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METROPOLITAN
WATER AGENCIES

American Water Works Association
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April 17, 2009

Committee on America's Climate Choices
The National Academies
500 5th St. NW, W603
Washington, DC 20001

**RE: Summary of Comments to the Committee on Climate Choices**

Dear Committee Members:

The Association of Metropolitan Water Agencies (AMWA), the American Water Works Association (AWWA) and the Water Research Foundation are submitting these joint comments to the Committee on America's Climate Choices. AMWA and AWWA together represent drinking water utilities of all sizes that serve more than 90 percent of the U.S. population. The Foundation sponsors research to enable water utilities to provide safe and affordable drinking water to consumers. In 2008 the Foundation established the Climate Change Strategic Initiative – a research program focused on impacts of climate change on water supplies.

Our associations are very concerned with the effects of climate change on water resources as many of the most critical impacts of global climate change will manifest themselves through the hydrologic system. Because the exact effects of climate change on water resources are uncertain and will vary by region, the drinking water, wastewater, flood management and stormwater utilities responsible for managing water resources for local communities face daunting challenges. These water utilities are already preparing to mitigate, adapt and plan for climate change in the midst of the uncertainties about the potential ranges of climate change impacts.

This joint letter summarizes the three documents being submitted for consideration during the study process. The documents include:

- **Comments on the Key Questions:** AMWA and AWWA reviewed the four key questions to be addressed by the Committee and provided responses to each. The responses include suggested short- and long-term actions and technological advances that can help the water sector address its needs related to the impacts of climate change on water resources. We submit these suggestions for the Committee to consider as recommended future actions.

- **Water Sector Statement on Climate Change and Water Resources:** In 2008 AMWA, AWWA and several other water, wastewater and storm water organizations developed a statement to Congress that identified three broad objectives that should be included in climate change legislation in order to address the nexus between climate change and water. The water sector continues to work toward the end result described in this statement and we submit these objectives for consideration as a recommended future action for the nation to respond to climate change.
- ***Implications of Climate Change for Urban Water Utilities*:** This white paper was developed by AMWA and published in December 2007. It addresses the impacts of climate change on water suppliers in various parts of the country and describes suggested adaptation and mitigation responses. As the paper provides for a full-spectrum discussion of relationships between climate change and drinking water utilities and would be of interest to all panels including the Committee, we submit it to you for consideration.

Our organizations are also jointly submitting more detailed comment letters to each of the four panels within the America's Climate Choices Study. Please forward this letter and comments to each of the four panels.

Sincerely,

Diane Van De Hei

Diane VanDe Hei
Executive Director, AMWA

Tom Curtis

Tom Curtis
Deputy Executive Director, AWWA

Robert C. Renner

Robert C. Renner
Executive Director, Water Research Foundation

Attachments:

Comments to the Committee on America’s Climate Choices
Water Sector Statement on Climate Change and Water Resources
*Implications of Climate Change for Urban Water Utilities*

## OVERARCHING THEMES

Climate change impacts many sectors, and the consequences and cross-cutting impacts of climate change must be considered across the spectrum of issues of concern in the scientific and policy realm – from research planning, to decision support, to policy making. Many of the most critical impacts of global climate change in the years ahead will manifest themselves through the hydrologic system, and there is already strong evidence that climate change is having an impact on the quality and quantity of water resources around the world. The nation's drinking water utilities are already making changes to mitigate, adapt and plan for climate change in the midst of the uncertainties about the potential ranges of climate change impacts.

Water utilities need decision-relevant information to best perform their essential job of providing safe water to the public. Right now, utilities are thinking about and analyzing how to incorporate their climate change response into water management and planning to ensure it becomes a fundamental component of how they plan for the future in terms of water supply, treatment and distribution. The water sector should be the lead in identifying its own needs and vulnerabilities, assessing and analyzing impact scenarios and developing appropriate solutions.

Because water utilities are on the front line in identifying, assessing, and responding to climate change impacts and trends, it is imperative that they be part of collaborative efforts to refine the science of climate change, the methods to address recognized risks and uncertainties and the means to incorporate climate change information into utility decision making. Vigorous engagement in understanding, improving and utilizing climate change information is necessary if utilities are to be proactive in seeking solutions to make water systems robust enough to address future growth and meet increasing regulatory requirements.

The most effective way for adaptation and mitigation strategies to be developed and implemented in the face of competing needs for limited resources is to include the water utility community as active partners with federal and academic researchers so that utilities can identify what information is needed in order to assess and prepare for the impacts of climate change. It is imperative that water utilities be partners in efforts to refine the science of climate change to create useful information and identify the most effective means by which climate change information can be incorporated into utility decisionmaking. They also must provide feedback regarding the most effective and feasible methods by which recognized risks and uncertainties can be addressed. In addition, such involvement will facilitate the development of greater institutional capacity on climate change issues in the water sector.

Climate change consequences will also vary regionally and locally, and stakeholders will need localized solutions. One sector's solution to climate change may be detrimental to another sector, and this potential conflict highlights the need for more integrated approaches that recognize unintended consequences and unrealized opportunities. For example, much of the focus of climate change mitigation has been on changing the types of energy and energy generation methods that the country uses. These changes can pose several challenges for water utility managers and regional environmental departments including:

- Increased water use and withdrawals by power plants will require expanded efforts to assure that drinking water availability is not compromised;
- Increased attention to potential nonpoint source pollution impacts of expanded agricultural production for biofuels on water quality;
- Increased monitoring of discharge permit conditions to address increased temperature and concentration of pollutants due to low flows; and
- Need for more efficient use of electrical energy at water facilities and production of power from methane at some wastewater treatment facilities.

Many of the decisions that will be made related to the type of energy generation we use as a country will undoubtedly affect drinking water utilities. Therefore it is important for scientists, policy makers and stakeholders to look at adaptive solutions and mitigation measures at the highest level across sectors to minimize cross-cutting impacts.

## RESPONSES TO KEY QUESTIONS

### What short-term actions can be taken to better inform decisions and actions related to climate change?

In the short term, utility managers need specific information on the implications of climate change on their water supply, on the energy that they need to operate their systems and on the infrastructure in which they continue to invest millions of dollars. Utility managers need the tools, resources and knowledge to include the impacts of climate change as part of utility sector planning, applied research efforts and community planning. They also must begin to think about the longer-term impacts on their customer base and their role in engaging the community on this issue.

The current state of availability of data and information to utility managers makes attaining that data and translating it into useful outputs extremely difficult. Programs conducting research and developing short- and long-term mitigation and adaptation methods related to climate change are spread throughout many different agencies and advocacy groups. Professional organizations, such as AMWA and AWWA, play an important role in consolidating this information. However, there is also a need for increased transparency and visibility on the part of researchers and planners.

A potential method for creating this transparency would be a clearinghouse or directory of information that could be made readily available for use by non-specialists in terms that they could understand. Both AMWA and the Water Research Foundation, and undoubtedly other associations and utilities, have begun to assess the current state of the knowledge for the benefit of the water sector. However, these efforts must be continued and broadened to include cross-cutting impacts with other sectors such as energy, agriculture and public health. Also, federal research efforts should evolve from this emphasis on the need to disseminate research and information to entities such as water utilities toward including water utilities in framing and identifying research needs. Elaborating on the effectiveness of "no regret", reversible and/or low cost strategies in addressing the impacts of climate change would also be helpful. Emphasizing the need to test the effectiveness of operational adjustments in enhancing system flexibility is one such strategy that should be explored and that can potentially have benefits now and in the future. Greater inclusion on the front end should lead to greater use of research by the water sector, which is in the interest of all parties.

Water utility managers need more information on the ways in which they can develop, implement and fund short-term greenhouse gas mitigation programs. With respect to energy and water efficiency, better planning, maintenance and operation of water delivery systems can provide for substantial savings to the supply side of a utility. Repairing leaking distribution systems is a major opportunity to recover water that would otherwise be lost from the system. Water utilities that invest in leak correction and detection technologies can realize significant savings in water and energy. On the demand side, the implementation and promotion of conservation programs can also effectively increase water and energy savings. Also, by encouraging water reuse and reduced water usage in the industrial sector, savings in treatment costs, including chemical consumption and energy usage, could be realized by water utilities. Currently, water managers are looking for tools that will enable them to identify these types of potential opportunities for water and energy savings and successfully incorporate them into water and energy management programs.

**Specific Example: Snowpack –** Climate change has already had a significant impact on snowpack in California's Sierra Mountains. There is agreement among the experts that the amount of snowpack is expected to significantly decrease, which will cause significant challenges for drinking water suppliers as they try to manage their water resources. The snowpack in the Sierras serves as California's largest water reservoir that typically enters the stream and river systems in the late spring and summer as it melts.

There are a number of issues related to future drinking water supply needs that must be reliably addressed to deal with reduced snowpack and increased flood flows that are anticipated because more precipitation is expected to occur as rain as opposed to snow in response to climate change. As the amount of Sierra snowpack is reduced due to global climate change, the expectation is that the snowpack will be only maintained at higher elevations and the reduction in the amount of fresh water storage as snowpack will increase the duration and frequency of flood flows during the winter months. The ability of the existing reservoirs and conveyance structures to manage more water due to reduced amount of snowfall is expected to challenge the existing source water infrastructure. The flood flows may overwhelm the Delta levees, which already are considered vulnerable due to lack of maintenance. During these flooding events, there may not be sufficient freeboard in the raw storage reservoirs to capture the flood flows, which will then be discharged through the Delta into the Bay. The ability to capture this water for use during the summer and late fall is questionable. Drinking water suppliers will be challenged to meet summer water demands without the capture of this water supply. While snowpack reduction may be primarily a western water issue, it is important to recognize that these types of needs must be addressed in the short term because long-term solutions, such as new reservoir projects, will take a long time to implement.

**Specific Example: Sea Level Rise –** Potentially the most damaging climate change impact is sea level rise. Yet very little is being done to describe the inundation and storm threat this poses or to quantify the structural requirements needed to minimize this impact across the board, in transportation, housing, ports, industry and water/wastewater infrastructure. Without such information, major national policy to adopt a "defend or retreat" strategy cannot be conducted. All utilities within low-laying coastal areas will have to address the defend-or-retreat decision at some point, but in the meantime, investment decisions are being made every day on siting new facilities and renovating existing ones. The sooner that good information is readily available, the sooner good investment decisions can be made and poor ones avoided. More accurate elevation maps are needed, as well as up-to-date maps of current floodways and localized estimates of sea level rise.

## What promising long-term strategies, investments, and opportunities could be pursued to better inform decisions and actions related to climate change?

Support for research to better project future climate conditions and their impacts on water supply and to develop appropriate response technologies, is critical. A deliberate shift to sustainable energy sources is certainly indicated for a variety of reasons, including the need to mitigate carbon emissions. Water conservation is probably the leading “no regrets” strategy for drinking water utilities. Additional research regarding the most effective ways to accomplish these strategies is certainly indicated and necessary. This research should be targeted on a regional level, as the approaches for implementing these strategies will vary depending upon the particular issues facing each region. For example, in the arid portions of the western United States, snowpack conditions and the resulting reservoir runoff concerns may be much less of an important factor than addressing potential flooding or sea level rise impacts.

The impact of climate change on groundwater is an area where research is sorely lacking. Groundwater basins usually cross multiple jurisdictional, interstate, and even international boundaries, and this resource is currently heavily utilized to meet agriculture and municipal needs. Groundwater is also being evaluated to meet future water needs when surface water sources are not available or under increasing stress. The federal government is in a unique and necessary position to facilitate groundwater studies, particularly through the U.S. Geological Survey (USGS) and the Natural Resources Conservation Service (NRCS).

## What are the major scientific and technological advances (e.g., new observations, improved models, research programs, etc.) needed to better inform decisions and actions related to climate change?

Utility managers require scientific and technological advances to help them better analyze the local impacts on their water systems. These could include:

- Climate modeling and more localized resource modeling that can characterize different climate scenarios;
- Development of more regional climate models to enable a better downscaled application of climate data to the topography and proximity to ocean conditions (the effort will be a long-term proposition, as many alternative methods will no doubt need to be tried and discarded to determine the most effective tools, but the availability of this information is imperative);

- Simple and understandable tools that can cut through the complexity and range of precipitation modeling, although its near-term feasibility is debatable;
- Development of understandable and usable statistical methods to identify significant trends in climate patterns [identification of climate trends in past and occurring climate patterns as distinct from past variation is difficult and can be subject to misinterpretation (examples of this include shifts in precipitation patterns, more intense storm events, changes in overall water output from a given sub-basin or temperature trends - particularly high temperatures during summer months)];
- The ability to evaluate and revise flood rule curves on existing Corps of Engineers and Bureau of Reclamation projects, which is an important aspect of utilizing downscaled GCM data and applications to hydrologic models; and
- Research and development of alternative treatment technologies that are more efficient and effective in addressing potential future water quality scenarios. This is particularly true due to the trend toward use of more energy-intensive advanced treatment technologies to address new regulatory requirements.

Even in areas of lower annual average precipitation, changes in intensity could lead to increased flooding. All flood planning (including water/wastewater infrastructure) is based on current and often out of date FEMA flood plain maps and on storms-of-record. Increased intensity of storms would render current flood-plain maps and storm of record calculations inadequate. Some form of assessment is needed on a region-by-region basis of the potential and possible magnitude for such changes. Scientists and engineers are finding that past methods of design and planning are unlikely to be suitable given the high uncertainty of global climate change. A new approach is needed to guide public agencies in making decisions about infrastructure that could exist for 100 years or more.

The Water Utility Climate Alliance (WUCA) has commissioned the development of a white paper to assess the strengths and limitations of GCMs, RCMs and downscaling in assessing the impacts of climate change on water supply systems. The paper will also identify, to the degree they exist, investments that can be made to improve the usefulness of these tools for the water sector. We would be happy to share this document with the Academy when it is completed. An abstract of this paper is included as an attachment of our submittal to the effective decisions panel.

## What are the major impediments (e.g., practical, institutional, economic, ethical, intergenerational, etc.) to effectively informing decisions and actions related to climate change, and what can be done to overcome these impediments?

Resource constraints and diversion of public attention in the current world of great economic uncertainty are probably the major impediments to maintaining focus on climate change issues. As the U.S. begins to engage much more directly and affirmatively on the world stage with respect to climate change, it seems likely that the international community may agree on protocols and actions. Over the past decade, there has been significant activity at the local and regional levels.

Making effective decisions and taking effective actions regarding mitigation of and adaptation to climate change requires a basic understanding of the practical impacts of climate change. Current climate change information is often physically inaccessible or written in a way that is difficult to understand for the non-specialist. Researchers must work with water utilities to ensure that information is presented in terms that are understandable and that it is made available through resources that utility managers know and trust.

There are some federal and interstate arrangements that may need to have increased flexibility to accommodate impacts from climate change. The water rights structure has been identified by some states to be both an impediment and an opportunity for adaptation to climate change impacts. Our comments to the adaptation panel address this issue in more detail.

Climate change services should be approached differently than weather services. What is needed is not a "forecast" but a roadmap of the future to inform decision support activities. The roadmap would address questions such as:

- What are the long-term future impacts?
- What routes lead to each of these impacts?
- What interim climate conditions can be expected on each route and which climate and policy milestones will determine the route of the future?
- Knowing these elements of the roadmap, how does this relate to short-term and long-term planning?

## What can be done to more effectively inform decisions and actions related to climate change at different levels (e.g., local, state, regional, national, and in collaboration with the international community) and in different sectors (e.g., nongovernmental organizations, the business community, the research and academic communities, individuals and households, etc.)?

Climate change is typically not considered holistically across all sectors in a geographic region, resulting in stove-pipe decision making. In order to determine the best use of available resources to address climate change, effective communication is needed between all of the different impacted sectors and stakeholders. This will allow for the development of a comprehensive local approach to the impacts of climate change that addresses local land use, population growth and other factors.

Effective communication across all of these sectors is important so that information about what works and what doesn't can be used to avoid repeating mistakes. Each sector needs to organize to share information particular to its operations, and at the same time, sectors must interact to optimize adaptation plans from individual communities to regions to states and to the nation. This interaction will identify additional specifically targeted research needs to be addressed by the scientific community.

As noted in our comments to the CCSP, AMWA and AWWA believe that climate change research should be conducted using "more user input and involvement to increase salience, legitimacy, and trust." This dialogue should begin when research is initiated to maximize opportunity for input from stakeholders and increase understanding of the research.

Climate change researchers, including governmental agencies, should work to develop partnerships with water sector organizations to improve communication and input between researcher organizations and the water sector.

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WUCA
Water Utility Climate Alliance

Water Environment Federation®
Preserving & Enhancing the Global Water Environment

NACWA
A Clear Commitment to America's Waters

WESTERN URBAN WATER COALITION
"For the Future of the West"

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**May 20, 2008**

# Water Sector Statement on Climate Change and Water Resources

To address the water resource challenges that climate change will bring, this coalition of major water associations calls on Congress to ensure that water resources are a central element of any federal legislation that establishes a framework for a comprehensive national response to climate change. The nation's existing drinking water, stormwater, flood management, and wastewater infrastructure is already in need of significant investments to maintain current levels of service over the coming decades, and climate change only exacerbates the need for additional resources. Federal law and policy on climate change must fully consider the effects on water supply and all elements of water management and treatment, and include provisions for increases in federal financial support and incentives to stimulate other forms of investment for responses ranging from research to mitigation and adaptation tools to infrastructure needs. These responses will be most effective when support and investments are undertaken in partnership with states, local governments, and the private sector.

Many of the most critical impacts of global climate change will manifest themselves through the hydrologic system, and there is already strong evidence that climate change is having an impact on the world's water resources. These impacts include changing precipitation patterns that may result in more severe drought or floods, changing snowpack amount and elevation, varying stream flow patterns, and rising sea levels along the coasts. Because the exact effects of climate change on water resources are uncertain and will vary by region, the drinking water, wastewater, flood management, and stormwater utilities responsible for managing water resources for local communities face daunting challenges. These utilities have relied upon historical precipitation patterns to manage source water supplies, stormwater runoff, and wastewater conveyance and treatment. Even as these patterns change, water systems must continue to provide uninterrupted, high-quality service to their present customers, and many must also accommodate rapidly growing populations.

Specifically, our coalition calls on Congress to:

1. Establish a comprehensive, coordinated and federally sponsored applied research program that addresses:

    - Predictive and decision-support tools, including necessary data resources, to help utilities plan for the future impacts of climate change. These tools and resources should include climate models that forecast precipitation changes and address other issues pertinent to water quantity and quality on a national, regional, and subregional scale; climate models that address sea level rise and its effect on coastal water supplies; and assessments to determine – on a national, regional, and subregional scale – the vulnerability of different regions to the anticipated impacts of climate change over different timeframes.

- Mitigation and adaptation strategies focused specifically on impacts of climate change on water quality and quantity, stormwater and flood control management and wastewater treatment. Examples of areas where research is needed include methods to increase water conservation; energy efficiency management techniques that help water utilities reduce their own greenhouse gas emissions; the development of alternative water sources such as reuse, recycling, and desalination; and multiple benefit quantification analysis of such practices as urban tree cover and green roofs to both control stormwater runoff and help cities adapt to the consequences of climate change.

- Surface and ground water resource impacts of new energy technologies such as biofuel development and mitigation strategies such as carbon sequestration projects.

2. Increase federal and other financial support, including the utilization of greenhouse gas emission auction revenues, to assist drinking water, stormwater, flood management, and wastewater utilities to adapt to climate change and address environmental and public health risks that could result from changes to the hydrologic environment. For example, we anticipate that potential public health risks could result from higher water temperatures breeding higher concentrations of certain organisms, from changes in ambient water quality, or from more intense rainfall events. These factors could compromise treatment processes, restrict wastewater utilities' ability to discharge effluent and cause greater risk of sewage overflows. We also anticipate that drinking water, wastewater and stormwater infrastructure enhancements will be necessary to deal with regionalized impacts of these consequences.

3. Provide federal support and incentives to enable utilities to reduce greenhouse gas emissions when feasible. While most greenhouse gas reductions will come from other sectors, utility managers around the country are nevertheless engaged in a variety of efforts to lower the greenhouse gas emissions of their utilities. Utilities that have taken proactive steps to reduce their emissions should be given credit for these advanced efforts under any new regulatory program that is implemented, including cap and trade programs.

Drinking water, wastewater, flood management and stormwater utilities will be among the principal actors dealing with the challenges that climate change will force upon our communities. Our members already struggle daily in meeting current demands placed on our water infrastructure and climate change will only exacerbate the resources needed to provide safe and clean water to the American people. We call upon our nation's leaders to consider water resources as a key element in upcoming climate change legislation and to provide the necessary support and leadership to ensure that the nation's water utilities have the tools and resources necessary to address the climate change challenge.

# #

Supporting Organizations:

American Water Works Association
Association of Metropolitan Water Agencies
National Association of Clean Water Agencies
National Association of Flood and Stormwater Management Agencies
National Association of Water Companies
Water Environment Federation
Western Urban Water Coalition
Water Utility Climate Alliance

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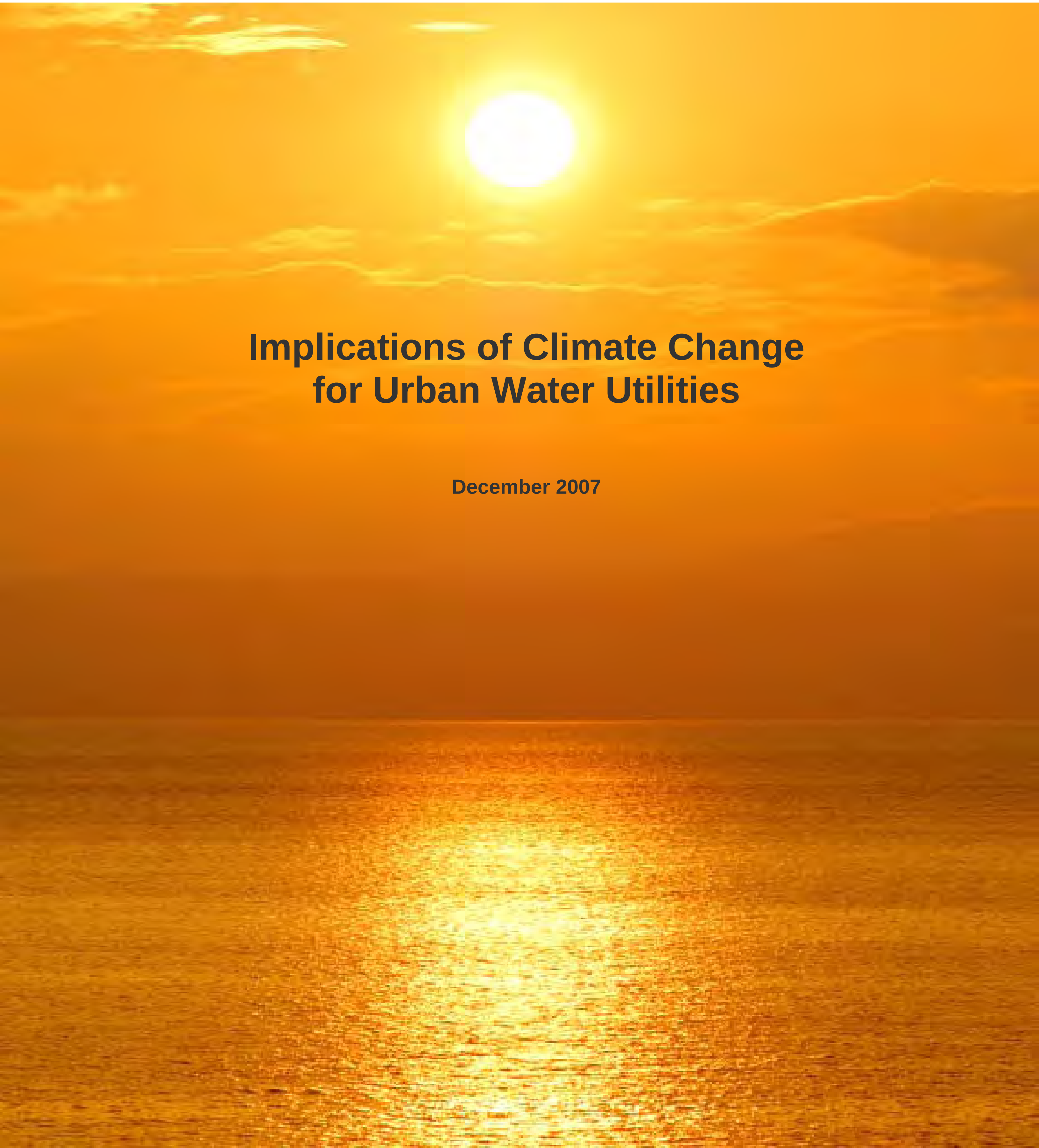

# Implications of Climate Change for Urban Water Utilities

December 2007

# Implications of Climate Change for Urban Water Utilities

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*The Association of Metropolitan Water Agencies is a nonprofit organization of the largest publicly owned drinking water systems in the United States. Member-utilities collectively serve more than 127 million people with safe drinking water.*

## 1. INTRODUCTION

There are many parts to the climate change story that come together to produce a picture of potentially significant implications for urban water utilities. This can create an information overload that, coupled with uncertainties, presents a barrier to understanding and to developing responses. This paper is designed to help move past this initial barrier in order to draw an effective focus on implications and responses. The story is broken into its main elements and considered in logical sequence without tangential details that are documented sufficiently in the scientific literature. The intent is to provide an essential understanding and then turn to consideration of the issues involved in developing suitable water sector responses to climate change.

A general description of climate change processes and effects follows the introduction. Impacts of these climatic changes on water suppliers are then identified and described, including regional differences. Responses to climate change are then discussed, both in terms of “adaptation strategies” to reduce or avoid impacts of climate change, and in terms of “mitigation strategies” that utilities may adopt to reduce the contribution of water utility operations to the production of greenhouse gas (GHG) emissions.

## 2. CLIMATE CHANGE PROCESSES

The understanding of climate change processes is supported by extensive scientific consensus that has been growing continually over the last twenty years and which will not be repeated here. This consensus has been led by the Intergovernmental Panel on Climate Change (IPCC), which was recently awarded a share of the Nobel Peace Prize for its efforts. The role of the IPCC, which involves thousands of scientists from around the world, is to assess the science of human-induced climate change, mainly on the basis of peer reviewed and published scientific/technical literature.

In 2006, the National Center for Atmospheric Research (NCAR) produced a primer on climate change for the American Water Works Association Research Foundation (AwwaRF) that provides a comprehensive overview of the current science supporting the understanding of climate change processes and effects. It builds on the consensus findings of the Third Assessment Report of the IPCC, published in 2001, and closely matches findings of the Fourth Assessment Report of the IPCC, published in 2007.

### 2.1 Increasing Temperature

NCAR defines climate change as any persistent change in the statistical distribution of climate variables. The fundamental climate change process is global warming. Increases in carbon dioxide ($CO_2$) and other GHGs resulting from human activities have caused a radiative heating effect that traps solar energy in the atmosphere that would otherwise be dissipated back into space. This has contributed to an increase of about 0.74°C (1.3°F) in global average temperature since 1900. There is a consensus that GHGs produced by human activities have already caused an increase in global mean temperature.

This trend is expected to accelerate as we continue to add GHGs to the atmosphere. By 2100, the additional rise in global average temperature is projected to be in a range of 1.1 to 6.6°C (~ 2 to 12°F) above 1990 levels. There is little doubt that this climate change process will continue to cause such warming for a long period into the future, even if it were possible to suddenly and drastically reduce GHGs. The range in estimates of the degree of warming that will occur between now and 2100 reflects the developmental state of the art of modeling global climate processes. Two factors stand out. One is that there is uncertainty about how much warming will happen with a given concentration of GHGs. For example, the IPCC concluded that there is a two-thirds chance that global temperatures will rise 2 to 4.5°C with a doubling of $CO_2$ levels in the atmosphere. That means there is a one-third chance the warming could be lower or higher than that range. A totally different source of uncertainty is introduced by the fact that modeling the climate in 2100 requires input assumptions regarding the rate of growth of GHG emissions. These reflect uncertainties about future development paths including population growth, economic growth and technological changes. It is not surprising, therefore, that climate models produce varying estimates of both $CO_2$ concentrations and global mean temperature. However, they all confirm the warming trend and predict it will accelerate within the next few decades.

### 2.2 Increasing Evaporation and Precipitation

One of the simplest ways to envision the effect of global warming on water resources is to follow the logic of what happens when water is heated; global warming will basically accelerate the pace of the hydrologic cycle. Warmer temperatures will cause water to evaporate more readily and cause the total amount of precipitation to increase at a global level. This accelerated hydrologic cycle is logically projected to result in an overall increased intensity of rainfall events. Consistent with the fact that global warming has already been occurring during the last century, streamflow records already document this increase in storm intensity.

In contrast to these consistent predictions of the effect of warming on the total amount of precipitation globally, forecasts of the amount of precipitation vary greatly from one region to another. Areas in the high latitudes and some wet tropics are generally expected to see increased precipitation, while dry regions in the mid-latitudes and the dry tropics are generally expected to see decreases in total precipitation. Climate models exhibit the least consistency with one another in predicting precipitation at a regional level; especially in the mid-latitudes.

At one extreme, warmer temperatures imply that areas subject to drought may see more extensive drought and heat wave events while, at the other extreme, areas accustomed to snowfall will see warmer winters. Warmer and shorter winters are already implicated in the reduction in the amount of water stored as ice in glaciers, and in seasonal snowpacks. The shorter cold season means that the spring melt can arrive much earlier and have significant implications for streamflows available downstream in late summer and early fall.

### 2.3 Rising Sea Level

With warmer temperatures, the oceans expand (because water expands in volume when heated) and glaciers and ice sheets melt, causing sea level to rise. Sea level is projected by the IPCC to rise from 0.2 to 0.6 meters by 2100. This assumes no catastrophic losses of either the Greenland or Antarctic ice caps. Studies which account for such melting find that rates of sea level rise could be well above one meter by 2100. The IPCC itself notes that it is difficult to project an upper bound for sea level rise.

## 3. IMPACTS ON WATER SUPPLIERS

It is important to make a distinction between the *processes* of climate change and the *impacts* on water suppliers resulting from these changes. Although global warming is fairly straightforward, the impacts on water suppliers may involve many additional cause and effect relationships.

It has become commonplace to mix discussion of the basic processes of climate change, for which there is good evidence documenting changes already underway (e.g., temperature rise), together with discussion of *impacts* that are more remote and uncertain in terms of both the chain of causation and timing. Weaving the story together in this way can add to information overload and leave an impression that impacts are already occurring at full strength when, in fact, their onset is still unfolding. The incidence of any given impact may come about as a threshold effect, or as a tipping point phenomenon, or as a smooth gradient, or in a number of ways. Recent extreme events such as droughts may support a belief that impacts are already upon us. While this may be the case, the worst may still be yet to come. We therefore have a need to understand much more about the cause and effect relationships that produce impacts. To emphasize these distinctions, *impacts* are discussed separately in this paper and further distinguished between direct impacts, indirect impacts, and compound impacts.

### 3.1 Direct Impacts

Direct impacts are defined as resulting from the effects of climate change on water utility functions and operations. In Exhibits 1 through 4, the direct impacts on water utilities are summarized for major regional scenarios in the form of simple cause and effect outlines.

### Exhibit 1 – Climate Change Impacts in the Mountain West

- Warmer and shorter winter seasons
    - Increased glacial melting
    - Decreased seasonal snowpacks
    - More rain, more rain-on-snow, and earlier spring snowmelt
        - Altered recharge of groundwater aquifers
        - Earlier runoff into surface waters
            - Lower summer/fall base flows in surface waters
            - Lower summer/fall reservoir levels
- Warmer and potentially drier summer seasons
    - Changes in vegetation of watershed and aquifer recharge areas
        - Altered recharge of groundwater aquifers
        - Changes in quantity and quality (e.g., TOC, alkalinity) of runoff into surface waters
    - Increased water temperature
        - Increased evaporation and eutrophication in surface sources
        - Water treatment and distribution challenges (disinfection, byproducts, regrowth)
    - Increased water demand
        - Increased irrigation demand in longer growing season
        - Increased urban demand with more heat waves and dry spells
        - Increased drawdown of local groundwater resources to meet the above
- More frequent and intense rainfall events
    - Increased turbidity and sedimentation
        - Loss of reservoir storage
            - Shallower, warmer water; increased evaporation and eutrophication
            - Potential conflicts with flood control objectives
        - Water filtration or filtration/avoidance treatment challenges
    - Increased risk of direct flood damage to water utility facilities

**Exhibit 2 – Climate Change Impacts in the Southwest**

- Warmer and probably drier overall with more extreme droughts and heat waves
    - Likely reduced quantities of surface water available from local runoff
    - Likely reduced quantities of water available to recharge groundwater aquifers
    - Very likely increased evaporative losses in inter-basin transfers of surface waters
    - Changes in vegetation of watershed and aquifer recharge areas
        - Altered recharge of groundwater aquifers
        - Changes in quantity and quality (e.g., TOC, alkalinity) of runoff into surface waters
    - Increased water temperature
        - Increased evaporation and eutrophication in surface sources
        - Water treatment and distribution challenges (disinfection, byproducts, regrowth)
    - Increased water demand
        - Increased irrigation demand
        - Increased urban demand with more heat waves and dry spells
        - Increased drawdown of local groundwater resources to meet the above
        - Increased difficulty of maintaining minimum in-stream flows in surface waters
- More intense rainfall events
    - Increased turbidity and sedimentation
        - Loss of reservoir storage
            - Shallower, warmer water; increased evaporation and eutrophication
            - Potential conflicts with flood control objectives
        - Water filtration or filtration/avoidance treatment challenges
    - Increased risk of direct flood damage to water utility facilities

**Exhibit 3 – Climate Change Impacts in the Humid East and Midwest**

- Warmer overall
    - More rain with seasonal shift
        - More rainfall in winter and late spring
        - Potentially less rainfall in late summer and fall with more extreme droughts
            - Lower summer/fall base flows in surface waters
            - Lower summer/fall reservoir levels
    - Changes in vegetation of watershed and aquifer recharge areas
        - Altered recharge of groundwater aquifers
        - Changes in quantity and quality (e.g., TOC, alkalinity) of runoff into surface waters
    - Increased water temperature
        - Increased evaporation and eutrophication in surface sources
        - Water treatment and distribution challenges (disinfection, byproducts, regrowth)
    - Increased water demand
        - Possible increased urban demand during drought periods
- More intense rainfall events
    - Increased turbidity and sedimentation
        - Loss of reservoir storage
            - Shallower, warmer water; increased evaporation and eutrophication
            - Potential conflicts with flood control objectives
        - Water filtration or filtration/avoidance treatment challenges
    - Increased risk of direct flood damage to water utility facilities

**Exhibit 4 – Climate Change Impacts in Coastal Regions**

- Rising Sea Levels
    - Increased saline intrusion into groundwater aquifers
        - Water treatment challenges: increased bromide; need for desalination
    - Increased salinity of brackish surface water sources
        - Water treatment challenges: increased bromide; need for desalination
    - Increased risk of direct storm and flood damage to water utility facilities
- Warmer overall
    - Changes in discharge characteristics of major rivers due to upstream changes
    - Changes in recharge characteristics of major groundwater aquifers due to upstream changes
    - Increased water temperature
        - Increased evaporation and eutrophication in surface sources
        - Water treatment and distribution challenges (disinfection, byproducts, regrowth)
    - Possible increased water demand
        - Increased irrigation demand
        - Increased urban demand with more heat waves and dry spells
        - Increased drawdown of local groundwater resources to meet the above
- More intense rainfall events
    - Increased turbidity and sedimentation
        - Loss of reservoir storage
            - Shallower, warmer water; increased evaporation and eutrophication
            - Potential conflicts with flood control objectives
        - Water filtration or filtration/avoidance treatment challenges
    - Increased risk of direct flood damage to water utility facilities

These cause-effect outlines illustrate the possible direct implications of climate change for utilities in the Mountain West, the Southwest, the humid East/Midwest, and in coastal areas. A number of similarities are evident across regions, but there are distinct differences also. In addition, the coastal checklist could be merged with any of the others wherever larger regions encompass both types of conditions.

The impacts indicated on these outlines are not expected to emerge all together or at once. As discussed above, there are gradient functions, threshold effects, and conceivably many other influences involved in the chain of causation that will stretch impacts over time. With many climate scientists predicting an accelerating pace of change over the next several decades, these prospective impacts have meaning for today's mid-to-long term (20-50 year) planning. We have every reason to believe these impacts are coming toward us. But utility planners will have to grapple with many of them prospectively rather than as phenomena that are already observable, except at the leading edge of the trend.

These cause-effect outlines make it possible to scan the full spectrum of potential direct impacts in a one-page summary for each regional scenario that follows a simple logic and organizes the impacts into related groupings. Taken together, it is believed that these four outlines provide complete coverage of direct impacts. Despite some common elements between them, it is also believed that these four constitute the minimum set needed to cover all the direct impacts. This first iteration of these impact outlines is regarded as a work-in-progress and refinements are invited to help improve it.

### 3.2 Indirect Impacts

Indirect impacts are defined as resulting from the effects of climate change on the baseline environment in which water utility functions and operations are carried out. In short, this distinction emphasizes the fact that the baseline operating environment is also changing. Our understanding of the impacts of climate change and our responses must incorporate this critical dimension.

There are at least three major categories of indirect impacts on water supply utilities that could result from the impacts of climate change on environmental and socioeconomic systems. Although these impacts are indirect, they are nonetheless profound and deserve as much attention as the direct impacts. In fact, there are some instances where indirect impacts may be more significant than the direct impacts. Unlike the direct impacts, the main categories of indirect impacts apply uniformly through all regions of the country.

**3.2.1 Baseline impacts on terrestrial and aquatic ecosystems.** Changes in basic climate variables such as temperature, rainfall, seasonal patterns, runoff characteristics and recharge patterns of both ground and surface waters can produce significant baseline changes in both terrestrial and aquatic ecosystems.

Changes in the vegetative composition of terrestrial ecosystems can change the baseline geophysical and chemical character of watershed runoff and of waters recharging groundwater aquifers. The character of clay and silt particles comprising turbidity could be changed by changed runoff patterns. The chemical composition of the total organic carbon (TOC) yielded by a source water could be changed by the change in vegetative species composition. In drier conditions, wild fires are a well-known menace to surface water treatment that could become more prevalent. Pest infestations and other changes in the species composition of terrestrial ecosystems that are unfavorable to water harvesting could also emerge.

Baseline changes in aquatic ecosystems could change the survivability and critical habitat requirements of threatened aquatic species. There are many situations across the country where in-stream flow requirements have been, or are being, negotiated to provide sufficient cold water to sustain fish species during summer/drought periods. In estuarine settings, the goal is to provide critical levels of freshwater inflow to maintain tolerable salinity levels during summer/drought periods.

**3.2.2 Baseline impacts on water pollution.** Increased frequency and intensity of rainfall is one of the most immediate effects of global warming that is already apparent in streamflow records from the last several decades. The expectation is that more severe storms will produce more severe flooding. This will inevitably result in additional water pollution from a large variety of sources. Chief among these are wastewater treatment, storage, and conveyance systems. Preliminary work by EPA has confirmed that, for the most part, wastewater treatment plants and combined sewer overflow control programs have been designed on the basis of the historic hydrologic record, taking no account of prospective changes in flow conditions due to climate change. As a result, it is conceivable that water suppliers will face a continually increased influent challenge from sewage overflows producing high concentrations of *Giardia*, *Cryptosporidium* and coliforms.

**3.2.3 Baseline impacts on socioeconomic systems.** Regardless of whether the water and wastewater utilities are separate organizations or combined as a single organization, their fates are always closely tied together by the water bill because affordability is indifferent to organizational distinctions. Threats to the cost-effectiveness of wastewater programs raised by climate change can have consequences for the water utility because capital resources and ratepayer resources are constrained. If the wet weather programs referred to above require expensive re-sizing to manage higher flows, it may reduce influent challenges for water utilities, but will still have an impact on the water supply side of the business through this financial connection. A different and equally worrisome set of financial threats to wastewater utilities may result from the dry weather extremes of climate change since discharge permits and waste load allocations are quite often grounded in the low flows documented in the historic hydrologic record.

At a regional level, existing institutional relationships between utilities (and other agencies involved in water management) may come under stress due to climate change. Climate change may be expected to affect every organization involved in regional collaborations, but it is less likely to affect every organization in equal measure. There may be winners and losers. The win-win equation that supported the existing constellation of interests may be thrown out of balance and require adjustment to suit everyone's interests in the new conditions. Moreover, because the baseline operating environment is changing and will continue to change in a manner that may not be linear, it may not be sufficient to simply replace old arrangements with new ones; it may be necessary to develop and apply a completely different dynamic in conceiving and managing institutional relationships.

At the very highest level of abstraction, coping with climate change challenges baseline concepts of environmental quality and environmental protection. We have a well-rooted understanding of the objectives of these efforts in a static world. What are the objectives in a world where the baseline environment is changing; do we muster to fight the warming trends and preserve the status quo, or is there a need for a more dynamic approach to managing environmental quality going forward? What is sustainability in the context of a changing baseline? Devising new partnering relationships with stakeholders and regulators will be pivotal in solving this part of the problem.

### 3.3 Compound Impacts

Not only does each individual type of direct and indirect impact exert its own effect on a utility, but the cumulative effect can amount to much more than a summation. Because many of the individual direct and indirect impacts affect the same natural systems or utility systems, the total impact can be magnified. It has more of the character of a compounding process. There are many conceivable challenges relating to water treatment, for example, that may have to be met in order to cope with alternative water sources in response to climate change. Evaluating them individually may not reveal all the issues, but looking at all of them together could indicate the need for a more extreme treatment solution (e.g., membrane treatment). Unintended side effects also result from such complex optimizations. It may not be a simple matter, for example, to distribute membrane treated water through an aged distribution system. Side effects could be manifest as health threats (e.g., efficacy of disinfection), or as destabilizing factors that could shorten the useful life of millions of dollars worth of buried assets.

## 4. RESPONSES TO CLIMATE CHANGE

Many water utilities have begun to respond to climate change through "adaptation" measures to modify plans and operations to minimize impacts. These adaptation efforts fall into two broad categories. The first consists of vulnerability analyses that are intended to identify the most near-term priorities in places where impacts could be felt the soonest. The second is long-term planning, or more formally, Integrated Resource Planning (IRP) that adopts the broadest possible strategic view of how a utility can plan to cope with such systemic changes over the longer term. Both of these types of adaptation responses are discussed individually below.

In addition, utilities are responding through adoption of measures to help mitigate the onset of climate change by reducing energy consumption that contributes to the production of GHGs. These efforts are also described in a final section, below.

### 4.1 Vulnerability Analysis

Water utilities across the country have initiated research efforts to investigate their vulnerability to climate change processes. Such efforts attempt to obtain a better analytical assessment of the possibility that current water resource development and facility plans could be disrupted by near-term (20-50 year) manifestations of climate change processes. This initial focus on vulnerability is a good means of identifying a utility's priority issues relating to climate change and laying the groundwork for follow-up actions. Two alternative approaches to vulnerability analysis have been articulated: "top-down" and "bottom-up." Many initial vulnerability analyses have related to water resource and facilities planning. However, direct impacts to water utility facilities from flooding due to more intense rainfall activity or sea level rise are other obvious priorities for such analysis.

Some of these efforts have employed climate models (referred to as GCMs – General Circulation Models) to attempt to build climate change forecasting into the front end of water supply planning. This has been labeled the "top down" approach to vulnerability analysis. The major drawback of this approach lies in the current level of analytical resolution of the GCMs. The nearly two dozen most recognized GCMs are consistent in projecting increasing global mean temperature, but across a range of variability that is also, in part, the product of various GHG "emission scenarios" that reflect alternative global assumptions about the future path of economic growth and efficacy of GHG controls. Projected changes in precipitation are less consistent between models at a regional level. Experts in the field have developed sophisticated "downscaling" techniques to interpret GCM outputs for smaller geographic areas, but there are trade-offs involved in such procedures and the level of spatial resolution is still quite broad. Finally, the "top-down" approach is challenged by one additional source of variability in that GCM precipitation forecasts must be converted to changes in surface runoff and groundwater recharge in order to connect with water resource planning models.

The interest in GCMs by water utilities is helping to advance the state of the art in climate modeling, but there are pros and cons to consider in assessing the priority of such research. On one hand, there is probably no other way to know how much more resolution can be obtained from these tools except to keep pushing forward. On the other hand, it is not clear that the level of precision needed to connect with water resource planning models is obtainable – or necessary to plot the next steps in coping with climate change. The general findings of climate research are sufficient to trigger concerns for water supply plans on the 20-50 year horizon. How much more precision is required? If the critical threshold is not tripped in 20 years, it is more likely that it will be tripped within 30 because climate change is already "in-the-pipeline" and we know the effects will emerge and build continually. There is reason to question whether climate modeling can catch up with climate change enough to provide useful precision, but in some cases, the research insights gained from such modeling may be as, or more, useful than the predictions.

In contrast, a "bottom-up" approach to vulnerability analysis has also been articulated as a recommended path for utilities to follow in investigating impacts of climate change. The central idea of this approach is that utilities can work with their own water resources planning models to assess the vulnerability of their 20-50 year supply plans to climate change. Based on the general findings of climate change research, utilities can identify the likely cause-effect pathways that could prove troublesome, such as many of those listed in Exhibits 1 through 4. A utility's own water resource modeling tools can then be applied to examine extreme scenarios, involving such features as decreased inflow from runoff, decreased recharge, increased evaporative losses, and seasonal shifts.

The "bottom-up" analysis enables a utility to test the robustness of current plans to upsets from changes in key climate-related variables. Once the thresholds or tipping points of a utility's plans have been identified in this manner (using familiar models in which a utility has relatively good confidence), it is then possible to turn to the climate scientists and ask how plausible such breaking point scenarios seem in light of the results of broader research with the various GCMs. This is a question that can draw on all of what has been learned in climate research without being limited to one or several models and without trying to undertake new climate modeling work. There is a considerable body of climate research that has been devoted to understanding the similarities and differences between the predictions of alternative climate models, focusing on their comparative consistency and overall accuracy versus precision. This type of comparative and interpretive analysis of climate modeling across the range of GCMs may be an important research priority for water utilities, enabling continuing improvements in the "bottom-up" approach to vulnerability analysis.

## 4.2 Integrated Resource Planning

The long-term response that is most prevalent in discussions of climate change is fortunately one that is familiar to many water utilities – IRP. A hallmark of this approach to long-term planning is the adoption of a very broad view of the problem that “integrates” all facets of it – environmental, socioeconomic and engineering – as a basic strategy for keeping a wide range of options open and providing a maximum of flexibility. All of the advice on adaptation to climate change begins with the same message: employ a portfolio approach – maintaining a maximum degree of flexibility and resiliency.

The IRP approach has been used extensively in water resource development and supply planning. It is often called Integrated Water Resources Planning, although it is sometimes undertaken without being explicitly labeled as IRP. Similar processes have also been used in regional or basin-wide studies of flood control. The continued improvement and refinement of best practice in IRP will be of significant value to water utilities in coping with climate change.

An essential part of maintaining a broadly “integrated” approach is the continuous involvement of all stakeholders. IRP is most appropriate to problems of sweeping proportions that involve complex trade-offs between multiple objectives and multiple constraints. The best solutions are made possible in such situations because IRP recognizes that stakeholders have the capacity to redefine some of the objectives and constraints when necessary to avoid an impasse. But this only works if stakeholders are fully involved.

The paragraphs below contrast IRP against the major impacts of climate change as a means of reviewing how well it matches up to the challenge at hand. It is plain from the sheer extensiveness of direct, indirect and compound impacts, that there may be a number of situations where negotiating marginal refinements to objectives and constraints with stakeholders could greatly ease the trade-offs otherwise involved.

Partnering water and wastewater utilities within a region and regulatory agencies constitute important subgroups of stakeholders with whom it may be necessary to devise entirely new institutional structures and methods of collaborating to meet multiple objectives and constraints on a changing playing field. Such restructuring is consistent with the IRP approach of redefining objectives and constraints to broaden the boundaries and admit a broader range of solutions.

Even before climate change emerged as such a dominant theme, it had been asserted that managing water resources within a basin or region to a “Triple Bottom Line” criteria (essentially containing all the same elements as “integrated” resource planning) could produce better environmental outcomes than managing to a disjointed array of standards established at national and state levels. The additional imperatives imposed by climate change may provide enough reasons to consider such innovative approaches. If programs such as those intended to control sewage overflows and waste load allocations are undermined by changes in hydrology, there may still be room to maneuver within the altered hydrologic system and attain good outcomes, if regulatory constraints are flexible.

Hydrologic changes will also change the balances between utilities within a region. There are no guarantees in the existing resource allocations. The potential for broader regional collaboration – up to and including consolidation of smaller utilities into larger entities – has often run aground because existing resource allocations create “have” versus “have-not” relationships that are difficult to convert into win-win relationships. Climate change has the potential to create situations in which no utility has a sure advantage, but in which there are clear advantages to operating at a larger regional scale to make more options available. Restructuring of regional and related institutional relationships may be an important theme in coping with climate change.

The bottom line in water supply planning has always been a matter of coping with variability. With the coming changes in climate, there will be a heightened need to respond to increased variability. The net effect of the direct impacts of global warming itemized in Exhibits 1 through 4 will be to change the variability of key parameters affecting the quantity and quality of water that would normally be expected to be available at any specific time and place. In addition, the capability to store water in various forms and the demand for water will be changed.

Given the sweeping extent of these changes, the IRP approach of taking the broadest possible view of the problem is indeed an ideal adaptation strategy. Working within broadly established system boundaries, it is possible to approach optimization in a manner that first derives maximum advantages from flexible operating strategies to expand the number of ways in which supplies can be managed to meet demands. This can have the benefit of deferring irreversible capital projects that may present more risk in a changing environment. Water utilities already employ sophisticated modeling tools (RIVERWARE, BASINS, OASIS, WEAP) to design such operating strategies, and it seems likely that applying such modeling tools to the design of adaptation strategies will be as, or more, important a priority as the climate models previously discussed.

Significantly, the IRP approach also features comprehensive assessment of strategies that can be applied to manage the water demand side of the equation. Warming processes will lead to altered demand patterns as a result of seasonal shifts in precipitation, more evaporation, more frequent heat waves, and more extensive droughts. Conservation programs offer a bonus in reducing both water supply needs and energy use. Bolstering conservation incentives (and disincentives to outdoor water use) may become more essential if warming processes otherwise increase water demands, especially during coincident peak demand periods when both water supply and electric power capacities are stretched to their limits.

### 4.3 Reducing Greenhouse Gas Emissions to Help Mitigate Global Warming

As has already happened in many water-short areas, it is possible to conceive of many ways to enhance the reliability of water resource management by essentially investing more energy to produce more water. But evaluation of these options must acknowledge the reality that water utilities account for a significant share of total electric consumption and that power plant emissions account for a significant share of GHGs. Moreover, the latest report of the IPCC holds out hope that global warming can indeed be mitigated through GHG reductions. The key for water utilities will be to fully incorporate the objective of reducing GHG emissions (i.e., reducing their "carbon footprint") as an additional objective within the IRP optimization framework.

As urban areas have grown, and continue to grow in the suburbs, water resource managers have already devised elaborate portfolio strategies to tap into multiple sources of supply coupled with strategic investments in capabilities to move and store water. While this flexibility in transmission and storage will be a valuable asset in re-optimizing current schemes to meet the challenges ahead, some features of the systems designed under the current understanding of climatic variability may not be reversible, or easily adaptable, under different operating regimes that were never previously envisioned or constrained by a desire to limit production of GHGs.

The rising cost of electric power has caused many water utilities to re-examine their operating strategies in transmission and distribution in search of ways to curtail electric usage during peak periods and generally conserve the use of electric power. Some cost saving strategies – such as using back-up generators to serve peak period loads (where not prohibited by air quality regulations) – may save money, but not reduce GHG emissions. On the other hand, renewable energy supply strategies such as solar or wind-powered pumping, or in-line hydro power generation, may be more expensive initially, but provide fuel cost savings and avoid GHG emissions. The challenge is to integrate such strategies within the IRP process to produce the best operating outcomes for the system as a whole in terms of cost, reliability and social/environmental consequences. For example, the reliability profile of a solar or wind-powered option may be such that it is only viable if a back-up generator is available to fill critical gaps, producing some GHG emissions, but less overall than a conventional power supply strategy.

Many water suppliers in over-constrained settings have also turned to energy-intensive membrane treatment processes to enable desalination of saline water sources and reuse of highly treated wastewater effluent. These processes make it possible to overcome a deterioration in the reliability of normal sources of supply by making it possible to meet part of the demand from sources that will be abundant under most climate change scenarios (i.e., yields from water reuse and desal supply options are drought-resistant). Although the cost – and especially the energy cost – of these technologies is significant, they should also be evaluated in the context of the overall IRP portfolio of options. If these technologies can plug a gap, or shore up a vulnerability produced by climate change processes, in a way that enables a broader scope for optimization across the entire portfolio, then they could play a critical role in improving the overall optimization.

## 5. SUMMARY

The broad range of impacts that could be produced by climate change on water suppliers is staggering. It is important to temper the understanding of these impacts with an informed sense of the pace at which climate change is becoming manifest. At the moment, the scientific consensus supports a view that: 1) global warming is already happening; 2) it is likely to accelerate over the next several decades; 3) it is possible to meaningfully mitigate it through GHG reductions; 4) it will get worse until we can stabilize the situation through mitigation. The leading edge of some types of impacts on water suppliers may be apparent today, but the larger part is yet to come, spread over the rest of the present century and continuing for centuries beyond.

The relevant responses to climate change are already being adopted by many water utilities. These include: 1) vulnerability analysis to identify near-term priorities for adaptation of capital and operating plans; 2) IRP to provide a comprehensive framework within which to further study the change processes and devise a broad array of adaptive measures that can sustain water supplies despite ongoing environmental changes; and 3) GHG reductions to help mitigate the global warming process.

The planning element of these response measures is especially significant. It is worth noting that climate change is not something the present generation of utility managers can solve. However, the present generation of managers can establish the right planning and related research processes needed to enable future success in coping with climate change.

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