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Awwa Research Foundation

Drinking Water Research

Climate Change and Drinking Water

AwwaRF Research Looks at Impacts on

- Water Resources
- Water Quality
- Infrastructure
- Energy & Environment
- Management & Communication

Awwa Research Foundation

Drinking Water Research

FEATURES

DEPARTMENTS

Beginning in 2008, *Drinking Water Research* will be published quarterly, plus two additional special issues on topics of high interest to water suppliers.

The Awwa Research Foundation is a member-supported, international, non-profit organization that sponsors research to enable water utilities, public health agencies, and other professionals to provide safe and affordable drinking water to consumers.

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Helping Utilities Prepare and Adapt to Climate Change Impacts

The consensus among climate scientists is overwhelming: Climate shift is occurring more rapidly than can be attributed to natural causes, and significant impact to water supply is expected. Some effects are already being felt by utilities.

Changes to patterns of precipitation will be one of the first and most critical impacts, affecting water availability not just for agriculture and industry, but also for the basic drinking water and domestic water needs of populations in many areas. Precipitation changes will lead—and have already led—to extended droughts. Changes will also include greater intensity of rainfall, which will increase erosion and the difficulty of capturing the water for storage, and wide variations in the timing of precipitation, which will affect the reliability of water supplies.

AwwaRF began to sponsor research to assess and plan responses to the impacts of climate change in 2003. That body of existing and ongoing research knowledge, much of it done in collaboration with other water utility research institutions from North America, Europe, Australia, and Asia, is highlighted in this special newsletter issue on climate change.

AwwaRF further strengthened its research efforts through the Strategic Research Initiative on Climate Change, established by the Board of Trustees early this year. This comprehensive, multi-year, multi-project approach will create valuable, practical information and tools to help drinking water utilities respond effectively to the challenges that lie ahead.

Much research has already been done or is underway. Given the unknown nature and scope of the many impacts of climate change on the water supply, much more is needed.

To help fund this research, U.S. Senate Majority Leader Harry Reid and Senator Dianne Feinstein have sponsored legislation to authorize climate change adaptation research for drinking water utilities. The recently introduced Climate Change Drinking Water Adaptation Research Act would, if approved, provide funding for applied research through AwwaRF to enhance the ability of drinking water utilities to develop and implement programs responding to climate change. The resulting research findings would help drinking water utilities adapt to climate change by focusing on such issues as impacts to water quality and quantity; desalination, reuse, and alternative supply technologies; energy efficiency and greenhouse gas minimization; regional and hydrologic basin cooperative water management solutions; and utility communications for public education and acceptance.

AwwaRF volunteers and staff are actively urging key legislators to support the bill, and we will keep you informed of its progress. AwwaRF is also reaching out to the philanthropic community and approaching foundations and individuals to fund this very important research. We will also keep you and your organization up to date on our ongoing climate change research through reports, Webcasts, the Web site, and newsletters.

Sincerely,

David E. Rager
Chair, Board of Trustees

Robert C. Renner, P.E., D.E.E.
Executive Director

Effects of Climate Change on Water Utilities

Chris Rayburn, AwwaRF director of research management

While climate scientists do not yet know with certainty the full scope of the effects of climate change on our planet, or how fast these changes will occur, the clear consensus is that significant impacts to the environment will be felt in the coming century. There is also a growing awareness that the first and perhaps most critical impacts will be on the world's freshwater resources. These impacts are not theoretical; they are already being felt in many parts of the United States and other countries. Climate change will affect the quality and quantity of water availability for municipal supply, food production, power generation, industrial use, and other vital services in many geographic locations, including areas that are not traditionally considered water-poor. The great variety and regional variability of potential impacts, as well as the many uncertainties associated with predicting the severity of the impacts, compound the challenge of assessing and responding to climate change vulnerability. Nonetheless, water providers in the United States and other countries have already begun to evaluate the possible impacts and to plan responses. Awareness of and interest in climate change impacts in general, and impacts on water resources in particular, is surging among water utilities and the public.

Climate Change Processes

While controversy persists over the relative contribution of human activities to climate change, the basic science behind the greenhouse effect and the data showing a sharp climatologic shift in recent decades are not controversial. Moreover, recent findings indicate that regional climate shifts can be relatively sudden and dramatic, suggesting that climate systems can reach a "tipping point" of greatly accelerated change. The 2006 AwwaRF report ***Climate Change and Water Resources: A Primer for Municipal Water Providers*** (order #91120), developed in partnership with the National Center for Atmospheric Research, provides an excellent overview of these processes and the basic science behind them. At the most fundamental level, climate change processes can be summarized as follows.

Increasing Temperature

Over the past century, the global average temperature has increased by approximately 0.6° C. Among the most undisputed predictions of climate change research is that average temperatures, particularly over land, will continue to increase. Estimates of the magnitude of this warming vary widely due to uncertainties in the models used to predict warming; however, the temperature increase is generally predicted to accelerate over the coming century. As reported in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC, 2007), 11 of the 12 warmest years in more than 150 years of instrumental records of global surface temperatures have occurred since 1995.

Increasing Evaporation and Precipitation

Another highly certain prediction of climate change research is that warmer temperatures will cause water to evaporate more readily, increasing total precipitation on a global scale. As with predictions of temperature increase, estimates of the magnitude of precipitation increase vary widely. It is generally accepted, however, that the pattern of precipitation change will be highly complex and variable; some regions will receive more precipitation and others less than they do now.

Rising Sea Level

Warmer temperatures will contribute to sea level rise through both melting of polar ice and expansion of water volume due to ocean warming. The IPCC reports that average global ocean temperatures have increased to depths of at least 3,000 meters (m) and that the ocean has been absorbing more than 80 percent of the heat added to the climate system. Estimates of the amount of sea level rise over the coming century range from 0.2 – 0.6 m (IPCC, 2007).

Increasing Extreme Events

Research suggests that climate change processes act to intensify the hydrologic cycle, leading to increases in the occurrence and intensity of extreme climatologic events. This intensification is likely to be manifested by more intense and temporally variable precipitation, greater incidence of flooding and drought, more intense tropical storms, and increased wildfire activity.

Water Utility Impacts

While it is safe to say that the impacts of climate change on water resources will vary widely by region, it is also relatively certain that no area will be untouched by these impacts. Potential climate change impacts on water utilities have been widely reported in publications by AwwaRF and many other organizations. These impacts can be broadly categorized as water quantity impacts, water quality impacts, operational reliability impacts, and financial and institutional impacts.

Water Quantity Impacts

The most widely publicized impacts of climate change on water resources concern availability of water supply. Direct impacts due to increasing temperature and precipitation variability include reduced in-stream flows, decreased snowpack, earlier and more intense snowmelt and runoff, and reduced aquifer recharge. While total precipitation may increase in some areas, it is likely not to come uniformly and predictably, leading to periodic flooding and water storage challenges. In addition, warmer temperatures may lead to increased demand by both water utility customers and competing users, with peak demand potentially coinciding with periods of most restricted supply.

Water Quality Impacts

Extreme precipitation events create well-known water treatment challenges by increasing sediment and pathogen loads, urban stormwater runoff, and combined sewer overflows. Source water quality will likely be impacted by other, more gradual processes such as more widespread and persistent algal blooms, changes in watershed vegetation, and increased water temperature with associated increases in eutrophication, disinfectant demand, and regrowth potential. In coastal areas, rising sea levels and associated salt water intrusion may increasingly impact groundwater resources.

Operational Reliability Impacts

Climate change will potentially impact utility infrastructure through a variety of means, including flood damage and pipe breaks due to soil drying and settling. Coastal facilities may be threatened by rising sea level and increased corrosion due to salt water intrusion.

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Warmer temperatures will likely increase the range and proliferation of invasive nuisance species such as quagga/zebra mussels and milfoil. Reservoir management is likely to be greatly complicated by changes in runoff timing and intensity, particularly for reservoirs that are required to balance both water supply and flood control needs.

Financial and Institutional Impacts

The potential for climate change-induced financial and institutional impacts on water utilities is less well recognized, but in some ways more potentially significant, than water supply and operational challenges. Although supply and operational challenges will be intensified by climate change, most water utilities are well-accustomed to dealing with such challenges. Utilities may be less prepared for challenges such as reduced revenue, the need for new rate structures to better reflect the increasing value of water (and associated affordability issues), and increasing conflict with competing water users. In the long term, climate change may lead to population shifts that strain utilities by increasing or decreasing their customer base. Greater stakeholder awareness and support will be needed to ensure that utilities can secure the necessary resources they need to adapt to climate change. Finally, utilities, like other enterprises, will be increasingly pressured (and perhaps required through regulation) to be as carbon-neutral as possible by minimizing energy consumption, turning to renewable energy sources, and optimizing fleet efficiency.

Conclusion

While the potential impacts and uncertainties associated with climate change will create unprecedented challenges, there are many reasons to believe that water utilities and the water supply community are up to the challenge. After a long period of deliberation, there is a growing consensus and urgency in the United States on the need to take action on climate change. Water utilities are recognizing and rising to the challenge with a strong clarity of purpose by developing response strategies, forming coalitions and alliances, and raising awareness among policy makers and government officials. Federal, state, and even local governments are responding with legislation to increase funding for climate change research and solutions.

This *Drinking Water Research* special issue on climate change details the efforts that AwwaRF and our many collaborators have completed and are undertaking to equip water utilities to cope with the varied impacts and uncertainties of climate change.

Addressing the Challenges of Climate Change

Kenan Ozekin, AwwaRF senior project manager

The awareness of climate change—and its potential impacts on drinking water in particular—is mounting among water utilities and the public. The recent drought in the southeastern United States sharpened this awareness and added a sense of urgency to the issue. Water agencies in the United States and in other countries have already begun to consider the possible effects and to plan responses. Work has also begun on reducing the greenhouse gas emissions from water management and provision practices.

AwwaRF, under the direction of its Board of Trustees, has moved quickly to respond to the needs of the water community, taking a leadership role in sponsoring research to understand the relationship between climate change and water quality and quantity issues, as well as the impacts of climate change at different points in the hydrologic cycle.

AwwaRF has already built a strong core of research related to climate change. One example is the popular report ***Climate Change and Water Resources: A Primer for Municipal Water Providers*** (2006, order #91120), co-sponsored with the National Center for Atmospheric Research. AwwaRF also has a strong body of related research on energy management through a strategic partnership with the California Energy Commission, and on desalination and other alternative water sources with several other major partners. Nonetheless, climate change affects many facets of water treatment and supply. Numerous knowledge gaps exist and much research remains to be done.

In 2008, AwwaRF established the Climate Change Strategic Initiative to enhance its efforts to address climate change challenges by developing a sustained, multi-year, integrated research effort built around achieving specific long-term objectives. AwwaRF has committed up to $1 million in funding per year for the initiative, which is expected to be substantially leveraged with partner co-funding and researcher in-kind contributions. The initiative will be sustained until the strategic initiative objectives outlined below are achieved; the target timeframe for the initiative is five to seven years.

A panel of professionals with expertise in climate change-related subjects was formed to provide direction and long-term stewardship for the strategic initiative. This expert panel has led the initial direction-setting and research plan development and will continue oversight through completion of the final projects authorized under the initiative. The expert panel is ultimately responsible for recommending projects under the initiative to the Board of Trustees for funding. The members of the expert panel for the Climate Change Strategic Initiative are:

- Andrew DeGraca, San Francisco Public Utilities Commission (chair)
- Paul Fleming, Seattle Public Utilities
- Lorraine Janus, New York City Department of Environmental Protection
- Mark Knudson, Tualatin Valley Water District
- Harold Reed, American Water
- Brad Udall, University of Colorado
- Steve Whipp, United Utilities (U.K.)
- Douglas Yoder, Miami-Dade Water and Sewer Department

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As with each of AwwaRF's strategic research initiatives, the Climate Change Strategic Initiative is based on specific objectives that represent problems to be solved or opportunities to be attained. The following four objectives have been established for the Climate Change Strategic Initiative. All projects funded under the initiative will contribute to meeting one or more of these objectives:

- Enhance and improve water industry awareness of climate change issues and impacts
- Provide utilities with a set of tools to assess their vulnerabilities and adaptation strategies
- Provide utilities with tools to assess and minimize their carbon footprint
- Communicate information to internal/external stakeholders

More information about the Climate Change Strategic Initiative can be found on AwwaRF's Web site at http://www.awwarf.org/theFoundation/ourPrograms/ResearchProgramSIClimateChange.aspx.

Research Planning and Development: Climate Change Research Needs Workshop

Kenan Ozekin, AwwaRF senior project manager

On January 8 and 9, 2008, 57 participants from multiple disciplines gathered in Denver, Colorado, at a workshop to identify climate change impacts on the water industry and to develop a comprehensive, multi-year research agenda spanning water, wastewater, and urban stormwater issues related to climate change. These representatives of water utilities, private research institutes, academia, the U.S. Environmental Protection Agency, consulting firms, and other industries came from the United States, the United Kingdom, Canada, and Australia. The workshop served as a forum to exchange varying perspectives on climate change impacts and to share information about the work each organization is engaged in. The workshop was jointly sponsored by the Awwa Research Foundation, the Water Environment Research Foundation, and United Kingdom Water Industry Research.

One of the primary goals of the workshop was to develop a research agenda to examine climate change impacts at a local level, develop approaches and tools for adapting to local climate change, and reduce greenhouse gas emissions from water management and provision practices. A second goal of the workshop was to develop a set of detailed project descriptions to fulfill the research agenda.

To facilitate the brainstorming and discussion of research needs, participants formed five workgroups, each focusing on a specific topic area and objectives. The workgroups sought to identify high priority issues for the topic area, identify the research gaps for each issue identified, develop research projects to fill those gaps, and prioritize issues and projects.

The **Water Resources Workgroup** considered climate change impacts on the hydrological cycle and mitigation planning, including global climate models, downscaling for use at regional levels, and assessment of watershed and water resource vulnerability due to hydrological cycle changes. The group also examined adaptations in water resource planning for drinking water supply and ecosystem protection.

The **Water Quality Workgroup** addressed climate change impacts to water quality as it relates to source and receiving waters, storage, conveyance and demand, and treatment. This workgroup also addressed the adaptations and management practices to protect and manage water quality.

The **Infrastructure Workgroup** examined the potential impacts of climate change on water, wastewater, and stormwater infrastructure, including risk exposure of key infrastructure nodes to weather extremes, the impact of rising sea level on coastal utility infrastructure, and the impact of changing permafrost on utility infrastructure. Adaptations in planning, design, and asset management were also addressed.

The **Energy and Environment Workgroup** studied how utilities can reduce greenhouse gas emissions and carbon footprints and adapt to changing energy sources and availability.

The **Management and Communications Workgroup** addressed the impacts of climate change on customers, utility management, and capital needs. It also discussed adaptations in communications, management models, and tools to maintain or improve robust, resilient, and responsive services.

During the course of the workshop, a total of 50 research projects were defined with an estimated cumulative research budget of approximately $17.5 million. The results of the workshop are summarized in a report available on the AwwaRF Web site at http://www.awwarf.org/theFoundation/ourPrograms/ResearchProgramSIClimateChange.aspx.

The following articles discuss the potential impacts of climate change on water utilities under each of the workgroup topics listed above. The articles summarize the highest priority issues identified by the workshop participants, provide information on AwwaRF resources currently available that can help utilities with climate change-related challenges, and outline topics for new studies.

Climate Change and Water Resources Issues

Shonnie Cline and Jennifer Warner, AwwaRF project managers

With uncertainty currently serving as the cornerstone of the climate change topic, many water resource managers are left to wonder what the future holds for their water supply. There is no single answer that will serve all utilities, as the complexity of global warming is as vast as the globe itself. Climate models, used to predict temperature and precipitation trends, point to varying impacts of climate change from region to region, with the potential effects on water supplies ranging from minimal to extreme. Water availability can be impacted by changes in precipitation, snowpack, runoff, increased evaporation and transpiration, and changes in demand. The challenge of water resource planning, therefore, will likely be greatly impacted if the value of historic precipitation and flow data diminishes in the wake of changes and variability in weather and temperature patterns.

As the earth warms, evaporation will increase. Higher levels of atmospheric moisture are expected to result in an average net increase in global precipitation, following the old adage of "what goes up must come down." This simple concept is quickly complicated by the fact that the greatest unknown factor is where the precipitation will fall. Unfortunately, while global models are mostly in agreement on anticipated regional temperature changes, models predicting expected changes in regional precipitation are not. Although there is disagreement among the models as to the exact locations where the greatest precipitation change will occur, most models indicate that the mid-latitude regions of the United States and much of Europe and Asia will experience the greatest changes (***Climate Change and Water Resources: A Primer for Municipal Water Providers***, order # 91120, research partner: National Center for Atmospheric Research). Some experts believe there may be fewer light and moderate rainfall events and more sporadic, heavy rainfall events, even in the areas that receive greater than historic precipitation. Likewise, areas with historic droughts may experience longer, more extreme drought events, and areas that have seen few droughts may find more frequent dry spells in their future.

In addition to changes in precipitation, the timing and intensity of snowpack runoff may also increase the likelihood of seasonal spring flooding events and decrease the amount of water available in rivers during the critical summer months. Water managers may find that existing infrastructure is less effective in managing greater extremes, from flooding to drought, and the capture and storage of water when it is available may have to be altered in areas where the greatest precipitation and temperature changes occur. Additionally, the potential for changes in seasonal flow will further stress sensitive ecosystems, increasing the tug of war between competing uses and reducing the amount of water available for human consumption during low flow.

AwwaRF Resources that Can Help Utilities

Several resources are available from AwwaRF to help water utilities make effective decisions related to water supply planning. Although only one of the following resources was developed in direct response to climate change challenges, all provide information that can assist water supply planners in the event that source-water quantity changes as a result of climate change.

Decision Support System for Sustainable Water Supply (2006, order #91107), a collaborative project with National Water Research Institute, describes a water-balance tool called Water Evaluation and Planning System (WEAP). Its purpose is to support water planners, stakeholders, and decision makers in developing a range of alternative water management scenarios and exploring the comparative advantages and disadvantages of each. Users can link water management simulations in WEAP to the EPA water quality model Qual2K and to the groundwater hydrology model MODFLOW.

Decision Process and Trade-Off Analysis Model for Supply Rotation and Planning (2006, order #91127), a Tailored Collaboration project with Tampa Bay Water, presents a decision-making process to aid annual water source rotation and planning objectives. A multi-attribute utility analytical tool, called the Source Management and Rotation Technology Tool (SMARTT), was developed to evaluate water source planning alternatives for short and mid-term source rotation decisions and for annual planning purposes. The decision-making process and SMARTT model were comprehensively tested at a large utility in the southern United States.

Water Efficiency Programs for Integrated Water Management (2007, order #91149), co-sponsored with the U.S. Environmental Protection Agency, provides two spreadsheet planning tools to analyze the direct costs that utilities can avoid through demand reduction, thereby defining the benefits produced by water use-efficiency programs. The tools also calculate water savings, costs, economic benefits, benefit-cost comparisons, and bill impacts for individual conservation programs. This report includes a compendium of water use efficiency, water savings, and cost estimates, as compiled from an extensive literature review and assessment. Key uncertainties are highlighted in the report.

An ongoing Tailored Collaboration project with Palm Beach County (Fla.) Water Utilities Department, "**Develop a Dynamic Decision Support System (D2S2) for Water Supply Planning in the Lower East Coast of Florida**" (project #4074), will develop a tool for water utilities and resource managers that allows scenario testing and rapid "what-if" analyses. The WEAP tool reported in ***Decision Support System for Sustainable Water Supply*** (see above) will be utilized in the project, expanding its applicability to a broader range of utilities by adding an alternative analysis dimension and expanding the alternative water supply options.

Ongoing project #3132, "**Incorporating Climate Change Information in Water Utility Planning: A Collaborative, Decision Analytic Approach,**" co-sponsored with the National Center for Atmospheric Research, will identify vulnerabilities of drinking water utilities to changing climate conditions and the adaptations utilities will need to make to manage risk, given unavoidable uncertainties regarding the specific nature of future changes in local hydrologic conditions. The project also aims to develop flexible and responsive short- and long-term management strategies to help utilities deal effectively with this new source of uncertainty when planning for and implementing changes in response to climate change.

Future Research

In early 2008, AwwaRF, along with other industry associations, organized and hosted a two-day workshop to develop a comprehensive, multi-year research agenda that addressed water, wastewater, and urban stormwater issues related to climate change (see the article on the Climate Change Research Needs Workshop).

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The Water Resources Workgroup, one of the five workgroups created for the workshop, comprised twelve experts representing climate modelers and water utilities. The workgroup was tasked with identifying and discussing the knowledge gaps in climate-related water supply planning that research could help fill. Changing weather patterns, including variant temperatures and precipitation patterns, and the changes in seasonal runoff were primary discussion topics in this workgroup. Planning for uncertainty and adaptation strategies were also common themes among the knowledge gaps identified.

Eight project concepts were ultimately identified in the Water Resources Workgroup with an estimated total budget of $3.7 million. The highest priority concept developed by the workgroup is a guide that would enable water utilities to interpret, navigate, and use existing and new climate change information and data to meet their specific needs. The group also discussed the lack of robust and reliable precipitation data available with existing models, and the need to develop a high resolution, regional climate change model. Such a model would take available climate model datasets and downscale them for ultimate usability by water utilities.

Other areas of research identified by this workgroup include the following:

- Development of a decision support approach and identification of leading practices for incorporating climate change into water resource plans
- Analysis of anticipated water demands and use patterns under a range of climate change scenarios
- Development of collaborative regional watershed scale hydrological models for climate change analysis, using historical and modeling analysis methods to link climate change, watershed changes, and water resource changes
- Creation and demonstration of a regional water budget to assess climate change impacts on water resource sustainability under climate change scenarios
- Identification and evaluation of alternative strategies and technologies to reduce water demand through conservation, and expand water supply using nontraditional sources in response to climate change
- Critical analysis of reservoir operations under a new climate regime and the evaluation of climate change impacts on large storage projects to develop flexible ways to operate and maintain reservoirs

Climate Change and Water Quality Issues

John Albert, AwwaRF project manager

The weight of current evidence suggests that climate change is occurring and will continue to occur in the foreseeable future. The rate and intensity of change is not immediately known; however, the impacts can already be observed in changes to the quality of drinking water utility source waters. Climate change models, in general, predict an overall warming of the earth. The warmer temperatures associated with climate change are predicted to decrease dissolved oxygen levels, increase contaminant load to water bodies, reduce stream and river flows, foster algal blooms, and increase the likelihood of saltwater intrusion near coastal regions. Climate change impacts to water quality are occurring over a very dynamic range. The wide variability of impacts is illustrated by regions in the United States such as the southeast, which experienced record drought, and the northeast, which experienced record snowfalls. All of these climate change impacts play a role in water quality and have implications for water, wastewater, and stormwater utilities. The need is pressing for utilities to address changing water qualities, and this will require fundamental changes in utility operations.

AwwaRF Resources that Can Help Utilities

Recently completed and ongoing AwwaRF research addresses issues related to the impacts of climate change on water quality. Although these projects were not developed solely in response to climate change impacts and issues, their results can be directly applied when assessing impacts and developing adaptations to climate change.

Algae

Periods of drought followed by runoff during episodes of heavy precipitation concentrate contaminants and increase nutrient loads to source waters. These higher levels of nutrients, in turn, increase the potential for algal blooms and the associated taste and odor and algal toxin problems. AwwaRF has supported research on detection and treatment of algae as well as utility guidance on controlling and mitigating algal events. A collaborative study with the Australian Cooperative Research Centre for Water Quality and Treatment (CRCWQT), ***Determination and Significance of Emerging Algal Toxins (Cyanotoxins)*** (2007, order #91170), evaluated methods for the detection of algal toxins in source water and assessed treatment operations for effectiveness in removing algal toxins. AwwaRF has also sponsored several projects that focus specifically on treatment options, including advanced treatment, for taste and odor compounds and algal toxins:

- ***Removal of Algal Toxins from Drinking Water Using Ozone and GAC*** (2002, order #90904, Tailored Collaboration partner: United Water International)
- "**Treatability of Algal Toxins Using Oxidation, Adsorption, and Membrane Technologies**" (project #2839, Tailored Collaboration partner: City of Cocoa, Fla.)
- "**Evaluation of Integrated Membranes for Taste and Odor and Algal Toxin Control**" (project #4016, research partner: CRCWQT)

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Finally, controlling algal growth will become increasingly important as temperature increases foster increased algal growth. ***Reservoir Management Strategies for the Control and Degradation of Algal Toxins*** (2008, order #91199), co-sponsored by the CRCWQT, focused on toxin degradation and ecological reservoir management approaches to control toxin production. The ongoing project "**Strategies for Controlling and Mitigating Algal Growth Within Water Treatment Plants**" (project #3111) aims to develop practical guidance for utilities in controlling algal events within treatment plants.

Invasive Species

The gradual warming predicted by climate change models may foster the spread of invasive species that can adversely impact both source water quality and water utility operations. A recently completed project co-sponsored with the U.S. Environmental Protection Agency, ***Milfoil Ecology, Control, and Implications for Drinking Water Supplies*** (2007, order #91207), identified invasive milfoil species that may be of concern to the water supply industry in North America. This research characterized the occurrence, as well as the negative and positive impacts on drinking water utilities, and reviewed known control strategies. A recent workshop co-sponsored by AwwaRF, Metropolitan Water District of Southern California, and Southern Nevada Water Authority—"**Workshop on Quagga/Zebra Mussel Control Strategies for Water Users in the Western United States**" (project #4200)—helped establish the state of current knowledge concerning quagga mussels, an invasive species closely related to the more familiar zebra mussel, that has recently been identified in water bodies throughout the Colorado River system. The workshop focused on biology and reproductive patterns, control methods, and research needs associated with quagga mussels, with particular emphasis on western United States waterways.

Disinfection By-Products

The predicted increase in nutrient load to source waters will impact the type and quantity of organic matter that may act as disinfection by-product (DBP) precursors. ***Long-Term Variability of BDOM and NOM as Precursors in Watershed Sources*** (2007, order #91186) aimed to determine loadings and the variability in loadings to watersheds from various point and non-point sources of natural organic matter that serves as precursors for DBPs and also as biodegradable organic matter for biological regrowth. ***Contribution of Wastewater to DBP Formation*** (2008, order #91206) aimed to characterize the DBP precursor material, and resulting types and quantities of DBPs in finished water, from source waters impacted by wastewater effluents. This project also identified control and treatment strategies that can be used in both wastewater and water treatment to help reduce precursors and DBPs. Both projects were co-sponsored by the U.S. Environmental Protection Agency.

Treatment

It is recognized that climate change-related impacts on source water quality will in turn impact drinking water treatment. Utilities will need to treat waters of increased contaminant loads due to concentration of contaminants during droughts or greater amounts of runoff during increased precipitation events. ***Screening and Evaluation of Treatment Alternatives for Challenging Waters*** (2005, order number #91064F) aimed to identify and evaluate technologies that would allow water treatment plants challenged with variable water quality to reliably produce high-quality water. As source water contaminant concentrations increase, many utilities will investigate other treatment options that can be integrated into conventional treatment trains. ***Integration of Membrane Filtration Into***

Water Treatment Systems (2006, order #91103) aimed to examine the process and design implications associated with the integration of membranes into existing water treatment plants and process schemes. An ongoing Tailored Collaboration project with Birmingham Water Works, "**GAC Biofilters in Retrofit Applications: An Approach for Cost Effective Regulatory Compliance**" (project #4155), will investigate the operational and performance-related features of GAC biofilters that operate without pre-ozone and develop practical guidance and tools that can be used by water utilities considering this treatment technology.

Adapting to the Future

Two ongoing Tailored Collaboration projects are geared toward scoping the impacts of climate change on utility treatment strategies.

"**Evaluating Effects of Climate Change on Water Quality Planning Criteria and Design Standards**" (project #4154, Tailored Collaboration partners: Contra Costa Water District, Seattle Public Utilities Commission, Los Angeles Department of Water and Power, and San Diego County Water Authority) will evaluate water utility planning criteria and design standards for their effectiveness in helping utilities adapt to future climate conditions, with the ultimate purpose of assisting water utilities in the engineering of new facilities.

"**Bay Area Water Utilities Operations Collaborative: Model for Inter-Regional Utility Cooperation**" (project #4157, Tailored Collaboration partners: East Bay Municipal Utility District, Contra Costa Water District, San Francisco Public Utilities Commission, and Santa Clara Valley Water District) aims to translate future trends and drivers into regionally actionable initiatives for San Francisco Bay area utilities. In doing so, the study will provide a template for action for other North American utilities.

Future Research

In early 2008, AwwaRF, along with other industry associations, organized and hosted a two-day workshop to develop a comprehensive, multi-year research agenda that addressed water, wastewater, and urban stormwater issues related to climate change (see the article on the Climate Change Research Needs Workshop). The workshop was divided into five workgroups, including the Water Quality Workgroup.

Thirteen participants in the Water Quality Workgroup focused on the impacts of climate change on water quality and the corresponding adaptations the water, wastewater, and stormwater industries should make to deal with them. The group identified 34 issues, compiled from a climate change research needs survey, participant input, and results from a late-2007 climate change workshop in Edinburgh. The issues were centered on the following themes:

- Water quality modeling/monitoring
- Source and receiving waters (including saltwater intrusion)
- Treatment
- Alternative sources
- Water quality management and practices

From these 34 issues, the workgroup developed a priority list of nine research ideas which are valued at $1.9 million. The highest priority issue centered on carbon sequestration and the unintended consequences it may have on groundwater supplies. This research idea has been approved for funding through AwwaRF's Rapid Response Research Program. (See the article "Underground Carbon Geologic

Sequestration and Drinking Water.") Other areas of research identified by the Water Quality Workgroup include the following:

- Identification of water quality and ecosystem monitoring parameters to assess climate change impacts
- Relating the LT2 database *Cryptosporidium* and *E. coli* with stream flow and climatic information
- Characterizing nitrous oxide (N_2O) emissions from wastewater treatment plants incorporating nitrification and denitrification
- Data collection and monitoring workshop to develop a tool for identifying the water quality impacts of climate change
- Impact of climate change on the ecology of algal blooms
- Climate change impacts on DBP precursors in source waters
- Evaluation of the potential impacts of climate change upon aquatic ecosystems and designated uses
- A "futures" workshop to frame water and wastewater treatment issues related to climate change

Climate Change and Infrastructure Issues

Traci Case, AwwaRF project manager

Climate change—natural change or change caused by human activities—can and will affect water, wastewater, and stormwater utility infrastructure today and well into the future. The tangible assets that make up water and wastewater utility infrastructure systems include large raw water storage facilities, stormwater collection systems, trans-basin diversion structures, potable and wastewater treatment plant equipment, transmission lines, local distribution systems, and finished water storage facilities. All are located in the natural and engineered environments affected by climate change.

There are two fundamental factors that water and wastewater utilities must consider when planning to address the implications of climate change: the direct and indirect impacts of climate change on infrastructure, and adapting infrastructure planning, design, and asset management to handle these changes. The risks of not planning for the potential impacts and subsequent adaptation of infrastructure systems to climate change are increased vulnerability to physical failure, deteriorating physical condition, internal and external corrosion, mechanical stress failure, and the inability to handle changing system demands and loads.

Impacts of Climate Change

The exact impacts of climate change on utility infrastructure have the potential to be very complex and will likely be largely unknown until they actually occur. However, the drinking water and wastewater research communities have started thinking through myriad possible direct and indirect impacts of the effects of climate change on infrastructure systems.

Direct impacts result from the effects of climate change on drinking water and wastewater infrastructure system functions and operations. Direct impacts may be caused by changes in average daily temperatures, more frequent and intense rainfall events, rising sea levels, and sustained and extreme droughts. Average daily temperature changes can alter soil temperatures and the buried infrastructure environment, challenge treatment systems by affecting the quantity and quality of runoff into surface waters, and change water demand for irrigation and urban uses. More frequent and intense rainfall events can challenge treatment systems by increasing turbidity and sedimentation, or cause direct flood damage to above-ground utility facilities and buried infrastructure. Rising sea levels can lead to saline intrusion into groundwater aquifers, challenging treatment systems and increasing corrosion of buried infrastructure. Sustained drought can change the buried infrastructure soil environment and can also increase water demand for irrigation and urban uses.

Indirect impacts result from longer-term secondary effects of climate change on drinking water and wastewater infrastructure systems. For example, indirect impacts may result from the shifting of population centers that can lead to changes in waste loads, water use patterns, and the needs for storage and distribution system capacity. Indirect impacts can also result from gradual changes in socioeconomic systems that affect capital resources or result in revenue challenges for utilities.

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Adapting to Climate Change

In order to address the impacts of climate change, water and wastewater utilities are adapting with a new way of thinking for planning, design, and working with asset management strategies. Utility rehabilitation, repair, or replacement decisions will need to account for climate change impacts. The water and wastewater industries will need to increase the resiliency of infrastructure by changing standards, specifications, and changing design criteria. New materials will be needed that can better withstand temperature fluctuations and drier or wetter conditions. The water and wastewater industries are also investigating decentralized systems as a way of managing climate change impacts. Decentralized systems provide distributed sites for water treatment and storage for potable water systems, and distributed sites for wastewater collection, treatment, and return for wastewater systems. These decentralized systems give utilities the ability to single out and manage individual zones of treatment or distribution during weather-related emergencies or in periods of demand or load changes.

A good example of adapting infrastructure design to address the effects of climate change is the U.S. Environmental Protection Agency (USEPA) Green Infrastructure program. Green Infrastructure was developed by a USEPA-led consortium to provide an approach to stormwater management that is cost-effective, sustainable, and environmentally friendly. Green Infrastructure management approaches and technologies allow infiltration, evapotranspiration, and the capture and reuse of stormwater to maintain or restore natural hydrologic systems. For more information on Green Infrastructure, consult USEPA's website at http://cfpub.epa.gov/npdes/home.cfm?program_id=298.

AwwaRF Resources that Can Help Utilities

Many water and wastewater utilities have begun to respond to climate change by understanding their system's vulnerability and then entering into long-term planning that allows for adaptation to climate change. Tools and reports are available from AwwaRF that can help utilities with this new way of thinking and planning.

One of the direct impacts of climate change is changing internal and external corrosion patterns in buried infrastructure due to a changing subsurface environment. ***Internal Corrosion of Water Distribution Systems, Second Edition*** (1996, order #90508) is a hard-bound comprehensive guidance manual on corrosion control for drinking water systems. The manual covers corrosion principles, corrosion of materials, mitigation of corrosion impacts, assessment technologies, and approaches to corrosion control studies. ***External Corrosion and Corrosion Control of Buried Water Mains*** (2005, order #90987) helps utilities by identifying the various causes of external corrosion, including bacteriological, galvanic, impressed current, changing soil conditions, and others. The report also presents economical solutions for each type of corrosion.

Several AwwaRF projects address the issues surrounding the indirect impacts of climate change. The ongoing project "**Changes in Water Use Patterns**" (project #4031) is quantifying changes in water use patterns to determine the recent macro-level trends across North America. The final report will discuss how water use trends affect distribution system operations, water quality, rates, and revenue. ***Distribution System Water Quality Issues Related to New Development or Low Usage*** (2006, order #91155) identifies the water quality changes that occur in distribution systems in areas of new development with low initial customer usage and in established areas undergoing diminished usage. This manual also recommends best management practices for minimizing water quality impacts in these areas. ***Impacts of Demand Reduction on Water Utilities*** (1996, order #90690) provides utilities with data to quantify the impacts of reduced flows resulting from demand reduction. This report evaluates the impacts of demand reduction on operating costs and provides water utilities with information on implementing a least-cost facility expansion or upgrade policy. Finally, for an analysis of the social, business, and utility trends that will shape the drinking water industry, consult the report ***A Strategic Assessment of the Future of Water Utilities*** (2006, order #91108). This report can help utilities position themselves to respond to the trends of the future, including those surrounding climate change.

In order to adapt to climate change, drinking water and wastewater utilities can use comprehensive asset management to minimize the total cost of designing, acquiring, operating, maintaining, replacing, and disposing of capital assets over their useful lives, while achieving desired service levels, all within a changing climate environment. There is a very large body of AwwaRF-sponsored research that addresses the various aspects of asset management, including condition assessment; repair, rehabilitation, and renewal decisions; long-term performance prediction; and planning, policy, and management tools. A tabular summary of these projects can be found in the report ***Asset Management Research Needs Roadmap*** (2008, order #91216), co-sponsored by the USEPA.

Future Research

In early 2008, AwwaRF, along with other industry associations, organized and hosted a two-day workshop to develop a comprehensive, multi-year research agenda that addressed water, wastewater, and urban stormwater issues related to climate change (see the article on the Climate Change Research Needs Workshop). During the workshop, the Infrastructure Workgroup was charged with investigating and identifying water, wastewater, and stormwater utility needs, prioritization criteria, and gaps and research needs to create a multi-year research agenda. Eight participants were assigned to this workgroup and identified eight projects with a total estimated research budget of $4.7 million.

The top-priority project identified by the Infrastructure Workgroup looks to develop a comprehensive planning framework for a new approach to infrastructure planning that incorporates emerging considerations such as long-term carbon impact with conventional criteria such as whole-life costs. This project would help utility managers adapt a new way of thinking to manage sustainable infrastructure systems under climate change conditions.

Other high-priority research ideas identified by the Infrastructure Workgroup include the following:

- Characterizing climate change impacts on infrastructure systems
- Planning new water, wastewater, and stormwater systems for a future with climate change
- Water system re-engineering for optimization of water resources
- Design and operation of water systems for resilience to climate change
- Responding to climate change by applying adaptive management techniques to infrastructure management
- Managing large-scale and old infrastructure under new climate conditions
- Case studies on extreme events and infrastructure interdependencies under climate change conditions

ENERGY & ENVIRONMENT

Climate Change and Water Utility Energy Management Issues

Linda Reekie, AwwaRF project manager

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The recognition by water utilities of their contribution to greenhouse gas (GHG) emissions and climate change through consumption of energy produced by fossil fuels is one driver for water utilities to reduce energy consumption. The recognition is driven by the adoption of climate policies by states and regions across the United States. These actions include the development of regional GHG reduction markets, the creation of state and local climate action and adaptation plans, and increasing renewable energy generation. Currently at least 18 states have GHG emission targets, which are emission reduction levels that states set out to achieve by a specified time. There are also at least half a dozen regional initiatives that encompass intra-state areas. Over the past few years, a number of the regional initiatives have begun developing systems to reduce carbon dioxide emissions from power plants, increase renewable energy generation, track renewable energy credits, and research and establish baselines for carbon sequestration.

The increasing cost of energy and increasing energy consumption are additional drivers for drinking water and wastewater utilities to reduce energy consumption. Energy use at drinking water utilities can represent a major component of operating costs, consuming as much as 35 percent of a utility's annual operating budget. Energy costs continue to increase with unstable energy prices and increased energy use by utilities. Drinking water utilities continue to implement advanced treatment processes such as nanofiltration, reverse osmosis, ozonation, and ultraviolet radiation. Advanced treatment processes are often necessary to meet the requirements of more stringent drinking regulations and to treat source waters of marginal quality, but are inherently more energy-intensive than conventional treatment.

AwwaRF Resources that Can Help Utilities

Since 2002, AwwaRF has funded 11 different projects to help advance the understanding of energy consumption and energy management at drinking water utilities. Seven of the projects have been funded through a strategic partnership with the California Energy Commission.

The AwwaRF-Energy Commission partnership began with a workshop in 2003 to identify and prioritize research areas and projects that would advance emerging technologies and best practices to improve energy efficiency, reliability, and costs for water and wastewater treatment facilities (see AwwaRF project #2923, "**Water and Wastewater Industry Energy Efficiency: A Research Roadmap**", co-sponsored with the Energy Commission). Twenty-nine participants representing water and wastewater utilities, energy providers, and energy affiliated research organizations attended the workshop and identified 44 research projects to address eight primary research areas, including advanced treatment processes, desalination, energy generation and recovery, societal and institutional issues, energy optimization, sustainability, decentralization, and total energy management. Twenty-five of the identified research projects were related to drinking water utilities; the remaining 19 were specific to wastewater utilities.Seven of the highest-priority research projects identified at the workshop have been funded through the AwwaRF-Energy Commission partnership. Five of these projects have been completed:

- ***Energy Index Development for Benchmarking Water and Wastewater Utilities*** (2007, order #91201)
- ***Zero Liquid Discharge for Inland Desalination*** (2007, order #91190)
- ***Water Consumption Forecasting to Improve Energy Efficiency of Pumping Operations*** (2007, order #91189)
- ***Risks and Benefits of Energy Management for Drinking Water Utilities*** (2007, order #91200)
- "**Evaluation of the Dynamic Energy Consumption of Advanced Water and Wastewater Treatment Technologies**" (project #3056, in publication)

The project ***Energy Index Development for Benchmarking Water and Wastewater Utilities*** developed and tested a multi-parameter benchmark score method that results in a metric score to give both water and wastewater utilities (two separate models) a relative assessment of energy performance. The project formed the foundation for the portfolio managers used in the U.S. Environmental Protection Agency's Water and Wastewater ENERGY STAR program.

Two additional AwwaRF-Energy Commission partnership projects are underway:

- "**Review of International Desalination Research**" (project #3055)
- "**Desalination Facility Design and Operation for Maximum Energy Efficiency**" (project #4038)

AwwaRF funded two Tailored Collaboration projects in 2007 to investigate GHG emissions and drinking water utilities. "**Greenhouse Gas Emission Inventory Guidance, Specialty Protocol Development, and Management Strategies for Water Utilities**" (project #4156), co-funded by the California Urban Water Agencies, will present a protocol and develop a guidance document for water utilities that will provide a common framework or platform for water utilities to inventory and report their GHG emissions. The study will assist users in understanding issues and terminologies and present a step-by-step approach to perform a water utility-specific GHG emissions inventory. "**Evaluating Effects of Climate Change on Water Quality Planning Criteria and Design Standards**" (project #4154) is co-funded by Contra Costa Water District, Seattle Public Utilities Commission, Los Angeles Department of Water and Power, and San Diego County Water Authority. This project will evaluate water utility planning criteria and design standards for their effectiveness in helping utilities adapt to future climate conditions. It will evaluate the need to develop new planning criteria and design standards related to GHG emissions.

Another project funded in 2007 will develop an energy management decision support system to help water utilities make better decisions for sustainable energy management. "**Decision Support System for Sustainable Energy Management**" (project #4090), which began in January 2008, will design the decision support system to identify economic, environmental, and social issues and impacts (i.e., triple-bottom line approach). The project will also develop the necessary parameters and methods for analysis to evaluate energy management options. A significant component of this research is integrating the knowledge related to existing tools in areas such as financial costs and the benefits of energy management into a coherent, analytical process. In this way the decision support system will help utilities make energy-management decisions that meet triple bottom line objectives. The project is a collaboration between AwwaRF, the Australian

Commonwealth Scientific and Industrial Research Organisation, the National Center for Atmospheric Research, and the New York State Energy Research and Development Authority.

Future Research

In early 2008, AwwaRF, along with other industry associations, organized and hosted a two-day workshop to develop a comprehensive, multi-year research agenda that addressed water, wastewater, and urban stormwater issues related to climate change (see the article on the Climate Change Research Needs Workshop). The Energy and Environment Workgroup, one of the five workgroups established for the workshop, investigated the research needs of water, wastewater, recycled water, and stormwater (urban water) agencies to help them reduce GHG emissions and carbon footprints and adapt to changing energy sources and availability.

Eight participants in the Energy and Environment Workgroup discussed mitigation opportunities for urban water utilities to better understand greenhouse gas (CO_2, NOX) emissions in process trains, embedded energy in process trains ("cradle-to-grave"), energy conservation opportunities, operations and process optimization opportunities to reduce energy consumption, and renewable and alternative energy sources. The workgroup also discussed adaptation issues and opportunities for water agencies to address the impacts of climate change on energy demand, reliability, and availability, and reducing utility risk exposure. Sixteen project concepts were ultimately identified with a total estimated budget of $4.5 million.

The highest priority concept developed by the Energy and Environment Workgroup focuses on optimizing wastewater processes for resource recovery, reducing greenhouse gas emission, and identifying best practices.

Other high priority projects identified by the workgroup include the following:

- Carbon footprinting in the capital improvement planning process
- Green certification program for water and wastewater utilities
- Carbon trading and the carbon market: opportunities for water and wastewater utilities
- Advancing process optimization in the water industry to include energy efficiency and control of GHG emissions
- Comprehensive guidance to help utilities develop integrated water, energy, and environmental resource planning strategies as global climate changes
- GHG emission projections for new water and wastewater technologies
- National and international application of the water utility carbon emission inventory protocol

Many of the projects reflect the underlying need for urban water utilities to (1) quantify their carbon footprints, (2) optimize operation and treatment processes to reduce carbon footprints, (3) understand incentives and drivers for GHG emission reductions, and (4) integrate environmental considerations into planning, operation, and maintenance to more holistically address global climate change. These needs will be an ongoing challenge for all of us as we look forward to addressing the complex issues presented by global climate change.

Underground Carbon Geologic Sequestration and Drinking Water

Kenan Ozekin, AwwaRF senior project manager

Carbon dioxide (CO_2) from industry and other human activities is a major contributor to greenhouse gas emissions and global climate change. Industrial facilities that emit large amounts of CO_2 include power plants, petroleum refineries, oil and gas production facilities, iron and steel mills, cement plants, and various chemical plants. CO_2 capture and sequestration (CCS) is a process of separating CO_2 from emission sources, transporting it to a storage location, and then injecting it under pressure into deep, underground geologic formations. The idea of CCS has been around for a long time. In the late 1970s and early 1980s, several commercial CO_2 capture plants were constructed in association with power plants in the United States. However, the technology was never implemented on a large scale due to the significant amounts of energy required for CO_2 capture, which reduces the power plant's net energy output.

Types of geologic formations capable of storing CO_2 include oil and gas reservoirs, saline formations, and deep coal seams. Studies suggest that the geologic storage capacity in the United States could be as high as 3,900 gigatons of CO_2 in approximately 230 possible locations. Among all the geologic formations, deep saline formations have the highest storage capacity—3,600 gigatons. As for CO_2 output, the 1,715 largest sources of CO_2 in the United States are reported to release about 2.9 gigatons per year. Aside from carbon capture and sequestration, other options for reducing greenhouse gas emissions include reducing energy demand through increased energy efficiency, shifting to less carbon-intensive fuels such as nuclear power and renewable energy, and reduction of non-CO_2 greenhouse gas emissions.

Despite high energy demand and other technical hurdles, CCS technology is being widely embraced as the best available technology for reducing greenhouse gas emissions. With growing awareness and acceptance of the role of human activities in exacerbating climate change, CCS is under intensive study in the United States by both federal agencies and industry groups. Many of these studies are focused on the long-term efficiency of structural trapping of CO_2 under sealing layers, and on identifying potentially suitable sites for CCS in the United States. Much less emphasis has been placed on the potential impacts of CCS on underground water sources.

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Table 1. Milestones Associated with the Underground Injection Control Rule for CCS

Activity	Milestone
Interagency review of proposed rule	Late May – early June 2008
Administrator's signature of proposed rule	July 2008
Public comment period for proposed rule	July – October 2008
Notice of data availability (if appropriate) 2009	2009
Final rule for CCS	Late 2010 – early 2011

Injection of fluids, including solids, semi-solids, and gases (e.g., CO_2) into the subsurface falls within the USEPA's authority under the Safe Drinking Water Act to ensure that injection activities do not endanger underground sources of drinking water. The Underground Injection Control regulations address the siting, construction, operation, and closure of injection wells to protect human health and the environment. In October 2007, the USEPA announced that the agency plans to propose regulations in the summer of 2008 to ensure consistency in permitting full-scale geologic sequestration projects. Table 1 (previous page) describes the milestones associated with the regulation.

Potential Impacts on the Quality of Groundwater Supplies

The injection of CO_2 into deep saline aquifers, and the potential leakage of CO_2 into overlying formations, may be of concern for drinking water sources. There is the potential for CO_2 to exceed the formation's storage capacity and breach the caprock, or migrate laterally to areas where the caprock is less competent, and thus interact with overlying or nearby freshwater supplies. The potential for CO_2 to affect aquifer pH and redox conditions, with associated impacts on groundwater quality, is poorly understood. Conceivably, CO_2 could also physically displace saline water from deeper aquifers into shallower outcrops, subcrops, or nearby freshwater aquifers. If such aquifers are current or potential drinking water sources, the quality of the water supply may be adversely affected. There is a need to identify potential impacts of CCS on the quality of groundwater supplies before the technology is widely pursued as an option for greenhouse gas emission control.

AwwaRF's Rapid Response Project

In early May 2008, AwwaRF released a request for proposals for a fast-track study to examine the potential effect of underground carbon sequestration on groundwater resources. The project is part of AwwaRF's Rapid Response Research Program, a mechanism through which AwwaRF responds quickly to urgent, immediate, or unforeseen research needs of the drinking water community. The project will include an information-gathering phase in which the research team will conduct a search and review of both published and unpublished "gray" literature, a synthesis of the available information, and an outreach phase in which the research team will identify how the project results will be prepared and disseminated to key audiences. In particular, the project results will be used to inform water utility comments during the public comment period for the proposed CCS rule. The expected completion date is late October 2008.

Climate Change and Water Utility Management and Communications Issues

Scott Haskins, CH2M Hill
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Climate change will likely have far-reaching impacts on water utilities and their management. Energy supply and use, system infrastructure, water quantity and quality, and customer expectations are just a few issues that will likely be affected by climate change. As a result, water utility managers will need access to analytical tools and management techniques to understand these impacts, to develop and implement appropriate responses to ensure reliable, affordable, and sustainable levels of service, and to communicate effectively with customers and stakeholders.

Utilities typically face many types of risks (e.g., security, infrastructure failure, and renewal), and they frequently need to make key risk management decisions in the face of uncertainty. Climate change adds a new array of significant uncertainties that are not yet well characterized, and imposes risks that carry potentially major consequences. The potential sources of utility risk are diverse (e.g., severe droughts, floods, water quality challenges), the probabilities and consequences of adverse events are often highly uncertain and may be severe, and any portion of the utility may be at risk (e.g., from source to tap). It is critical that utilities identify and prioritize the key threats and begin to consider response and adaptation options that are targeted at the most significant risks.

Unfortunately, utilities must manage the risk in an environment where the level of climate change awareness, beliefs, and expectations may vary widely among customers and other stakeholders. As utilities develop programs to address the resource, infrastructure, and financing challenges presented by climate change, they must communicate with and build support within their customer base and governing bodies. Effective and consistent customer/stakeholder communications are built upon an awareness of customer/stakeholder expectations, viewpoints, and levels of knowledge.

AwwaRF Resources that Can Help Utilities

AwwaRF began sponsoring research to assess and plan responses to the impacts of climate change in 2003. The initial project, co-sponsored by the National Center for Atmospheric Research (NCAR), was published in 2006 as ***Climate Change and Water Resources: A Primer for Municipal Water Providers*** (order #91120). This guide summarizes the best available scientific evidence on climate change. It also identifies the implications of climate change for the water cycle and the availability and quality of water resources, and provides general guidance on planning and adaptation strategies for water utilities. The primer is currently the only climate change research report available that is specific to water utilities.

Since publication of this initial report, AwwaRF has moved ahead with a number of other climate change-related projects.

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The body of knowledge and tools funded by AwwaRF that focus on climate change spans several topic areas. In the category of utility management, AwwaRF and NCAR are co-funding a follow-up study to the primer—"**Incorporating Climate Change Information in Water Utility Planning: A Collaborative, Decision Analytic Approac**h" (project #3132)—which is using large climate models to develop climate modules for small-scale, long-range water supply planning software used by water utilities. The project builds on an existing water supply planning application called ***Water Evaluation and Planning (WEAP)***. Related ongoing projects are "**Evaluating Effects of Climate Change on Water Quality Planning Criteria and Design Standards**" (project #4154, Tailored Collaboration partners: Contra Costa Water District, Seattle Public Utilities Commission, Los Angeles Department of Water and Power, and San Diego County Water Authority) and "**Greenhouse Gas Emission Inventory Guidance, Specialty Protocol Development, and Management Strategies for Water Utilities**" (project #4156, Tailored Collaboration partner: California Urban Water Agencies).

In addition, select AwwaRF projects and reports offer tools and approaches of particular use to water utilities considering climate change adaptation strategies. In management and communications, reports and tools are available to assist with demand management, risk management, financial planning and implementation, and institutional approaches. Several projects that are underway include:

- "**Water Conservation: Customer Behavior and Effective Communication**" (project #4012, research partner: U.S. Environmental Protection Agency)
- "**Tool for Risk Management of Water Utility Assets**" (project #4126, research partners: Water Environment Research Foundation, UK Water Industry Research Limited, Water Services Association of Australia)
- "**Setting Water Utility Investment Priorities: Assessing Customer Preferences and Willingness to Pay**" (project #4085)
- "**Changes in Water Use Patterns**" (project #4031, research partner: U.S. Environmental Protection Agency)

Utilities may also be interested in the information available in the following published research reports:

- ***Water Budgets and Rate Structures: Innovative Management Tools*** (2008, order #91205)
- ***Impacts of Demand Reduction on Water Utilities*** (1996, order #90690)
- ***Water Efficiency Programs for Integrated Water Management*** (2007, order #91149, research partners: California Urban Water Agencies, U.S. Environmental Protection Agency)
- ***Decision Support System for Sustainable Water Supply*** (2006, order #91107, research partner: National Water Research Institute)
- ***Regional Solutions to Water Supply Provision*** (2006, order #91146, research partners: American Water Works Association, U.S. Environmental Protection Agency)
- ***Risk Analysis Strategies for Credible and Defensible Utility Decisions*** (2007, order #91168)

Soon to be published in 2008:

- "**Development and Demonstration of Practical Methods for Examining Feasibility of Regional Solutions for Provision of Water and Wastewater Service**" (project #4075, Tailored Collaboration partner: Lehigh County (Pa.) Authority)

- "**Improving Water Utility Capital Efficiency**" (project #3119, research partners: Water Environment Research Foundation, U.S. Environmental Protection Agency, Public Utilities Board Singapore)

Future Research

In early 2008, AwwaRF, along with other industry associations, organized and hosted a two-day workshop to develop a comprehensive, multi-year research agenda that addresses water, wastewater, and urban stormwater issues related to climate change (see the article Climate Change Research Needs Workshop). During the workshop, the Water Utility Management and Communications Workgroup was charged with addressing the impacts of climate change on customers, utility management, and capital needs. It also focused on the adaptations in communications, management models, and tools to be considered to maintain or improve robust, resilient, and responsive services. Ten participants were assigned to this workgroup, which identified nine projects with a total estimated research budget of $2.65 million.

Prior to the workshop, the workgroup held several conference calls to frame some of the key impacts created or amplified by climate change within the broad category of management and communications. It also identified areas where utility management and communications functions would need to adapt in order to address the emerging challenges and the impacts of climate change. The workgroup additionally considered the services that utilities would need to provide. With an initial identification of possible impacts and adaptation approaches, the workgroup assessed existing research; developed problem statements, research goals, project scopes and descriptions, milestones, and budgets; and formulated a recommended list of research priorities. The workgroup also collaborated with the other workgroups during the workshop in an effort to identify areas of overlap and potential synergies.

The highest priority concept identified by the Water Utility Management and Communications Workgroup is the need of water and wastewater utilities for a suite of approaches and tools to navigate the essential steps of vulnerability assessment and risk management as applied to the threats associated with climate change. Other areas of research identified by the workgroup include:

- Addressing water/wastewater stakeholder beliefs about climate change
- Guidance for water and wastewater utilities to assess and manage the impacts of climate change
- A case for smart regulation
- Assessing the financial implications of climate change on water and wastewater utilities
- Best practices in carbon accounting for water and wastewater services
- Developing a climate change resource clearinghouse for the water and wastewater industry
- Willingness to pay for managing climate change impacts
- Assessing cooperative watershed-scale opportunities for adapting to climate change

REPORTS OF NOTE

Brief summaries of reports related to climate change released by the Foundation

Climate Change and Water Resources: A Primer for Municipal Water Providers

(order #91120, project #2973)

Kathleen Miller and David Yates

There is a great deal of misunderstanding surrounding the subject of climate change, often leading to profound confusion regarding its potential impacts on natural resource systems and public well-being. Well-intentioned but misguided attempts by the media to call attention to the prospect of climate change have left much of the public with the impression that the Earth's climate system is either poised at the brink of cataclysmic change or that global climate change is a myth that they can safely ignore. Neither of those extreme views provides useful guidance to anyone attempting to make informed decisions about the management of climate-sensitive resources.

In this report, the research team summarized the best available scientific evidence on climate change. In particular, this primer focused on what is known about the implications of climate change for the water cycle and the availability

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Decision Support System for Sustainable Water Supply Planning

(order #91107, project #2853)

Annette Huber-Lee, Chris Swartz, John Sieber, James Goldstein, David Purkey, Charles Young, Elizabeth Soderstrom, James Henderson, and Robert Raucher

Traditional water utility planning efforts do not typically focus on sustainability and a long planning horizon. Both of these elements require a broad perspective on water supply planning and are characterized by high degrees of uncertainty. To tackle these elements, a wide array of management objectives and opportunities must be considered. This requires the use of a tool that extends beyond sequencing potential supply enhancements in response to unrelenting, unmanaged increases in demand.

The main objective of this project was to develop a computerized decision support system (DSS) tool that will allow utility strategic planners to effectively evaluate options for managing and developing reliable, adequate, and sustainable water supplies for their customers over the next 50 to 100 years. This tool

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Energy Index Development for Benchmarking Water and Wastewater Utilities

(order #91201, project #3009)

Steven Carlson and Adam Walburger

Sixty thousand water systems and 15,000 wastewater systems account for three percent of the national electricity use. Ten percent or more of a utility's total operating cost is for energy. Tracking energy use over time can be a valuable tool, especially when load and operational influences can be linked to energy use. Furthermore, comparing energy use to peers can be a valuable exercise for motivating improvement, assuming that peers can be properly identified with load and operational factors. The purpose of this project was to develop metrics that allow comparison of energy use among wastewater treatment plants and among water utilities.

The research team reviewed literature for existing energy use data and methods of characterizing a utility. The literature review provided information on characterizing utility energy use and operating characteristics for the

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Water Efficiency Programs for Integrated Water Management

(order # 91149, project #2935)

Thomas W. Chesnutt, Gary Fiske, Janice A. Beecher, and David M. Pekelney

Water utilities have increasingly come to appreciate the value of water use efficiency (WUE) for accomplishing their long-term mission of providing a safe and reliable water supply. The importance of water efficiency goes well beyond the short-term measures invoked to respond to drought emergencies, and is much broader in scope. Improved water use efficiency is seen as a viable complement to, and in some instances, a substitute for, investments in long-term water supplies and infrastructure. At the heart of the new understanding of water efficiency is an economic standard: a good WUE program produces a level of benefits that exceeds the costs required to undertake the program.

The objectives of this project were to (1) develop a rigorous and universally-applicable set of definitions of benefit and cost components from different perspectives;

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Climate Change and Water Resources: A Primer for Municipal Water Providers

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and quality of water resources. The report includes a CD-ROM, which contains an interactive version of the primer, an annotated bibliography, the final report in a PDF file, and additional resources.

The research team concluded that to plan effectively for the future, utilities should assess the potential impacts of a range of plausible climate change scenarios on their ability to meet customer needs and comply with quality standards and environmental objectives in a cost-effective manner. This requires rethinking traditional approaches to the planning process. Scenarios based on climate model output are a tool that utilities can use for these assessments, but it is important to understand that no single climate model can yield a reliable projection of future climatic conditions. If climate model output is used, it must be appropriately downscaled to the relevant watershed level, and any analysis should use projections from several models to generate a range of physically plausible scenarios of the impacts of climate change on the utility's water resources. The utility can then use the resulting hydrologic projections to evaluate the robustness of alternative response strategies given the unavoidable uncertainties arising from climate change.

Water industry professionals are keenly aware of the fact that climate variability affects the availability and quality of water resources and that runoff or temperature extremes can affect their operations. Unanticipated extremes, such as an unprecedented drought, are likely to pose particularly severe problems. Prudent management focuses on anticipating and mitigating the potential adverse impacts of such natural variability. To plan efficiently, it is important to understand how and why climate may change in the future and how that may affect the resources upon which the water utility industry depends.

Decision Support System for Sustainable Water Supply Planning

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will allow for the evaluation of multiple future water management scenarios that include integrated social, financial, and economic analyses that are required for sustainable, long-term water supply planning.

The research identified, through a utility-attended workshop, priority elements of a water planning DSS. The research also demonstrated that an integrated DSS framework can facilitate the analysis of actual utility-defined future scenarios dealing with long-term sustainable water planning—analyses that comprise multiple elements associated with a range of common planning challenges facing water utilities. In addition to a financial planning module that was added to the DSS, there may also be a widespread need for research on ecosystem flow needs (both quantity and quality), social cost accounting, and demand management that can be translated into additional modules. The report includes a CD-ROM with the Water Evaluation and Planning (WEAP) software and a user manual.

For utilities already implementing DSS tools extensively, it is recommended that these tools be benchmarked against an integrated system like the WEAP-based DSS. DSS tools should be assessed for their ability to respond to a full spectrum of considerations important to long-term sustainable planning. For utilities considering increased investment in DSS tools, a test application of the WEAP-based DSS can illuminate the potential benefits and opportunities of an integrated water supply planning analysis relative to using separate DSS tools.

Energy Index Development for Benchmarking Water and Wastewater Utilities

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development of survey instruments. Surveys were then mailed to 2,725 wastewater treatment plants and 1,723 water utilities. The researchers also applied and evaluated a multi-parameter benchmark score method similar to the U.S. Environmental Protection Agency's ENERGY STAR rating system for buildings and reviewed the resulting metric application at sample utilities.

The multi-parameter metric developed from the research, including flow, pumping, and distribution characteristics, provides a means to score energy use of drinking water utilities. Sub-metrics that included additional treatment and distribution details can segregate scores for drinking water production, treatment, and distribution, when energy use is available at that level. The project also developed a multi-parameter metric including flow, loading, and treatment processes, providing a means to score energy at wastewater treatment plants. A similar metric scores the collection system. The final report package includes a CD-ROM with the energy benchmark metric score sheets and the raw survey data.

In spite of the vast amount of utility data tracked by regulatory agencies and industry organizations, little industry-wide information about utility energy use beyond total energy financial expenditures existed before this project. Having metrics is a first step in support of active energy management. Low-scoring utilities can pursue investigations as to why they score low, which might lead to implementing improvements. High-scoring utilities might be identified as a source to investigate for examples of best practices. Internally, for tracking over time, the metrics provide a convenient way to track energy performance accounting for variations in loading. Externally, it provides a comparison to other utilities and a framework in which to make the comparison.

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Water Efficiency Programs for Integrated Water Management

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(2) compile, in an easily accessible form, the best available information on WUE program costs and savings; and (3) present clear guidance to water utilities on program cost and benefit estimation.

The research provides a conceptual framework organizing information about WUE programs (costs, savings, and benefits) in ways that make for more informed water resources decisions. A compendium of working assumptions for WUE savings and costs estimates was compiled from an extensive literature review and assessment. Key uncertainties are highlighted. The research team undertook a telephone survey of the participating utilities to obtain a better understanding of current WUE planning practices and perceived needs for improvements.

A CD-ROM accompanies the research report containing two adaptable spreadsheet-based WUE planning tools: a Water Utility Direct Avoided Cost Model and a Benefit-Cost WUE Planning Model. The Water Utility Direct Avoided Cost Model analyzes the direct costs that utilities can avoid via demand reduction, thereby defining the benefits produced by WUE programs. The Benefit-Cost WUE Planning Model calculates water savings, costs, economic benefits, benefit-cost comparisons, and bill impacts for individual conservation programs.

Water use efficiency programs are most valuable when they have been incorporated into ongoing utility planning for meeting future water demand. The conceptual framework, analytical planning tools, and informational results of this research project directly address the needs identified by water industry professions in the initial survey of this project. This research describes the logic of efficiency that applies to all these practices while focusing development of applied work on water use efficiency programs. The project provides practical tools to enable water utilities of different sizes and differing levels of sophistication to better integrate their supply-side and demand-side planning.

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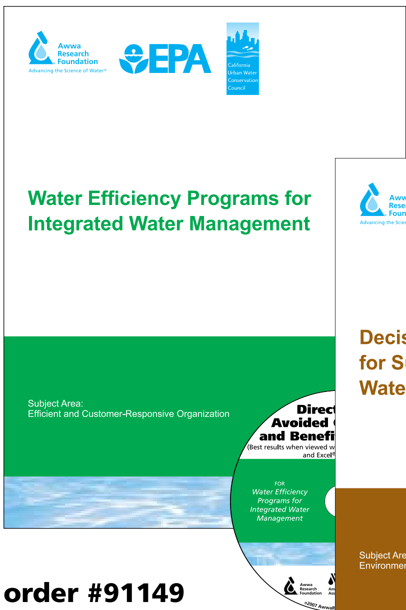

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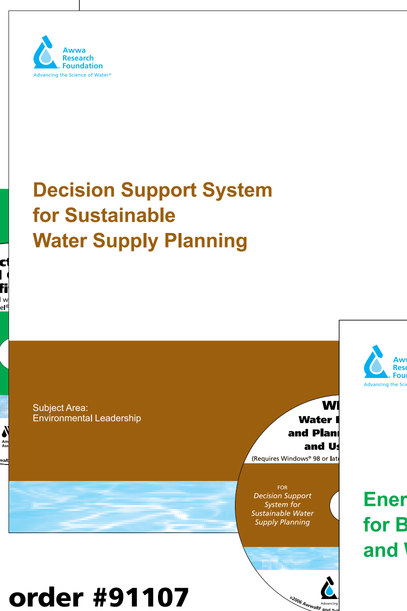

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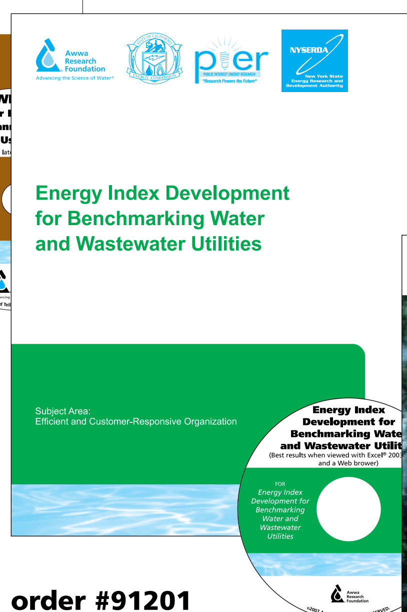

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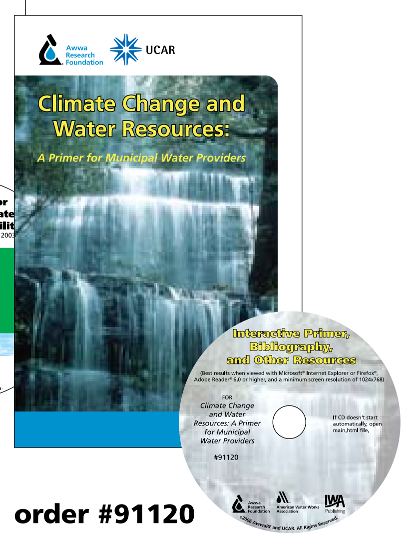

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