCII format and processed using ArcGIS and Microsoft Office Access to determine spatial averages for each of the six defined regions.

EXHIBIT C1-2
Summary Description of Climate Projection Data

Characteristic	Description
Data Source	ClimateWizard (www.climatewizard.org)
Emissions Scenarios	High (A2), Medium (A1B)
Ensemble GCMs	MIROC3.2(medres), CSIRO-Mk3.0, UKMO-HadCM3
Spatial Coverage	Coterminous United States
Resolution/Grid Cell Size	12 km
Baseline Climate Definition	1971–2000
Future Climate Definition	2050 (2040–2069)
Time Periods Evaluated	Annual, winter (December–February), spring (March–May), summer (July–August), fall (September–November)
Variables	Average Temperature (°F), Precipitation (inches)

C.1.4 Results

Results are shown on Exhibits C1-3 to C1-6.

C.1.5 Emissions Scenarios

Climate data projections are generated by general circulation models, which are driven by GHG emissions scenarios. A scenario is a coherent, internally consistent, plausible description of a possible future state of the Earth’s climate. It is not a forecast. Each scenario is an image of how the future can unfold. A set of scenarios is often adopted to reflect the uncertainty inherent in projections in future conditions.

EXHIBIT C1-3

Changes in Annual Temperature by 2050. Model Ensemble Average, IPCC SRES emission scenario: A2

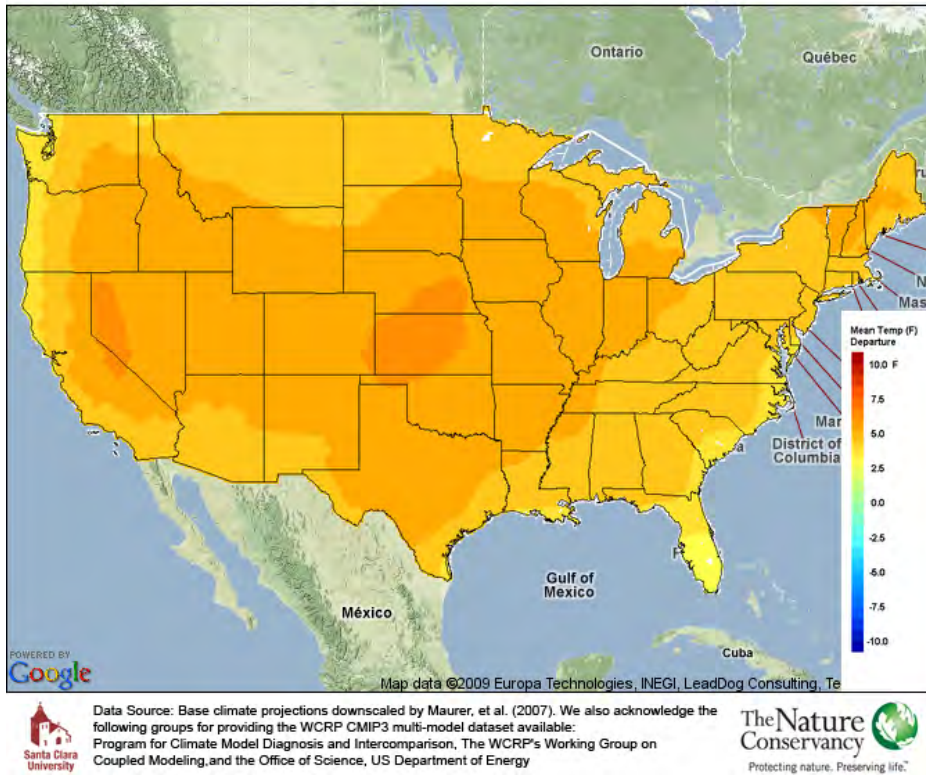


EXHIBIT C1-4

Changes in Annual Temperature by 2050. Model Ensemble Average, IPCC SRES emission scenario: A1B

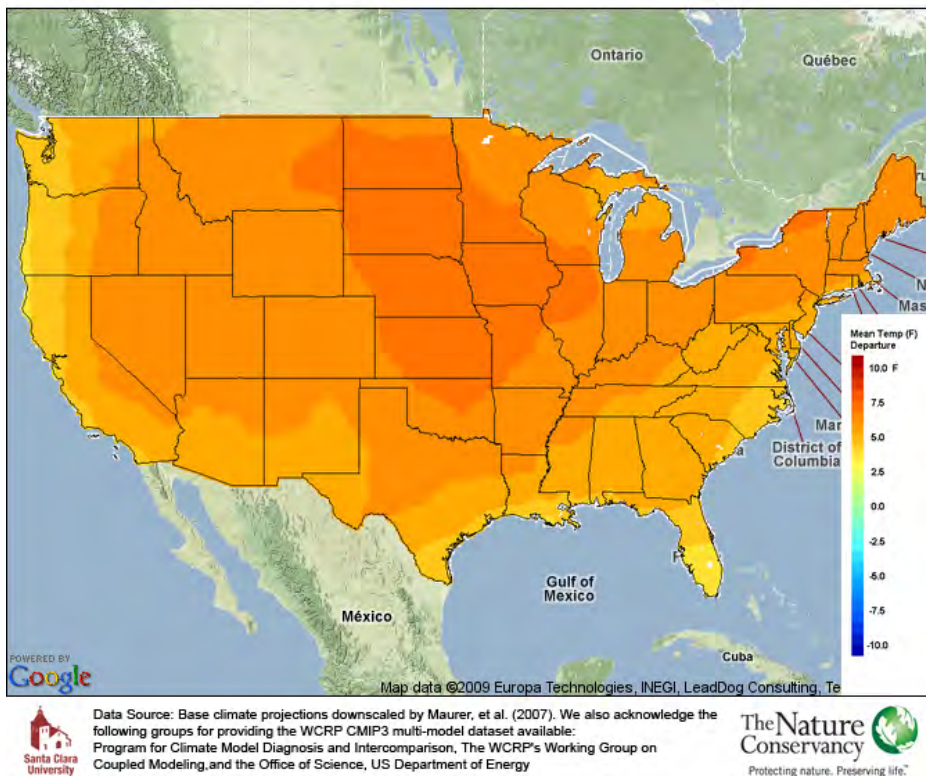
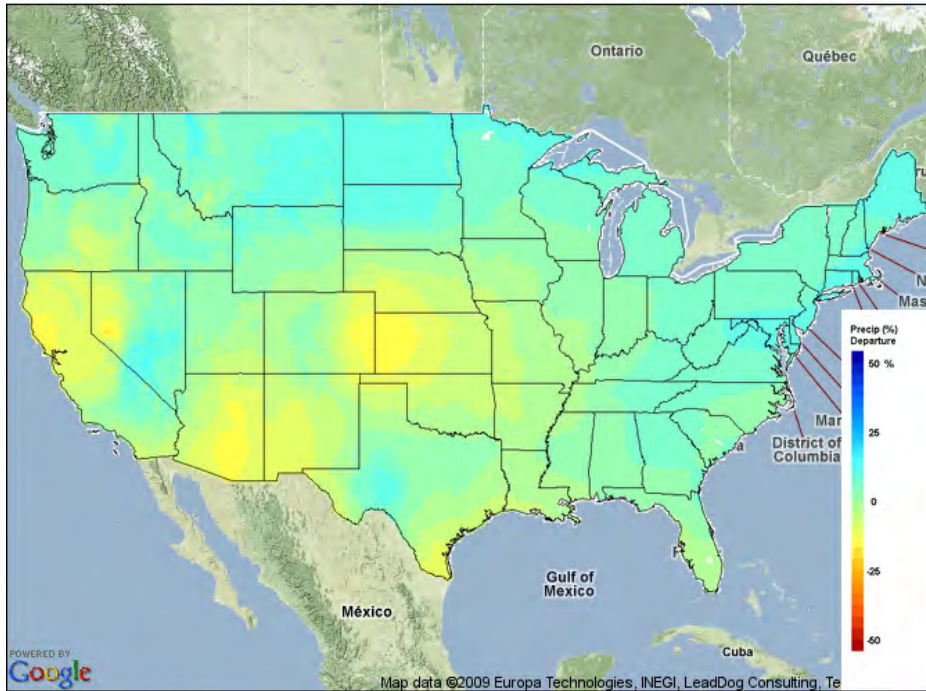


EXHIBIT C1-5

Changes in Annual Precipitation by 2050. Model Ensemble Average, IPCC SRES emission scenario: A2

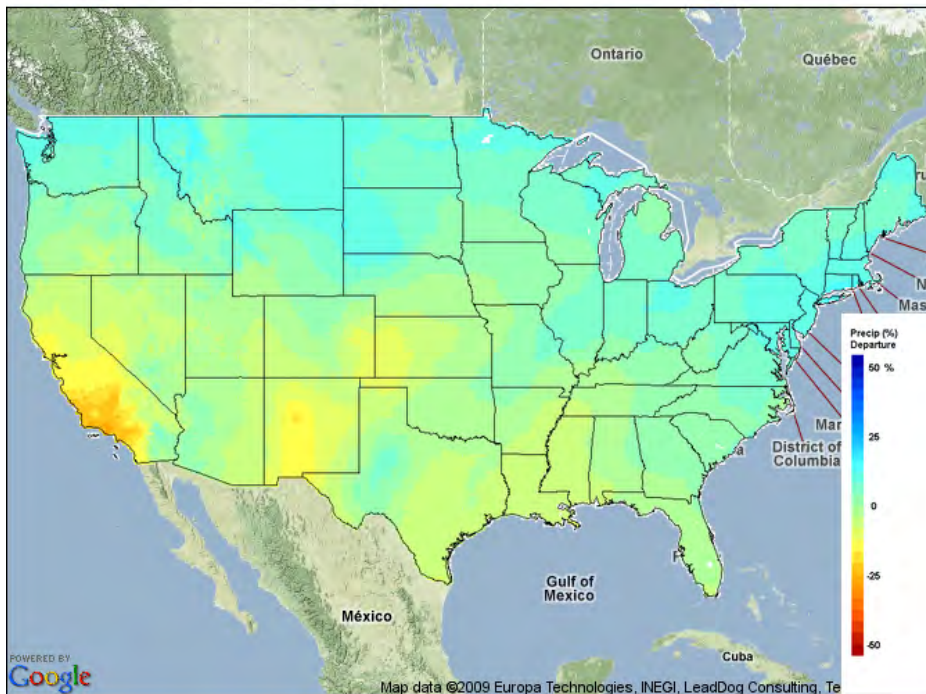


Data Source: Base climate projections downscaled by Maurer, et al. (2007). We also acknowledge the following groups for providing the WCRP CMIP3 multi-model dataset available: Program for Climate Model Diagnosis and Intercomparison, The WCRP's Working Group on Coupled Modeling, and the Office of Science, US Department of Energy



EXHIBIT C1-6

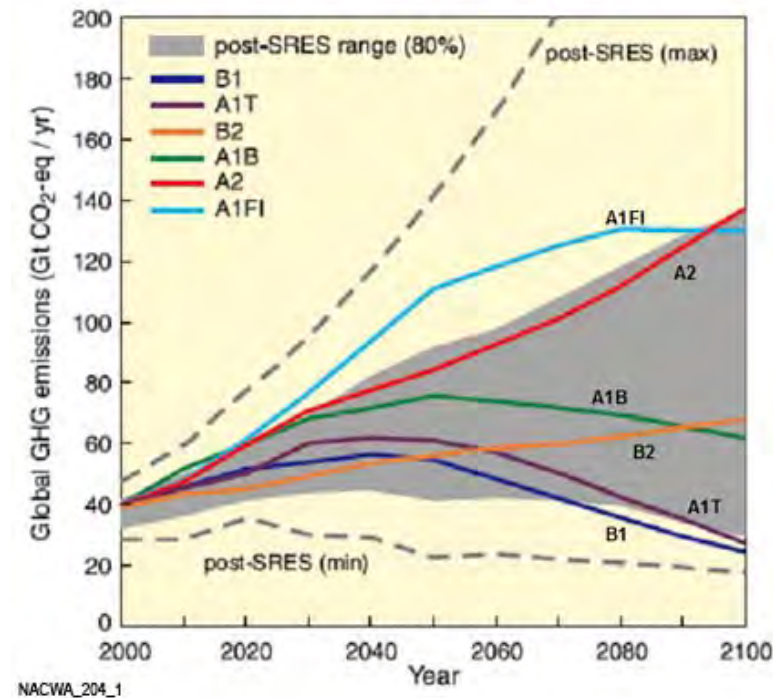
Changes in Annual Precipitation by 2050. Model Ensemble Average, IPCC SRES emission scenario: A1B



Data Source: Base climate projections downscaled by Maurer, et al. (2007). We also acknowledge the following groups for providing the WCRP CMIP3 multi-model dataset available: Program for Climate Model Diagnosis and Intercomparison, The WCRP's Working Group on Coupled Modeling, and the Office of Science, US Department of Energy



EXHIBIT C1-7
Scenarios for GHG emissions from 2000 to 2100 in the absence of additional climate policies (IPCC, 2007)



projected total emissions in 2100.

C.1.6 General Circulation Models

Climate models use quantitative methods to simulate the interactions of the atmosphere, oceans, land surface, and ice. When combined with emissions scenarios, they can be used to generate projections of future climate. ClimateWizard contains output from three models selected to represent a relatively broad range of future projections of all general circulation model projections.

- **MIROC3.2(medres)**—Japan’s Model for Interdisciplinary Research on Climate GCM
- **CSIRO-Mk3.0**—Australia’s Commonwealth Scientific and Industrial Research Organization GCM
- **UKMO-HadCM3**—United Kingdom’s Hadley Centre for Climate Prediction and Research GCM

Analysis of future climate change is complex, because there are many future projections from combinations of different GCMs run with a range of CO₂ emissions scenarios (IPCC 2007b). To better address uncertainty, an ensemble analysis can be used to combine the analyses of multiple GCMs and quantify the range of possibilities for future climates under different emissions scenarios. ClimateWizard uses a simple, nonparametric quantile-rank approach that maps the median (50th percentile) future predicted mean temperature and precipitation values for the 3-GCM ensemble.

In 2000, the IPCC published The Special Report on Emissions Scenarios (SRES) that describes six emission scenarios now commonly used with global climate models (IPCC, 2000) (Exhibit C1-7). The SRES scenarios cover a wide range of the main drivers of future emissions, from demographic to technological to economic developments. None of the scenarios includes future policies that explicitly address climate change.

The high (A2) and medium (A1B) emissions scenarios are selected as representative of the climate futures we could reasonably expect to face. They represent high and medium emission pathways based on

C.1.7 Downscaling

Quantitative climate change scenarios often are derived from the results of GCMs under varying emission scenarios. Despite continuing improvements in the development and application of these models and dedicated computational resources, the resolution of the current suite of GCMs is too coarse for direct use in watershed-scale impact assessments. To overcome the resolution issues, “downscaling” to higher spatial resolution is a common approach for translating macroscale climate information either observed or identified in climate models to changes in meteorological parameters at the local scale.

The following describes the data presented the ClimateWizard:

A statistical technique was used to generate gridded fields of precipitation and surface air temperature over the conterminous United States and portions of Canada and Mexico. The method involves (1) a quantile-mapping approach that corrects for GCM biases, based on observations of 1950–1999; and (2) interpolation of monthly bias-corrected GCM anomalies onto a fine-scale grid of historical climate data, producing a monthly time series at each 1/8-degree grid cell. The method has been used extensively for hydrologic impact studies (including many with ensembles of GCMs) and in a variety of climate change impact studies on systems as diverse as wine grape cultivation, habitat migration, and air quality (Maurer et. al., 2007).

C.1.8 Baseline and Future Time Period

The Climate Wizard creates a dataset of “change” that captures the difference between projected 2050 average temperature or precipitation values and a baseline time period. In the case of ClimateWizard, the baseline is defined as the average temperature and precipitation between 1971 and 2000. Meaningful statistical representations of modeled future climate predictions are best achieved by examining a range of time rather than a single year. The 2050 climate projections are characterized by data for the period 2040–2069 to provide the user with a range that most accurately describes the predicted conditions for the mid century (2050).

C.1.9 Results for Temperature and Precipitation for Six Continental U.S. Regions

Results from the three GCMs and two emissions scenarios provide a representative depiction of climate for 2050 at the resolution needed to support this analysis. Results from the three GCMs and two emissions scenarios provide a representative depiction of climate for 2050 at the resolution needed to support the analysis performed for this assessment. Results are tabulated in Exhibits C1-8 through C1-11. In Exhibits C1-8 through C1-16 “SON” represents September, October, November; “DJF” December, January, February; “MAM” March, April, May; and “JJA” June, July, August.

C.1.10 Results for Temperature and Precipitation Projections for Alaska, Hawaii, and Puerto Rico

Temperature and precipitation projections are not available for Alaska and Hawaii on the ClimateWizard Web site, and there is limited coverage for Puerto Rico. To meet climate change data needs for the study, baseline temperature and precipitation data were obtained from NOAA Historical Climatology Series No. 4-3 publication, United States Climate Normals (NCDC, 2002). This publication provides area-weighted temperature (°F) and precipitation (inches) normals for each U.S. state and territory for the period 1971–2000, the same as used by ClimateWizard.

While both seasonal and annual data are provided, note that seasonal precipitation is reported as a “monthly average,” while annual precipitation represents the average cumulative annual total. Baseline values for Alaska, Hawaii, and Puerto Rico are shown in Exhibits C1-12 and C1-13.

EXHIBIT C1-8

Projected 2050 Average Temperature (°F, with °C in parentheses) for High (A2) and Medium (A1B) Scenarios

High (A2)–Scenario					
Region	Annual	Fall (SON)	Winter (DJF)	Spring (MAM)	Summer (JJA)
Central Plains	56.3 (13.5)	57.3 (14.1)	33.8 (1.0)	54.5 (12.5)	79.1 (26.1)
Midwest	53.1 (11.7)	55.6 (13.1)	29.2 (-1.5)	51.6 (10.9)	77.2 (25.1)
Northeast	51.4 (10.8)	54.3 (12.4)	30.2 (-1.0)	49.0 (9.4)	72.5 (22.5)
Northwest	48.7 (9.3)	49.4 (9.7)	30.6 (-0.8)	46.0 (7.8)	66.6 (19.2)
Southeast	66.5 (19.2)	67.8 (19.9)	48.7 (9.3)	65.3 (18.5)	83.9 (28.9)
Southwest	56.8 (13.8)	57.7 (14.3)	38.0 (3.4)	54.2 (12.4)	76.5 (24.7)
Medium (A1B)–Scenario					
Region	Annual	Fall (SON)	Winter (DJF)	Spring (MAM)	Summer (JJA)
Central Plains	57.2 (14.0)	57.8 (14.3)	34.8 (1.6)	55.3 (12.9)	79.0 (26.1)
Midwest	54.0 (12.2)	55.9 (13.3)	29.0 (-1.6)	52.3 (11.3)	77.3 (25.2)
Northeast	52.5 (11.4)	54.8 (12.7)	30.5 (-0.8)	50.5 (10.3)	73.2 (22.9)
Northwest	49.4 (9.6)	49.9 (9.9)	31.5 (-0.3)	46.0 (7.8)	66.4 (19.1)
Southeast	67.2 (19.5)	67.8 (19.9)	49.3 (9.6)	66.8 (19.3)	84.0 (28.9)
Southwest	57.4 (14.1)	58.2 (14.6)	39.0 (3.9)	54.5 (12.5)	76.8 (24.9)

EXHIBIT C1-9

Projected 2050 Change in Temperature (°F, with °C in parentheses) Relative to Baseline Climate (1971–2000) for High (A2) and Medium (A1B) Scenarios

High (A2)–Scenario					
Region	Annual	SON	DJF	MAM	JJA
Central Plains	5.2 (2.9)	5.3 (3.0)	4.4 (2.4)	4.1 (2.3)	7.2 (4.0)
Midwest	5.2 (2.9)	5.7 (3.2)	6.5 (3.6)	4.1 (2.3)	6.9 (3.8)
Northeast	4.8 (2.7)	5.5 (3.1)	5.6 (3.1)	3.8 (2.1)	5.4 (3.0)
Northwest	4.9 (2.7)	5.0 (2.8)	3.4 (1.9)	3.5 (2.0)	5.9 (3.3)
Southeast	4.6 (2.5)	5.2 (2.9)	3.6 (2.0)	3.3 (1.8)	6.1 (3.4)
Southwest	5.3 (2.9)	5.1 (2.8)	4.3 (2.4)	4.5 (2.5)	6.8 (3.8)
Medium (A1B)–Scenario					
Region	Annual	SON	DJF	MAM	JJA
Central Plains	6.4 (3.6)	6.0 (3.4)	5.6 (3.1)	5.1 (2.8)	7.2 (4.0)
Midwest	6.5 (3.6)	5.9 (3.3)	6.3 (3.5)	5.4 (3.0)	7.0 (3.9)
Northeast	6.1 (3.4)	6.0 (3.3)	5.9 (3.3)	5.8 (3.2)	6.1 (3.4)
Northwest	5.6 (3.1)	5.7 (3.2)	4.1 (2.3)	3.5 (1.9)	5.7 (3.2)
Southeast	5.4 (3.0)	5.1 (2.8)	4.1 (2.3)	5.3 (2.9)	6.1 (3.4)
Southwest	5.9 (3.3)	5.9 (3.3)	5.0 (2.8)	4.7 (2.6)	7.0 (3.9)

EXHIBIT C1-10

Projected 2050 Precipitation (inches) for High (A2) and Medium (A1B) Scenarios

High (A2) – Scenario					
Region	Annual	SON	DJF	MAM	JJA
Central Plains	22.7	5.6	3.4	6.8	6.5
Midwest	34.5	8.7	5.3	10.1	10.2
Northeast	46.1	11.7	10.3	11.5	12.2
Northwest	35.2	9.1	14.6	8.4	3.0
Southeast	52.9	11.9	13.4	13.2	13.4
Southwest	15.1	3.5	5.3	3.3	3.2
Medium (A1B) – Scenario					
Region	Annual	SON	DJF	MAM	JJA
Central Plains	23.2	5.9	3.4	6.9	6.6
Midwest	35.3	8.5	5.4	10.1	10.7
Northeast	46.7	11.0	10.6	11.4	12.5
Northwest	36.1	9.0	15.0	8.8	3.1
Southeast	51.7	12.0	13.2	12.3	13.6
Southwest	14.9	3.4	4.6	3.3	3.2

EXHIBIT C1-11

Projected 2050 Change in Precipitation Relative to Baseline Climate (1971–2000) for High (A2) and Medium (A1B) Scenarios

High (A2)–Scenario					
Region	Annual	SON	DJF	MAM	JJA
Central Plains	1.1%	3.5%	10.7%	3.2%	-12.3%
Midwest	2.8%	8.3%	9.2%	7.6%	-10.4%
Northeast	7.8%	5.0%	11.2%	7.0%	5.2%
Northwest	3.3%	5.0%	10.7%	0.6%	-22.4%
Southeast	2.2%	7.0%	5.4%	-2.6%	-6.6%
Southwest	-4.2%	-3.0%	7.6%	-15.8%	-1.3%
Medium (A1B)–Scenario					
Region	Annual	SON	DJF	MAM	JJA
Central Plains	1.9%	11.1%	7.1%	5.3%	-13.5%
Midwest	4.5%	4.7%	15.0%	8.5%	-6.2%
Northeast	8.0%	2.0%	13.3%	7.7%	6.3%
Northwest	3.8%	2.1%	12.0%	5.7%	-19.2%
Southeast	-0.6%	7.5%	3.2%	-6.6%	-5.5%
Southwest	-6.4%	-1.7%	-5.6%	-19.7%	-5.1%

EXHIBIT C1-12

Average Seasonal Baseline Temperatures (1971–2000) (°F)

	Annual	DJF	MAM	JJA	SON
Alaska	26.6	2.6	24.7	52.3	26.7
Hawaii	70	67.4	68.6	72.2	71.8
Puerto Rico	76.3	73.4	75.4	78.8	77.6

Source: NOAA

EXHIBIT C1-13

Average Seasonal Baseline Precipitation (1971–2000) (inches)

	Annual	DJF	MAM	JJA	SON
Alaska	22.5	1.61	1.15	2.26	2.49
Hawaii	63.7	5.99	5.94	4.22	5.23
Puerto Rico	65.65	3.46	4.94	5.58	7.97

Source: NOAA

Information on projected changes in precipitation and temperature for Alaska, Hawaii, and Puerto Rico comes from the IPCC's Fourth Assessment Report describing the physical science basis for climate change. The values provided in that report are based on the projections from 21 GCMs driven by the A1B medium scenario for the period 2080–2099. The projected changes in temperature and precipitation are calculated as the difference between the resulting projected 2080–2099 temperature and precipitation values and simulated baseline temperatures for the 1980–1999 period (Christensen et. al., 2007). The mean (50 percent) change between baseline and projected temperatures is shown in Exhibits C1-14 and C1-15.

EXHIBIT C1-14

Projected Changes in Temperature (°F) between Baseline and 2080–2099, A1B Scenario

	Annual	DJF	MAM	JJA	SON
Alaska	8.1	11.34	6.3	4.32	8.1
Hawaii	4.14	4.32	4.14	4.14	4.32
Puerto Rico	3.6	3.78	3.96	3.6	3.6

Source: AR4, WG1, Chapter 11: Regional Climate Projections. Christensen et. al. (2007)

EXHIBIT C1-15

Projected Changes in Precipitation between Baseline and 2080–2099, A1B Scenario

	Annual	DJF	MAM	JJA	SON
Alaska	21%	28.0%	17.0%	14.0%	19.0%
Hawaii	5%	3.0%	1.0%	8.0%	6.0%
Puerto Rico	-12%	-6.0%	-13.0%	-20.0%	-5.0%

Source: AR4, WG1, Chapter 11: Regional Climate Projections. Christensen et. al. (2007)

The projected changes in temperature and precipitation are applied to the baseline values given by NOAA to derive projected climate values. The projected 2080–2099 temperature and precipitation values associated with the A1B scenario are shown in Exhibits C1-16 and C1-17.

EXHIBIT C1-16

Derived Projected Seasonal Temperatures for AK, HI, & PR - A1B Scenario (2080 - 2099) (°F)

	Annual	DJF	MAM	JJA	SON
Alaska	34.7	13.94	31	56.62	34.8
Hawaii	74.14	71.72	72.74	76.34	76.12
Puerto Rico	79.9	77.18	79.36	82.4	81.2

Sources: NOAA, 2002; Christensen et. al. (2007).

EXHIBIT C1-17

Derived Projected Seasonal Precipitation for AK, HI, & PR - A1B Scenario (2080 - 2099) (inches)

	Annual	DJF	MAM	JJA	SON
Alaska	27.2	2.1	1.3	2.6	3.0
Hawaii	66.9	6.2	6.0	4.6	5.5
Puerto Rico	57.8	3.3	4.3	4.5	7.6

Sources: NOAA, 2002; Christensen et. al. (2007).

C.2 Runoff Calculations

The primary source for projected changes in runoff for 2050 is from research by Milly et al. (2005) as published by the USGCRP (2009) (see Exhibit C2-1).

C.2.1 Constraints and Assumptions

Assessing runoff is complicated by the complexity of tracing the path of water once it strikes the ground. Hydrologic models vary in their ability to simulate the flow of surface and groundwater due to the heterogeneous nature of the earth's surface. To expedite streamflow/runoff analysis at large scales, generalized assumptions of vegetation, soils, terrain elevation are made in order to provide basinwide results. The USGCRP has accepted the results of the Milly research in assessing the projected changes in runoff for 2041–2060, and this information is used for this assessment.

C.2.2 Method Milly-Projected Annual Runoff

The projected annual runoff is derived from hydroclimatic simulations with the lowest root-mean-square in long-term discharge per unit area from ensemble runs of 12 GCMs. The 12 GCMs were extracted from the 20C3M simulations of climate (IPCC, 2007a) using the SRES A1B medium emission scenario.

Monthly discharge time series used to verify the hydroclimatic simulations come from the Global Runoff Data Center (GRDC, 2009) and averaged to annual values for all analysis.

General Results

Climate models consistently project that the Eastern U.S. will experience increased runoff, but there will be substantial declines in the interior West, especially the Southwest. Projections for runoff in California and other parts of the West also show reductions, although less than in the interior West. In short, wet areas are projected to get wetter and dry areas drier.

EXHIBIT C2-1

Projected Changes in Runoff for U.S. Regions after Milly et. al. (2005)

Region	Range in Change by Region
Northeast	2 to 5
Midwest	2 to 20
Southeast	-10 to 5
Central Plains ^a	-25 to -2
Southwest ^b	-20 to -5
Pacific NW	-2 to 3
Alaska	20 to 40
Hawaii	-15 to -5
Puerto Rico	-15 to -5

^a Central Plains Milly value of -10 to -2%, modified to -25 to -2% based on Colorado River (Texas) modeling for 2050 performed by CH2M HILL (2008).

^b Southwest Milly value of -40 to -5%, modified to -20 to -5% based on Colorado River modeling assessments organized by the Western Water Assessment (Hoerling et al, 2009).

For this study we use the projected changes in runoff as an approximation of the projected net change in water system delivery capability. Specific studies on individual water system effects as a result of climate change are not available in adequate samples size, and therefore could not be used for this national analysis. We reviewed specific studies in California (California DWR, 2009), Colorado (Hoerling et al., 2009), and Texas (CH2M HILL, 2008y) to evaluate the validity of this assumption. These studies generally confirmed that the ranges provided by Milly et al. (2005) are reasonable for estimating changes in water supply. In the Southwest and Central Plains regions, however, minor changes were made to the results from Milly to better characterize the more detailed region-specific analyses.

C.3 Projected Shifts in Streamflow Timing by Region

Projections from the USGCRP (2009) are available for the West for the period 2080–2099 as shown in Exhibit C3-1. Streamflow shift publications are available for the Northeast, but very few publications describing projected shifts in streamflow timing for the Central Plains, Midwest, Southeast, Hawaii, and Puerto Rico. Projected shifts for those regions are based on professional judgment and experience.

C.3.1 Regional Values

Pacific Northwest: 10 to 30 days earlier in snow dominated basins, 5 to 20 days later for coastal, non-snowmelt dominated basins (Stewart, 2004).

Southwest: 10 to 20 days earlier in snow dominated basins (Stewart, 2004).

Northeast: 5 to 14 days earlier (Hayhoe, 2007; Lettenmaier, 2008).

Central Plains: Estimate 2 to 7 days earlier. No definitive research available.

Midwest: Estimate 2 to 7 days earlier No definitive research available.

Southeast: Estimate 2 to 5 days earlier because of more evaporation in the summer. No definitive research available.

Alaska: 15 to 25 days earlier (Stewart, 2004).

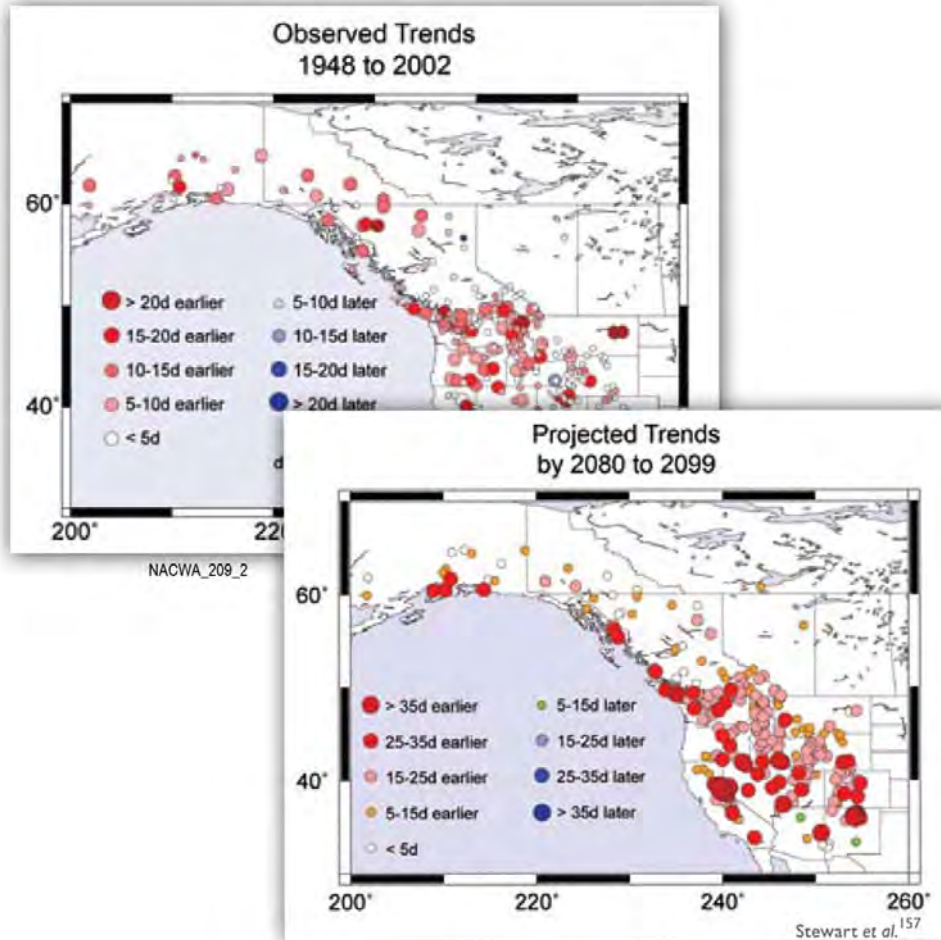
Hawaii: No change. No definitive research available.

Puerto Rico: No change. No definitive research available.

EXHIBIT C3-1

Trends in Peak Streamflow Timing

Top map shows changes in runoff timing in snowmelt-driven streams from 1948 to 2002 with red circles indicating earlier runoff, and blue circles indicating later runoff. Bottom map shows projected changes in snowmelt-driven streams by 2080–2099, compared to 1951–1980, under a higher emissions scenario. Source: USGCRP, 2009.



C.4 Sea Level Rise Calculations

C.4.1 Sea Level Rise Components

Sea level rise includes two components. Global sea level rise is a consequence of the increase in the volume of the Earth's oceans resulting from thermal expansion of warming ocean water and the addition of water to the ocean from melting ice masses on land (glaciers and ice sheets). Sea level rise is measured directly by coastal tide gauges that record the movement of the land on which they are located and changes in global sea level.

Most local sea level rise assessments use projections of global-mean sea-level change. As is the case with changes in climate variables such as temperature or precipitation, sea level does not change uniformly around the world. Different rates of oceanic thermal expansion and regionally specific changes in oceanic and atmospheric circulation affect the level of the sea surface differently, giving rise to regional patterns of sea level change. These regional patterns are

evident from the output of the increasingly sophisticated coupled atmosphere-ocean general circulation models (AOGCMs) that can be integrated with the long-term, non-climate change related trends, usually associated with vertical land movement that affect relative sea level.

C.4.2 Sea Level Rise Projection Methods

To integrate AOGCM projections for oceanic thermal expansion and the effects of regionally specific changes in changes in oceanic and atmospheric circulation, an environment must be established to hold AOGCM results and allow regional assessments of vertical land movement. The SimCLIM modeling tool (Warrick, 2009), provides an environment to integrate AOGCM results with local land movement to assess impacts on coastal communities. The SimCLIM sea level rise scenario generator contains tabular year-by-year output from a suite of GCMs forced by the greenhouse gas emission scenarios used in the IPCC Third Assessment Report (IPCC, 2001). For each scenario, global mean changes in temperature, sea level thermal expansion, and sea level total (including ice melt) are available near coastal communities.

Five AOGCMs were selected for sea level rise assessments in this study from the IPCC Assessment Report 4 (AR4) Coupled Model Intercomparison Project (CMIP3) (Meehl et al., 2007): ECHAM5 (Max Plank Institute for Meteorology, DKRZ, Germany), GFDLCM-21 (Geophysical Fluid Dynamics Lab, USA), UKHADCM3 (Hadley Centre, United Kingdom), CCSM-30 (National Center for Atmospheric Research, USA), and the CCCMA-31 (Canadian Climate Centre, Canada). Consistent with precipitation and temperature projections used in this study, two greenhouse gas emissions scenarios, A1B (medium) and A2 (high) were selected to as input to the AOGCM.

Historical observed tide data from 13 tide stations representing the coasts of the United States were obtained from the National Oceanic and Atmospheric Administration (NOAA) Tides and Currents website (<http://tidesandcurrents.noaa.gov/>) to assess historical trends and to provide projected sea level rise for the selected stations (NOAA, 2009).

For each of the five selected AOGCMs, two emissions scenarios—A1B and A2—were run for the period 1990 through 2100. SimCLIM produced five annual projections of median sea level rise for each emissions scenario. At the 2050 target date, results from the A1B and A2 emissions scenario are very similar. Exhibit C4-1 lists coastal stations analyzed by region and contains historical sea level rise trends in inches/year, land subsidence in the area near the tide station in inches/year, and projected sea level rise in feet and inches. The SimCLIM model incorporated land subsidence for the stations selected in this study.

Sea level rise projections for 2050 are largest (13 to 30 inches) along the Texas Gulf Coast and the Florida Panhandle where land subsidence makes a significant contribution to relative sea level rise. Projected sea level rise along the West Coast ranges from 7 to 9 inches, with the largest rise, 9 inches, in the Puget Sound area. Southern Florida and the Southeastern Atlantic Coast projected sea level rise is roughly 9 inches. Projected sea level rise for the Northeastern Atlantic coast is between 10 and 11 inches.

Projected range of sea level rise for Anchorage, Honolulu, and San Juan are estimated based on research performed by Siddall et al. (2009) that examined sea-level fluctuations in response to changing climate by reconstructing the past 22,000 years from fossil data, a period that covers the transition from the Last Glacial Maximum to the warm Holocene interglacial period.

EXHIBIT C4-1

Sea Level Rise Projections

SimCLIM 2050 sea level rise projections from five AOGCMs and the A1B medium and A2 high emissions scenarios for selected tide stations on the coastal United States. Historical sea level rise trends obtained from NOAA Tides and Currents database. Historical subsidence obtained from a variety of study sources.

Region/Station Name	Historical Sea Level Rise Trend (in./yr) NOAA Tides	Historical Subsidence (in./yr)	Sea Level Rise Projection 1990–2050 (ft)	Sea Level Rise Projection 1990–2050 (in.)
West Coast Pacific				
Seattle, WA	0.08	-0.06	0.79	9.46
South Beach, Newport, OR	0.11	-0.01	0.58	6.90
San Francisco, CA	0.08	-0.01	0.59	7.07
San Diego, CA	0.08	-0.01	0.59	7.08
Los Angeles, CA	0.03	-0.01	0.59	7.06
Central Plains Texas Coast				
Corpus Christi, TX	0.20	-0.11	1.13	13.55
Galveston, TX	0.27	-0.39	2.52	30.23
Southeast Gulf Coast				
Pensacola, FL	0.08	-0.13	1.22	14.64
Clearwater, FL	0.10	-0.04	0.76	9.11
Southeast Atlantic Coast				
Virginia Key, Miami, FL	0.09	-0.04	0.76	9.08
Charleston, SC	0.12	-0.04	0.76	9.17
Northeast Atlantic Coast				
Boston, MA	0.10	-0.04	0.90	10.77
Washington, DC	0.12	-0.05	0.83	10.00
Alaska, Hawaii, Puerto Rico				
Anchorage, AK	0.03	N/A	0.66 to 1.2	7.9 to 13.8
Honolulu, HI	0.06	N/A	0.66 to 1.2	7.9 to 13.8
San Juan, PR	0.06	N/A	0.66 to 1.2	7.9 to 13.8

C.4.3 Recent Sea Level Rise Research

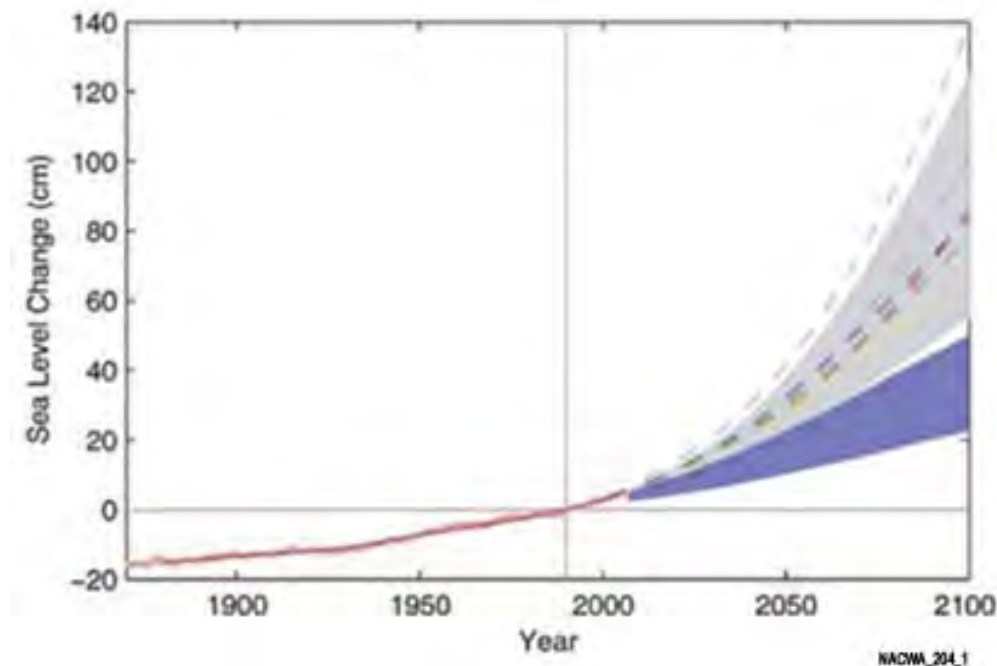
The IPCC Fourth Assessment Report (AR4) provides estimates of global sea level rise ranging from 0.18 to 0.59 meter (7.1 to 23.2 inches) over the next century as shown in the blue shaded area of Exhibit C4-3. At the time of the Assessment, there was a more limited understanding of some effects driving sea level rise; therefore AR4 does not assess the likelihood of, nor provide a best estimate or an upper bound for, sea level rise. The AR4 projections include a contribution from increased ice flow from Greenland and Antarctica at the rates observed for 1993–2003. If this contribution were to grow linearly with global average temperature change, the upper ranges of sea level rise would increase by 0.1 to 0.2 m (3.9 to 7.9 inches) to a total of 0.28 to 0.79 m (11.0 to 31.1 inches) by 2100 (Meehl et al., 2007; IPCC, 2007).

Rahmstorf et al. (2007) and other climate scientists suggest that a global sea level rise of 1 meter (3 feet) (Exhibit C4-3 shown in gray) could occur within this century if increased melting of ice sheets in Greenland and Antarctica is added to the factors included in the IPCC estimates.

EXHIBIT C4-3

IPCC Observed and Projected Sea Level Rise. Plot in Centimeters (cm) Rise over time of Past Sea Level Observations and Several Future Sea-Level Projections to 2100.

The blue-shaded area is the sea level rise projection by Meehl et al. (2007) corresponding to the A1B emissions scenario, which forms part of the basis for the IPCC (2007) estimates. The higher gray and dash line projections are from Rahmstorf (2007). (Modified from: S. Rahmstorf, 2007, "A Semi-empirical Approach to Projecting Future Sea Level Rise." *Science*, 315[5810], 368–70).



C.5 Drinking Water

The methods for estimating costs for adaptations for water and wastewater utilities are necessarily dissimilar. For this reason the methods discussions for water and wastewater cost calculations in this appendix are organized differently.

C.5.1 Source Water Cost Estimating Methods

For each region, the percent decrease in available withdrawals is determined based on percent decrease in runoff. If runoff is expected to increase, the percent decrease in available withdrawals is set to zero. The Runoff Values Derivation described earlier in this Appendix (C.2) outlines the analysis procedure for determining the projected changes in runoff. Based on the range of runoff projections, two scenarios are used—one where runoff decreases are greatest and one where runoff decreases are lowest. These two scenarios are carried throughout the analysis.

Total current withdrawals for each region are derived from Table 5 of the USGS report *Estimated Use of Water in the United States in 2000* and represent public withdrawals. Withdrawals are assumed to increase between now and 2050 in proportion to population increases on a state by state basis. Population increase projections are based on census data for

2000–2025 (U.S. Census Bureau), and population is assumed to increase from 2025 to 2050 at the same rate as for 2000–2025. For the purposes of determining withdrawals, we assumed that per capita water demand remains constant. Conservation is treated as an available make-up water source. Total withdrawals from each region are multiplied by the percent decrease in available withdrawals to get the source water make-up needed because of decreases in runoff.

A shift in the timing of runoff likely will limit ability to capture water, therefore further decreasing the water available. We assume that approximately 2/3 of annual runoff occurs in flood season and that flood season is approximately 120 days. The loss in supply is equal to the days that the runoff is shifted, divided by 120 days, and multiplied by 2/3. This loss in supply is added to the source water make-up needed. We further assume that seawater intrusion resulting from sea level rise will further compromise groundwater sources in regions where intrusion is already starting to occur. A factor is developed for those regions for the compromised source water based on the proportion of groundwater used in each state in the region, and the presence of coastal aquifers subject to intrusion. This compromised flow is added to the source water make-up needed as a result of decreased runoff to determine the total source water make-up needed.

For each region, we create three categories of utilities: large (serving > 100,000 people), medium (serving 10,000–100,000 people), and small (serving < 10,000 people). Each size category is given a mix of source water solutions to achieve its required source water make-up. The mix is allocated as follows:

- Conservation: 10 percent
- Reuse: 25 percent reuse projects, by definition, involve collaboration between drinking water and wastewater utilities. While the cost allocations will vary considerably in different areas depending on water supply needs, water and wastewater governance structures, and other factors, this report divides the costs of wastewater reuse evenly between water and wastewater utilities.
- Seawater Desalination: 40 percent for large utilities in coastal regions, 20 percent for medium utilities in coastal regions, zero for other utilities. The proportion of large utilities using desalination is relatively high, given that most large utilities in a given region are located on the coast. It is assumed that medium utilities may partner with large utilities on desalination facilities.
- Groundwater and new surface water make up the balance. Proportions of new groundwater and surface water are equal to current groundwater vs. surface water proportions.

An average cost per gallon per day (gpd) is calculated by multiplying the percent of each source used by its unit cost (Exhibit C5-1). The unit costs for reuse and desalination are assumed to be quite similar. Although the actual percentages of desalination and reuse in each region may shift from the allocations assumed here, such shifts will little impact on overall costs. Note that the unit costs provided here represent only capital costs borne by water utilities. The estimates do not include energy costs associated with increased pumping, for example, nor do they include costs for agriculture to urban transfers associated with upgrading infrastructure on the agriculture side.

The percent of the regional population served by a given utility size (based on U.S. EPA SDWIS database) is multiplied by the make-up withdrawals needed to determine volume of new

withdrawals for each size category in each region. Population is used as a surrogate because utility withdrawal numbers are not available.

EXHIBIT C5-1
Unit Cost Assumptions for Source Water Adaptation Measures

Adaptation Strategy	Assumed Cost for Small (\$/gpd)	Assumed Cost for Med (\$/gpd)	Assumed Cost for Large (\$/gpd)	Basis
Groundwater	\$3.82	\$2.11	\$0.43	Multiple projects with cost ranges from \$0.43/gpd to \$3.82/gpd
Seawater desalination	\$16.00	\$12.00	\$8.00	<i>USBR Desalting Handbook for Planners</i> (http://www.usbr.gov/pmts/water/media/pdfs/report072.pdf): \$8–\$16/gpd
New surface water (storage and conveyance)	\$17.00	\$7.19	\$3.36	Multiple projects with cost ranges from \$3.36/gpd to \$17/gpd
Conservation	\$0.05	\$0.03	\$0.00	Multiple programs across utilities
Reuse	\$9.50	\$8.20	\$7.90	Jochem et al. 2009. "Groundwater Reliability Improvement Program (GRIP) for the Upper San Gabriel and Central Basins."
Distribution (added to reuse and desalination)	\$13.11	\$3.84	\$1.63	CPES – CH2M HILL Parametric Cost Estimating System

The average cost per gpd for each size category is multiplied by the new withdrawals for that category to get total cost for that size category.

Size categories are summed to obtain total cost for the region.

Average utility costs are determined by dividing the total cost for each size category by the number of utilities in that size range in that region. We recognize that per-utility costs may represent capital costs that utilities would be contributing to a larger regional project (with a higher overall capital cost).

Costs for each region are added to obtain total source water cost.

C.5.2 Drinking Water Treatment Cost Estimating Methods

Filtration

This assessment assumes that the major costs associated with filtration will be incurred by major utilities that have filtration waivers. Increased turbidity and algal blooms will cause major utilities to add filtration to their unfiltered source water. Major waiver utilities include:

- San Francisco Public Utilities Commission
- New York Department of Environmental Protection
- Portland Water Bureau
- Seattle Public Utilities
- Massachusetts Water Resources Authority

Average flows for these agencies come from information on their websites.

The agencies are assigned to their associated regions, and costs are determined by multiplying the unit cost by the total currently unfiltered flow. Unit costs for all water treatment adaptation measures are included in Exhibit C5-1.

Additional Unit Processes

Algal blooms in surface water storages occur when average summer temperatures exceed 21°C (69.8°F). In regions where average summer temperatures are below 21°C in the baseline condition and will exceed 21°C in climate change conditions, additional unit processes (presumably GAC units) are added across all surface water flows.

For those regions where temperature increases, the percent of the regional population served by a given utility size (based on USEPA SDWIS database) is determined. Population is used as a surrogate because utility withdrawal numbers are not available.

In the affected regions, the proportion of water used by each size category that is surface water is determined using the U.S. EPA SDWIS database.

The percent of population in each size category in each region is multiplied by the percent that is surface water for each size category, and then by total withdrawals for that region (from the USGS report) to get treated flow for that size category. For each size category, the cost for additional unit processes is determined by multiplying the flow by the unit cost for that size category. Costs for size categories are summed to get total cost for unit process additions in the region.

For regions already above 21°C summer average, no unit process addition costs are added.

Advanced Treatment

We assume that all new source water acquired from surface and groundwater sources will need additional advanced treatment as a result of degraded quality. We also assume that the most common quality consideration will be increased total dissolved solids (from salinization of surface waters and accessing brackish groundwater sources). The associated advanced treatment will be microfiltration and reverse osmosis plus disinfection with ultraviolet light.

The percent of utilities in each size category in each region is multiplied by the percentage of new supplies that are groundwater and surface water, and then multiplied by the make-up source water flow for that region to get the flow that requires advanced treatment for each size category in each region. The unit cost associated with advanced treatment for each size category is multiplied by the new flow for that size category to get the advanced treatment cost for each size category.

Costs for size categories are summed to obtain total cost for advanced treatment in the region.

Unit Costs

Exhibit C5-2 presents the assumed unit costs for water treatment adaptation measures.

EXHIBIT C5-2
Unit Cost Assumptions for Water Treatment Adaptation Measures

Adaptation Strategy	Assumed Cost for Small (\$/gpd)	Assumed Cost for Med (\$/gpd)	Assumed Cost for Large (\$/gpd)	Basis
Water Treatment				
Add filtration	\$—	\$—	\$1.80	Cost from multiple large utilities with cost ranges from \$0/gpd to \$1.80/gpd
Add GAC to address algae, DBPs, taste and odor	\$2.50	\$1.30	\$1.00	Multiple utility costs
Advanced treatment (saltier source water: microfiltration and reverse osmosis)	\$12.00	\$9.00	\$6.00	<i>USBR Desalting Handbook for Planners</i> (http://www.usbr.gov/pmts/water/media/pdfs/report072.pdf): Brackish water desalination \$3–\$6/gpd. Zero liquid discharge for brine doubles cost.

C.5.3 Drinking Water Flood Management Cost Estimating Methods

Two categories of flood management costs are included—those for inland plants, and those for coastal plants. For inland plants, we assume that flood management costs are half those for wastewater (described later in this Appendix) on a regional basis. The rationale for using a lower number is that, to take advantage of gravity, wastewater treatment plants tend to be at the bottom of a watershed; water treatment infrastructure tends to be at higher elevations in the watershed for the same reason, and therefore in many geographies are less likely to flood.

For coastal plants, a similar approach is taken, but we assume that costs associated with protecting drinking water facilities from sea level rise are 2 percent of the costs for sea level rise protection costs for wastewater infrastructure, based on the assumption that currently very few water treatment facilities are located on the coast (relative to the number of coastal wastewater facilities).

In both cases, the adaptation measures used for drinking water infrastructure are assumed to be the same as those used for wastewater infrastructure—levees and sea walls. For sea level rise expected by 2050, we assume that building protections will be less costly than relocating facilities to higher ground.

C.6 Wastewater

The methods for estimating costs for adaptations for water and wastewater utilities are necessarily dissimilar. For this reason the methods discussions for water and wastewater cost calculations in this appendix are organized differently.

The costs of adaptation to climate change for wastewater systems are assessed based on the following impacts and adaptation strategies:

- Increases or decreases in average annual rainfall are assumed to translate directly into changes in wet weather program costs, as estimated for combined sewer overflow programs and

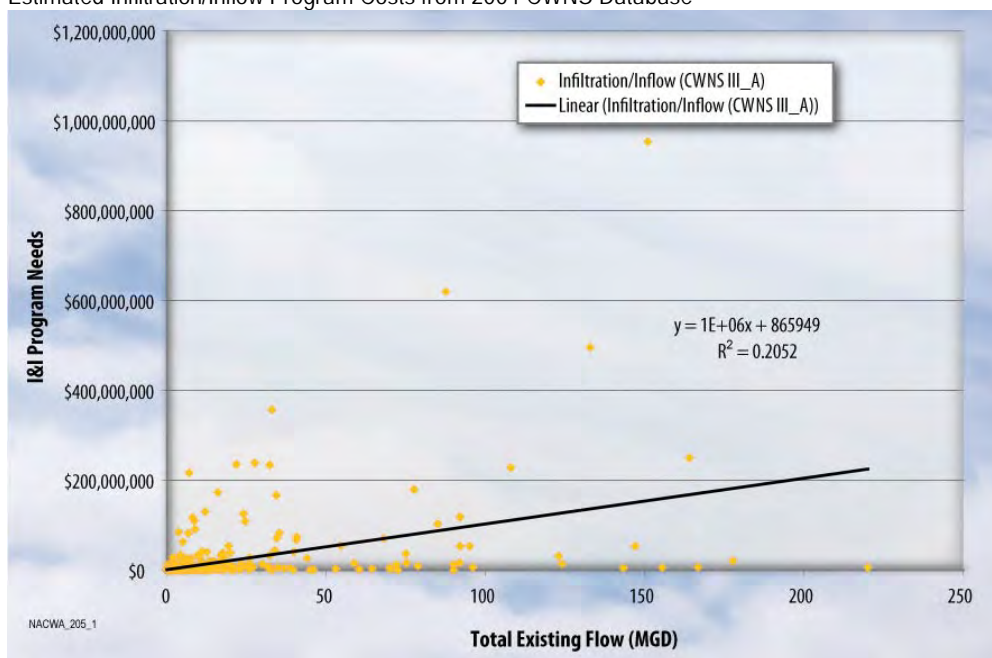
infiltration/inflow control programs, previously estimated in the U.S. EPA's 2004 Clean Watersheds Needs Survey (CWNS). The exceptions were the Southwest and Puerto Rico, which are expected to see decreases in total annual precipitation and frequency of storms by 2050, although the intensity of events is expected to increase. The greater intensity is assumed to require greater cost to reduce infiltration/inflow into sewers.

- Higher rainfall volume or intensity is expected to require flood proofing of wastewater treatment plants in floodplains along inland waterways.
- Increases in maximum summer temperature above 22.5°C (72.5°F) by region are assumed to require cooling systems for all wastewater systems on the west coast to protect salmonid fisheries.
- Increases in sea level rise are assumed to be addressed by providing or raising a levee, and by effluent pumping. Costs for levees are not varied based on the difference in sea level rise, but a range in costs is assigned based on the difference in cost from raising a levee to adding a new earthen levee of 10 to 20 feet high. All coastal or tidally influenced wastewater facilities are assumed to require protection and effluent pumping.

Specific steps in the analysis were as follows:

- The 2004 CWNS database of wastewater facilities was obtained from the U.S. EPA web site. It contains 18,016 wastewater facilities and includes name, location, CWNS number, state, current flows, design treatment capacity, and population served.
- The CWNS contains wastewater needs assessments in several categories. Only needs for combined sewer overflow and infiltration/inflow systems are included in this assessment. Costs for system rehabilitation and replacement, for wastewater treatment system upgrades, and for stormwater systems needs are not included.
- Total wet-weather program costs are taken as the sum of actual estimated combined sewer overflow program needs, and infiltration/inflow program needs. All wastewater systems are assumed to have some infiltration/inflow program needs. Where the 2004 Needs Survey did not show any costs for a given facility, costs are estimated using the relationship shown in Exhibit C6-1. The relationship is derived based on all CWNS facility data, including 1,600 systems with non-zero infiltration/inflow program cost data. Relationships were tested using total existing flow, total design flow, and total population, and the total existing flow was selected because it yielded the best relationship. This relationship is only used where no infiltration/inflow program costs are assigned in the database.

EXHIBIT C6-1
Estimated Infiltration/Inflow Program Costs from 2004 CWNS Database



- Reuse projects, by definition, involve collaboration between drinking water and wastewater utilities. While the cost allocations vary considerably in different areas depending on water supply needs, water and wastewater governance structures, and other factors, this report divides the costs of wastewater reuse evenly between water and wastewater utilities.
- All costs are adjusted to 2009 dollars using the Engineering News Record Construction Cost Index.
- Each region is assigned a percent increase or decrease in total annual rainfall projected for 2050 based on the method described above, except the Southwest and Puerto Rico where observed increase in the intensity of the top 1 percent of events is used (Exhibit C6-2). The spatially averaged increase/decrease across each region is used, not the largest or smallest decreases projected at any location in the region. The percent increase/decrease is assigned for both the high GHG emissions (A2) and medium GHG emissions (A1B) scenarios. For each facility in the 2004 CWNS the percent increase was assigned using lookup tables that correlate the state and climate region to the projected annual rainfall change.
- Estimates of total climate change impacts on wet-weather program costs are derived directly facility by facility, but applying the percent change in total annual rainfall to the total projected wet weather program costs. So for example, a facility in the Northeast with a total combined sewer overflow plus infiltration/inflow program cost of \$100 million is projected to have an increase in wet-weather program costs associated with climate change impacts of between \$8.03 and \$7.78 million, depending on the GHG emissions scenarios.
- Summer high temperatures were determined for each region, as tabulated in Exhibit C6-2. Based on consultations with wastewater regulatory experts in California and Oregon, temperature limitations on wastewater discharges to salmonid streams might be limited to 72.5 to 80°F. Therefore cooling systems may need to be installed to meet temperature TMDL

limitations for salmonids. For California and the northwest region, cooling systems are assumed to be required when summer average temperatures exceeded 22.5°C (72.5°F). Cooling systems were estimated to range from \$10,000 to \$60,000 per mgd per °F, depending on whether evaporative or mechanical cooling systems are used (2003 dollars) (CH2M HILL-HDR, 2003). \$77,000 per mgd, per °F difference between projected and 72.5° F target was assumed in 2009 dollars.

EXHIBIT C6-2
Change in Precipitation and Temperature

Region	Annual % Precipitation Change (Mid GHG)	Annual % Precipitation Change (High GHG)	Summer High Temp. °C (Mid GHG)	Summer High Temp. °C (High GHG)
Northeast	8.03	7.78	28.09	27.76
Southeast	(0.57)	2.15	31.86	31.56
Midwest	4.55	2.83	30.50	30.90
Central Plains	1.93	1.10	33.71	33.39
Northwest	3.81	3.27	26.13	26.21
Southwest	9	9	38.23	38.05
Alaska	25	4	22	25
Hawaii	8.00	8.00	30	32
Puerto Rico	37	37	31.86	31.56

- Sea level rise impacts were calculated for all wastewater facilities on the coast or in tidal areas. These systems were located by using GIS spatial overlay with a buffer of 5 miles from the coastline, including tidal estuaries. This approach is intended to capture all tidally sensitive systems, and not just those with ocean discharges, as illustrated for the Chesapeake Bay and Delaware Bay below (Exhibit C6-3).

EXHIBIT C6-3
Chesapeake and Delaware Bay Sea Level Rise Impacts



- For all coastal systems, a range of sea level protection measures was assumed from raising levee walls to installing new 10- to 20-foot-high earthen levees. These were estimated in the Pacific Institute using USACE cost estimating procedures to be \$530/LF and \$1,500/LF respectively (in 2000 dollars). The perimeter length of wastewater facilities was estimated based on assumption that facilities require 1 acre per mgd of capacity and that facility sites are square in shape (Glen Daigger, CH2M HILL, personal communication, September 16, 2009).
- All coastal wastewater systems are assumed to require effluent pumping systems to raise the hydraulic grade line in the plant. The cost of these systems are estimated using CH2M HILL's CPES cost estimation system, for plants ranging from 10 to 100 mgd. Based on that analysis, a relationship was developed for effluent pump stations of $\$ = X \times (474,900 \times X^{-0.1777})$ where X is the flow of the facility in mgd.
- Wastewater plants along inland waterways were located for the 100- and 500-year floodplain maps available using the Q3 GIS data layers from FEMA. Those plants are assumed to require additional flood protection by raising levee walls using the same unit cost and methods used for coastal plants. High and low costs are estimated for plants in the 100-year floodplain, and then for the 100- and 500-year floodplain.
- A range of costs is derived by adding the costs for all components, using high and low GHG estimates, and high and low sea level rise cost estimates (Exhibit C6-4).

EXHIBIT C6-4
Wastewater Data Table

Region	Data	Total Cost (\$1,000)
Northeast	Sum of Total Wastewater Costs (Low)	\$6,280,000
	Sum of Total Wastewater Costs (High)	\$11,500,000
Southeast	Sum of Total Wastewater Costs (Low)	\$1,520,000
	Sum of Total Wastewater Costs (High)	\$3,950,000
Midwest	Sum of Total Wastewater Costs (Low)	\$1,780,000
	Sum of Total Wastewater Costs (High)	\$1,260,000
Central Plains	Sum of Total Wastewater Costs (Low)	\$323,000
	Sum of Total Wastewater Costs (High)	\$414,000
Northwest	Sum of Total Wastewater Costs (Low)	\$765,000
	Sum of Total Wastewater Costs (High)	\$1,600,000
Southwest	Sum of Total Wastewater Costs (Low)	\$2,150,000
	Sum of Total Wastewater Costs (High)	\$3,337,000
Alaska	Sum of Total Wastewater Costs (Low)	\$180,000
	Sum of Total Wastewater Costs (High)	\$228,000
Puerto Rico	Sum of Total Wastewater Costs (Low)	\$172,000
	Sum of Total Wastewater Costs (High)	\$394,000
Hawaii	Sum of Total Wastewater Costs (Low)	\$232,000
	Sum of Total Wastewater Costs (High)	\$454,000
Total Sum of Total Wastewater Costs (Low)		\$13,300,000
Total Sum of Total Wastewater Costs (High)		\$23,100,000

C.7 Summary of High and Low Estimate Assumptions

For each water and wastewater adaptation measure, low and high cost estimates were developed to represent the range of costs that might be incurred. Exhibit C7-1 summarizes the assumptions associated with the low versus high estimates.

EXHIBIT C7-1

Low and High Cost Estimate Assumptions for Water and Wastewater Climate Change Adaptations

Adaptation Measure	Assumptions for Low Cost Estimate	Assumptions for High Cost Estimate
Drinking Water		
Source Water	Lowest projected runoff. Highest projected shift in runoff timing (see Appendix Sections C2 and C3 for details on methodology used).	Highest projected runoff. Lowest projected shift in runoff timing (see Appendix Sections C2 and C3 for details on methodology used).
Treatment–Filtration and GAC	Temperature based on A1B (medium) emissions scenario.	Temperature based on A2 (high) emissions scenario.
Coastal Flood Protection	Based on wastewater cost projections—see assumptions below.	Based on wastewater cost projections—see assumptions below.
Inland Flood Protection	Based on wastewater cost projections—see assumptions below.	Based on wastewater cost projections—see assumptions below.
Wastewater		
Wet Weather	Annual Runoff based on A1B (medium) emissions scenario, except in Southwest where took historic change in high intensity storms (Fig. p.42 in GCRP).	Annual Runoff based on A2 (high) emissions scenario, except in Southwest where took historic change in high intensity storms (Fig. p.42 in GCRP).
Coastal Flood Protection	All WWTPs on the coast, with assumed unit cost for raising levees from Pacific Institute report.	All WWTPs on the coast, with assumed unit cost for new 10- to 20-foot levees from Pacific Institute report.
Inland Flood Protection	All inland WWTPs within 100-year floodplain based on FEMA Q3 GIS mapping, with assumed unit cost for raising levees from Pacific Institute report.	All inland WWTPs within 100- and 500-year floodplain based on FEMA Q3 GIS mapping, with assumed unit cost for raising levees from Pacific Institute report.
Effluent Cooling	Summer temperature above 72.5°F based on A1B (medium) emissions scenario.	Summer temperature above 72.5°F based on A2 (high) emissions scenario.

C.8 Calculation of Net Present Value of Costs to Address Climate Change for the Water and Wastewater Sectors, 2009–2050

The net present value of cost estimates, inclusive of capital and O&M, are developed for the forecast period 2009–2050, according to the following method:

- Capital cost estimates in 2009 dollars, developed according to the assumptions outlined in Appendix B and the methods described in Appendix C, are compiled into subtotals for the water and wastewater sectors in the six U.S. regions (and for Alaska, Hawaii, and Puerto Rico), and for both the low and high cost scenarios that represent the estimated range.

- These capital cost estimates are converted to annual debt service payments over the forecast period using a financing term of 30 years and an interest rate of 4.5 percent. Annual debt service payments are scheduled from 2009 through 2038, the end of the debt term. No additional capital costs are included for 2039 through 2050.
- Annual O&M costs are 10.0 percent of the initial capital cost estimate (exclusive of financing costs), and are subject to an annual inflation rate of 2.0 percent. Annual O&M costs are estimated from 2009 through 2050.
- To simplify the analysis, annual debt service payments and O&M costs begin in Year 1 (2009) of the forecast period, and are not staged or phased.
- Annual debt service payments and O&M cost estimates are added to develop total expected nominal costs for each year of the forecast period. The forecast of nominal cash flows is then discounted at the nominal discount rate (4.5 percent), per OMB guidance for evaluation periods greater than 30 years according to the formula

$$\text{estimated annual cost, year } N \div (1 + \text{discount rate})^{N-1}$$

where N is the number of the year within the forecast period (e.g., N = 1 in 2009, N = 2 in 2010, etc.).

- The total discounted costs, including capital and O&M, are then added over the forecast period to develop net present value estimates for the water and wastewater sectors in the nine U.S. climate change regions for both low and high ends of the estimated range.

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Appendix D
Information Needs



Appendix D. Information Needs

As we have assessed the effects of climate change and its impacts on regional water and wastewater services, and estimated the costs of implementing the adaptations necessary to mitigate these impacts, certain scientific data and research needs, as well as water and wastewater industry needs, have become apparent.

Scientific Data Collection and Research

Improved support for data collection and research by the scientific, academic, national laboratory, and engineering consulting technology communities is needed to:

- Reduce uncertainty in projections of climate change effects by improved and refined General Circulation Models and downscaling techniques
- Improve development and application of regional climate models for high-resolution risk assessments at a scale useful for agency and utility decision-making
- Develop a national climate observation/data collection system that collects, maintains, and disseminates standardized and relevant data on the past and current state of climate variables
- Improve understanding of changes in runoff patterns, including early snowmelt, which affects the availability of water for capture and storage, and therefore the sizing and location of facilities
- Improve decision support tools that combine climate change risk assessments with other standard utility risk assessments, such as security risk, economic risk, and system infrastructure failure risk
- Improve coordination among utilities and federal agencies that affect water supply and flood management solutions and improve their knowledge of, and responses to climate change impacts and adaptation

Industry Information

Databases and information that would help the water and wastewater utility industry to refine its climate change risk and cost assessments include those focused on the:

- Industry-wide assessment of our progress on understanding climate change impacts, and of our planning and adaptation implementation activities
- Costs associated with the planning and implementation of current climate change adaptation measures
- Differences among small, medium, and large utilities regarding the needs and opportunities for addressing climate change impacts
- A record of green infrastructure implementation, costs, and return

- Costs of developing and implementing conservation programs, and their expected returns
- Impacts of temperature increases on water quality and treatment processes
- Easy access to impacts of treatment processes on temperature and other water quality variable
- Operations and Maintenance costs including energy as a specific component of those costs
- Emergency response and recovery costs for events that are consistent with climate change projections
- Means by which we can estimate the costs of not adapting to climate change, and the costs of degrading our water and wastewater services

This combination of improved scientific understanding, and databases that collect and maintain relevant information regarding the status of the water and wastewater industry with respect to the variables and costs related to climate change, could improve the resolution of our early cost estimates included in this assessment.



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