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National Water Infrastructure Adaptation Assessment

Part I: Climate Change Adaptation Readiness Analysis



Office of Research and Development
Water Supply and Water Resources Division

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DISCLAIMER

The U.S. Environmental Protection Agency, through its Office of Research and Development, conducted, funded and managed the research described herein. The report “National Water Infrastructure Adaptation Assessment: Part I – Climate Change Adaptation Readiness Analysis”, EPA/600/R-15/138, has been subjected to the Agency’s peer and administrative review and has been approved for external publication. Any opinions expressed in this paper are those of the authors and do not necessarily reflect the views of the Agency, therefore, no official endorsement should be inferred. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

The U.S. Environmental Protection Agency (USEPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

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Cynthia Sonich-Mullin, Director
National Risk Management Research Laboratory

PREFACE

Water is essential to life. Uneven distribution of population and water resources in the world results in more than 1.1 billion people with a lack of access to clean drinking water and 2.6 billion people deprived of adequate water sanitation. Today fresh water is being consumed at an alarming rate almost doubling every 20 years. Global climate change further exacerbates this already stressed situation. Thus water availability becomes not only a problem for developing countries, but one faced by developed nations that are now saddled with an aging water infrastructure. Pressed by water resource challenges, however, civilizations have always found innovative solutions to meet water resource needs and adapt to evolving social and environmental conditions. This spirit of adaptation continues to this day and will continue into the future.

One of the most complex challenges facing our nation today revolves around water supply sustainability, many times in the context of water-energy-climate nexus. The challenge is acute in light of occurring and future climate changes and rapid socioeconomic developments. Sustainable solutions to the challenge require a holistic management approach for the water sustainability issues. For this purpose, interdisciplinary research and developments are often a first step toward supplementing and improving current water management and engineering practice.

The national water infrastructure adaptation reports synthesize the results of multidisciplinary research and development conducted during the past six years. These reports present the conditions and readiness for adaptation of our nation's water infrastructure, characterize hydroclimatic provinces and future climate conditions, and further introduce the means to develop quantitative science basis for adapting water infrastructures. This systematic adaptation approach is structured in multiple levels from urban-scale planning to individual water engineering processes. A suite of developed tools, ranging from strategic master planning, to watershed modeling and water plant adaptive engineering, have been developed and are illustrated with case studies in the reports.

Considering the specialized needs of technical managers, the adaptation reports are structured with necessary theoretical deliberations, technical details, and illustrated by case studies. The focus is on developing actionable science and engineering basis, a subject pertinent to technical managers and other stakeholders who face technical complexity of climate change adaptation. While providing a wide range of technical data and information, these reports only mark a beginning of the long march toward the goal of sustainable water resources and resilient infrastructures.

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The project and writing team would like to acknowledge the participation in this research by numerous technical staff and participants from EPA staff and individuals to contracting research organizations. This investigation of both a wide breadth and a substantial depth was made possible only with their participation and contribution. Administrative and contract supports are acknowledged of Dr. Michael Moeykens, Michelle Latham, Steve Herman, and Stephen Wright. Finally, technical data and collaboration efforts by the U.S. Department of Energy National Climatic Historical Network, the Manatee County Water Department, the Great Cincinnati Water Works, and the Las Vegas Valley Water District are also acknowledged.

The national adaptation assessment report was originally prepared in 2010 and reviewed by individuals inside and outside of the U.S. EPA. Based on review comments, additional technical contents were added with newly developed adaptation tools and methods. This development led to rewriting and reorganization of the entire report. In the process, three rounds of internal and external peer reviews were conducted. After two rounds of peer-review, all three documents of the national water infrastructure adaptation report have been subjected to administrative review and have been approved for publication. The contributing teams to this volume include:

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ABSTRACT

The report "National Water Infrastructure Adaptation Assessment" is comprised of four parts (Part I to IV), each in an independent volume. The Part I report presented herein describes a preliminary regulatory and technical analysis of water infrastructure and regulations in the United States (U.S.) under the climate and socioeconomic changes. Specifically, a nation-wide assessment was conducted to analyze priority issues facing water and wastewater utilities. Utilities' responses are found to be consistent with those of five similar national assessments conducted by non-EPA organizations. To water utilities and local governments, climate change is not rated as the highest priority, but as an important concern. A lack of actionable science often impedes immediate planning and engineering actions. This Part-I report also describes a regulatory analysis in which the potential impacts of climate change on a set of water and air regulatory programs are evaluated. It is further found that the vulnerability to climate change is compounded by the deterioration of aging water infrastructure that lags behind socioeconomic changes. In summary, the confluence of these factors – climate change, aging water infrastructure, regulatory programs and utility priority setting in water utilities forms a "perfect storm" with implications for desired service functions and long-term sustainability of Nation's water infrastructure.

The other three volumes cover the subjects of climate change impact characterization in different spatiotemporal scales, for which a range of water infrastructure adaptation techniques and methods are presented. Part II of the adaptation report describes the hydroclimatic changes in contiguous U.S. in the next 30-50 years, the time frame common for water infrastructure master planning. The analysis was based on a detailed analysis of long-term (~98 years) precipitation records, hydroclimatic provinces and major climate factors. These datasets, along with climate teleconnection study results, are available to assist climate model projections. Part III of the adaptation report provides datasets, tools and methods aimed to develop actionable science for adaptation. Part IV of the report covers infrastructure adaptation techniques and methods that range from urban-scale adaptive planning to infrastructure engineering for adaptation. Tools and methods are described along with case studies.

These technical reports discuss the challenges facing the Nation's water infrastructure and the ways to improve its sustainability. Major findings are: 1) climate impacts on hydrology and surface water quality are significant demanding for proper adaptation actions in water resource and water infrastructure programs; 2) the nation's water and wastewater utilities are not well-prepared to act on climate change adaptation, partially because of the lack of actionable climate data and adaptation methods, amendable to well-accepted water engineering practice; 3) climate change adaptation requires usable projections of the impacts for which integrated model-monitoring techniques are outlined for use at watershed scales; and 4) the adaptation methods and tools in urban-scale planning and in system-scale engineering can make the effective adaptation possible even under the uncertainties in future climate and precipitation projections. For managers, policy-makers, and a broader audience, these technical findings and essential information are summarized in a companion synopsis report.

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ABBREVIATIONS AND NOTATIONS

Definitions and Abbreviations

AMWA	Association of Metropolitan Water Agencies
ASCE	American Society of Civil Engineers
AWWA	American Water Works Association
AWWARF	AWWA Research Foundation
BMP	better management practices
CA	cellular automata
CBO	Congressional Budget Office
CDF	cumulative density function
CSO	combined sewer overflow
CSS	combined sewer system
CWA	Clean Water Act
CWNS	clean watershed needs survey
CWS	community water systems
CWSRF	Clean Water State Revolving Fund
DBP	disinfection by-products
DW	drinking water
ET	evapotranspiration
GAC	granular activated carbon
GDP	gross domestic product
GHG	greenhouse gas
GPCD	gallons per capita per day
HSPF	hydrologic simulation program – Fortran
IDF	precipitation intensity – duration – frequency
IPCC	Intergovernmental Panel on Climate Change
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MGD	million gallons per day
MRDL	maximum residual disinfectant level
NACWA	National Association of Clean Water Agencies
NAWC	National Association of Water Companies
NOAA	National Oceanic and Atmospheric Administration
NOM	natural organic matter
NPDES	National Pollution Discharge Elimination Systems
NPS	nonpoint source
NRC	National Research Council
NRCS	National Resources Conservation Service
NRMRL	USEPA National Risk Management Research Laboratory
NTNCWS	non-transient non-community water system
NWS	National Weather Service
ORD	USEPA Office of Research and Development

OW	USEPA Office of Water
POTW	publicly owned treatment works
R&D	research and development
RBC	rotating biological contactors
SDWA	Safe Drinking Water Act
SRF	State Revolving Fund
SSO	sanitary sewer overflows
THM	trihalomethane
TMDL	total maximum daily load
TNCWS	transient non-community water system
TOC	total organic carbons
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Service
UWC	United States Conference of Mayors Urban Water Council
WTP	water treatment plant
WW	wastewater

Part One: Climate Change Adaptation Readiness Assessment

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1. Overview

The combination of aging water infrastructure and ongoing climate change demand a systems approach to managing the Nation's water assets and improving infrastructure sustainability. The looming need for capital improvement in the water sector poses a challenge, but it also provides a rare opportunity to deliberately incorporate principles of sustainability and climate change adaptation into the planning, design, and operation of the next generation of water infrastructure (Yang, 2010). In this context, sustainability refers to the ability or pre-planned capacity reserve of water infrastructure to effectively respond to stresses, including both the impacts associated with traditional demographic and socioeconomic drivers, and also those that are associated with global climate change. In order to incorporate principles of sustainability and climate change adaptation effectively, it will be necessary to develop actionable data at the local scale on climatic trends as well as demographic and socioeconomic trends.

Climate Change as Pressing Driver

Climate change is an important factor that further complicates the way in which the nation's water infrastructure must be upgraded, managed and operated. Recent reports from International Energy Agency (IEA) and Intergovernmental Panel on Climate Change (IPCC) have shown that global greenhouse gas (GHG) emissions have been growing rapidly (IPCC, 2013). In May 2013, global carbon dioxide (CO_2) atmospheric concentrations exceeded 400 parts per million by volume (ppmv) for the first time in several hundreds of thousands of years. Expressed as CO_2 equivalent (CO_2-eq), GHG emissions increased from 27.9 to 50.1 gigatons per year (Gt/yr) between 1970 and 2010, and the GHG emission trend is very likely to increase global temperatures by 3.6-5.3 ^{o}C within this century (IPCC, 2013; 2014; IEA, 2013a).

Because of the close connection and feedbacks in water-energy-climate nexus, the challenge in climate change mitigation and adaptation is complex yet prominent. The changing climate can potentially change water availability and urban energy consumption, including water production and management. Societal response through mitigation and adaptation can also change future GHG emission, resulting in a climate response and creating a new set of environmental conditions (Princiotta, 2009; PNNL, 2012). For instance, a future energy portfolio responding to the need for climate mitigation would likely move toward low-carbon but more water-intensive forms of energy production. Specifically, biomass-based energy is expected to increase by 215 percent over 25 years to 4.1 million barrel oil equivalent per day by 2035 (IEA, 2013b). In the U.S., where ambitious corn ethanol production goals have been established in

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order to reduce reliance on fossil fuels, increased evapotranspiration may increase corn irrigation rates by 9 percent over the course of 40 years under projected climate change scenarios, even as yields decline by 7 percent (Dominguez-Faus et al., 2013). The impact of mitigation and adaptation measures on water resources (and hence water infrastructure) is expected to be particularly significant in water-stressed regions (IPCC, 2014; Friedrich et al., 2009; Cooley et al., 2011).

Even in the most optimistic case, if atmospheric CO_2 levels are reduced and radiative forcing is reversed, hydrosphere system inertia is likely to continue to drive hydroclimatic changes (IPCC, 2013). Continental precipitation, for example, will be altered. Changes in continental precipitation could adversely impact water supply, wastewater and storm water management programs, and civil works. This is because precipitation and its spatial distribution dictate water availability, surface water hydrology, water quality, stream flow, and groundwater recharge. In sum, water sector adaptation to climate change is a necessity. This has been recognized in Europe, in Australia, and increasingly in the U.S. as well (e.g., Ashley et al., 2007; Wilby, 2007; Hamin and Gurran, 2008; Pielke Jr., 2007; Barsugli et al., 2009; Yang and Goodrich, 2014).

Climate change affects all aspects of design, operation, and management of water infrastructure. In most cases, water infrastructure in the U.S. was designed and built in anticipation of population, demographic, and economic changes over a 30-50 year horizon. This forward-planning and engineering is commonly captured in development of master plans or in infrastructure master planning and capital improvement programs. Climate stationarity is commonly assumed in all practices. The statistics of historical climate observations such as precipitation are taken to represent the future condition under which the water infrastructures will provide services. As the climate changes, facilities built upon the assumptions of climate stationarity could experience failure and potentially lead to interrupted services and expensive rehabilitation or replacement in a short time period.

Infrastructure Improvement as Opportunity

In the interest of a safe drinking water supply and sustainable storm water and wastewater management, local governments, counties, regional authorities, states, and the federal government in the U.S. have made substantial investments in the construction, maintenance, and operation of water resource infrastructure assets (Mays, 2002; U.S. EPA, 2002a). Between 1956 and 2008, local governments alone spent an estimated combined total of $1.61 trillion nominal dollars on drinking water and wastewater construction, maintenance, and operation (Anderson, 2010). State and local government spending on wastewater and drinking water in 2008 was an estimated $93 billion (ASCE, 2013). Yet investments have not kept pace with needs to renovate and replace an aging and deteriorating water infrastructure; this deterioration poses an increasingly serious challenge to the provision of uninterrupted water supply and storm water and wastewater management services (ASCE, 2013; U.S.GAO, 2006; AWWA, 2012). Over the past decade, the American Society of Civil Engineers (ASCE) has consistently given the condition of the U.S.' water resource systems (including drinking water and wastewater infrastructure, dams, and navigable waterways) a grade of D or D- (ASCE, 2005; 2009; 2013). The most recent comprehensive estimates of capital investment needs in the U.S. wastewater and drinking water sectors for a 20-year timeframe stand at $298.1 billion and $384.2 billion, respectively (U.S. EPA, 2008a; 2013a).

In addition to existing infrastructure footprint, climate change adaptation takes place also in the context of existing laws and regulations. A broad review of the existing water and air laws as well as new GHG rules, indicates that climate change can affect various parts of the regulatory program from NPDES permitting, TMDL allocations, to drinking water D/DBP rules, and to water resource impacts from sustainable energy productions. See Appendix I-A and other parts of the national adaptation report.

Infrastructure Adaptation Approach and Methods

The ways to recognize and adapt to climate change were investigated through multi-scale infrastructure adaptation studies. The results are presented in four parts in four volumes. The report Part I contains an overview of anticipated climatic changes at the national scale, the condition of U.S. water infrastructure, other (non-climatic) factors affecting water infrastructure sustainability, the regulatory regimes affecting water infrastructure adaptation, and the results of surveys that shed light on water industry priorities and trends and the place of climate change among other perceived challenges. The report Part II describes in detail the principal climate change factors, most notably those related to precipitation, that affect water infrastructure planning and operations. It provides datasets for "top-down" quantitative assessments of climate change impacts in the form of precipitation. Additionally, hydroclimatic variability is analyzed for the contiguous U.S. over long-range historical precipitation records. The results provide a basis for climate model downscaling simulations and evaluating the validity of climate projections in local water resource planning and engineering.

The reports Part III and Part IV in the last two volumes discuss the methods and tools, respectively, for determining climate change impact characteristics and for planning and designing climate change adaptation. The Part III report describes a modeling-monitoring platform in climate change impact assessment. It consists of satellite-based water quality and water availability monitoring, and an integrated model simulation for land use and hydrological changes in a watershed. The hydrologic simulation leverages on Hydrological Simulation Program FORTRAN (HSPF) and cellula-automada Marchov (CA-MC) models. The hydrological responses from climate and land use changes are simultaneously considered. Lastly, the Part IV report describes planning and engineering techniques for water infrastructure adaptation. Illustrative case studies are provided.

The multi-disciplinary research and technical investigations were initiated by the Environmental Protection Agency's (EPA) Water Resources Adaptation Program (WRAP) team of scientists and engineers in October 2007. In this research, principal factors affecting the U.S. wastewater, stormwater, and drinking water infrastructures were systematically evaluated with a focus on future climate and socioeconomic conditions for the next 30-50 years (approximately 2007-2050). This approach aims to link climate change and adaptation research to tools and actions at local levels. In 2010, as a result of a reorganization of the ORD research portfolio, WRAP research activities were incorporated into projects under the new Air, Climate and Energy (ACE) and Safe and Sustainable Water Resources (SSWR) programs. This adaptation assessment report is tailored to meet specific ACE program needs. Specifically, this national climate change adaptation assessment report attempts to address the following research questions:

- What is the current state of the Nation's water infrastructure in relation to the Clean Water Act and the Safe Drinking Water Act programs? Are current infrastructure conditions sustainable, and what stressors restrict water infrastructures from providing intended services and achieving long-term management goals?
- Is climate change a major stressor, in addition to land use and socioeconomic factors that must be considered in the design, operation, and management of water infrastructures?
- What are the major concerns of U.S. drinking water and wastewater managers and to what extent do these concerns include climate change adaptation? Are they ready to take on these challenges for improved infrastructure sustainability?
- How do hydroclimatic changes and their impacts vary among different regions of the U.S.? How can water infrastructure vulnerability be evaluated? How can water utilities be assisted with adaptation solutions at local scales?
- Can climate change and its projection uncertainties be effectively managed in the design, engineering, and operation of water infrastructures? How can climate change be considered simultaneously with the other more traditional variables in infrastructure planning?

2. Drinking Water and Wastewater System Infrastructure Condition and Stressors

2.1. Climate Change as an Important Driver

Climate change is a global phenomenon that affects both human and natural systems. Houghton (2004) demonstrates the interaction of climate change with adaptation and mitigation activities in an integrated framework, as depicted graphically in Figure 1-1 (Figure originally appeared in IPCC, 2001).

Starting with the box in the lower right hand corner (and moving clockwise), socio-economic activities result in increased emissions of greenhouse gases and aerosols. Greenhouse gases, such as CO_2, methane (CH_4), and nitrous oxide (N_2O), absorb heat radiating from the earth and trap it, thus raising global temperature. Aerosols have complex interactions with the climate that include both increases and decreases in temperatures, effects on cloud formation, and increased melting of polar and glacial ice. Increased global mean temperature results in an increased capacity to retain water vapor in the atmosphere. Stratospheric water vapor may contribute to climate feedback; research in this area is ongoing (IPCC, 2013). Nevertheless, it is clear that climate change affects the spatial distribution and quantity of precipitation, temperature distribution, extreme events, and sea level. These climate changes affect human and natural ecosystems (including water use and wastewater generation), altering resource availability and affecting human activities and health. Various adaptation and mitigation activities can further exacerbate or reduce climate change or its impacts.

The U.S. generally has adequate water resources. Yet the challenge to provide uninterrupted water supply and to manage wastewater and stormwater is increasing in the time of continuing climate and land use changes. Reports by The National Academies (2009) and the U.S. Global Change Research Program (2014) describe the roles of climate change and human activities that are pertinent to the sustainability of water infrastructures. IPCC (2013) is an authoritative general review of the state of scientific knowledge about climate change. Other notable summary reports include those to Congress by the Congressional Budget Office (e.g., CBO, 2002). These recent research reports strongly suggest that the effects of climate change on water infrastructure and water resources programs are apparent in multiple ways. For example, changes in hydrologic cycles due to climate change can affect both water quantity and water quality, thus potentially affecting water infrastructure engineering and management (Milly et al., 2008; Brown, 2010; IPCC, 2013). The change in environmental conditions also affects the integrity of water infrastructure assets. Corrosion of buried pipes in the increasingly moist soil, and physical damage to water facilities during extreme meteorological events such as hurricanes, are common examples. Furthermore, there is interdependency among climate change, land use change, demographic and population shifts, and socioeconomic activities (Ewing et al., 2007; USGCRP, 2014). The interdependency among these principal variables complicates the planning and design of water infrastructure adaptations.

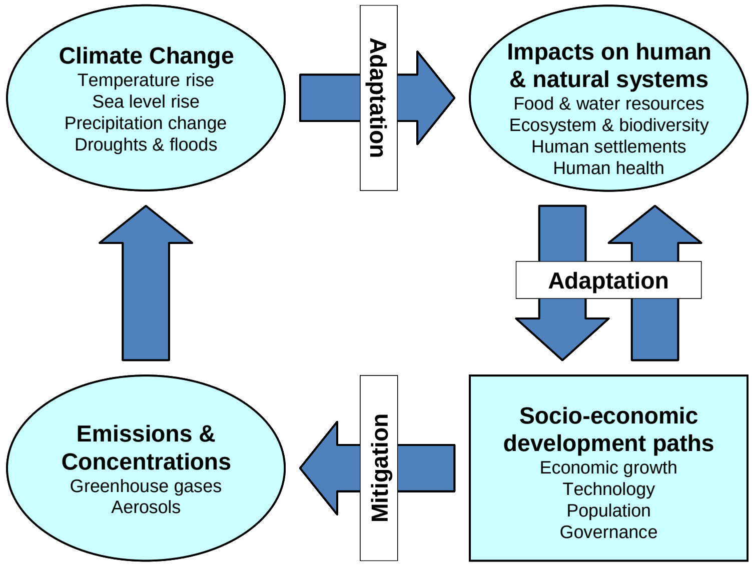


Figure 1-1. Climate change – an integrating framework (based on Houghton, 2004; IPCC, 2001).

The general climate change impacts in these categories have been widely reported in literature and technical reports (e.g., IPCC, 2013; USGCRP, 2014; The National Academies, 2009; and references therein). Yet reports on how these types of climate changes affect water infrastructure at local levels are scarce. In this multi-scale adaptation assessment, attention is focused on the changes in continental precipitation and their impacts on local water resources and water infrastructure. Other forms of climate change impacts such as sea level rise, disruptive meteorological storms, and groundwater recharge are not considered within this report.

2.1.1. Changes in Temperature and Precipitation

Changes in precipitation (e.g., intensity, frequency, duration, and spatial distribution) due to global climate change can directly affect the water quality of streams, lakes, and rivers

(McKenney et al., 2006; Coulibaly, 2006; IPCC, 2013). A more detailed analysis and case studies are provided in the Part III report. The changes in water quality directly affect the performance of water infrastructure and the management of water-related regulatory programs. For example, increases in high-intensity precipitation can result in runoff events with more intensive first flush impacts and higher peak flows. Likely consequences of this change include increased levels of pesticides and pathogenic bacteria, viruses, and protozoa in lakes, rivers, and streams and problematic levels of turbidity in the source water of drinking water supplies (e.g., Charron et al., 2004; Whitehead et al., 2006; Macdonald et al., 2005; van Verseveld et al., 2008). Although some areas may experience increases in runoff, other areas may experience droughts and consequently, water quality changes from elevated levels of potentially toxic cyanobacteria and high concentrations of organic matter, macronutrients, etc. Global climate change may also include increases in ambient temperature and changes in precipitation seasonality, surface water, and groundwater hydrology. In general, increased precipitation is expected in the northern U.S. while decreased precipitation is predicted for the southern U.S. and for the southwest in particular (USGCRP, 2014).

Those areas that experience decreased precipitation and increased temperatures will likely experience reduced stream flows and a worsening water availability problem. For streams receiving wastewater effluent, reduced flows are typically associated with lower levels of dissolved oxygen, diminished assimilative capacity, increased pollutant concentrations, and a deteriorating stream ecologic habitat. Another climate change impact, known with higher certainty, is the melting of mountain ice storage and ice caps at Earth's poles (IPCC, 2013; USGCRP, 2014). The early melt of mountain glaciers in the northwestern U.S. and in the Colorado River Upper Basins has resulted in changes in stream hydrology and water quality, such as changes in the timing of Spring peak river flows, stream ecologic changes such as changes in Pacific Salmon migration patterns, and changes in water supply in general for the region (Barnett et al., 2005; Stewart et al., 2004; Hamlet and Lettenmaier, 1999; Mote et al., 2003; Battin et al., 2007).

It is worth to note, however, that changes in continental precipitation are difficult to project quantitatively. For simplicity, precipitation patterns have long been assumed by the water resource and infrastructure engineering professionals to be static in the long run. In other words, future precipitation at a given location is projected by assuming precipitation variability in the future will resemble precipitation variability in the past. Such an analysis is commonly based on Bayesian statistics of historical precipitation records, typically of a few decades. Observed variations in the past are assumed to represent the future for which an infrastructure is designed, constructed and managed (see details in Section 5.1-5.2 of Part III report). From this viewpoint, the existing practice has accounted for climate variability but neglects the effects of climate change. In particular, the following water resource parameters are likely to be affected if significant climate change occurs during the service life of a piece of water infrastructure:

Precipitation intensity-duration-frequency: Rainfall intensity-duration-frequency (IDF) is a key climate-related hydrological parameter permeating almost all aspects of hydrological engineering, such as in storm runoff, water reservoir, groundwater infiltration, flood control, etc. Commonly used IDF curves from NOAA (e.g., NWS Atlas-14) take a given length of observed precipitation records in Bayesian statistics to predict precipitation intensity for a given storm (e.g., 24-hours). No attempt is made to discern trends over the course of the observation period, and IDF statistics are normally applied as if they were equally descriptive of the future as they are of the past. Precipitation intensity is important to water infrastructure because, for example, in urban areas it affects the frequency of combined sewer overflows and can therefore affect the risk of bacterial contamination of drinking water sources.

Precipitation areal distribution: Areal coverage of precipitation events changes with season, hydroclimatic region, and the region's topography. This variable is not among the most frequently discussed in climate science and in hydrological studies. However, it can play a significant role in watershed modeling and water resources management, and can affect urban hydrology and performance of stormwater and wastewater infrastructures.

Form of precipitation: Precipitation can take the form of rainfall or snow. The hydrological effects of rainfall and a snow event with the same water content differ in several ways, including the duration and timing of water release to the watershed, and consequently also on peak runoff amounts, soil moisture, and watershed hydrology. This difference is stark for snow packs in high altitudes, such as the Rocky Mountains and the U.S. northwest.

Air and water temperature: For the temperate contiguous U.S., water temperature varies seasonally and will change in response to changes in ambient air temperature. Climate models (IPCC, 2013 Chapter 11) project for the near-term an increase of global mean surface air temperature of 0.3 to 0.7 degrees Celsius (°C) for the period 2016-2035, relative to the reference period 1986-2005. Over most parts of the United States, air temperatures are projected to rise by 2 to 4°F (1.1 °C- 2.2 °C) over the next few decades. Under various emissions scenarios, by 2100 temperature increases are projected to be between 3 to 5 degrees Fahrenheit (°F), equivalent to1.7 °C- 2.8 °C) higher on the low end (assuming substantial reductions in emissions) and 5 to 10°F (2.8 °C- 5.6 °C) on the high end (assuming continued increases in emissions) (USGCRP, 2014).

Effects of temperature increases on surface water bodies have been reported in the literature (Kaushal et al., 2010; Mantua et al., 2010; Walther, 2010; Whitehead et al., 2009; Woodward et al., 2010). Kaushal et al. (2010) reported rates of temperature increase in the range of 0.009-0.077 °C per year (/yr) for 20 major rivers and streams in the contiguous U.S. These changes in temperature can lead to changes in water quality that consequently affect drinking water production (Delpla et al., 2009). In addition, the increases in sediment, nitrogen, and other contaminants can be expected in rivers and lakes as the result of increasing air and water temperatures, increased frequency of intense rainfall events, and more intense droughts (USGCRP, 2014).

Indirect hydrological changes: There are several other hydrological changes that, if induced by climate change, could materially affect water infrastructure, its service functionality, and environmental compliance. The indirect impacts of climate change originate from interactions of climate change (temperature, precipitation, heat waves, droughts, hurricanes, etc.) and the environment. For example, higher ambient temperature and extended duration can affect vegetation cover, increase direct runoff and evapotranspiration (ET). The indirect effect can be decreased soil moisture and water replenishment to groundwater, potentially affecting stream base flow. Satellite data indicate that soil moisture has decreased in parts of North America over the past couple of decades and increased in others; observed decreases in evapotranspiration (ET) have tended to occur in water-rich areas (USGCRP, 2014). Limited climate modeling studies available in the literature indicate likely future changes in soil moisture. In urban areas, the storm water runoff from an increased precipitation intensity in the future climate is compounded by an increased impervious surface as urbanization continues. Sometimes the relationship is implicit, such that it can be identified only by detailed investigations to be the result of climate change. Yet these implicit indirect hydrological changes can influence or affect infrastructure planning, design, and management.

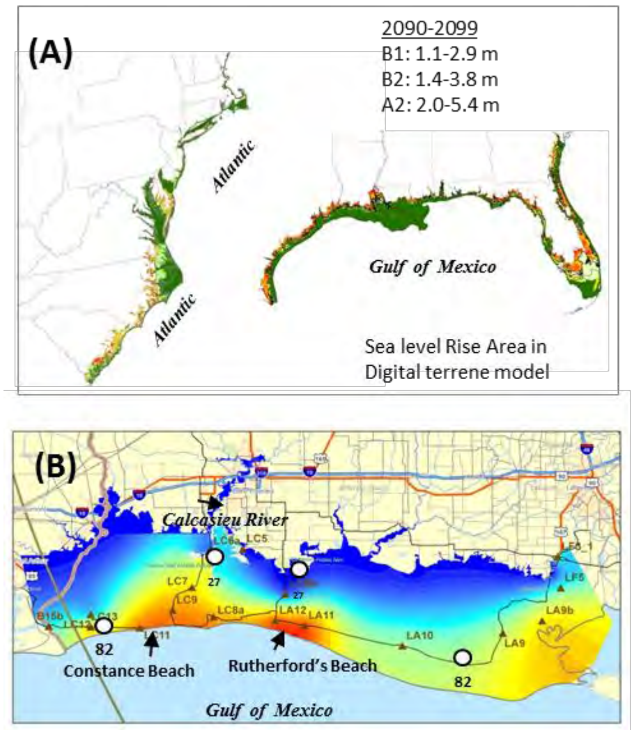
Warmer temperatures and changes in precipitation patterns can contribute to the risk of other types of extreme events, such as wildfires. Depending on the proximity of the raw water source and water treatment plant to the fire, deforestation and the resulting hillslope runoff from erosion can dramatically increase reservoir sedimentation, clog the water delivery system, and create long-term treatment problems for water treatment plants. Research sponsored in part by EPA indicates that higher turbidity, nitrate, dissolved organic carbon, ash deposition, and changes in aromaticity of soil organic matter may affect water quality and treatment requirements (Sham et al., 2013). Watershed recovery takes between 4 to 8 years and the raw water sources may be affected for 4 to 5 years after a fire (Clark, 2010). Components of the utility's infrastructure itself may also be vulnerable to damage from wildfires.

The indirect hydrological changes in water quality are often substantial and show in multiple dimensions. For example, the occurrence of cyanobacterial blooms (i.e., microcystin, etc.) increases in frequency, magnitude and location over surface water bodies (Paerl and Paul, 2012; Chang et al., 2014). With higher water temperatures and altered micronutrient ratios, climate change can foster aquatic environments favoring outsized cyanobacteria growth. Other water quality parameters that can be affected include total organic carbon (TOC), natural organic matter (NOM), turbidity, and micronutrients (e.g., nitrogen and phosphorus). In the Part III report, climate-change-related alterations in water quality in simulations for two watersheds are described.

2.1.2. Sea Level Rise and Storm Surge

Sea level rise and changes in frequency and magnitude of extreme events such as storm surge and hurricanes can also affect water infrastructure. Observed sea level rise is attributed to the melting of polar ice shields (USGCRP, 2014) and to expansion of the upper oceanic layer as ocean temperatures rise (Meehl et al., 2006; Rial, 2004; Overpeck et al., 2006). Along the U.S. east coast and the Gulf coast, the increase in sea level between 1992 and 2100 could be in the range of 0.2-2.0 meters (NOAA, 2012), which could, in turn, result in a greater degree of salt water intrusion into drinking water sources in those regions. Currently, approximate 53 percent of the U.S. population currently lives on what are considered coastal lands. Seawater intrusion, along with more frequent disruptive meteorological events in a warmer atmosphere of intensified circulations, likely present a problem to U.S. coastal communities including those of Florida, the Gulf Coast, Southern California, and the Northeast.

Direct consequences of sea level rise and extreme meteorological events (e.g., hurricanes) include the denudation of low-land coastal area (Figure 1-2) and physical damage to water infrastructures. Hurricane Sandy, for example, damaged infrastructure and water services in much of the Mid-Atlantic region including New York and New Jersey (USGCRP, 2014). Sea level rise can also cause salt water intrusion, changing the quality of water sources and causing corrosion of infrastructure.



(A) Elevation digital mapping of SLR impacts in Atlantic and the Gulf of Mexico coasts;
(B) Denudation of hurricane Rita on the Gulf coast based on Data from Robert Mason of US Geological Survey.

Figure 1-2. Examples of coastal inundation due to sea level rise and disruptive storm surge impacts. Arrows indicate approximate hurricane landfall locations.

Although sea level rise and storm surge are important manifestations of climate change and have effects on water infrastructure, later parts of this report focus primarily on long-term trends in precipitation. Nevertheless, advances in our understanding of the factors contributing to sea level rise and improved agreement of models with observations have allowed researchers to make these projections. Recently, NOAA published an online tool to predict sea level rise and storm surge. One can calculate expected sea level rise at a specific coastal location of interests. EPA Office of Water (OW) has developed a tool for assessment of water infrastructure risk under the GHG emission and sea level rise scenarios[6]. It is noted, however, that uncertainty still exists on the upper bound of future sea level rise. Sea level will continue to rise for centuries, even if GHG emissions are reduced to the extent that atmospheric concentrations are stabilized. Details are provided by the IPCC (2013).

2.2. U.S. Drinking Water and Wastewater Infrastructure

Public drinking water systems are regulated under the Safe Drinking Water Act of 1974 (SDWA) and its amendments. The 1948 Federal Water Pollution Control Act, which was significantly reorganized in 1972 and is now referred to as the Clean Water Act (CWA), is the principal law that regulates pollution discharged into the nation's streams, lakes, and estuaries.

[6] http://water.epa.gov/infrastructure/watersecurity/climate/stormsurge.cfm

SDWA defines three types of public water systems, all of which provide water service to at least 15 service connections or an average of at least 25 people for at least 60 days a year: community water systems (CWS), transient non-community water systems (TNCWS), and non-transient non-community water systems (NTNCWS). CWSs serve year-round residents and can serve populations ranging from as few as 25 people to as many as several million people. TNCWSs serve non-residential facilities such as campgrounds or gas stations, where individuals consume the water for only a limited period of time. NTNCWSs also serve non-residential populations, but serve at least 25 of the same people for at least 6 months per year, though not year-round. Examples of NTNCWSs include drinking water systems at schools, hospitals, and office buildings.

In 2011, there were approximately 153,000 water systems in the U.S. that met the federal definition of a public water system (Table 1-1) (U.S. EPA, 2013b). Approximately one-third of these systems were CWSs. This includes 11,721 CWSs using surface water and 39,624 CWSs using groundwater sources, together serving approximately 300 million people (Table 1-2). Although the vast majority of public water systems are relatively small (serving fewer than 3,300 people), most residential customers get their water from large systems (82 percent of CWS customers are served by systems with a customer base of over 10,000 people). It should be noted that not all public water systems deliver water directly from the source; some receive and distribute treated water from another CWS. Public water systems that obtain their water through interconnections with other public water systems are referred to as “consecutive systems.”

As of 2008, there were approximately 14,800 wastewater treatment utilities (publicly owned treatment works, or POTWs) in the United States, 96 percent of which had an existing flow range of less than 10 million gallons per day (MGD). These POTWs provided service to 226 million people or 74 percent of the U.S. population. The remaining 26 percent of the population are not connected to centralized treatment, but instead use some form of on-site treatment system (U.S. EPA, 2008a).

Table 1-1. Size Category, Type, and Number of Public Water Systems in the U.S. in 2011*

System Size by Population served		Ver Small <500	Small 501-3,300	Medium 3,301-10,000	Large 10,001-100,000	Very Large >100,000	Totals
CWS	#Systems	28,462	13,737	4,936	3,802	419	51,356
	Population served	4,763,672	19,661,787	28,737,564	108,770,014	137,283,104	299,216,141
	% of Systems	55%	27%	10%	7%	1%	100%
	% of Population	2%	7%	10%	36%	46%	100%
NTNCWS	#Systems	15,461	2,566	132	18	1	51,356
	Population served	2,164,594	2,674,694	705,320	441,827	203,000	6,189,435
	% of Systems	85%	14%	1%	0%	0%	100%
	% of Population	35%	43%	11%	7%	3%	100%
TNCWS	#Systems	80,347	2,726	92	13	1	83,179
	Population served	7,171,054	2,630,931	514,925	334,715	2,000,000	12,651,625
	% of Systems	97%	3%	0%	0%	0%	100%
	% of Population	57%	21%	4%	3%	16%	100%

Note: * - U.S. EPA (20013b).

Since the passage of the Clean Water Act in 1972, biological or "secondary" treatment of wastewater (as a supplement to "primary" mechanical treatment) has become increasingly widespread. Between 1972 and 2008, the population served by POTWs that do *not* employ biological treatment fell from 50 million to 3.8 million (U.S. EPA, 2008a). In 2008, there were approximately 600,000 miles of publically owned sewer pipe (U.S. EPA, 2008a).

Table 1-2. Number of Public Water Systems and Population Served by Source of Water*

System Size by Population served		Groundwater	Surface Water	Unknown	Totals
CWS	#Systems	39,624	11,721	11	51,356
	Population served	86,585,984	212,573,760	7,914	299,216,141
	% of Systems	77%	23%	0%	100%
	% of Population	29%	71%	0%	100%
NTNCWS	#Systems	15,461	2,566	132	51,356
	Population served	2,164,594	2,674,694	705,320	6,189,435
	% of Systems	85%	14%	1%	100%
	% of Population	35%	43%	11%	100%
TNCWS	#Systems	80,347	2,726	92	83,179
	Population served	7,171,054	2,630,931	514,925	12,651,625
	% of Systems	97%	3%	0%	100%
	% of Population	57%	21%	4%	100%

Note: * - U.S. EPA (20013b).

2.2.1. Drinking Water Infrastructure National Needs

Drinking water system infrastructure includes the surface water intakes and wells, treatment plants, transmission and distribution pipes, pumps, valves, storage tanks, meters, fittings, and other appurtenances that are necessary for providing safe drinking water to consumers' taps. Public water systems maintained more than 2 million miles of distribution mains as of 2006, of which half were between six and ten inches in diameter (U.S. EPA, 2009a). As of 2003, public water systems also had an estimated 154,000 finished water storage facilities (AWWA, 2003). Community public water systems replaced over 56,000 miles of pipe between 2001 and 2006, and added nearly 225,000 miles of new pipe in that same period (U.S. EPA, 2009a). In addition to providing consumers with potable water, water distribution systems often must also supply water for non-potable uses, such as fire suppression and landscape irrigation.

Upkeep of the nation's drinking water infrastructure represents an enormous financial liability. In its fifth report to Congress on the Drinking Water Infrastructure Needs Survey and Assessment (DWINSA), U.S. EPA (2013a) estimated that the 20-year drinking water infrastructure needs of the country's CWSs will reach $384.2 billion for the period of January 1, 2011 through December 31, 2030. This estimate reflects the needs of CWSs and not-for-profit non-community water systems to continue to provide clean and safe drinking water to their customers for the year-2011 population levels. The need includes installation of new and advanced infrastructure as well as rehabilitation or replacement of deteriorated or undersized infrastructure as such rehabilitation or replacement becomes necessary during the 20-year DWINSA study period of January 2011 through December 2030.

Table 1-3. 2011 DWINSA Findings by Public Water System Size*

Total National 20-Year Need (in $billion of January 2011 dollars)		
System Size and Type	Need	
Large Community Water Systems (serving ≥100,000 people)	$145.1	
Medium Community Water Systems (serving 3,301 to 100,000 people)	$161.8	
Small Community Water Systems (serving ≤3,300 people)	$64.5	
Not-for-profit Non-community Water Systems	$4.6	
Total State and U.S. Territory Need		**$376.0**
American Indian Water Systems	$2.7	
Alaska Native Village Water Systems	$0.6	
Costs Associated with Proposed and Recently Promulgated Regulations (Taken from EPA Economic Analysis)	4.9	
Total National Need		**384.2**

Note: * -- U.S. EPA (2013a).

The findings of the 2011 DWINSA show that the nation's largest CWSs (serving >100,000 people) account for $145.1 billion, or 39.1 percent, of the total national need. Medium-sized CWSs (serving from 3,301 to 100,000 people) and small CWSs (serving 3,300 and fewer people) also have substantial needs of $161.8 billion and $64.5 billion, respectively (Table 1-3). The total national 20-year infrastructure funding need of over $380 billion reported by the 2011 DWINSA represents a continued increase over previous assessments (Table 1-4).

Table 1-4. DWINSA Comparison of 20-Year National Need*

DWINSA Year	1995	1999	2003	2007	2011
National Need	$227.3	$224.8	$375.9	$379.7	$384.2

Note: * - The Need Estimate in Billions of January 2011 Dollars. From U.S. EPA (2013a)

An American Water Works Association (AWWA) analysis has incorporated future population growth into its estimates of capital needs. AWWA reported that it would cost at least \$1 trillion between 2011 and 2035 and \$1.7 trillion between 2011 and 2050 to restore existing drinking water systems as they reach the end of their useful lives and expand them to accommodate projected population growth (AWWA, 2012). AWWA also concluded the costs were distributed more heavily in the south and west regions of the country (Table 1-5). Figure 1-3 defines the regions used in the AWWA report. The AWWA regions were delineated based on population dynamics and historical patterns of pipe installation, so their populations are not identical in size.

Since 1988, ASCE has periodically prepared a Report Card that assesses the condition of the nation's public infrastructure. The assessment considers 16 types of infrastructure, including drinking water, wastewater, inland waterways, levees, ports, and dams. Of the 16 general infrastructure areas, the water resources categories receive among the lowest marks. Since 2001, drinking water has consistently received a mark of "D" or "D-" (ASCE 2013).

Figure 1-3. Regions used in the AWWA "Buried no Longer" report (AWWA, 2012).

The 2011 DWINSA breaks the total national need into five categories (Figure 1-4). As in the previous four DWINSAs, a majority of the need (in this case \$247.5 billion, or 64.4 percent) is for transmission and distribution pipe, pump stations, and appurtenances. Although treatment plants or elevated storage tanks are usually the most visible components of a water system, most of a system's infrastructure is underground in the form of transmission and distribution mains. Failure of transmission and distribution mains can interrupt the delivery of water or lead to a loss of pressure, which can allow backflow of contaminated water into the system. Broken transmission lines can also disrupt the treatment process.

Table 1-5. Aggregate Needs for Investment in Water Mains through 2035 and 2050 by Region*

Region	2011-2035 Totals (millions of 2010$)				2011-2050 Totals (millions of 2010$)			
	Replacement	Growth	Percent Increase	Total	Replacement	Growth	Percent Increase	Total
Northeast	$92,218	$16,525	17.9%	$108,743	$155,101	$23,200	15.0%	$178,301
Midwest	$146,997	$25,222	17.2%	$172,219	$242,487	$36,755	15.2%	$279,242
South	$204,357	$302,782	148.2%	$507,139	$394,219	$492,493	124.9%	$886,712
West	$82,866	$153,756	185.5%	$236,622	$159,476	$249,794	156.6%	$409,270
Total	**$526,438**	**$498,285**	**94.7%**	**$1,024,723**	**$951,283**	**$802,242**	**84.3%**	**$1,753,525**

Note: * - from AWWA (2012)

The second largest category of need is treatment projects, totaling $72.5 billion or 18.9 percent of the total need. Treatment projects involve the installation of technologies such as filtration, disinfection, corrosion control, and aeration to reduce or eliminate contaminants. The remaining categories of need include finished (i.e., treated) water storage infrastructure ($39.5 billion or 10.3 percent), source water infrastructure ($20.5 billion or 5.3 percent), and miscellaneous projects ($4.2 billion or 1.1 percent). The storage project category includes the cost to construct new tanks or rehabilitate or replace existing finished water storage tanks. Construction of new tanks is necessary if the system cannot provide adequate flows and pressure to existing consumers during peak demand periods. Many projects in this category involve rehabilitating existing tanks to prevent structural failures or sanitary defects that can allow microbiological contamination. The source water infrastructure category includes projects that are necessary to obtain or sustain safe supplies of surface water or groundwater, such as groundwater wells or surface water intake structures. Examples of projects in the miscellaneous category include emergency power generators not associated with a specific system component, computer and automation equipment, and projects for system security.

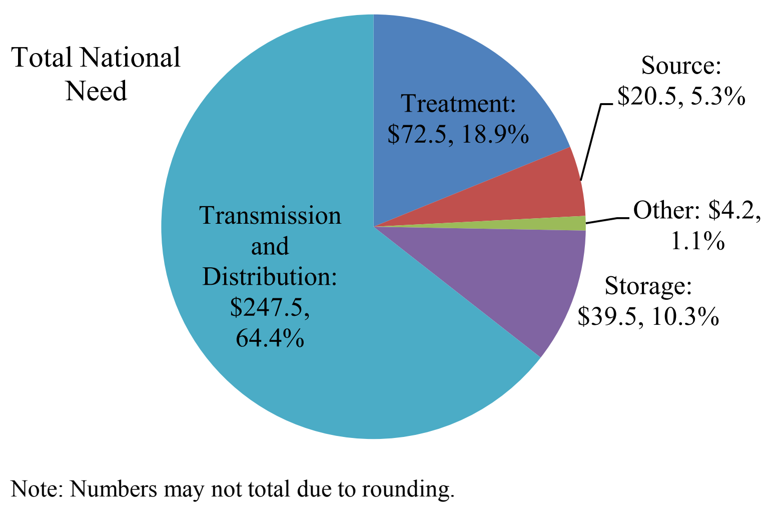


Figure 1-4. Total 20-year need by project type (in billions of January 2011 Dollars) (U.S. EPA, 2013a).

The SDWA requires that public water systems meet national standards to protect consumers from the harmful effects of contaminated drinking water. Some of the infrastructure funding needs (10.9 percent) reported by the 2011 DWINSA are directly attributable to SDWA regulations (U.S. EPA, 2013a). While most of the total need is not driven by compliance with a particular regulation, properly maintaining water system infrastructure is both economical in the long run and protective of public health.

For the 2011 DWINSA, EPA sought to capture data on climate readiness projects to help facilitate communications about this emerging issue. Climate readiness was defined as adapting to and addressing climate change impacts on drinking water system infrastructure. The intent of the effort was to compile additional information to estimate, in very general terms, the extent to which projects that were included in the DWINSA are also related to climate change adaptation. Identifying a project as related to climate readiness was voluntary and did not affect project evaluation and acceptance for the DWINSA.

Survey respondents were asked to identify which projects were related to climate readiness and to indicate the concern being addressed and the type of information identifying the concern. EPA did not explicitly define what constitutes a climate readiness project or what are the appropriate rationales or data to support the consideration of climate readiness; respondents' best professional judgment was relied upon for the determination.

Only a limited number of 2011 DWINSA respondents reported climate readiness projects (164 projects from 44 systems, or fewer than 1.5 percent of the responding systems). One state accounted for over half the reported climate readiness needs. It is not clear whether that particular state actually has more climate readiness projects than other states or whether there were state-by-state differences in willingness to answer the question. Since the question was voluntary and did not play a role in determining infrastructure needs, it is likely that many climate readiness projects went unreported. This is corroborated by recent research, funded by the Water Environment Research Foundation (WERF), which found via a series of regional workshops that utilities throughout the country were engaged in efforts of one kind or another. The next iteration of the DWINSA, in 2015, may delve further into climate readiness; the limited 2011 data on climate readiness may at least help to increase dialogue around the DWINSA regarding climate readiness.

The need to replace aging infrastructure is compounded by a number of factors. In addition to climate change, these include conservative or traditional design methods, increasingly stringent standards and regulations, negligence in maintenance and repair, and public concern about the quality of water at the tap. Utilities and government will need to take the lead in order to ensure a reliable supply of high quality water at the tap, to meet regulatory requirements, and to respond to customer needs while controlling costs (Clark et al., 1988; 1991a,b; 1999; Westerhoff et al., 2005).

2.2.2. Wastewater Infrastructure National Needs

In 2008, EPA conducted its 15th assessment of the estimated cost of needed construction of all POTWs in the U.S. (U.S. EPA, 2008a). The Clean Watersheds Needs Survey (CWNS) was based on a comprehensive census survey of more than 30,000 water quality programs and projects that are generally eligible for funding under the Clean Water State Revolving Fund (CWSRF) program.

According to the 2008 CWNS, the estimated total POTW construction needs for the nation for the next 20 years is $298.1 billion. This represents a 41 percent increase over the needs reported in the 2004 CWNS. Figure 1-5 summarizes these needs. Of the total national need of $298.1 billion, $82.6 billion is for collection systems (pipe repair and new pipes), $105.2

billion is for treatment systems, $63.6 billion is for combined sewer overflow (CSO) corrections, and $42.3 is for stormwater management.

Of the $82.6 billion in needs for pipe repair and new pipe in 2008, 51 percent of the needs are associated with repairs. This reflects a steady increase compared with previous years. The increase in the relative need for pipe repair reflects communities' efforts to plan for the correction of problems related to separate storm sewer systems (namely, sanitary sewer overflows or SSOs). SSO occurrence is associated with wet weather flows, primarily due to storm water infiltration or overflows in heavy rains, structural failure of pipes, pump station failures, and operator errors in treatment facilities. Climate-related precipitation changes are highly relevant to these needs.

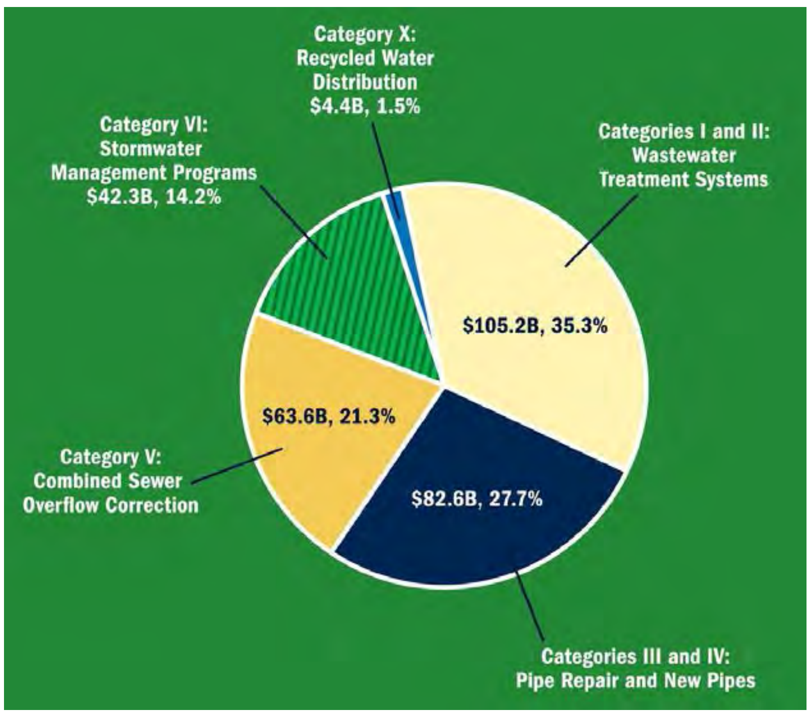


Figure 1-5. Total documented needs in the clean water needs survey (January 2004 dollars) (U.S. EPA, 2008a).

In addition, many communities have needs associated with CSOs ($63.6 billion nationally) (U.S. EPA, 2008a). CSOs occur in many older cities where sanitary sewage and stormwater runoff are collected in a single sewage system. This type of sewer system provides partially separated channels for sanitary sewage and stormwater runoff. It provides backup capacity for the runoff sewer when runoff volumes are unusually high. However, it is considered to be antiquated and is vulnerable to overflow during peak rainfall events. A combined sewer system allows a certain amount of untreated flow to discharge into a water course to keep the systems from becoming surcharged in storm conditions. It often contains a screen which may be a mechanical or static arrangement depending on the frequency of spills per year. During heavy rainfall, when the stormwater exceeds the sanitary flow, the sewage from homes would be diluted. However, combined sewage can be a major environmental problem and municipalities have begun to look for ways to mitigate the environmental effects of such overflows. As with SSO needs, the climate-related precipitation changes are highly relevant to CSO needs.

The cost of providing adequate stormwater infrastructure represents another major need in many urban areas. U.S. EPA (2008a) estimated that the development of adequate stormwater infrastructure would require an expenditure of $42.3 billion.

Table 1-6. Comparison of total needs for water quality projects 2000-2008 in billions of dollars*.

Category Number	Name	2000	2004	2008	Change 2004 to 2008	
					$bil	Percent
I	Secondary Treatment	48.6	52.9	59.9	7.0	13.2
II	Advanced Treatment	26.9	29.0	45.3	16.3	56.2
III-A	Infiltration/Inflow Correction	10.8	12.2	8.2	-4.0	-32.8
III-B	Sewer Replacement /	22.2	24.9	33.7	8.8	35.3
IV-A	New Collector Sewers	18.8	19.9	21.4	1.5	7.5
IV-B	New Interceptor Sewers	19.6	20.4	19.4	-1.0	-4.9
V	Combined Sewer Overflow	66.7	65.0	63.6	-1.4	-2.2
VI	Stormwater Management	7.3	25.4	42.3	16.9	66.5
X	Recycled Water Distribution		5.1	4.4	-0.7	-13.7
Total needs		220.9	254.8	298.1	43.3	17.0
Treatment (Categories I and II) only		75.5	81.9	105.2	23.3	28.4
Pipe Repairs and New Pipes (Categories III and IV) only		71.4	77.4	82.7	5.3	6.8
Category I to V subtotal		213.6	224.3	251.5	27.2	12.1

Note: * - from U.S. EPA (2008a).

Table 1-6 compares (in January 2008 dollars) the total needs for water quality projects in the United States based on the 2000, 2004, and 2008 CWNS Reports to Congress (U.S. EPA, 2008a). The needs reported for the wastewater treatment, collection, and CSO correction categories (Categories I through V) increased from $224.3 billion in the 2004 CWNS to $251.5 billion in 2008. This is a $27.2 billion (or 12.1 percent) increase. For collection and treatment system needs, increases of $100 million or more each in only 100 facilities account for total increases of $34.7 billion. These 100 facilities serve approximately 43 million people, or 14 percent of the U.S. population. An additional 55 facilities had needs that decreased by at least $100 million each. The most significant increase in needs related to wastewater treatment and collection is for advanced treatment (i.e., treatment for nutrient removal). Advanced treatment needs increased by $16.3 billion, or 56.2 percent. In addition, needs for sewer line replacement or rehabilitation increased by $8.8 billion or 35.3 percent, and needs associated with secondary (biological) wastewater treatment increased by $7.0 billion or 13.2 percent. Increases in Categories I and II could be due to a variety of issues, including rehabilitation of aging infrastructure, facility improvements to meet more protective water quality standards, and in some cases, providing additional capacity to respond to and prepare for population growth.

As mentioned, the ASCE's periodic infrastructure Report Card evaluates the condition of the nation's public wastewater infrastructure. Since 2001, wastewater has consistently received a mark of "D" or "D-" (ASCE 2013).

2.3. Other Factors Affecting Infrastructure Sustainability

Sustainable infrastructure is designed to meet a range of future stresses and contingencies. As discussed above, traditional water planning and engineering practices assumed a stationary climate, and that assumption needs to be revisited. Other major planning considerations that need to be taken into account when designing sustainable infrastructure include population growth, spatial migration and demographic shifts, public health and regulations, economic development, and other emerging issues such as energy production. These factors are briefly described below.

2.3.1. Population Growth and Demographic Shifts

Population projections for the U.S. are available from the U.S. Census Bureau (among other source). The Census Bureau's Population Projections Program creates projections of the resident population for the U.S. and for each of the 50 states and the District of Columbia[7]. Projections of total U.S. populations are available on a yearly basis from 2012 to 2060 by age, gender, and race. Projections at the state or regional level are also available for the period 2000-2030. The U.S. Census Bureau projects an increase in the population of the U.S. from 314 million in 2012 to 420 million in 2060 (U.S. Census Bureau, 2012). Figure 1-6 illustrates expected population change (expressed as percentage change from 2012 to 2017) at the county level. Figure 1-6 also shows the U.S. hydroclimatic province boundaries (red lines) that are described in the Part II report. There is a great amount of spatial variation among different regions, states and even counties. Notable population increases are expected across much of the West, in parts of the Southeast (including along the Gulf and Atlantic coasts), and in many large metropolitan areas. Comparatively, the Great Plain states and those in the traditional industrial "rust belt" are expected to experience population declines. These population change trends are projected to continue into the foreseeable future, though all population projections are associated with some uncertainty and the uncertainty increases as the time horizon extends.

Population is a major factor affecting the quantity of water usage and the amount of wastewater generated. Population change will have a strong impact on the adequacy of the water resources infrastructure in the future. In order to plan for future water resources needs, utilities and local planners typically make population projections. These projections utilize different growth and development scenarios to predict future population at various spatial scales ranging from the entire world, to countries, to regions and even at local levels. Means et al. (2005a) note that both increases and decreases in population pose challenges to water utilities. Whereas communities with burgeoning populations will have to find the resources to fund new facilities,

[7] http://www.census.gov/population/projections/

areas with static or shrinking populations face the challenge of a diminishing customer base, resulting in a limited rate capacity to replace aging water infrastructure. On a local watershed scale, especially in urban areas, the rate of population change with time and space is exacerbated by land use policies in addition to natural constraints such as topography, surface water, meteorological properties, etc.

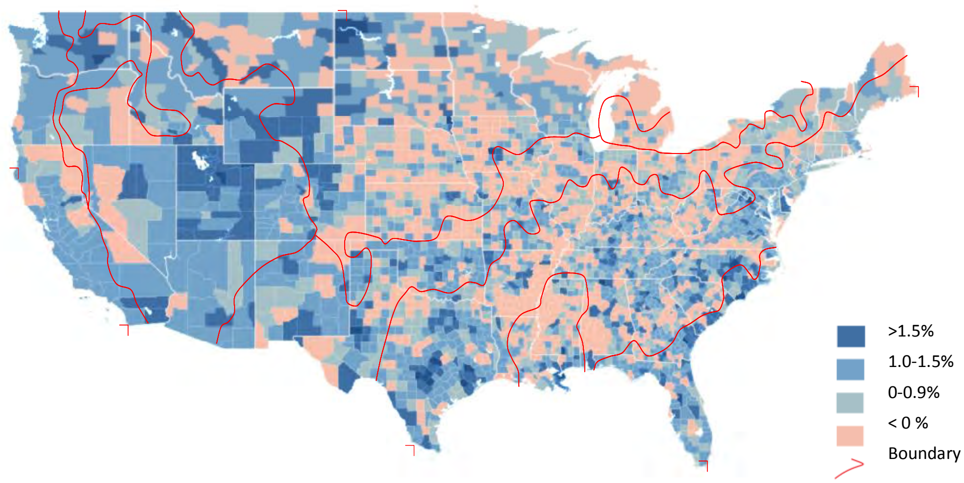


Figure 1-6. Population change rate projections for 2012-2017 in contiguous U.S., showing spatial disparities across the continent. Population data in 2014 are from ESRI.

In 2003, the Bureau of Reclamation (2003) observed that explosive population growth was occurring in areas where water supplies are limited. Population growth in such regions continues to place a significant burden on water resources. Some areas in the western U.S., for example, where population is expected to continue to grow, receive less than one-fifth of the annual precipitation that other areas of the country enjoy. In some areas the water supply will not be adequate to meet all demands for water even in normal water years, while ongoing and projected climate change will further worsen droughts and magnify the impacts of water shortages (Brekke et al., 2009).

Local demographic changes drive land use changes and conversion that can further compound and enhance the hydroclimatic and water quality changes in watershed scales. The land use factor is examined comprehensively in Part III of this report. Demographic changes can also confound adaptation measures. For example, water usage per capita in Las Vegas metropolitan, Nevada shows an overall trend of steady decrease since 1990. The per-capita water usage decreased by 20 percent due to water conservation measures. However, the total population growth outpaced the water conservation effect. The population grew by 2 folds from 852,000 in 1990 to 1,951,000 by 2010 in the metropolitan statistical area. The combined effect of climate-induced decrease in water availability and an increase in water demand led to a steady decline of water level in the Lake Mead, a primary source water of the region. According to the monitoring data[8], the water level declined more than 100 feet in the same period; this challenges the local government in seeking for sustainable water resource management (Ranatunga et al., 2014). This example obviously points to the importance that utilities will need to consider human activity and incorporate projections of population change in water infrastructure planning.

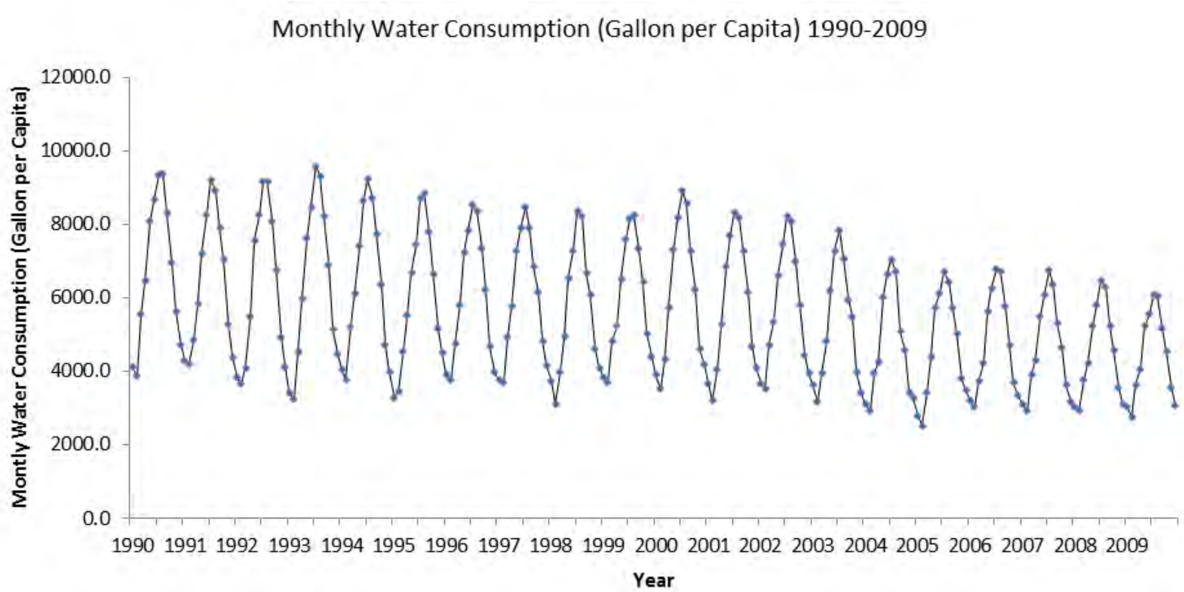


Figure 1-7. Decrease of monthly average water consumption per capita in Las Vegas metropolitan area, Nevada, showing steady decline since 1990. Data from Southern Nevada Water Authority.

2.3.2. Public Health and Social Development

Historically, public health was the primary driving force behind the establishment of both public drinking water supplies and municipal sewer systems and treatment plants in the U.S. As a result of these advances, the most serious waterborne diseases such as cholera and typhoid were virtually eliminated. However, public health concerns remain a challenge in water supply and water/wastewater management.

Levin et al. (2002) assess the challenges facing the drinking water industry in the U.S. in the 21st century from the public health viewpoint. Their analysis points to the inadequate capacity of public water infrastructure to meet current needs, the compounding factors of climate and land use changes, the risks of waterborne infectious diseases, the need for source water protection, and the need to update and reevaluate regulations for addressing legal requirements and new health data. Failures or inadequacies in sewer and stormwater infrastructure provide a source of microbial contaminants that can enter into the water supply or contaminate natural water courses. In fact, many of the recent significant waterborne disease outbreaks in North America have been attributed to failures in the water supply and/or wastewater/stormwater

[8] www.usbr.gov/lc/region/g4000/hourly/mead-elv.html

infrastructure. Examples of such failures include the *Salmonella* contamination of the Gideon, Missouri water system in 1990, the 1994 *Cryptosporidium* outbreak in Milwaukee, and the 2000 waterborne outbreak of *Escherichia coli* O157:H7 in Walkerton, Ontario.

There is a direct relationship between the state of the water/wastewater/stormwater infrastructure and the incidence of waterborne disease. Microbial contaminants can enter drinking water supplies through the following methods:

- Water treatment failure (breakthrough)
- Contamination of tanks by birds, humans, etc.
- Intrusion into pipes through cracks during transient negative pressure episodes
- Pipe breaks (after the break and/or during repair)
- Cross connections (opportunities for non-potable water to enter a potable water supply)
- New main installation
- Intentional contamination of a distribution system associated with a terrorist or criminal act.

Kirmeyer et al. (2001) prioritized potential pathogen routes of entry and based on the input from an expert panel identified the following infrastructure-related routes as high priority mechanisms: water treatment breakthrough, transitory contamination (i.e., intrusion during negative pressure episodes), cross connection, and water main repair/break.

In a presentation accepting the 2006 ASCE Simon W. Freese Award, Glen T. Daigger (Daigger, 2007) highlighted the continuing public health challenges facing the environmental and wastewater fields globally in the 21st century. He observed that as water demand increases with a rising global population, simultaneously addressing the goals of environmental protection and public health protection will pose a major challenge. To meet that challenge, an integrated approach to urban water management will be necessary. Despite the traditional division of water versus wastewater, both should now be viewed as resources and managed coherently to sustain the needs of an increased population.

2.3.3. Economic Development

Economic development can increase resources available for infrastructure, including those for water services, but can also increase the level of stress on infrastructure. One common measure of economic development is growth of gross domestic product (GDP). GDP is defined as the total market value of all final goods and services produced within a country in a given period of time (usually a calendar year). Real GDP in the United States increased nearly 2.5 times between 1980 and 2013, as shown in Figure 1-8. This general pattern of long-term overall growth masks differences by region. While growth has been positive in all regions since 2010, annual regional growth has varied between a high of 5.8 percent in southwestern U.S. in 2012 down to a low of 0.6 percent in the southeastern U.S. in 2011, as shown in Figure 1-9.

As is the case with population increases, economic development can lead to increased use of potable water and increased wastewater production. If development is associated with increased urbanization, it also can increase stormwater runoff and non-point source pollution. An expansion or intensification of agriculture, including the animal and poultry industries, also can increase water use, runoff, and non-point source pollution. While economic development has historically led to increased demands on water, the impact of future economic development on water use in the U.S. is uncertain.

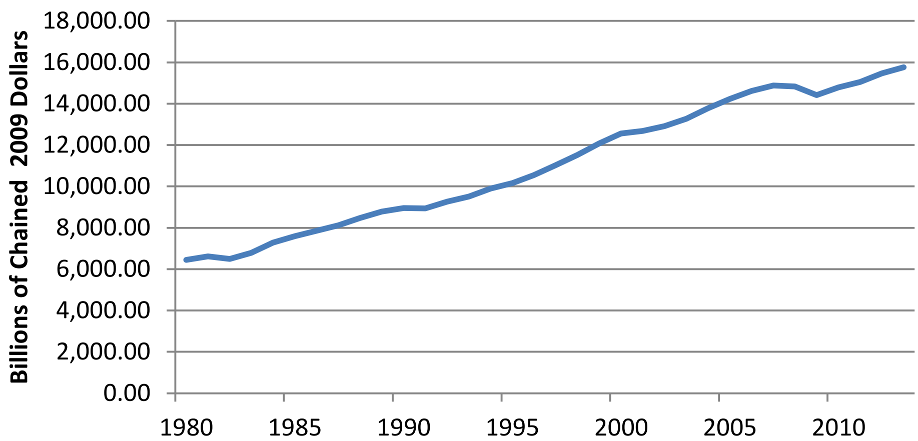


Figure 1-8. United States real GDP, 1980-2013. Data from U.S. Bureau of Economic Analysis.

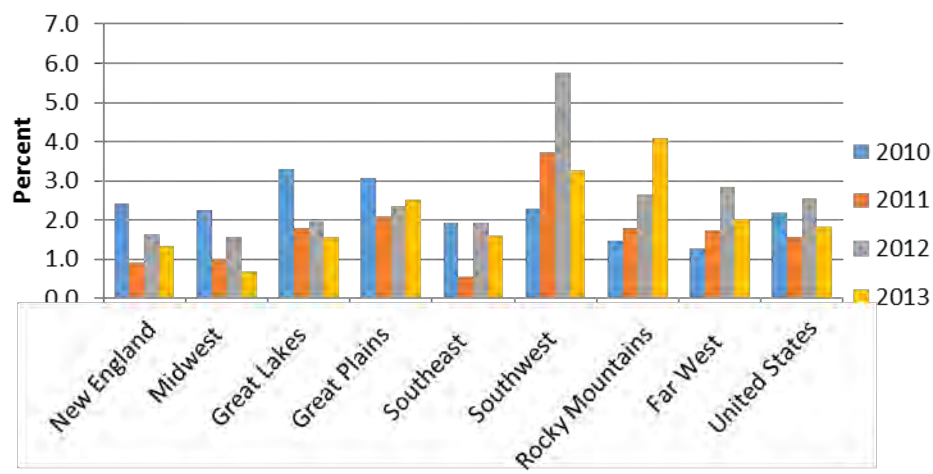


Figure 1-9. Annual percent change in real GDP by region, 2010, 2011, 2012, and 2013. Data from U.S. Bureau of Economic Analysis.

The implications for water demand from some aspects and consequences of economic development are not clear. Globalization and the shift of the U.S. economy from an industrial-based economy to a service-oriented economy could significantly affect rates of water consumption in the U.S. and internationally. Changes in agricultural practices, such as expanded adoption of drip irrigation, can reduce water demand and the amount of runoff, while increased demand for certain crops can increase water use. In general, technological change could foster further development that could increase the strain on the water resources infrastructure or, more optimistically, could provide methods for mitigating the impacts of development. Daigger (2007) argues that "further technological developments are crucial to fully and effectively implement new approaches to urban water management that are inherently and significantly more sustainable and that better serve the full range of people irrespective of their economic situation."

2.3.4. Emerging Drivers in Energy-Water Nexus

In water-energy nexus, the energy usage around the world is increasing and is a major political, economic and environmental factor that requires consideration in planning of water infrastructure adaptations. Figure 1-10 is an estimate of worldwide power usage from 1965 to 2006, broken down by the energy source. As illustrated, the world is experiencing an increasing rate of growth in energy use and is largely dependent upon fossil fuels as sources of energy.

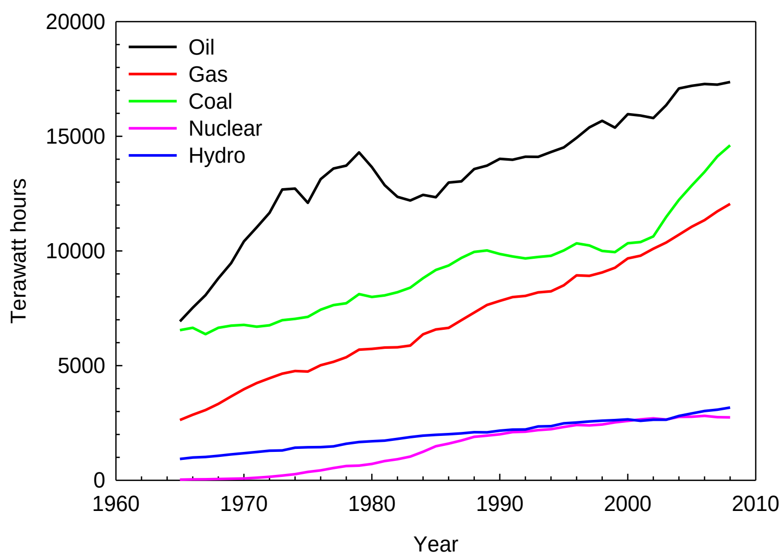


Figure 1-10. Annual worldwide energy usage in terawatt-hours, 1965-2008 (BP, 2014).

Gleick (2006) observed that there is a strong linkage between the water and energy sectors since water is required to produce and use energy, and energy is used to clean, transport and use water. Most water supply and wastewater systems are dependent upon pumping and most water and wastewater treatment plant components need sources of energy to perform their functions. According to the Alliance to Save Energy (2002), the water and wastewater sectors are responsible for about 2 to 3 percent of global energy use. However, in the absence of a comprehensive energy policy for the U.S., there is much uncertainty of the likely impacts of energy on the water resources infrastructure. Some potential impacts include:

- Significantly increased water usage in parts of the country to accommodate agriculture and processing costs associated with biofuels (NRC, 2006).

- Increased construction costs due to increased energy costs and petrol-based products such as PVC and HDPE pipes.
- Potential (unknown) impacts of renewable energy methods (wind, solar, hydro power) and increased nuclear power generation.
- Increasing global energy usage and its likely impact on energy availability and cost. This may force water and wastewater utilities to achieve greater energy efficiency in order to offset energy costs.
- Possibly, increased frequency in energy shortages. Water and wastewater systems will need increased capability to switch to alternate or backup energy supplies (Means et al., 2005b).
- The possibility that new energy-intensive treatment technologies may not achieve their expected potential despite their advantages (Means et al., 2005b).

These reported general trends in energy production are consistent with the investigation results of the EPA WRAP research activities (U.S. EPA, 2014e). Detailed data and analysis on the water-energy nexus is contained in a separate companion EPA report titled "The Impact of Traditional and Alternative Energy Production on Water Resources: Assessment and Adaptation Studies" (U.S. EPA, 2014o).

2.4. Summary of Regulations and Regulatory Programs

In recent years, extensive legal reviews have been undertaken to evaluate the capacity of existing legal and regulatory frameworks for policy-making in the areas of climate change mitigation and adaptation (e.g., Ruhl, 2010; Fischman, 2012; Craig, 2010). The Supreme Court, in *American Electric Power Co. v. Connecticut,* 131 S. Ct. 2527 (2011), held that the Clean Air Act and EPA action authorized by the Act displace any federal common-law right to seek abatement of CO_2 emissions from fossil-fuel fired power plants. This opinion, in effect, reaffirms EPA's authority to regulate in this area. See also, *Massachusetts v. EPA,* 549 U.S. 497 (2007). Regulatory actions driven by court litigations and legal clarification are less optimal than stand-alone climate change laws (Ruhl, 2010; Craig, 2010), but certain climate change mitigation and adaptation activities can be undertaken based upon existing environmental statutes, including CWA, the Clean Air Act (CAA), and the National Environmental Policy Act (NEPA) (Craig, 2010; 2009; Reitze, Jr., 2011; Adler, 2010).

This section of the report highlights sections of major legislation and aspects of existing regulatory programs relevant to climate change. Specifically, the discussion on the Safe Drinking Water Act (SDWA) in Section 2.4.1 profiles existing drinking water regulations and identifies possible compliance and public-health protection challenges that utilities may face as a result of climate change. Section 2.4.2 summarizes the Clean Water Act (CWA) regulations and programs and the mechanisms they provide for managing climate change impacts to surface waters. Secondly in Section 2.4.2, the CAA regulations are described on how they are designed to reduce or track GHG emissions and mitigate the effects of climate change, and in due course, how the climate mitigation actions affect water resources and the function of water infrastructures. Finally, Section 2.4.4 identifies programs and initiatives at EPA specifically intended to produce a better understanding of the impacts of climate change, mitigate these impacts, or help water systems improve infrastructure sustainability in response to climate change.

2.4.1. Safe Drinking Water Act

Concern over waterborne disease outbreaks in the U.S. since the late 1890s, especially in industrialized river valleys, has translated into water quality legislation at the federal level starting with the Interstate Quarantine Act of 1893. The first drinking water regulation, promulgated in 1912, prohibited the use of a common drinking water cup on trains. Federal drinking water standards for 28 substances were issued by the U.S. Public Health Service (PHS) prior to 1962, but they applied only to interstate carriers (Grindler, 1967; Clark, 1978). In 1974, Congress passed the Safe Drinking Water Act (SDWA) to ensure consistent drinking water standards across the country and initially adopted the PHS standards. Historically most drinking water utilities concentrated on ensuring the quality and safety of drinking water through treatment at the treatment plant. Amendments to the SDWA in 1986 and 1996 shifted the focus from contaminant prevention through treatment to source water protection and enhanced water system management, that is, a comprehensive protection program from source water to the tap (U.S. EPA, 2013c). Water quality in the distribution system became a focus of regulatory action and has become a major focus of drinking water utilities. However, maintaining a high level of water quality at consumer's tap is a challenge because water quality change occurs in extensive, lengthy distribution pipe networks (NRC, 2007).

Rules and regulations promulgated under the SDWA (Figure 1-11), requiring drinking water utilities to meet guidelines and standards to protect public health from specific drinking water contaminants. When regulating a contaminant, EPA first sets a non-enforceable standard referred to as a maximum contaminant level goal (MCLG). An MCLG is set at a level at which no known or anticipated adverse human health effects occur, with a margin for safety. Then EPA sets an enforceable public health standard for levels of a contaminant allowable in drinking water or (where numeric standards are not appropriate) a mandatory treatment approach. An enforceable drinking water standard is known as a maximum contaminant level (MCL). Depending on technological limitations (taking cost into account), sometimes MCLs are set equal to MCLGs and sometimes they diverge. EPA has published standards for 93 constituents, including 68 organic and inorganic chemicals, seven radioactive contaminants ("radionuclides"), 11 pathogens/microorganisms, and seven disinfectants or disinfection by-products. Together, the EPA guidelines, standards, and treatment approaches are designed to ensure that drinking water is adequately treated and managed by water utilities to protect public health (Clark and Feige, 1993).

2.4.1.1. Climate Change Impacts and Relevance

Several SDWA rules specifically target drinking water quality within the distribution system, including the Total Coliform Rule (TCR) and Revised Total Coliform Rule (RTCR), the Disinfectants/Disinfection By-Products Rules (DBPRs), the Surface Water Treatment Rules (SWTRs), the Lead and Copper Rule (LCR), and the Ground Water Rule (GWR). A brief description of these rules and programs are provided in Appendix I-A. Climate change may affect the ability of water utilities to comply with many of these regulations (WRF, 2009). An

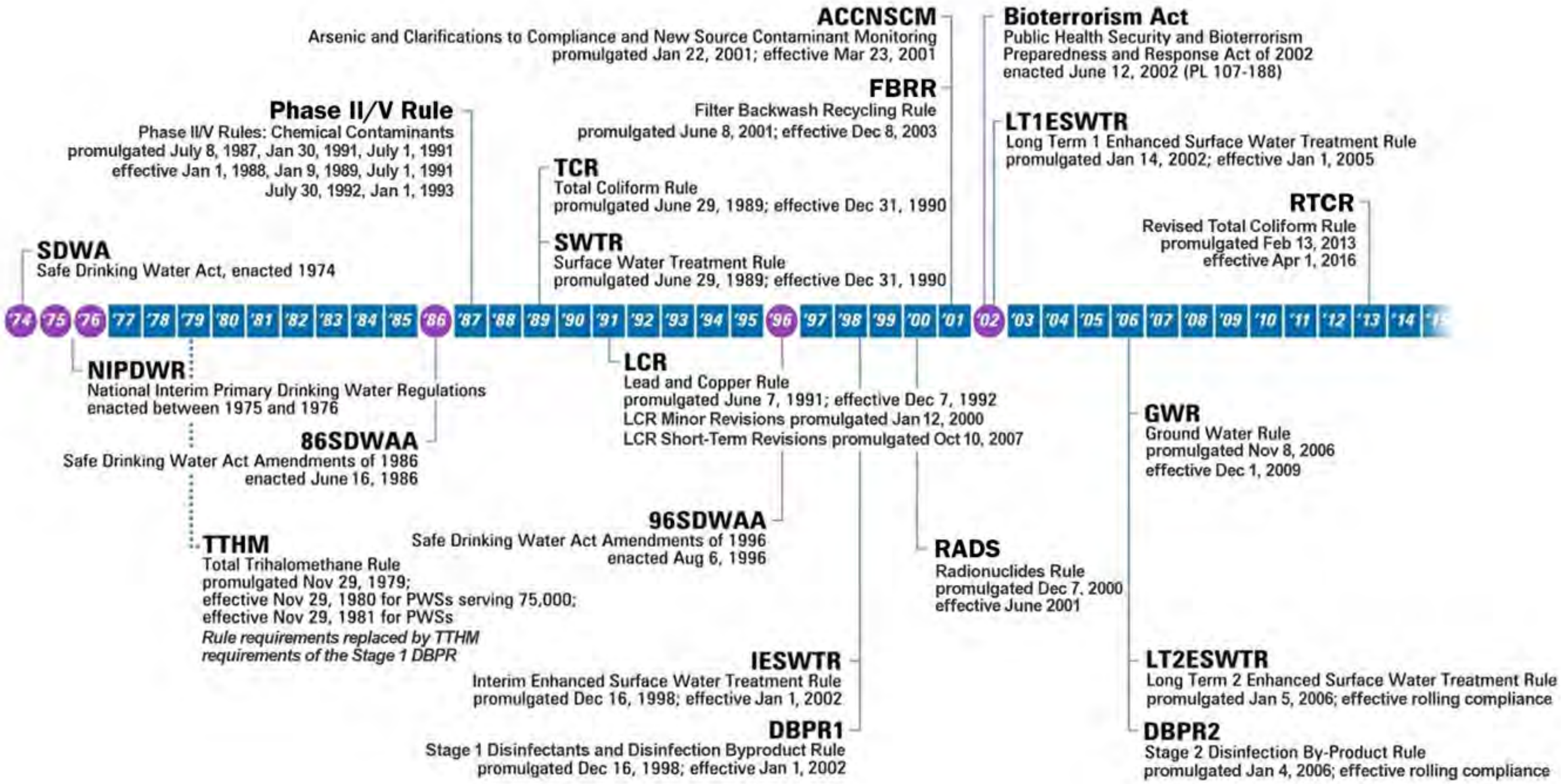


Figure 1-11. Evolution of federal drinking water regulations (updated from Panguluri et al., 2006).

increase in extreme storm events increases the risk of flooding and wildfires, resulting in erosion and surface runoff which may affect the quality of source waters and potentially pose problems for water treatment plants. Examples of water quality issues related to flooding and wildfires include elevated levels of turbidity, debris in reservoirs, and nutrient and pollutant loading. Changes in precipitation amounts and seasonal variation can also challenge management of water supplies. For instance, changes in rainfall and snowpack can change patterns of spring runoff, cause coastal and inland flooding, decrease the summer water supply, and affect the rate of groundwater recharge. Sea level rise will threaten coastal infrastructure, possibly damaging water intakes located in estuaries and causing salt water corrosion of buried infrastructure. Salt water intrusion into vulnerable groundwater supplies or salinization of freshwater supplies due to flooding represent additional risks. These effects may be compounded by storm surges. Higher temperatures may lead to drought conditions, as less summer rainfall and increased evapotranspiration lead to a decrease in surface water availability and an increase in urban and agricultural water demand. Warmer freshwater temperatures will also affect water quality, due to reduced dissolved oxygen levels, increased rates of algal blooms, increased bacteria and fungi content, and concentration of pollutants.

More information of climate risk imposed on regulatory programs is available in EPA's National Water Strategy on Climate Change (U.S. EPA, 2014o). The aspects discussed in this adaptation report includes:

- The Total Coliform Rule (54 FR 27544; U.S. EPA, 1989a) requires adequate disinfection of drinking water to manage biological risk. As discussed in Section 2.1.1, higher risks of bacterial contamination drinking water may occur under conditions of climate change due to higher water temperatures and increased frequency of sewer and treatment plant overflows. The increased risk from biological contaminants such as cyanobacteria in source water is further detailed in investigations in Part II of this report.
- In the U.S., chlorine and chloramines are most often used for treatment because they are very effective disinfectants, and residual concentrations can be measured and maintained in the water distribution system. Some utilities (primarily in the U.S. and Europe) use ozone and chlorine dioxide as oxidizing agents for primary disinfection prior to the addition of chlorine or chloramines for residual disinfection. While disinfectants are effective in controlling many microorganisms, they can react with naturally occurring organic matter (NOM) and inorganic matter in the treated and/or distributed water to form potentially harmful disinfection by-products (DBPs). As shown later in this report (Part II, III and IV), climate change can induce significant changes in natural organic matters (NOM) and total organic carbon (TOC) in source water. The case studies and modeling analysis conclusively point to the risk of DBP regulation violations. For adaptation, a framework of monitoring-modeling and engineering adaptation analysis has been established and presented in this report.

  Higher water temperatures under future climate scenarios could result in different NOM reactivity to disinfectants and thus different DBP-formation potential. Under such circumstances, current standards and treatment may not adequately address future risks to public health from DBPs. This possibility is not assessed in this report, but is indicated in published studies (e.g., Towler et al., 2011; Whitehead et al., 2009).

- The SWTR and its three subsequent rules – the Interim Enhanced SWTR (63 FR 69478, U.S. EPA, 1989b), Long-Term 1 Enhanced SWTR (67 FR 1812; U.S. EPA, 2002b), and Long-Term 2 Enhanced SWTR (LT2ESWTR) (71 FR 6135; U.S. EPA, 2006a), collectively increase the stringency of turbidity standards with a purpose to control *Cryptosporidium* and pathogen control while complying with DBPR requirements.

  As noted in Section 2.1.1, climate change can induce changes in surface water quality including total organic carbon (TOC), NOM, turbidity, micronutrients (e.g., nitrogen and phosphorus), and potentially also biological contaminants such as microcystin. The research described in Part III and IV of this report further quantify some of these changes and their potential impacts on drinking water supplies. Such changes may make it more challenging for systems to meet the requirements of the SWTR rules. For instance, climate-induced flooding may increase sediment loading into reservoirs which may increase turbidity levels and could significantly reduce the useful life of a storage reservoir or require sediment removal. During a drought, pollutants accumulate on land surface and on other surfaces, such as pavement and structures. These pollutants may be rapidly flushed as large loads of pollutants into surface water bodies during high precipitation events that may follow the drought conditions (e.g., Walker et al., 1991).

- Climate change may affect compliance with the Lead and Cooper Rule (LCR) in two ways. One is the effect of temperature on pipe corrosion. The relationship is not entirely straightforward. Secondly, treatment undertaken to mitigate climate change effects may indirectly affect the lead and copper action levels. Treatment to address one public health risk may have unintended consequences on the chemical or biological composition of the water and contribute to other risks. Treatment installed to meet the DBPRs, for example, may affect compliance with the LCR: e.g., the use of chloramine as a residual disinfectant can affect the chemical properties of the water, which subsequently can increase lead and copper corrosion.

- The Ground Water Rule (GWR) (71 FR 65574; U.S. EPA, 2006b) require that states use a risk-based methodology to determine which groundwater systems are vulnerable to fecal contamination, which may contain viruses or bacteria that are harmful to humans (Appendix I-A). Climate change can change ground recharge and flow systems, such as groundwater depletion in current drought-stricken California, and thus may affect the GWR-related groundwater qualities. However, climate change impacts on groundwater is relatively less understood than on surface water.

- The EPA Chemical Phase Rules apply to three contaminant groups: Inorganic Chemicals (IOCs), Synthetic Organic Chemicals (SOCs), and Volatile Organic Chemicals (VOCs) (Appendix I-A). Changes in temperature and precipitation could lead to increased concentrations of contaminants covered by these Rules: for instance, as noted in Section 2.3, there may be circumstances where climate change may lead to increased nitrification of source water. In addition, in cases where drought or source degradation require a water system to seek an alternate water source, any new source must be evaluated to ensure that the system will be able to deliver water that complies with the Chemical Phase Rules.

- Under SDWA, as amended, EPA is required to periodically publish Candidate Contaminant List (CCL) that includes microbial and chemical contaminants not currently regulated but known or considered likely to occur in water systems as candidates for regulation (74 FR 51850; U.S. EPA, 2009c). More information is provided in Appendix I-A. The CCL and Regulatory Determinations programs provide a flexible mechanism to identify and respond to emerging threats to drinking water quality as climatic conditions change over time. The climate change can alter the environmental conditions under which the risk is evaluated and CCL is developed.

- The Underground Injection Control (UIC) Program under SDWA regulates CO_2 injection in GHG geological sequestration. It also regulates injection of production water, reclaimed water, or storm water into underground formation for storage and later retrieval. The practice, known as aquifer storage and recovery (ASR), can be used to reduce the water supply vulnerability due to climate-induced water availability problem and strong seasonable variations. However, ASR is known to associate with groundwater quality concerns. The holding aquifer can be contaminated from micro-contaminants from injected water, such as personal care products, and from remobilization of indigenous contaminants (e.g., arsenic) in the formation materials.

2.4.1.2. Additional measures to protect public health

Adequate protection of public health requires drinking water utilities to do more than simply satisfy federal and state regulatory requirements. This fact was highlighted in February 2014 by the case of a water utility in Charleston, West Virginia, where over 300,000 people were affected by a 5-day boil water notice after a release of 4-methylcyclohexanemethanol (MCHM) from a Freedom Industries facility into the Elk River, a tributary of the Kanawha River. While MCHM is not a contaminant currently regulated under SDWA, the community experienced health effects such as rash, nausea, vomiting, and cough from drinking the water.

The case of Charleston, West Virginia, illustrates the confounding effects that weather and climate can have as a utility seeks to fulfill its public health mission. The spill's effects were compounded because the water system could not take the river intake off-line on account of extreme weather. The water system reported that it had "experienced a significant number of line breaks caused by extreme cold associated with the polar vortex followed by warming weather. Because of the line breaks and customers letting their water drip to prevent freezing of their pipes (which we encourage), the system storage was low and losing water even though the water treatment plant was running at near full capacity" (West Virginia American Water, 2014).

Therefore, SDWA required the development of source water assessment plans, which can take account of risks posed by both regulated and unregulated contaminants from upstream pollution sources, but implementation of plans and protection activities has been left up to the discretion of states and systems. One of the strategic actions identified in EPA's 2012 National Water Program Strategy is to encourage and support states and local authorities in implementing their source water assessments, delineations, and protection plans to address anticipated climate change impacts (U.S. EPA, 2013d). Wellhead protection plans, which are not required by the GWR, will become increasingly important to protect the integrity of wellheads during floods. Storm surges or flooding may inundate low-lying wells or treatment plants, which may introduce contamination into the well casing and affect the ability of water systems to treat and provide safe water.

2.4.2. *Clean Water Act*

The Clean Water Act (CWA) is the principal law governing the physical, chemical, and biological condition of waters of the United States (33 U.S.C. Section 1251(a); CWA Section 101(a)). Enacted in 1948 as the Federal Water Pollution Control Act, the CWA was revised by amendments in 1972. The 1972 amendments created a framework for regulating pollutant discharge to the nation's waters for implementation at federal and state level. Although additional amendments enacted in 1977, 1981, and 1987 modified some provisions, the basic elements of the 1972 amendments remain in effect today.

The primary relevance of the CWA to climate change is the regulatory and non-regulatory mechanisms it offers for managing climate change impacts to surface waters rather than climate change mitigation (i.e., reduction of GHG emissions) (Craig, 2010). Recognizing the fundamental link between climate and aquatic ecosystem conditions, EPA and states have already begun to incorporate climate change considerations in CWA program planning and implementation (U.S. EPA, 2012f). Major CWA sections that relate to water infrastructure and climate change adaptation include:

- Water quality standards (WQS) can be used to address climate change impacts in several ways. New WQS may be established as climate-driven pollutant loading issues emerge and existing WQS can be updated to reflect current climate change concepts and data. WQS revisions may include updates to each of the three WQS components (designated uses, numeric/narrative criteria, anti-degradation provisions). For example, existing water temperature criteria may be updated to reflect actual and expected climate-driven shifts in stream thermal regimes. In addition, EPA has pointed to anti-degradation policy updates as a means to protect designated uses that are particularly susceptible to climate change (U.S. EPA, 2012f). New and revised WQS can have cascading effects on stormwater and wastewater dischargers, including modifications to NPDES permits as discussed next.
- NPDES permits for separate sanitary sewer and combined sewer systems typically include provisions to report, minimize, and prevent SSOs and CSOs. Because SSOs and CSOs can occur during periods of heavy rainfall, the climate change impact is apparent. Regions projected to receive more frequent and intense storm events are at-risk for increased SSO or CSO discharges. In 2012, the NPDES Permit Writers' Manual (U.S. EPA, 2010c) was updated calling attention to climate change considerations when setting effluent limitations for NPDES permits. These revisions reflect a shift from the use of historic data alone to incorporating projected future conditions as well.
- Section 303(d) of the CWA requires states to develop a list of impaired waters (those waters not meeting applicable water quality standards) and to develop one or more TMDLs for each impaired water body. See Appendix I-A for details. Climate change has the potential to increase the number of water body impairments and TMDLs required. This is due to increased stress placed on aquatic ecosystems and/or as a result of modified WQS. Climate change can be integrated into TMDL calculations by evaluating pollutant loads and impacts under a range of projected climatic shifts. The use of climate change projections may result in wasteload allocations (WLAs) and load allocations (LAs) that differ from those calculated if static climate conditions were assumed. Furthermore, climate change may be factored into decisions on the specific water quality target used to

determine the TMDL. Although water quality targets are usually equivalent to criteria set forth in water quality standards, alternative targets may be used where water quality standards have not been updated to reflect climate change impacts. Finally, because TMDLs follow an adaptive management approach, existing TMDLs may be revisited and revised to incorporate actual and expected climate change data.

- The Clean Water State Revolving Fund (CWSRF) and Section 319 NPS program both have the potential to serve as key funding sources for projects that increase the resiliency of wastewater and stormwater infrastructure to climate change. For example, the CWSRF can fund infrastructure upgrades to prevent SSOs or CSO during large rainfall events. The CWSRF also sets aside a portion of funds for green infrastructure projects in the Green Project Reserve (GPR). The GPR and Section 319 grants can fund stormwater BMPs that prevent runoff from entering sewer systems such as bioretention basins, constructed wetlands, and pervious pavement.

2.4.3. Clean Air Act

A comprehensive response to climate change includes both adaptation and mitigation. Under the Clean Air Act, EPA has enacted regulatory actions to control air pollutant emissions including GHG. This section provides an overview of EPA's regulatory efforts that also have implications for water resources management and water infrastructure adaptations. A complete analysis of the impact of regulatory programs on water resources from the Nation's energy productions is provided in an EPA companion report (U.S. EPA, 2014o).

On December 7, 2009, the EPA Administrator signed an Endangerment Finding and a Cause or Contribute Finding for GHG under section 202(a) of the CAA (U.S. EPA, 2009a). Six well-mixed GHGs in the atmosphere were found to threaten public health and welfare. Additionally, emissions of these gases from new motor vehicles were found to contribute to GHG pollution (which, again, threatens public health and welfare).

In addition to the findings related to GHG mobile sources, EPA has also published a set of regulations under the CAA for stationary source GHG mitigation. New regulations were proposed in June 2014 to reduce carbon pollution from existing power plants by 30 percent by 2030 when compared to 2005 carbon emissions (U.S. EPA, 2014c). EPA identified four measures available to significantly reduce carbon intensity from the power sector:

- Improving efficiency at existing coal-fired power plants
- Increasing utilization of existing natural gas fired power plants
- Expanding the use of wind, solar, or other low- or zero-emitting alternatives, and
- Increasing energy efficiency in homes and businesses.

As described in a recent EPA report (U.S. EPA, 2014o), traditional and alternative energy production can exert significant impacts on water resources in the context of air and fuel programs. The intensity of water use via consumptive water loss for the major forms of thermoelectric generation in the U.S. were assessed from detailed engineering analyses (Table 1-7). Note that the lower values within the ranges for nuclear and coal systems represent older single-pass (i.e., no cooling tower with direct discharge of cooling water) systems that are being phased out of use due to EPA regulations limiting water discharge temperatures. With respect to general trends, transitioning electric generation from coal-fired power plants to plants with Integrated Gasification Combined Cycle (IGCC)/CO_2-capture represents an opportunity to reduce water use intensity by approximately 50 percent per plant that is transitioned. Transitioning from coal or natural gas-fired boilers (Rankine cycle) to natural gas combined cycle (NGCC) represents an opportunity to reduce water intensity by approximately 75 percent per plant that is transitioned (U.S. EPA, 2014o). In these areas, reducing the carbon intensity of electric power generation is expected to provide significant opportunities to simultaneously reduce water use. Reductions in water use would include efficiency improvements, shifting to increased use of renewable or zero-carbon-emission alternatives, and shifting to types of thermoelectric generation that offer both reduced carbon-intensity and reduced water consumption.

Table 1-7. Water Consumption Normalized by Net Electric Generation for Thermoelectric Power Plants*

System	Water consumption
	gal/MWh
Coal	4 - 1100
Coal/CO_2-capture	815 - 942
Coal/IGCC/CO_2-capture	522 - 604
Nature Gas/Rankine	95 - 1170
NGCC	0 - 300
Nuclear	100 - 845

Note: * - from U.S. EPA (2014o)

2.4.4. EPA Climate Change Programs and Sustainability Initiatives

EPA has established several programs to help advance the science, educate the public, develop tools and strategies, and implement actions pertaining to climate change mitigation and adaptation. It its *National Water Program 2008 Strategy: Response to Climate Change* (U.S. EPA, 2008b), EPA established five climate-change-related goals for Agency water programs. EPA updated its strategy in 2012 (U.S. EPA, 2012f) and provides annual updates of its progress in meeting these goals (U.S. EPA, 2013d; 2014f). Under these programs, the Agency is undertaking efforts to prevent contamination of drinking water sources, assess risks of waterborne disease, develop biological indicators, examine the implications of ocean acidification on water quality criteria, examine criteria for hydrologic conditions, and include climate-sensitive parameters in national waterbody surveys. The Agency is also considering climate implications for future effluent guidelines, TMDL analyses, the Coastal Wetlands Initiative, CWA Section 404 permitting, NPDES permitting, nonpoint source management, and the proposed stormwater rulemaking. Moreover, the Office of Water is working with stakeholder partners on initiatives such as assisting water utilities in developing and deploying water-metering technologies, developing location-specific information about climate change impacts for different sectors in each watershed and aquifer, monitoring research developments associated with the disposal of desalinization waste brines, and many more. These climate change adaptation program actions have been periodically updated; for example in U.S. EPA (2012f, 2013d; 2014f).

Worthy to note, EPA undertakes the climate change adaptation in a comprehensive approach from both water and air programs related to the laws and regulations described in Section 2.4.1-2.4.3. In addition to the regulatory programs, several initiatives have been developed to improve the capability of U.S. utilities in achieving effective climate change adaptation, for which the systems' resilience and sustainability are emphasized. Examples of the vulnerary programs are briefly described below in each of the three categories:

Climate Change Adaptation

- *WaterSense.* WaterSense is an EPA-sponsored voluntary partnership among water utilities, product manufacturers and retailers, consumers, federal, state, and local governments, and other stakeholders to decrease indoor and outdoor nonagricultural water use through more efficient products and practices. WaterSense helps consumers make water-efficient choices and encourages manufacturers to meet rigorous certification criteria that ensure product efficiency, performance, and quality. To help meet its climate change goals, EPA plans to continue to develop specifications for water-efficient products, encourage water efficiency in landscape design, building operations, and codes, and educate the public on the value of water use efficiency through its WaterSense program (U.S. EPA, 2014g). By increasing the water use efficiency, the program contributes our ability to adapt climate-related water availability problems now in many parts of the contiguous U.S.
- *Climate Ready Water Utilities.* Climate Ready Water Utilities (CRWU) is an Agency initiative to help the drinking water, wastewater, and stormwater utilities in advancing their understanding of climate change science and in developing adaptation options. Under this program, EPA has developed clear, easy-to-use tools that help translate complex climate projections into accessible formats so that water utilities can better prepare their systems for the impacts of climate change. Through the CRWU, EPA also provides guidance to water and wastewater utilities on preparing for extreme weather events (U.S. EPA, 2014h), along with several simulation tools for climate risk assessment in water utilities and for coastal areas under the threat of storm surge and sea level rise. Examples include the Climate Risk Evaluation and Assessment Tool (CREAT). More detailed information on the program and tools are available[9].
- *Climate Ready Estuaries.* Estuaries and coastal areas are particularly vulnerable to the impacts of climate change. The Climate Ready Estuaries (CRE) program, which is jointly administered by EPA's Office of Water and Office of Air and Radiation, provides funding or direct technical assistance to estuary programs to assess climate change vulnerability related to sea level rise, increasing temperatures, and other effects. In addition, the CRE program works to build capacity to respond to climate change (U.S. EPA, 2013f).

[9] Http://water.epa.gov/infrastructure/watersecurity/

- *Promotion of Green Infrastructure.* Green infrastructure refers to natural systems or engineered systems designed to mimic natural processes. Green infrastructure can help manage stormwater and reduce water quality impacts on receiving waters. These systems are often soil or vegetation-based and include approaches such as tree preservation, impervious cover reduction, or structural interventions such as rain gardens and permeable pavements. Through this strategy, EPA aims to increase national and local capacity to evaluate the role of green infrastructure and the benefits that green infrastructure can provide. (U.S. EPA, 2013g).

<u>*Climate Change Mitigation*</u>

Several voluntary programs at EPA go beyond the water industry to mitigate the effects of climate change by reducing GHG emissions. EPA's voluntary energy and climate programs promote partnerships with industry to reduce GHG emissions (U.S. EPA, 2014i). Examples of industry partnerships include:

- *Center for Corporate Leadership*: A group that provides resources to companies interested in expanding their work in GHG measurements and management.
- *WasteWise:* A program to eliminate municipal solid waste and select industrial waste to reduce deposits in landfills and reduce GHG emissions.
- *Clean Energy*, *Transportation and Air Quality Voluntary Programs:* Programs that form partnerships with businesses, industry, state and local governments, and many other stakeholders to reduce pollution and improve air quality in the transportation sector. For example, EPA's Clean Energy Programs promote collaboration with policy makers, electric and gas utilities, energy customers, and key stakeholders to design and implement clean energy solutions (U.S. EPA, 2014k). The initiative includes several program areas to advance clean energy, reduce GHG emissions, and improve energy efficiency
- *Clean Automotive Technology*. This effort consists of a range of programs that aim to reduce air pollution and GHG emissions from vehicles and increase fuel efficiency (U.S. EPA, 2014l). EPA's Office of Transportation and Air Quality leads these programs and focuses on public-private partnerships to engage the automotive industry and develop new engine technologies.

<u>*Sustainability and R&D programs*</u>

EPA has also initiated several programs and collaborative efforts across the Agency to address sustainability. Many programs specifically address sustainability in areas affected by regulations described in this report, namely those related to water, air, climate, and energy. These efforts promote sustainability and address adapting to a changing climate and reducing vulnerabilities to climate change. Examples of initiatives under the area of sustainable water include:

- *Water Infrastructure: Moving Toward Sustainability*. In response to a request in the FY 2010 President's budget, EPA released its Clean Water and Drinking Water Infrastructure Sustainability Policy (U.S. EPA, 2014j). The goal of this policy is to identify and promote more sustainable practices in the water industry. The policy identified three levels at which this goal can be achieved: Sustainable Water Infrastructure, Sustainable

Water Sector Systems, and Sustainable Communities. The Sustainable Water Sector Systems level primarily addresses effective utility management, which helps drinking water, wastewater, and stormwater systems build and sustain technical, managerial, and financial capacity. Efforts on the Sustainable Communities level expand infrastructure planning beyond the water sector based on the understanding that community growth involves multiple infrastructure sectors. This cross-sector approach attempts to align the long-term goals of sectors such as housing, transportation, and water to promote sustainable growth.

- *Water and Ecosystems Research*. EPA spearheads many research efforts under the areas of water and ecosystems. Areas of research address a broad set of topics such as climate change, the water and energy nexus, watershed protection, sustainable water infrastructure, chemical and microbial risks, nutrients, ecosystem services, air quality, ecological risk assessments, and health.
- *Air Research.* EPA's air research supports the development of outdoor air regulations under the CAA (U.S. EPA, 2014m). EPA addresses linkages between air quality and several research areas such as energy, health, ecosystems, and climate change. Climate change research focuses on identifying health impacts of climate change and providing solutions to mitigate and adapt to these impacts (U.S. EPA, 2014n). Research areas in climate change address threats to ecosystems, impacts on public health, and improving scientific tools to develop adaptation and mitigation strategies.

Through this wide array of policies, programs, and research initiatives, EPA is identifying potential impacts of climate change on the water sector in the U.S. and mitigation strategies. Research organized in the EPA Air, Climate and Energy (ACE) research program is focused specifically on climate change as it relates to water infrastructure sustainability. As detailed above, these activities also include climate change mitigation efforts to reduce the effects of climate change, and they develop and implement adaptation strategies to lessen the nation's vulnerability to climate change.

3. Utility Assessment of Future Trends and Needs

Several recent research efforts have focused on identifying trends and needs within the water industry by means of surveys. In some cases, these surveys asked utilities and other stakeholders to rank climate-related needs against other issues faced by the industry, such as financing and water availability. The results of these surveys provide insight into how the water industry views climate change and what priority it assigns to climate adaptation among other pressing concerns. The results suggest (without explicitly indicating) the degree to which drinking water utilities would be willing or inclined to consider climate change when planning infrastructure updates. This section provides a summary of six research efforts, each of which is described briefly below and in more detail in the subsections that follow.

Although results of the first two surveys listed below are nearly 10 years old, they are included in the report to provide additional context for how utilities and stakeholders have prioritized climate change over the past decade. It is important to note that the availability of information about climate change and its impacts on utilities has changed considerably over the past decade. Also, disruptive events (e.g., terrorism, extreme weather) and other factors such as economic outlook can have a significant influence on the trends and needs that utilities identify as important at any given moment. These considerations suggest the value of taking a long view, and should be kept in mind when reviewing and analyzing the results of any survey.

- *U.S. Conference of Mayors National City Water Surveys.* Conducted in 2005, this survey collected information about four key water resource areas from 414 cities. Survey results include a ranking of issues of current or future concerns.
- *AWWARF Assessment of Trends and their Implications for Water Utilities.* This effort polled attendees at a Futures Workshop in 2004 to examine significant trends affecting water utilities. Results consist of a ranked list of the top ten trends in the industry.
- *University of Cincinnati Region Poll of Five Cities Plus Conference***.** Researchers at the University of Cincinnati conducted a poll of wastewater representatives at the Five Cities Plus Conference in 2008. The results from six participants, previously unpublished, provided a rank order of 20 issues facing Midwest wastewater utilities.
- *University of Cincinnati National On-line Questionnaire.* This national on-line survey was an effort conducted by the University of Cincinnati researchers concurrent with the Five Cities Plus poll in 2008. The on-line survey collected information on a broader set of questions about the current state and future trends of water and wastewater utilities.
- *AWWA State of the Water Industry.* AWWA's 2014 State of the Water Industry report summarized the results of a survey that included 1,739 respondents in the U.S. and abroad. The results rank 30 issues facing the water industry, and a comparison of how the rank of these issues has changed since AWWA's 2013 report. The report also provides information on how well prepared respondents believe the water industry is to address climate change.
- *Water Research Foundation (WRF) Forecasting the Future.* This 2012 report summarizes the results of a survey in which 17 utilities in North America and abroad ranked the trends to identify their top five trend areas for the water sector. Researchers refined the survey results through a workshop and provided a final list of the top 10 key trends in the water industry.
- The 2014 seventh study, titled *Effective Climate Change Communication to Water Utility Stakeholders,* is based on a survey from the perspective of water utility customers. A survey of a statistical sample of 1,021 water utility customers nationwide highlights customers' expectations of their water utilities in preparing for climate change. The results are summarized in Section 3.7.

Collectively, these surveys and studies conclude that the water utilities are aware of the potential impacts of climate change to the water infrastructure and water programs; some are taking actions in the impact assessment and adaptation planning. However, the water utilities are facing multiple pressing needs other than climate change impacts. A lack of actionable science and engineering design basis, which are important to conventional water engineering and financing practice, further ferments the reluctance toward taking immediate climate adaptation actions. As a result, climate change adaptation actions are often imbedded in other capital improvement programs, rather than listed as an independent priority factor. Details of the results are presented in Section 4.0 and are analyzed in the context of the water regulatory programs and water infrastructure conditions for climate change adaptation.

3.1. U.S. Conference of Mayors National City Water Surveys

Most water and wastewater infrastructure in the U.S. is managed at the local level by cities and municipalities. In 2005 the United States Conference of Mayors Urban Water Council (UWC) task force conducted a survey to examine water resources priorities and trends in the U.S. (Anderson et al., 2005). Its purpose was to elicit information about issues affecting cities' provision and protection of community water and wastewater services. The task force focused on issues including development and rehabilitation of surface and subsurface water infrastructure, water infrastructure financing, watershed management, water supply planning, water conservation, wetlands construction and education programs, water system program management and asset management.

Current information was requested from respondents in the following four key water resources areas: issues and priorities, recent and planned major capital investments in water and wastewater infrastructure, adequacy of water supplies, and water conservation activities. The survey was distributed to nearly 1,200 cities with mayoral forms of government (with populations of 30,000 or greater). Nearly 35 percent (414 cities) responded to the survey. Mayors were asked to designate issues of current or future concern from a list of 24 possible water resources issues. Results are presented in Table 1-8.

The report also summarized the planned infrastructure investments by city size. As illustrated in Table 1-9, the percentage of municipalities planning infrastructure investments in the near future increases with city size. Other significant results of the 2005 survey are summarized below.

- *Water supply adequacy:* A critical water shortage could occur by 2025 in cities nationwide. Thirty-five percent of the surveyed cities indicated that they have an adequate water supply for less than 20 years; 56 percent indicated that they have an adequate water supply for more than 20 years.
- *Water conservation:* Two-thirds of the surveyed cities indicated they had water conservation plans in place. A higher proportion of large cities (80 percent) had conservation plans in place that smaller cities (59 percent).
- *Public-private partnerships:* Fifty-three percent of the surveyed cities indicated that they were willing to consider a Public-Private Partnership (PPP) approach to water infrastructure projects if cost savings in operation and maintenance or construction could be achieved.

In a 2007 follow-up study, the U.S. Conference of Mayors conducted a national survey of Drinking Water and Wastewater Asset Management (Anderson, 2007). Objectives of this survey included an examination of the extent to which asset management programs have been integrated into water and wastewater programs as well as the generation of information on the challenges cities face in managing these assets.

The 2007 report found that repair and replacement cycles for assets were mainly determined by budget allocations. City managers were asked to report how many years it takes to complete a repair and replacement (rehabilitation) cycle for the water system pipes that they operate and maintain at current or projected spending levels. According to the survey, the mean rehabilitation period is 90.6 years and the median rehabilitation period is 50 years. Estimated annual spending on drinking water distribution system pipes ranged from $1,500 to $15 million in the 235 participating cities, with a mean of $1.4 million per year and a median of $400,000 per year.

Table 1-8. Ranked Order of 24 Water Resources Issues*

Rank	Water Resources Issue	Percent of Cities
1	Aging water resources infrastructure	60.6
2	Security/protection of water resources infrastructure	54.6
3	Water supply availability	46.4
4	Permits, regulatory issues	45.2
5	Water quality of urban streams and rivers	42.3
6	Flooding	38.4
7	Emergency planning and management for storms, hurricanes	34.3
8	Drought management	32.6
9	Regional conflict over water use	26.8
10	Water rights	25.1
11	Groundwater depletion	23.4
12	Sediment management	19.6
13	Inter-basin transfer	16.2
14	Best practices – technology transfer	13.0
15	Endangered species	11.6
16	Loss of river corridors / green-space	10.6
17	Loss of wetlands	10.4
18	Other	9.7
19	Water transportation (channels, ports, dredging)	8.5
20	Beach / shoreline erosion	7.5
21	Neglected / decaying waterfront areas	6.8
22	Channel / harbor adequacy	4.8
23	Insufficient water-oriented recreation	3.9
24	Waterborne traffic	3.4

Note: * - from Anderson et al. (2005)

The mean reported number of years for sewer pipe repair and rehabilitation was 78; the median was approximately 40 years. Average annual expenditure on wastewater collection pipe repair/replacement in participating cities was $1.7 million, though ten cities reported spending $10 million or more.

Table 1-9. Percentage of 414 Cities Planning Infrastructure Investments in 2005-2009*

Infrastructure Category	Small Cities[1] (%)	Medium Cities[2] (%)	Large Cities[3] (%)
Water supply	44.7	52.1	71.1
Water treatment plants	38.8	40.7	61.5
Water distribution system	68.2	72.1	79.8
Wastewater treatment plants	41.2	46.4	62.5
Wastewater collection system	58.2	64.3	72.1

Note: * - from Anderson et al. (2005)
[1] Small cities - fewer than 50,000 people.
[2] Medium cities - between 50,000 and 100,000 people.
[3] Large cities - more than 100,000 people.

3.2. AWWARF Assessment of Trends and their Implications for Water Utilities

AWWARF conducted a Futures Workshop in 2004, following up on earlier efforts in 2000, to examine significant trends affecting water utilities. The starting point for the assessment was the identification of major utility trends by prominent leaders in the water community (Table 1-10).

This exercise led to the development of a trend paper serving as a briefing for a subsequent expert futures workshop (McGuire Environmental Consultants and R. Patrick, 2005; Means et al., 2005b). The objective of the workshop was to develop a consensus around the top ten primary trends and to formulate strategies for dealing with each trend. The resulting list of top ten trends is summarized below:

- Population and demographic changes
- Political environment complexity
- Increasing regulations
- Workforce issues
- Technology improvements
- Total water management
- Changing customer expectations
- Utility finance constraints
- Energy cost and supply reliability
- Increased risk profile

Results from the 2000 and 2004 workshops were compared to identify changes in trends over the four-year period. Though many of the year 2000 trends continued in 2004, a notable addition was the emergence of a utility risk profile, largely attributed to the events of September 11, 2001. Other continuing/emerging trends included total water management, regulations and infrastructure management. Climate change, though discussed as part of the total water management topic, was not recognized in 2004 as one of the top ten trends. These results suggest that utilities may benefit from revisiting long-range plans, if they have not done so already, to ensure that they address current needs related to climate change. In particular, improvements were found necessary to ensure infrastructure sustainability in the context of climate change.

Table 1-10. Utility Trends Identified in Expert Interviews*

Societal	Business	Utility
▪ Population / demographics ▪ Environmental trends ▪ Economic trends ▪ Medicine / health trends ▪ Terrorism / wars (post Sept 11 environment)	▪ Employment trends ▪ Customer expectations ▪ Outsourcing / globalization ▪ Technology (IT & others) ▪ Public confidence in markets	▪ Regulatory trends ▪ Political environment ▪ Rate sensitivity ▪ Infrastructure aging ▪ Privatization ▪ Physical and IT security ▪ Workforce demographics ▪ Total water management ▪ Water resources / drought ▪ Treatment technology ▪ Regionalization ▪ Reuse

Note: * - from Means et al. (2005b)

3.3. University of Cincinnati Regional Poll of Five Cities Plus Conference Participants

3.3.1. Assessment Methods

The Five Cities Plus Conference convenes each year at a rotating location in the Midwest and provides a forum for regional wastewater utilities to meet and discuss common operational concerns. One session typically includes a meeting of utility directors, chief engineers and other high level staff. Working with conference organizers, researchers from the University of Cincinnati distributed the ranking matrix shown in Figure 1-12 to senior representatives from six major Midwestern wastewater utilities. The locations of the six utilities are indicated by the yellow dots on the map in Figure 1-13.

UNIVERSITY OF Cincinnati

Water **R**esources **A**daptation **P**rogram – Infrastructure

Two Minute Survey on

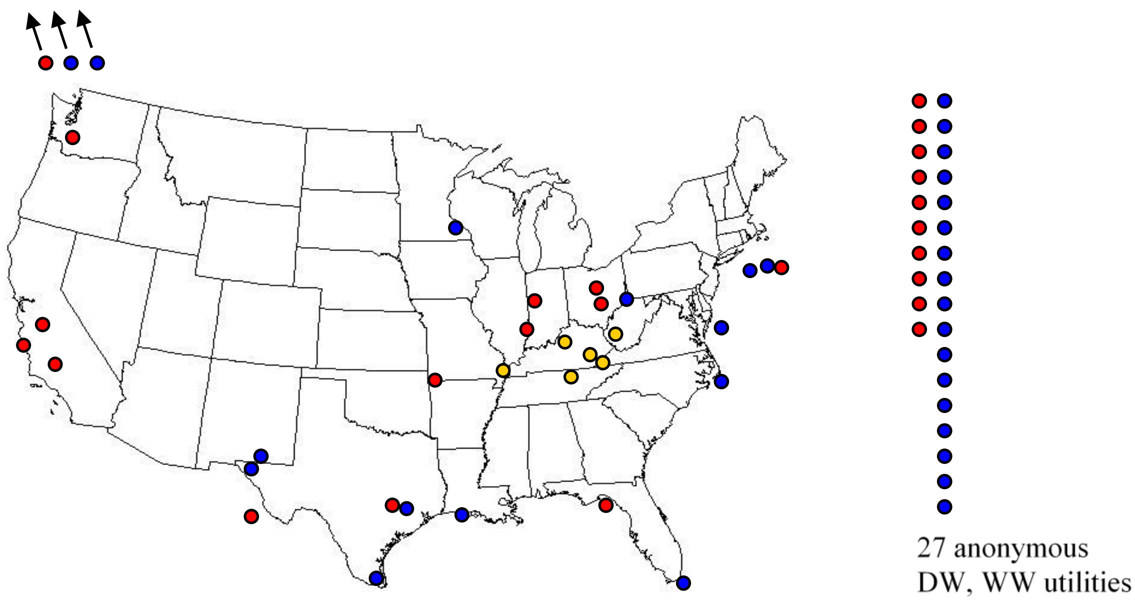
Future Operation and Performance of Wastewater Utilities

Instructions: Listed alphabetically below are 21 problem areas which may adversely affect the operation of your wastewater utility over the next 50 years. Put a "✓" in the appropriate box to score each problem on a scale of 5 (very serious; high impact) to 1 (not serious; no impact) according to its anticipated impact on operation of your wastewater utility. Please return with stamped self-addressed envelope. Thank you.

Specific Issue or Problem Affecting Your Utility Operation Over Next 50 Years	Very Serious [5]	[4]	Somewhat Serious [3]	[2]	Not Serious [1]
[01] Aging water system infrastructure					
[02] Climate change					
[03] CSOs and/or SSOs					
[04] Decline in local revenue stream					
[05] Decline in state or federal aid					
[06] Emergency plans for storms/hurricanes					
[07] Endangered species					
[08] Inadequate treatment capacity					
[09] Increased cost of energy					
[10] Infiltration and Inflow (I/I)					
[11] Lack of skilled work force					
[12] Lack of asset management plan					
[13] Prospect of privatization					
[14] Nutrients and pharmaceuticals					
[15] Outdated treatment technology/equipment					
[16] Reduced flow in receiving water body					
[17] Regional conflicts over water use					

[18] Stringent government regulations						
[19] Vulnerability to cyber attacks						
[20] Vulnerability to physical attacks						
[21] Other						

Figure 1-12. Ranking matrix distributed to wastewater utility directors attending the Five Cities Plus Conference held in Columbus Ohio, June 2008.



yellow = wastewater participants in the Five Cities Plus Conference survey
red = wastewater participants in the National Water Infrastructure Questionnaire
blue = drinking water participants in the National Water Infrastructure Questionnaire

Figure 1-13. Participants in the Five Cities Plus Conference Survey and the National Water Infrastructure Questionnaire.

3.3.2. Findings

Results of the poll (previously unpublished) are given in Appendix I-A and summarized here. The data were normalized for consistency[10] with Table 1-8, and the ranked results are presented in Table 1-11. Three of the top five concerns in Table 1-11are linked to finances (decline in state or federal aid, decline in local revenue streams, and increasing cost of energy). Aging infrastructure and CSOs/SSOs share second place in matrix ranking. Both issues (understanding CSOs and SSOs as key contributors to water quality problems in urban rivers and streams) also appear among the top five categories cited in Table 1-8.

Table 1-11. Ranked Order of 20 Issues Facing Midwest Wastewater Utilities (N=6)

Rank	Wastewater Utility Issue	Score [0-100]
1	Decline in state or federal aid	91.7
2.5	Aging water system infrastructure	87.5
2.5	Combined sewer overflows; sanitary sewer overflows (CSO/SSO)	87.5
4.5	Decline in local revenue stream	83.3
4.5	Increasing cost of energy	83.3
6	Nutrients and pharmaceuticals	75.0
7.5	Infiltration and Inflow (I/I)	70.8
7.5	Lack of skilled work force	70.8
9	Stringent government regulations	66.7
10	Lack of asset management plan	54.2
11	Outdated technology/equipment	50.0
12	Climate change	45.8
13.5	Emergency plans for storms/hurricane	41.7
13.5	Inadequate treatment capacity	41.7
15	Vulnerability to physical attacks	37.5
16	Vulnerability to cyber attacks	33.3
17	Reduced flow in receiving water body	29.2
18	Endangered species	20.8
19.5	Prospect of privatization	8.3
19.5	Regional conflicts over water use	8.3

[10] The matrix scoring system allowed a minimum value of "6" if an issue received six "1s", and a maximum value of "30" if an issue received six "5s". Actual scores (Appendix I-A) range 8-28. The scores were transformed to the scale in Table 1-11, with $Y = 4.167(X-6)$; X is original score and Y is the transformed score.

3.4. University of Cincinnati National On-line Questionnaire

3.4.1. Methods

The University of Cincinnati research team developed a second, more comprehensive and extensive data gathering instrument to reach a broader cross section of the nation's water industry. The research team partnered with three national drinking water and wastewater industry organizations to collect information on utility perceptions of key issues that they will likely face in the future. The original questionnaire is given in Appendices I-C and I-D. In each case, the research team worked closely with the organizations to develop a vehicle to collect representative and meaningful information from member utilities. The participating water organizations included the following:

- *Association of Metropolitan Water Agencies (AMWA)* - AMWA is an organization comprised of the largest publicly owned drinking water systems in the U.S. AMWA's membership serves more than 130 million Americans with drinking water from Alaska to Puerto Rico. http://www.amwa.net/
- *National Association of Clean Water Agencies (NACWA)* – NACWA represents the interests of the country's wastewater treatment agencies that serve the majority of the sewered population in the U.S., and collectively treat and reclaim over 18 billion gallons of wastewater daily. http://www.nacwa.org/
- *National Association of Water Companies (NAWC)* - NAWC represents all aspects of the private water service industry. Member business includes ownership of regulated drinking water and wastewater utilities, many forms of public-private partnerships and management contract arrangements. NAWC's membership ranges in size from large companies owning and/or operating many hundreds of utilities in multiple states to individual utilities with only a few hundred customers. http://www.nawc.org/index.html

Table 1-12. Main Sections of the On-line Water Utility Questionnaire

Section Number	Number of Questions		Questionnaire Topic
	Drinking Water	Wastewater	
1	0	0	[Introduction]
2	11	9	Utility Profile
3	22	18	Infrastructure and Operation
4	5	5	Agents of Change
5/6	6	5	Thinking Ahead / Master Plan
7/8	3	3	Contact Information (optional)
Total	47	40	

The questionnaire developed during spring 2008. The researchers posted two versions of the on-line questionnaire: one for the drinking water industry with 47 questions and the other for the wastewater industry with 40 questions. Both were designed to be completed at one sitting in an hour or less. The main topics covered in the questionnaire are summarized in Table 1-12.

Copies of the on-line questionnaires for the drinking water industry and wastewater industry are presented in Appendices 1-C and 1-D, respectively.

3.4.2. Findings

Representatives from a total of 55 water utilities responded to the on-line questionnaire. These 55 utilities, representing nearly 43 million customers, declared infrastructure assets that included 110 water treatment plants, over 640 storage tanks, more than 1,320 pumping stations and nearly 85,000 miles of pipeline. A profile of participating utilities is given in Table 1-13. The geographic distribution of the participating water utilities is shown by the red and blue dots in Figure 1-13.

Table 1-13. Participant Profile of Water Utilities Completing On-line Questionnaire

Feature	Drinking Water	Wastewater	Total
Number of Utilities	32	23	55
2008 Customers (million)	16.83	25.91	42.74
2008 Summer Flow (MGD)	2,686	3,450	6,136
2008 Water Use (GPCD*)	160	133	293
20-yr Projected Growth*	19.1%	13.5%	15.7%
Miles of Pipeline	58,500	26,200	84,700
Pumping Stations	589	735	1,324
Storage Tanks	643	0	643
Treatment Plants	62	48	110

* GPCD is gallons per capita per day

** Growth rates are the weighted averages based on population.

The questionnaire-based assessment was designed to protect the anonymity of the participants to encourage participation and candid responses. Utility respondents were neither required nor encouraged to reveal their identity. However, utility participants did have an option to provide contact information. Participating utilities that elected to share their identity are identified on the map in Figure 1-13. While the identity of nearly half of the participants (27 of 55) was unknown, the on-line questionnaire instrument recorded the internet protocol (IP) addresses of all utility participants for quality assurance purposes and to ensure that a water utility contributed at most only one set of responses for the on-line questionnaire.

The key results of the on-line water resources infrastructure questionnaire are presented in the following sections. The results of the on-line data collection exercise for the drinking water and the wastewater industries are presented in parallel where possible. This approach was taken because the questionnaires for both groups were similar in structure and, it turns out, the responses revealed a remarkable consistency between the two water sectors. This strategy provides a convenient effective way to contrast, compare and comprehend responses from both groups.

For clarity of exposition, the color blue and designation "DW" signifies results from the drinking water responses (AMWA and NACW members) while the color red and designation "WW" is used to represent results from the wastewater responses (NAWCA and NACW members). While many respondents answered most questions, the completion rate varied from question to question across the assessment. Therefore, whenever possible and where appropriate, the sample size is included in summary tables and graphs.

3.4.2.1. Utility profiles

System Size

As shown in Table 1-14, respondents represented a broad collection of service conditions with customer bases ranging from 35,000 to 3 million people in the drinking water group and from 35,000 to 10 million people in the wastewater group. Interestingly, the mean population served among wastewater respondents was more than twice the mean population served among drinking water respondents; however, the medians for both groups were reasonably close. This underscores the large influence of a few high outliers, particularly in the wastewater group. The distribution of utility sizes in 2008 in terms of service area size and number of employees is shown graphically in Figures 1-14 and 1-15. In the case of service area size, almost all of the drinking water and wastewater responses were in the range of 10 to 1,000 square miles. For number of employees, nearly 60 percent of the responses in both groups were in the range of 100 to 499 employees. There was a statistically significant relationship between connections and population served (Figure 1-16) and between flow and population served (Figure 1-17). A multiplicative power function describes this relationship with a high degree of correlation, as indicated in Table 1-15.

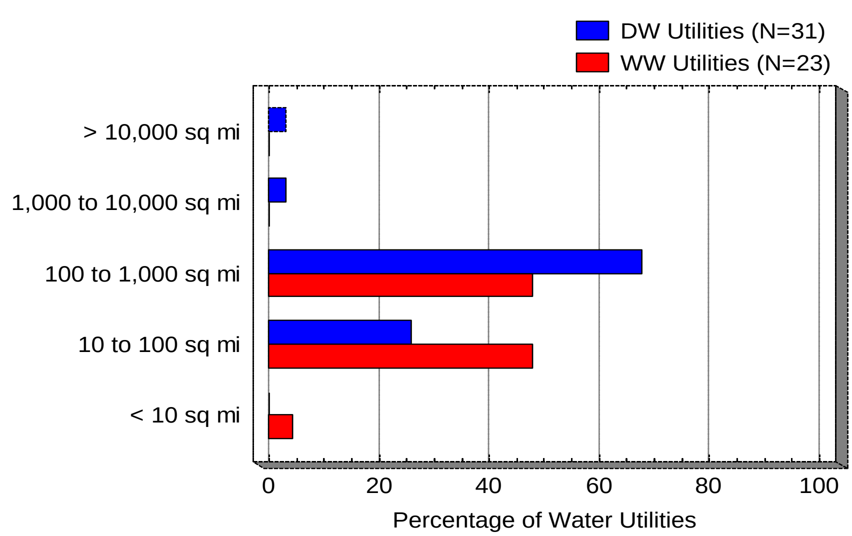


Figure 1-14. Size of service area for 54 drinking water and wastewater utilities.

Table 1-14. Statistics for Service Connections and Population Served at 55 Water Utilities

Feature	Mean	Median	Stan Dev	Min	Max	Total
Drinking Water Utilities (N=32)						
Service Connections	139,525	95,000	174,327	8,500	950,000	4,464,800
Population Served	525,829	352,500	592,605	35,000	3,000,000	16,826,528
Wastewater Utilities (N=23)						
Service Connections	255,286	81,000	626,941	8,500	3,000,000	5,616,292
Population Served	1,126,626	275,000	2,215,230	35,000	10,350,000	25,912,388

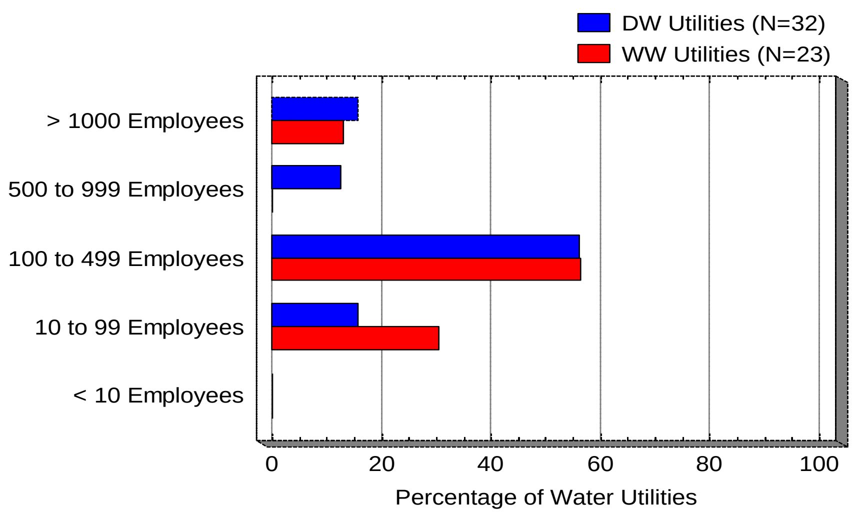


Figure 1-15. Number of employees at 55 drinking water and wastewater utilities.

Wholesale Water

Approximately 75 percent of the utilities sell a relatively small amount of their water (<20 percent) wholesale (i.e., to another utility, rather than to end users). The amount of wholesale water sold is expected to increase slightly by 2028.

Water Source

As shown in Figure 1-18, surface water is the primary source for 80 percent of the drinking water utility respondents. Surface water provided just over 77 percent of the total water volume produced by the 32 drinking water utilities. By 2028, over 90 percent of the respondents expect that surface water will be their primary source of drinking water.

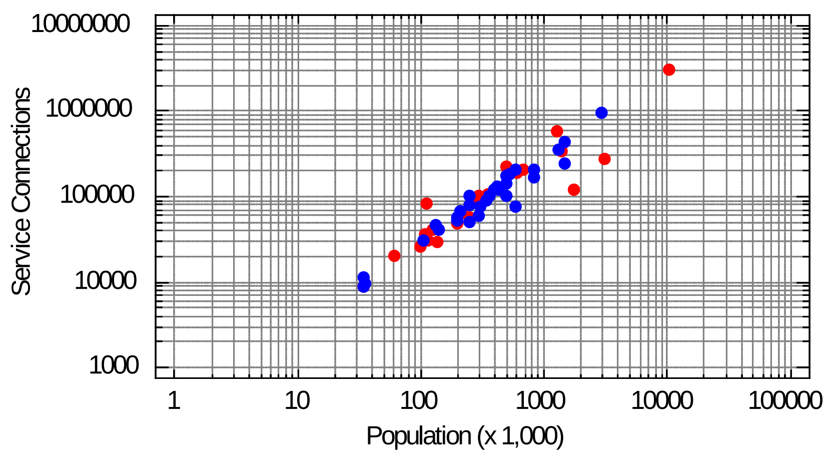


Figure 1-16. Service connections versus population at 55 water utilities (DW=blue; WW=red).

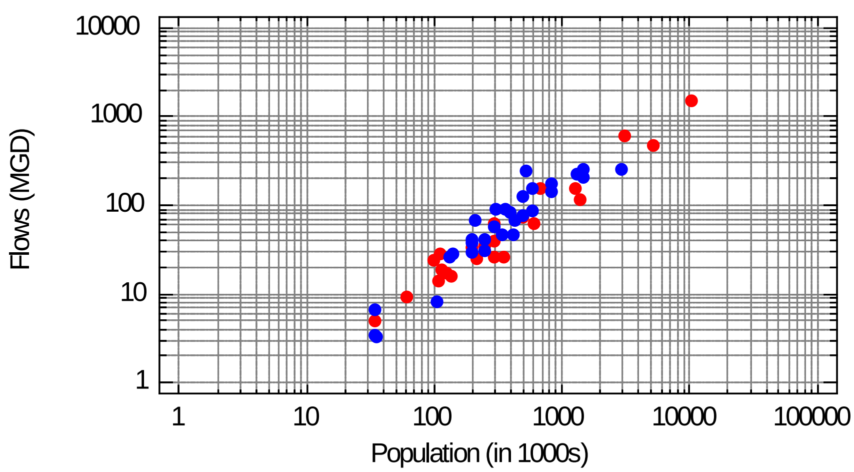
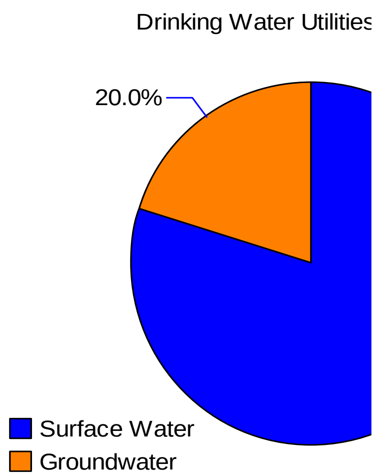
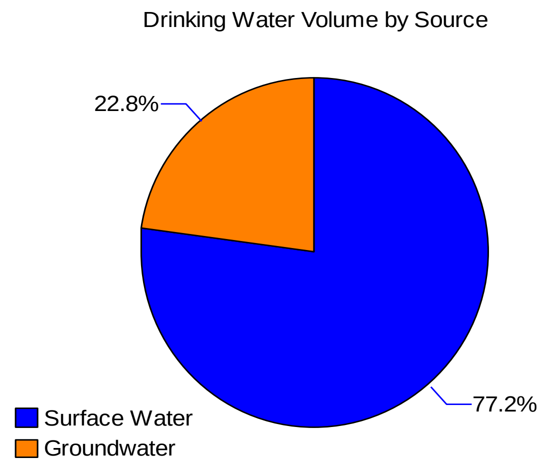


Figure 1-17. Flows versus population at 55 water utilities (DW=blue; WW=red).

Table 1-15. Relationship between Connections, Flows, and Population, $Y=aX^b$

Independent Variable, X	Dependent Variable, Y	Coefficient (a)	Exponent (b)	Correlation (R)	Figure
Population in 1000s	DW Service Connections	340.4	0.956	0.974	4.5
Population in 1000s	WW Service Connections	540.2	0.878	0.936	4.5
Population in 1000s	DW Flow (MGD)	0.123	1.05	0.944	4.6
Population in 1000s	WW Flow (MGD)	0.185	0.95	0.972	4.6





at drinking water

utilities.

Projected Change in Population Served

An overwhelming majority of responding water utilities expect their customer base to increase in the next 20 years (Figure 1-19). Based on 55 responses, the overall industry-wide average rate of growth for the next 20 years was estimated to be about 16 percent (or 0.80 percent per annum). At the extremes, on the high side, one drinking water utility (in the southern U.S.) expected a growth rate over 50 percent, while on the low side, one wastewater utility (in the northern U.S.) expected a negative growth rate.

Current and Projected Water Use

Respondents provided information on current (2008) and projected (2028) flows. Flow information included both summer and winter estimates for average and maximum daily flows. The estimates are summarized in Table 1-16. On average, the daily flows during the summer and winter seasons are projected to increase by 25 to 40 percent in the next 20 years. These rates of increase in system-wide flows exceed the anticipated average growth in customer base mentioned in the previous section.

Climatic Information

Average annual temperature and precipitation information for the water utilities is summarized in Figure 1-20 and Figure 1-21, respectively. As evident on the map in Figure 1-13, the participating water utilities represent a wide range of geographic and climatic conditions, from cold (< 40 ºF) to warm (> 70 ºF) climates and from dry (< 10 inches per year of precipitation) to wet (> 55 inches per year of precipitation) regions.

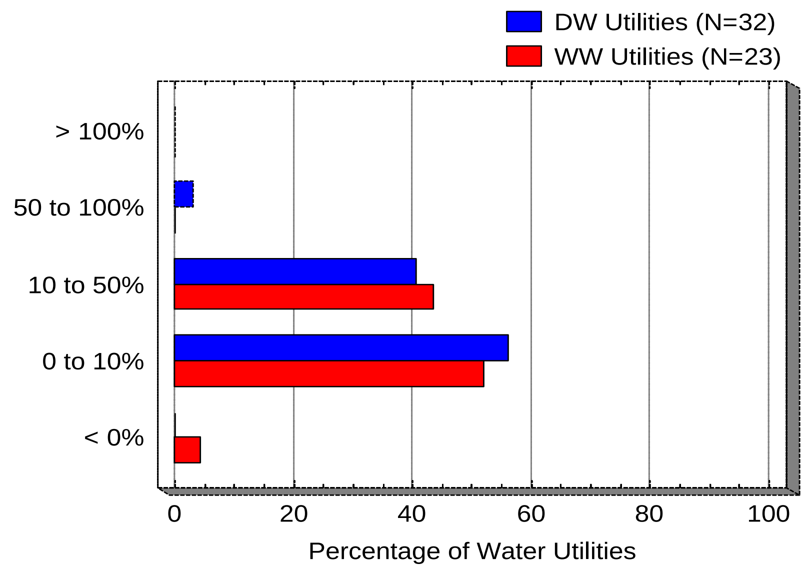


Figure 1-19. Distribution of projected growth in utility customer base over next 20 years.

Table 1-16. Estimated Flows by Water Utility Respondents

Water Use Statistic	Average Daily Usage (MGD)				Maximum Daily Usage (MGD)			
	Summer		Winter		Summer		Winter	
	2008	2028	2008	2028	2008	2028	2008	2028
Drinking Water Utilities								
Sample Size	30	23	29	22	29	21	26	20
Minimum	3.2	4	2.8	13	4.2	26	3.6	22
Average	90	113	58	82	110	154	69	46
Maximum	250	300	200	250	300	384	210	260
Wastewater Utilities								
Sample Size	23	16	23	15	22	16	23	16
Minimum	4.9	9	4.5	9	7	28	9	11
Average	150	195	155	196	244	311	249	304
Maximum	1463	1609	1367	1504	2226	2449	2410	2651

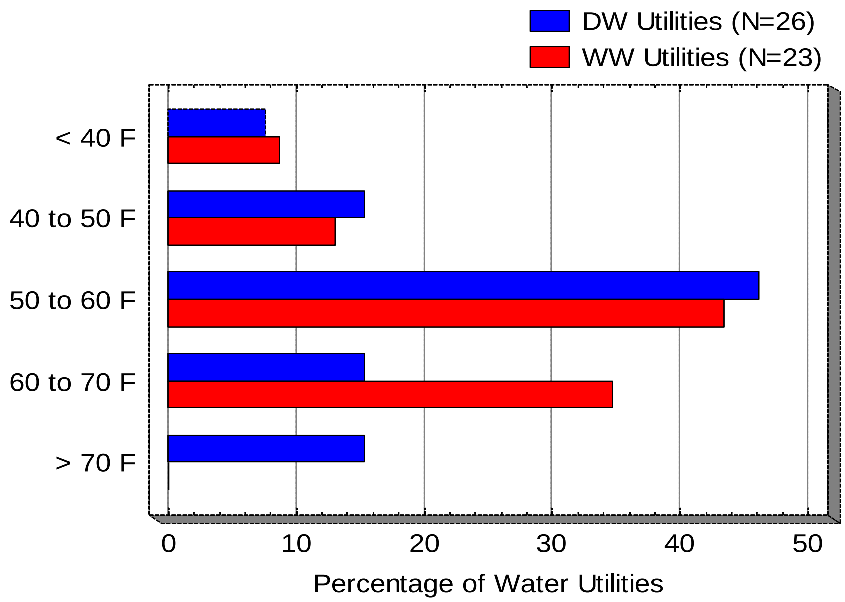


Figure 1-20. Distribution of annual average temperature at 49 water utilities.

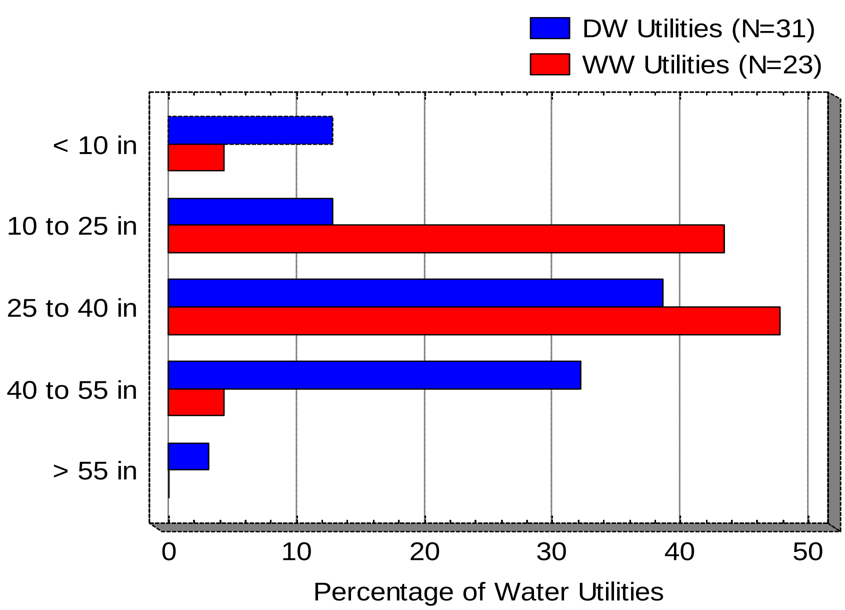


Figure 1-21. Distribution of annual average precipitation at 54 water utilities.

3.4.2.2. *Infrastructure and operation*

<u>Water Treatment</u>

Water treatment process information from the on-line survey is summarized in Tables 1-17 and 1-18 for the drinking water and wastewater groups, respectively. Most (about 75 percent) of the drinking water respondents operate one or two treatment plants, with the remaining 25 percent of the systems reporting a larger number of plants. Four main processes (rapid mix, flocculation, settling basins, and filtration) were used at the majority (over two-thirds) of drinking water treatment plants, though not necessarily in tandem with each other. The full suite of these four unit processes appeared in just over half (52 percent) of the 25 drinking water treatment plants that provided a complete response to this question. Eight other drinking water processes were used in less than half of the water treatment plants, as indicated in Table 1-17. Neither diatomaceous earth filtration nor bank filtration were used by any of the drinking water respondents.

Most (75 percent) of the wastewater respondents indicated that they operate one or two wastewater treatment facilities; a smaller fraction (15 percent) indicated they operate three to five wastewater treatment facilities. The remaining 10 percent of wastewater respondents were evenly distributed between operating six to ten and greater than ten wastewater treatment facilities. Five main treatment processes—screening, sedimentation, activated sludge, anaerobic digestion, and disinfection—are used at the majority (nearly 70 percent) of the wastewater plants examined. The complete collection of these five unit processes appears together in only about 39 percent of the wastewater treatment plants in this assessment. Filtration is used by about half the treatment plants. As listed in Table 1-18, ten other processes were used by less than half of the responding wastewater treatment facilities. Rotating biological contactors (RBC) were not used by any of the wastewater respondents.

Table 1-17. Drinking Water Treatment Plant Processes (N = 25 responses)

Water Treatment Processes	Percent of DW Utilities
Pre-sedimentation basin	32.0
Rapid mix	68.0
Flocculation	84.0
Settling basin	72.0
Filtration	84.0
Granular activated carbon (GAC)	32.0
Microfiltration / Ultrafiltration (MF/UF)	12.0
Nanofiltration	8.0
Slow sand filtration	20.0
Diatomaceous earth filtration	0.0
Bank filtration	0.0
UV disinfection	8.0
Ozone chamber	40.0
Contact tank	32.0

Table 1-18. Wastewater Treatment Plant Processes (N = 23 responses)

Water Treatment Processes	Percent of WW Utilities
Screening	78.2
Sedimentation	78.2
Flotation	30.4
Filtration	52.2
Gas stripping	8.7
Chemical precipitation	21.7
Adsorption	13.0
Activated sludge	87.0
Aerated lagoons	17.4
Trickling filter	26.0
Rotating biological contactors (RBC)	0.0
Anaerobic digesters	69.6
Nutrient removal	34.8
Stabilization ponds	13.0
Disinfection	82.6
Ozone chamber	4.3
UV light	26.0

<u>Treatment Plant Capacity</u>

Some statistics for treatment plant capacity are summarized in Table 1-19 based on two metrics: [i] absolute plant capacity expressed in million gallons per day (MGD) and [ii] plant capacity per population served expressed as gallons per capita per day (GPCD). The sample skewness for the wastewater data sets is relatively high (2.91 for MGD and 3.70 for GPCD), indicating the presence of one or more extreme values which can influence estimates of other sample statistics. In contrast, the skewness for both drinking water data sets is relatively mild and decreases from 1.41 (MGD) to -0.03 (GPCD) when the plant capacity is expressed on a per capita basis.

This behavior is evident in Figure 1-22, which shows the cumulative distribution on normal probability of plant capacity (GPCD) for drinking water and wastewater operations. The drinking water data set follows a linear trend on the graph, suggesting that these values are normally distributed. The pronounced upward curvature in the wastewater data indicates that these values are not normally distributed and confirms the presence of a strong positive skewness. The high outlier in the wastewater group (1,333 GPCD) is from a participant who provided contact information. In a follow-up discussion, the participants confirmed that the data provided in the original responses are correct. It should also be mentioned that the minimum point in the drinking water group (23 GPCD) corresponds to a utility whose source is a protected groundwater supply requiring little treatment.

Table 1-19. Treatment Plant Capacity of 51 Water Utilities

Statistic	Drinking Water Utilities		Wastewater Utilities	
	(MGD)	(GPCD)	(MGD)	(GPCD)
Sample Size	30	30	21	21
Minimum	5.3	23	8.0	94
Average	138	308	301	260
Median	90	305	54	192
Maximum	510	560	2,506	1,333
Standard Deviation	123	142	631	265
Skewness	1.41	-0.03	2.91	3.70

While the connections and flows per population are similar between the drinking water and wastewater groups (see Figures 1-16 and 1-17), their volumetric treatment capacities per capita are quite different. The difference is also revealed in Figure 1-22. Based on the sample obtained in this questionnaire, the plant treatment capacity expressed as GPCD is significantly less for wastewater operations than for drinking water operations. It is not known if this is a general rule of the industry or simply an artifact of the sample.

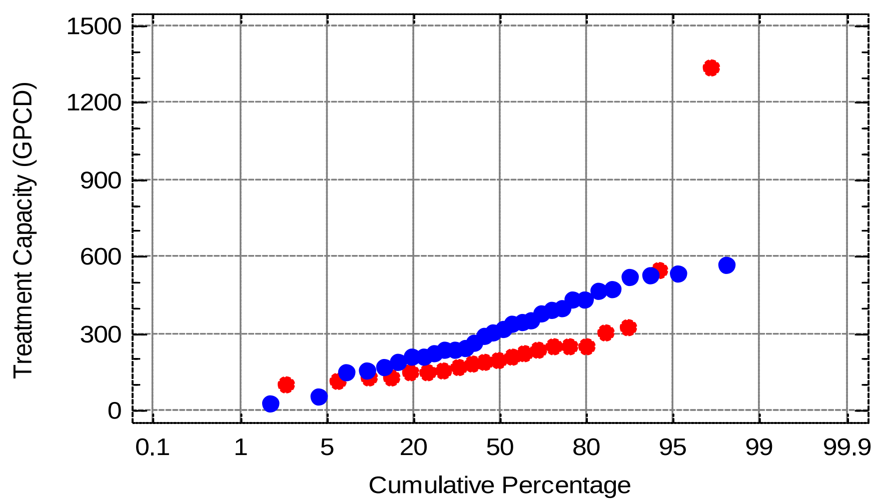


Figure 1-22. Distribution of treatment plant capacity expressed as GPCD. (DW=blue; WW=red).

According to Harr (1987), one measure of system reliability is the *factor of safety,* defined as the dimensionless ratio of system capacity $\tilde{C}$ to system demand $\widetilde{D}$, or

$$FS = \frac{\tilde{C}}{\widetilde{D}}$$

Conventional engineering practice requires that FS≥1. If the nominal plant treatment capacity is interpreted as the "system capacity" and the peak flows (mentioned in Table 1-19) are viewed as the "system demand", then data collected from the questionnaire can be used to develop a probability distribution of safety factors for drinking water and wastewater treatment operations. Results for current (2008) and future (2028) conditions appear in Figure 1-23 and Figure 1-24, respectively.

Figure 1-23 indicates that during peak summer demand in 2008 approximately 80 percent of drinking water respondents and 55 percent of wastewater utility respondents could operate with FS≥1. This implies that the volumetric capacity of the water treatment plant is sufficient to satisfy demand (or loading) during periods of peak use.

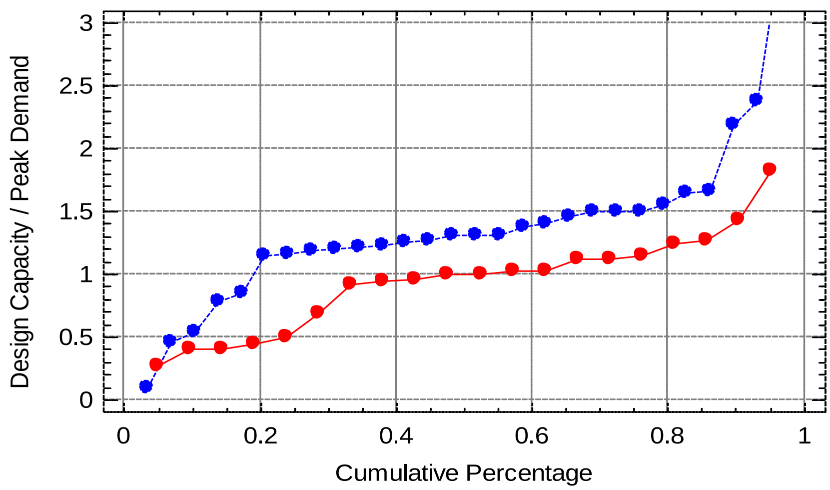


Figure 1-23. Factor of safety for drinking water and wastewater operations based on summer 2008 peak flows. (DW=blue; WW=red).

Furthermore, Figure 1-24 suggests that during peak summer demand in 2028 about 65 percent of drinking water utilities and 30 percent of wastewater utilities will operate with FS≥1. This exercise clearly demonstrates that the treatment performance of water utilities will diminish with increasing future demands. Consistent with the trend noted in Figure 1-22, the wastewater industry seems to have a smaller operating buffer than the drinking water industry, and consequently will be challenged more often and more severely in the future to provide adequate treatment under increased peak loading periods. The expected reduction in performance is due strictly to future increases in peak demand as forecast by the utility respondents. No attempt has been made here to account for likely plant expansions needed to accommodate increasing demand.

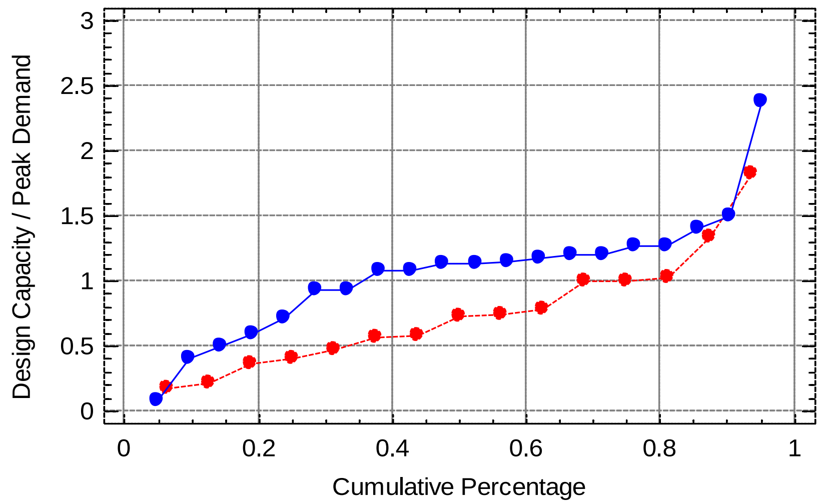


Figure 1-24. Factor of safety for drinking water and wastewater operations based on summer 2028 peak flows. (DW=blue; WW=red).

<u>Pumping Stations, Tanks, and Pipes</u>

Statistics on the number of water treatment plants, pumping stations and tanks, total tank capacity and miles of pipes for drinking water respondents are presented in Table 1-20. Based on this table it is apparent that the sample of drinking water utility respondents encompassed a wide range of distribution system characteristics.

Figure 1-25 summarizes the relative frequency of pipe material based on responses from 39 utilities. Cast iron and ductile iron are the most prevalent pipe materials in the drinking water industry, while concrete and other pipe materials tend to be more common in the wastewater industry. In conversations with local utilities, other categories of assorted pipe materials were described, including vitrified clay, brick or stone culvert, wood, and lined pipes (concrete or iron pipes lined with plastic or resins). For example, the 14-foot sewer at the bottom of Queen City Avenue in Cincinnati is made of brick and was constructed in place (personal communication, M. Flanders, Metropolitan Sewer District).

The pipe age is an indicator of system's integrity. Figure 1-26 provides information on the percentage of pipes that are older than 50 years. The distribution of pipe ages is quite similar for both utility groups, perhaps reflecting the prevailing practice of installing water and sewer lines during the same construction period. From the graph, it can be deduced that about one-third of the drinking water and the wastewater respondents have a pipe network in which over half of the total length of pipe exceeds 50 years in age. This finding further highlights the advancing age of the nation's water infrastructure.

In term of annual pipe breakage, Figure 1-27 shows a statistics of utility responses. The reported breakage rate varies dramatically between the drinking water and wastewater industries; wastewater utilities tending to have a much lower rate of pipe breakage. This may reflect the fact that most wastewater collection systems do not operate under pressure whereas drinking water distribution systems operate continuously under high pressures.

Table 1-20. Number and Size of Facilities in Drinking Water Supply Systems

	No of Water Treatment Plants	No of Pumping Stations	No of Finished Water Tanks	Total Tank Capacity (MG)	Distribution System Pipes (miles)
Sample Size	30	29	29	27	29
Minimum	1	1	3	5	161
Average	2	20	22	90	2,018
Maximum	> 5	150	100	300	10,000
Total	> 62	589	643	2,428	58,521

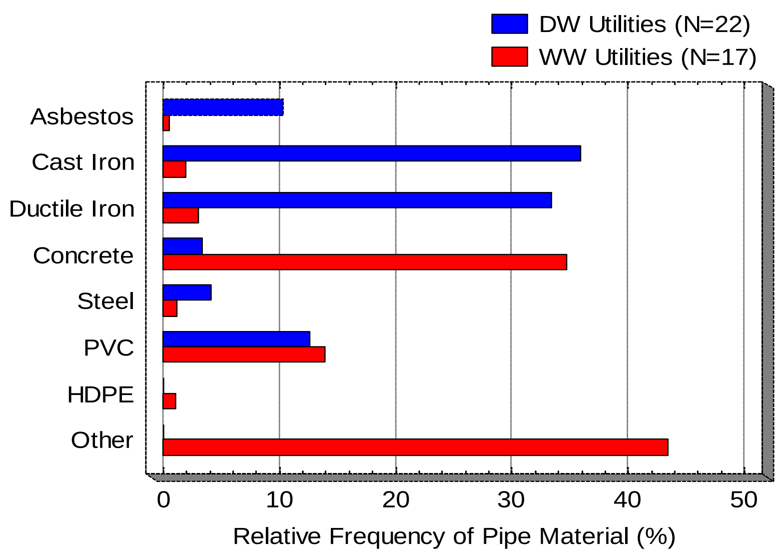


Figure 1-25. Pipe material used in drinking water distribution networks and wastewater collection systems.

Furthermore, Figure 1-28 presents information on the percentage of pipe that is replaced annually. Most respondents reported a low pipe replacement rate; over a half indicated that they replace less than 0.5 percent of their piping each year. At this rate, it would take these utilities more than 200 years to replace all existing pipes in their infrastructure.

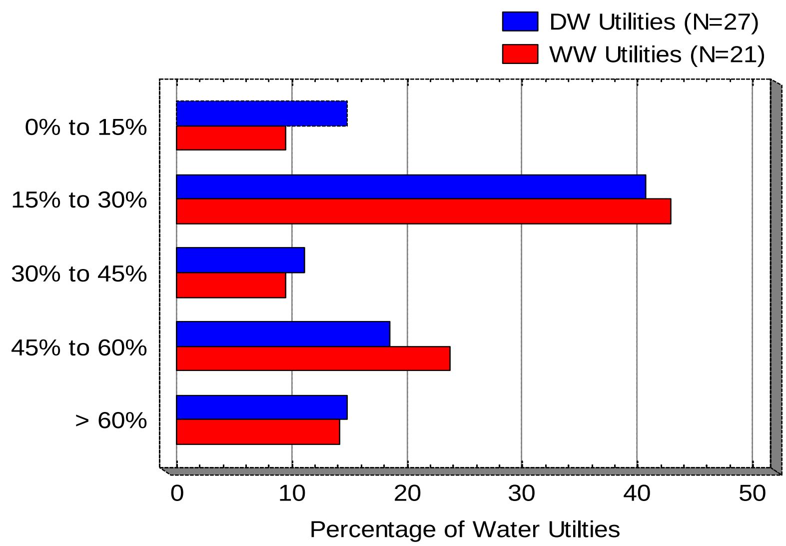


Figure 1-26. Percentage of pipes older than 50 years.

Respondents were asked to rate the condition of various components of the water infrastructure using a scale of 1 to 10 with 1 being the worst and 10 the best. This response was scaled up to a 100-point score system. As shown in Figure 1-29, except for the pipe network category, the overall average self-assessment results for drinking water and wastewater infrastructure (pumps, tanks, plants) were in the moderate range (75 to 85). Pipe networks were rated slightly lower.

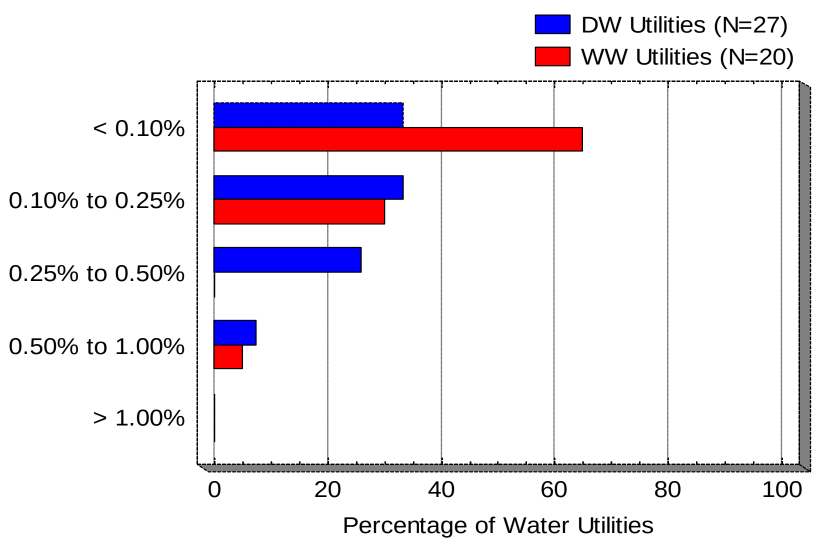


Figure 1-27. Annual breakage rates per mile of pipe.

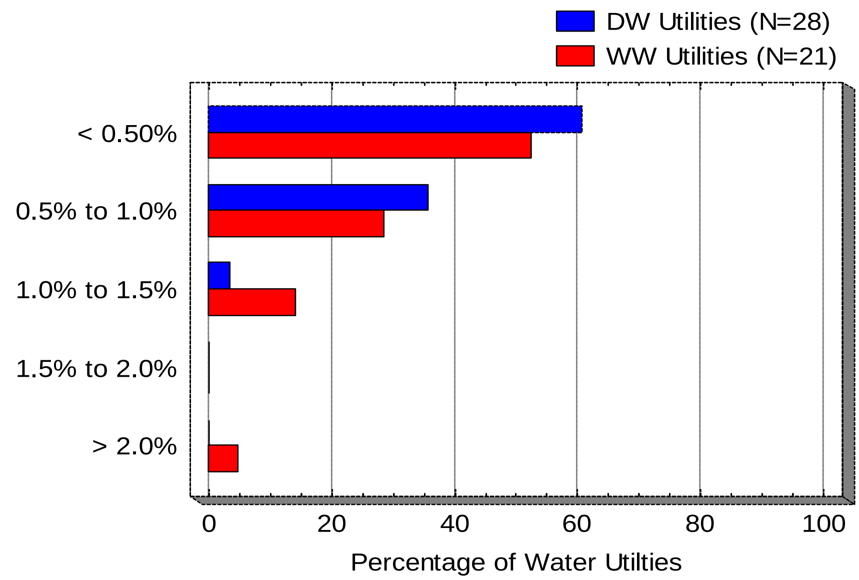


Figure 1-28. Percentage of pipes replaced annually.

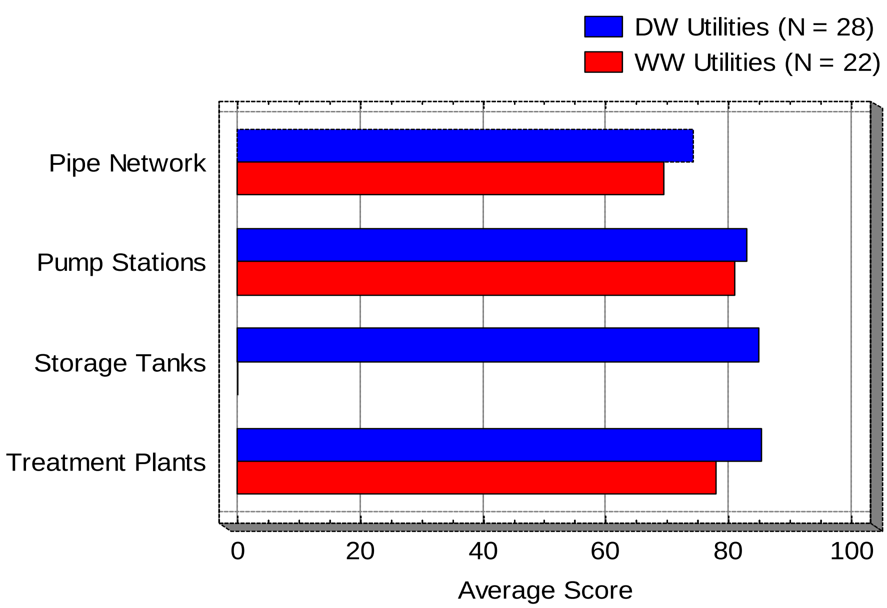


Figure 1-29. Self-assessment of infrastructure performance and condition by 50 utilities.

While the piping network is the portion of the national water infrastructure that is least in the public eye, it often represents the single largest capital investment for most water utilities. Hence, the relatively low scores consistently assigned to the condition of the pipe network signify a significant impending capital cost at many water utilities.

Figure 1-30 indicates the distribution of responses regarding the percentage of wastewater infrastructure (pumps, pipes, plants, etc.) inspected annually. Just over one-third (36.4 percent) of the responses indicated that 5-10 percent of the infrastructure is inspected each year. The overall industry-wide average suggested by these results is an inspection rate that covers about 20 percent of the wastewater system per year. This implies the entire collection of infrastructure assets for the wastewater sector is inspected on average about once every 5 years (assuming that no piece of infrastructure is inspected twice before each has been inspected once—if that assumption is relaxed, the complete inspection cycle at the average wastewater system may take somewhat longer). Given the enormous variability among systems in annual inspection rates, some system-wide inspection cycles may require 40 or more years to complete. There was no correlation between wastewater utility size and infrastructure inspection schedule.

In response to a question regarding the time interval since the last major facility upgrade (excluding routine maintenance), about 75 percent of the assessed water utilities indicated that a major upgrade has been made since 2005. The discrepancy is shown in Figure 1-31. Most of the remaining responses indicated that significant upgrades had been made during the previous 15 years (1990 to 2004), with a small percentage (<10 percent for drinking water and <20 percent for wastewater) reporting the most recent upgrade as occurring prior to 1990.

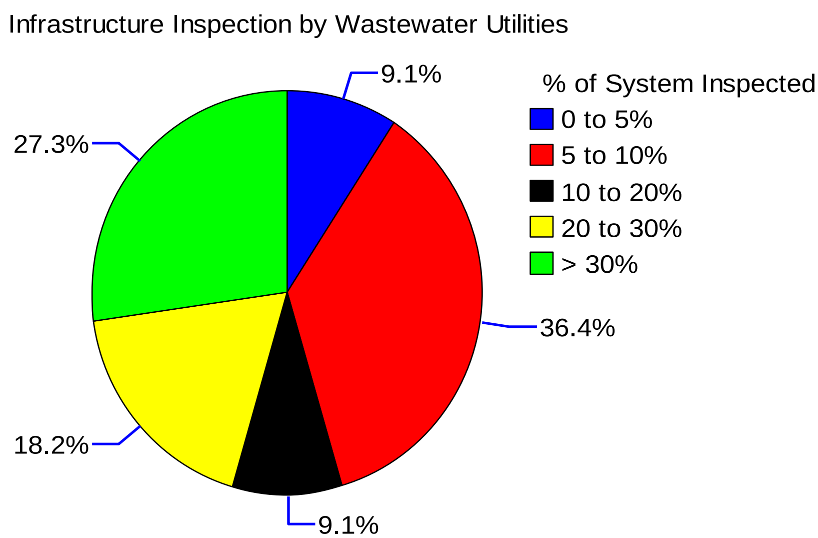


Figure 1-30. Annual inspection rates for wastewater infrastructure.

Grey Water Usage

In response to a question pertaining to finished water after it has been drawn from the distribution system for some initial use, 70 percent of the respondents answered that no "grey" water is subsequently reclaimed and reused in their service area. Of those who indicated that they do use grey water, in most cases only a small percentage (< 5 percent) was reused. A slight increase of grey water usage is projected for 2028.

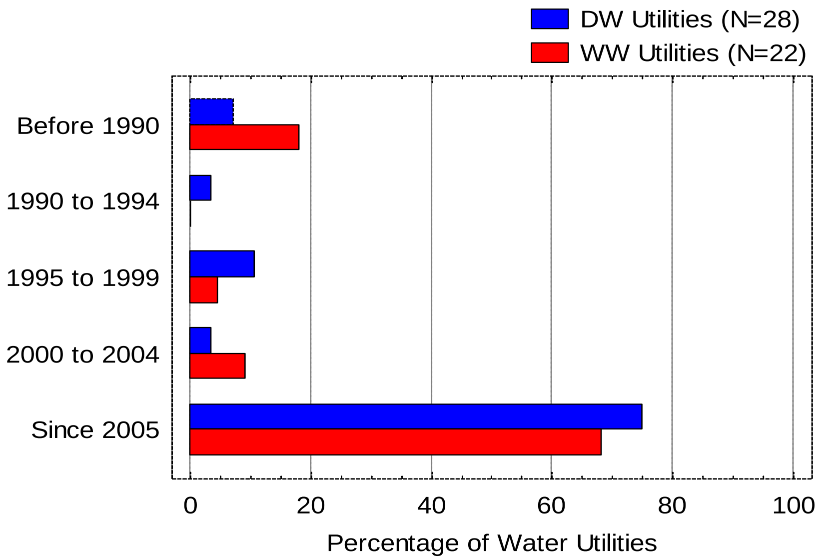


Figure 1-31. Most recent major upgrade to water system facilities.

CSOs and SSOs

Figure 1-32 summarizes the relative frequency of combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) experienced by 22 of the wastewater respondents. About 14 percent of the respondents did not experience any overflows. Another 14 percent experienced CSOs only, while half of those assessed experienced SSOs only. The balance (23 percent) experienced both CSOs and SSOs.

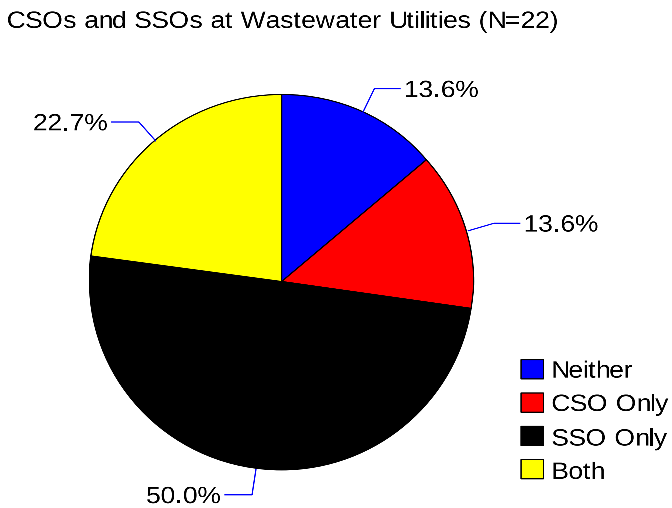


Figure 1-32. Occurrence of CSOs and SSOs at wastewater utilities.

Unaccounted for Water

Figure 1-33 summarizes responses from drinking water utilities on unaccounted-for water. As shown, approximately 48 percent of the respondents indicated relatively low values (< 10 percent), 44 percent reported moderate losses (10 to 20 percent), and just over 7 percent reported high losses (> 20 percent).

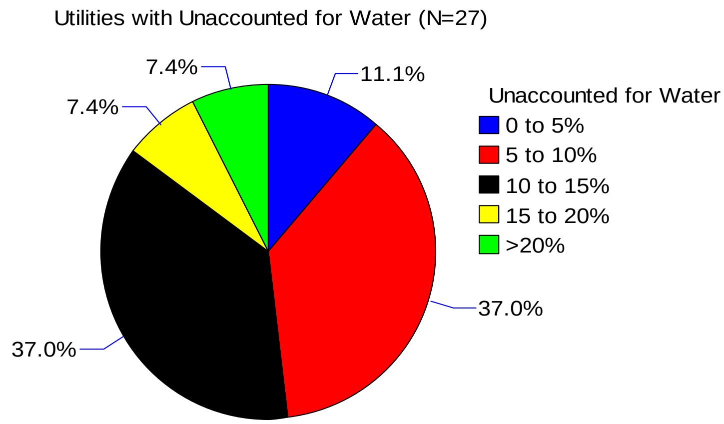


Figure 1-33. Occurrence of unaccounted for water at drinking water utilities.

Water Conservation Measures

Figure 1-34 presents results on the incidence of water conservation measures implemented by drinking water respondents in the past 10 years. As shown, some form of conservation measures (voluntary or mandatory or both) were imposed by approximately 65 percent of the utilities. About a third of the drinking water utilities did not implement any form of water conservation in the past 10 years.

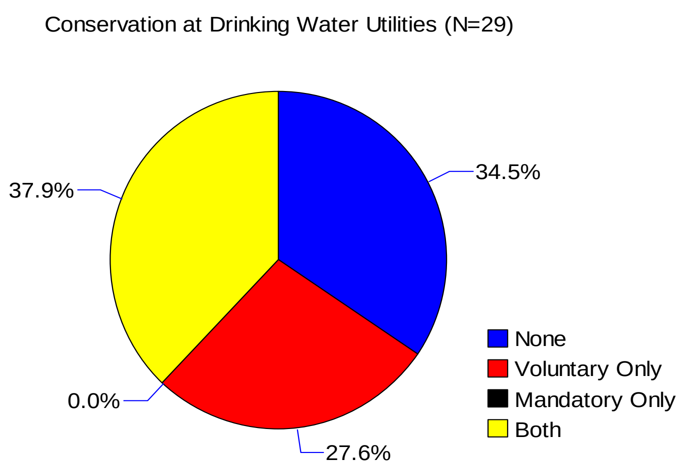


Figure 1-34. Incidence of water conservation measures at drinking water utilities.

Infiltration and Inflow

Figure 1-35 summarizes the responses on infiltration and inflow at wastewater utilities. As shown, almost 20 percent indicated low (< 5 percent) infiltration and inflow, approximately half (48 percent) of the responses indicated moderate (5 to 20 percent) infiltration and inflow, while the balance (34 percent) indicated relatively high (> 20 percent) infiltration and inflow.

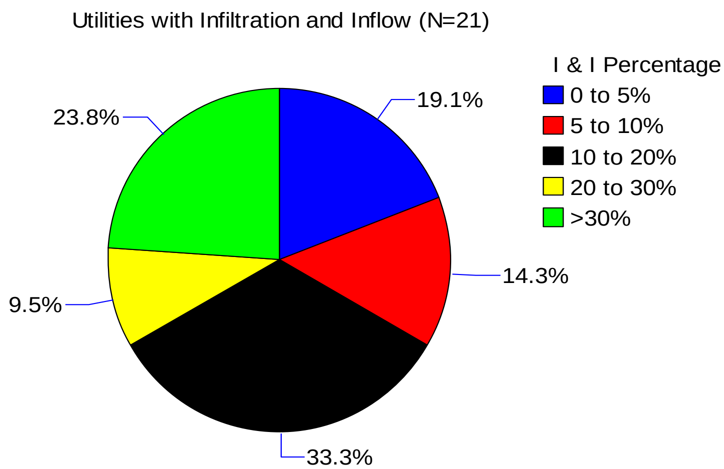


Figure 1-35. Incidence of infiltration and inflow at wastewater utilities.

3.4.2.3. Agents of change

Future issues and potential problems were addressed in two questions posed to the utilities. The first question asked utilities to rank six very broad issues that may affect their operation and possibly require infrastructure changes in the next 40 years. A ranking of "1" was given to the most important issue while a ranking of "6" was assigned to the least important. Under this scoring system, a rank of 3.5 represents a mid-point or average outcome.

As shown in Figure 1-36, responses were remarkably consistent between the drinking water and the wastewater sectors. Environmental regulations and economic constraints were consistently flagged as the two most important issues with final average rankings between 2.0 and 2.5, well above the mid-point rank of 3.5. Population growth, institutional change, climate change and lack of federal funds all ranked, on average, below the 3.5 mid-point for both the drinking water and wastewater sectors.

The second question asked utility respondents to rank the potential severity of ten specific problems that could impact operation, as indicated in the following instruction:

> "Listed below are ten specific problems which may adversely affect the operation of your (drinking water / wastewater) utility over the next 50 years. Please rank the ten problems according to the seriousness of their anticipated impact on the operation and sustainability of your water utility."

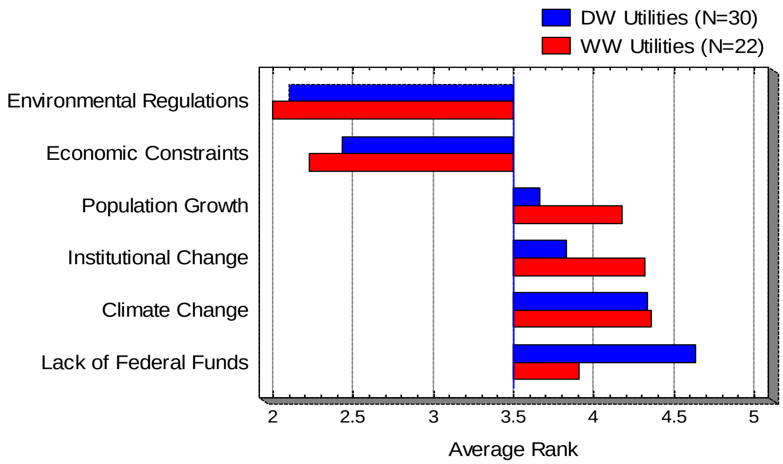
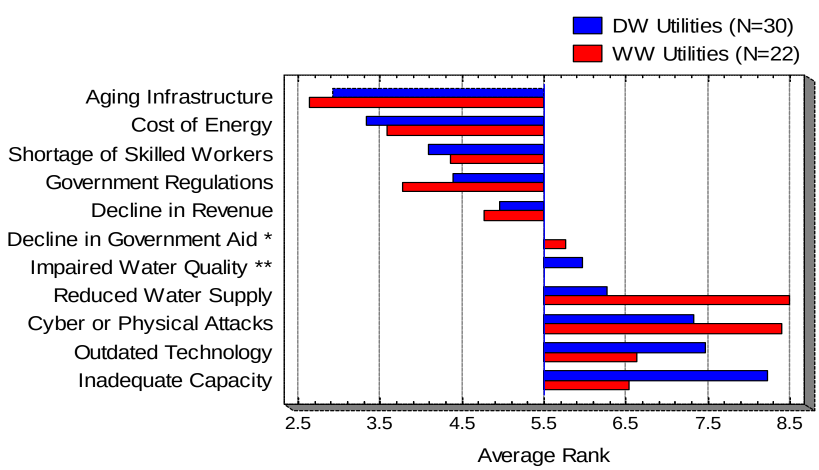


Figure 1-36. Major issues affecting water utility operation.

A rank of "1" was assigned to the most serious problem and "10" to the least serious. Under this scoring system, a rank of 5.5 represents a mid-point or average outcome. Results, summarized as an average rank in Figure 1-37, again show remarkable agreement between the drinking water and wastewater sectors. In both cases, the top five challenges were identified as: aging infrastructure, cost of energy, shortage of skilled work force, government regulations, and decline in revenue. While potential climate change impacts were recognized as an impending issue (indirectly through impaired water quality and reduced water supply), this issue was viewed as a more distant concern in comparison to the immediate operational needs of the water utility. It is worthwhile to recall that, during the period of this data gathering exercise in the summer of 2008, oil prices around the globe and gasoline prices in the U.S. had reached new historical highs. Concern over the rising cost of gasoline may be reflected in the high ranking for the cost of energy.



* Issue considered by wastewater sector only

** Issue considered by drinking water sector only

Figure 1-37. Major issues affecting sustainability of water utility operation.

3.4.2.4. Master plan and next steps

Projected Growth

Four out of five utility respondents expected demand for water service to increase over the next 20 years (see Figure 1-38). This is consistent with population projections for the United States, which forecast the number of U.S. residents to grow from 280 million to 420 million during the period 2000 to 2050 (Hobbs and Stoops, 2002). About one in five water utilities expected to maintain the status quo, while one utility in each sector anticipated a net decrease in utility size and service over the next 20 years.

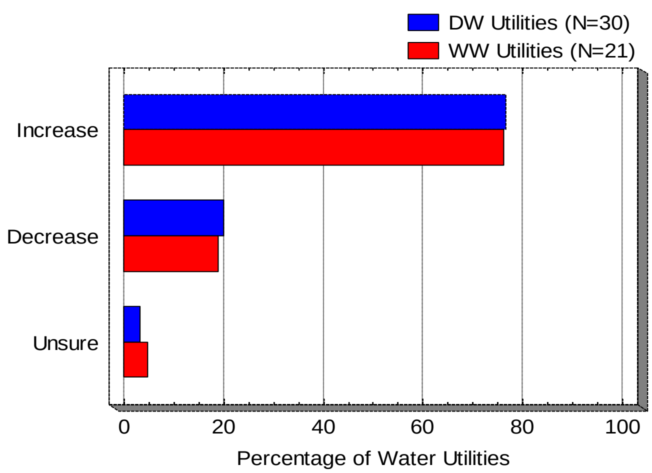


Figure 1-38. Projected utility growth over 20 years.

Master Plan

A master plan is a framework to facilitate future planning decisions. As shown in Figure 1-39, most respondents reported that they had developed a formal master plan. The response for the master plan query closely mirrors the picture of anticipated growth (e.g., by comparing Figures 1-38 and 1-39). It seems that most water utilities expect growth and most have a formal mechanism in place to help plan for it. It is interesting to note, however, that of the 20 percent in the drinking water group with no master plan, half of them (3 of 6 utilities) expect positive growth over the next 20 years.

When asked whether the master plan is available to the public, over half indicated that it is available, about 15 percent responded that a summary is available to the public, roughly 20 percent said that it is not available to the public and the balance were unsure if the master plan is available to the public. When asked about the biggest challenge in implementing the master plan, over half of the drinking water respondents identified funding as the primary challenge, and over half of wastewater respondents pointed to government regulations. Other challenges that were mentioned included growth, personnel, source water, competition with other utilities for funding, politics, aging systems, timing for infrastructure expenditures, aligning financing with prioritized work, and rate requirements. Planning horizons ranged from 5 to 40 years with a median of about 20 years (see Figure 1-40).

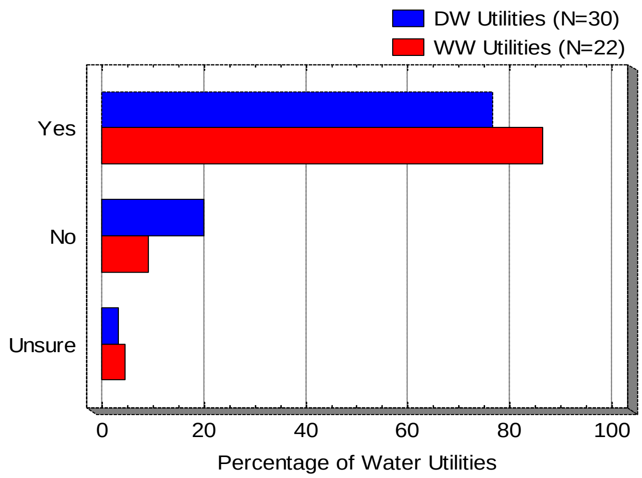


Figure 1-39. Water utilities with a master plan.

Asset Management

A significant percentage of water utilities have not implemented a formal asset management program (see Figure 1-41). When asked if their utility is using a formal asset management program in their treatment, storage, and distribution system operations, approximately 50 percent of the drinking water respondents indicated that they had such a program in place. A recent survey by the U.S. Conference of Mayors (discussed in detail in Section 3.1) found that cities employing asset management practices are "gaining the information and knowledge they seek to determine the level of user rates that can lead to system sustainability" (Anderson, 2007).

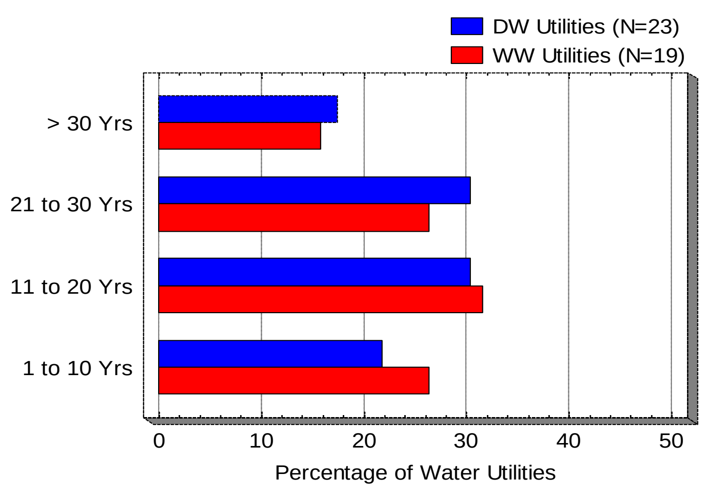


Figure 1-40. Time horizon for utility master plan (median is roughly 20 years).

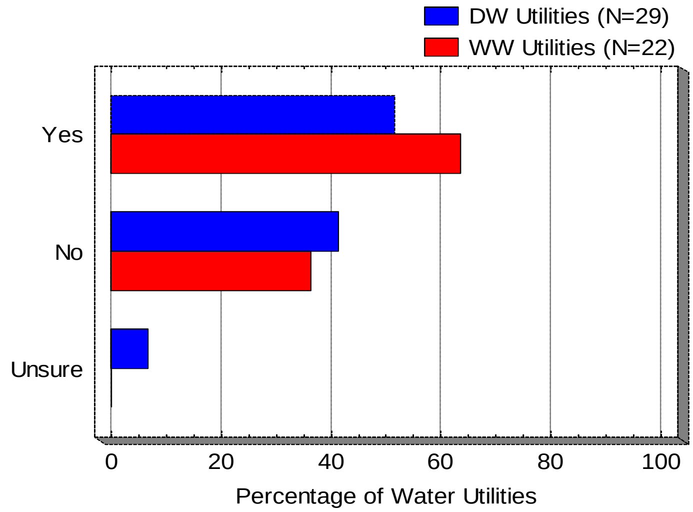


Figure 1-41. Water utilities with asset management program.

3.5. AWWA State of the Water Industry

3.5.1. Methods

The American Water Works Association (AWWA) has conducted the State of the Water Industry (SOTWI) annual survey since 2004 to identify and track issues in the water industry. For its most recent report, issued in 2014, AWWA collected data from a random list of AWWA members and contacts (AWWA, 2014). AWWA contacted 91,180 members and nonmembers located in the U.S. and internationally via e-mail. A total of 1,739 respondents participated in the survey on a voluntary basis. Survey respondents represent a variety of careers, and the majority of respondents reported working in a drinking water or combined water/wastewater utility, or working as a consultant, as illustrated in Figure 1-42.

The survey asked respondents to rate 30 issues affecting the water industry on a scale of 1 (unimportant) to 5 (critically important). These issues encompass a range of topics including the state of water and sewer infrastructure, workforce composition, availability of financial resources, security, climate change, and many more. The survey also included questions to identify the prominence of climate change issues facing the water industry and the degree to which the water industry is prepared to address these issues. The following questions directly addressed climate change vulnerability:

- Overall, how prepared do you think the water sector is to address any impacts associated with potential climate variability? (This question was asked of all respondents.)
- Does your utility include potential impacts from climate variability in your risk management or planning processes? (This question was asked of utility personnel.)

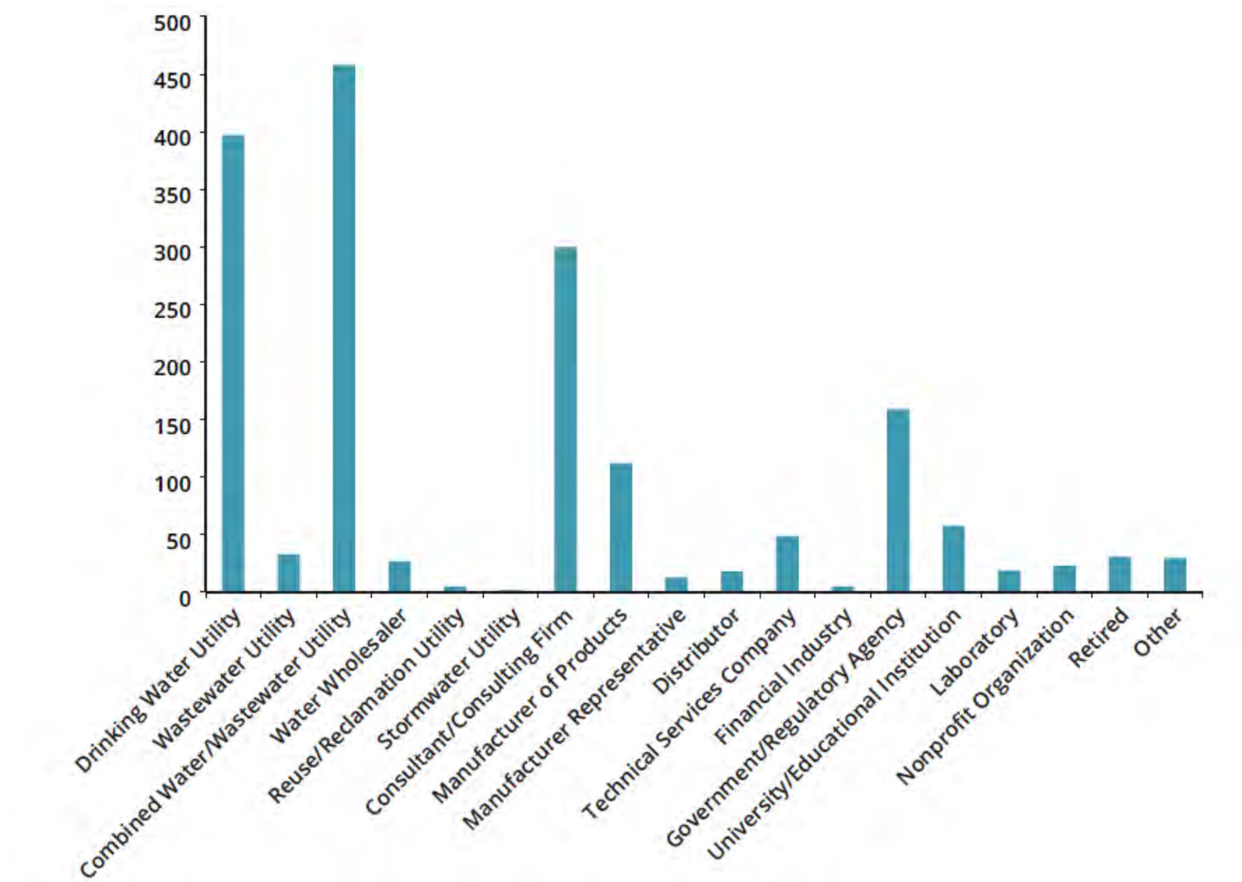


Figure 1-42. Number of respondents for the 2014 SOTWI survey by career category (AWWA, 2014).

3.5.2. Findings

Results indicate that the state of water and sewer infrastructure is the largest issue facing the water industry. Long-term water supply and financing are also ranked in the top five issues by survey respondents. The complete results are presented in Table 1-21, which ranks the issues according to the average score they received by survey respondents (on a scale of 1 to 5). The table also presents the percentage of respondents that ranked the issue as "critically important" (score of 5), and the number of respondents that scored each issue. Besides infrastructure, water supply, and financing, other issues that ranked highly in this survey include public understanding of the value of water resources and water systems and services, groundwater management and overuse, watershed protection, and drought. Climate risk and vulnerability ranked only as number 24 in this list of issues. It is important to note that the survey treated the "state of water and sewer infrastructure" as a separate issue than "climate risk and resiliency," but this report illustrates that these issues are closely related. Furthermore, it is unclear to what extent respondents consider infrastructure impacts of climate change under the "state of water and sewer infrastructure" category.

Table 1-21. Issues Ranked by all 2014 SOTWI Respondents*

Rank	Issue Facing Water Industry	Average Score	Critically Important	Number of Respondents
1	State of water and sewer infrastructure	4.57	63%	1,665
2	Long-term water supply availability	4.51	64%	1,646
3	Financing for capital improvements	4.41	53%	1,660
4	Public understanding of the value of water	4.31	48%	1,661
5	Public understanding of the value of water	4.27	44%	1,650
6	Groundwater management and overuse	4.19	41%	1,641
7	Watershed protection	4.18	40%	1,643
8	Drought or periodic water shortages	4.10	38%	1,642
9	Emergency preparedness	4.05	33%	1,642
10	Cost recovery	3.96	28%	1,659
11	Acceptance of rate increases	3.94	30%	1,658
12	Talent attraction and retention	3.93	29%	1,614
13	Compliance with current regulations	3.90	27%	1,622
14	Compliance with future regulations	3.87	25%	1,623
15	Water conservation/efficiency	3.87	26%	1,607
16	Water loss control	3.86	22%	1,609
17	Aging workforce/anticipated retirements	3.82	29%	1,607
18	Certification and training	3.81	24%	1,614
19	Energy use and costs	3.77	18%	1,611
20	Expanding water reuse/reclamation	3.74	24%	1,625
21	Improving customer, constituent, and	3.67	16%	1,657
22	Cyber-security issues	3.64	23%	1,620
23	Wastewater resource recovery	3.60	16%	1,625
24	Climate risk and resiliency	3.54	18%	1,643
25	Physical security issues	3.52	17%	1,624
26	Stormwater management and costs	3.44	10%	1,625
27	Affordability for low-income households	3.44	15%	1,658
28	Fracking/oil and gas activities	3.40	22%	1,642
29	Price and supply of chemicals	3.38	7%	1,614
30	Workforce diversity	2.96	8%	1,612

Note: * - From AWWA, 2014.

A comparison of the SOTWI survey results with those of the AWWA's 2013 and 2014 surveys demonstrates a shift in the relative prominence of issues facing the water industry. While the state of water and sewer infrastructure remains a top concern for survey respondents, water supply availability has gained importance (as number 2 in 2014 versus number 4 in 2013). Issues related to costs remain in the top 10 issues in 2014. Notably financing of capital costs is the #3 issue in both years (named "capital costs and availability" in 2013 versus "financing for capital improvements" in 2014), and cost recovery as the number 10 (previously number 8 in 2013). The relative importance of climate risk and resiliency dropped from number 12 in 2013 to number 24 in 2014. A full comparison of the top 15 issues in the 2013 and 2014 surveys is shown in Table 1-22.

Table 1-22. Top 15 Issues from the 2014 and 2013 SOTWI Surveys*

2014			**2013**		
Rank	Issue	Avg. Score	Rank	Issue	Avg. Score
1	State of water and sewer infrastructure	4.6	1	State of water and sewer infrastructure	4.6
2	Long-term water supply availability	4.5	2	Lack of public understanding of the value of water	4.3
3	Financing for capital improvements	4.4	3	Capital costs and availability	4.3
4	Public understanding of the value of water resources	4.3	4	Water supply and scarcity	4.1
5	Public understanding of the value of water systems and services	4.3	5	Aging workforce/ talent attraction and retention	3.9
6	Groundwater management and overuse	4.2	6	Drought	3.9
7	Watershed protection	4.2	7	Customer, constituent, and community relationships	3.9
8	Drought or periodic water shortages	4.1	8	Cost recovery	3.9
9	Emergency preparedness	4.1	9	Regulation and government oversight	3.8
10	Cost recovery	4.0	10	Emergency preparedness	3.8
11	Acceptance of rate increases	3.9	11	Energy demand/use/costs	3.7
12	Talent attraction and retention	3.9	12	Climate risk and resiliency	3.6
13	Compliance with current regulations	3.9	13	Security	3.5
14	Compliance with future regulations	3.9	14	Declining water demands	3.0
15	Water conservation / efficiency	3.9	15	Privatization and out-sourcing	3.0

Note: * - From AWWA (2014).

The survey addressed the topic of climate change resiliency in more detail through two questions. All respondents were asked how well prepared they believe the water industry is to address impacts from climate variability. The results in Figure 1-43 show that 40 percent of respondents indicated that they believe the water industry is moderately prepared to address the impacts of climate variability, while 50 percent believe that the industry is not at all prepared or only slightly prepared. Only two percent of respondents believed that the industry was fully prepared to address these impacts.

The survey also asked utility personnel whether their utilities have included potential impacts from climate variability in their risk management or planning processes. Figure 1-44 shows the survey results, which indicate that only 29 percent of respondents were aware of an active risk management or planning process designed to address impacts of climate variability at their utility. In contrast, 50 percent of respondents indicated that their utilities had not addressed the impacts of climate variability in these planning processes.

Overall, AWWA's SOTWI report (AWWA, 2014) indicates that vulnerability to climate change is a concern in the water industry but that it is not as prominent as other issues troubling this sector, such as the state of water and wastewater infrastructure and availability of financing for capital improvements. Yet, as discussed earlier in this section, these issues are intrinsically connected to climate risk and vulnerability. Some utilities are beginning to address potential impacts of climate variability in their planning processes, and half of the survey respondents believe that the industry is prepared moderately to fully to address the impacts of climate variability.

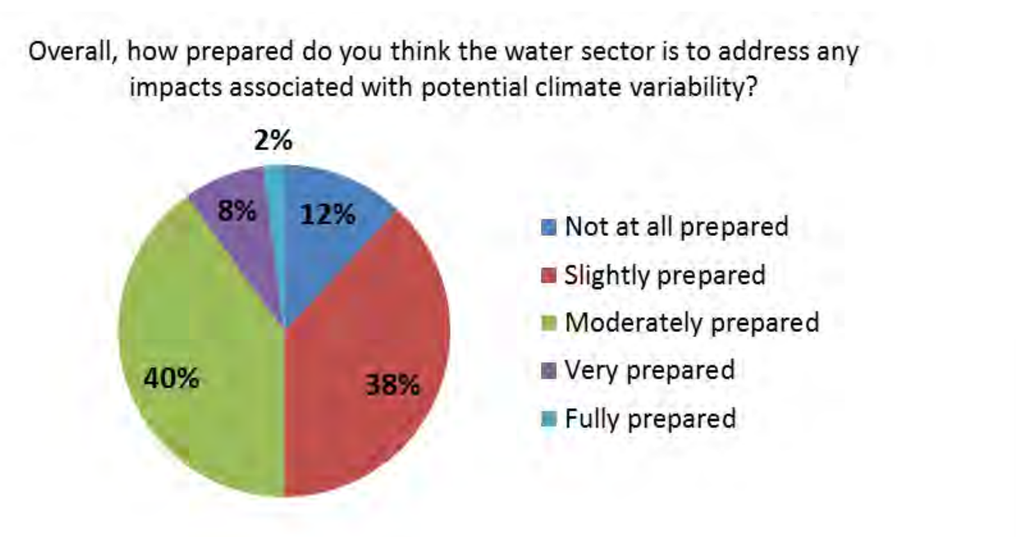


Figure 1-43. Responses from all SOWTI survey participants on readiness for potential climate change impacts (n=1,459) (AWWA, 2014).

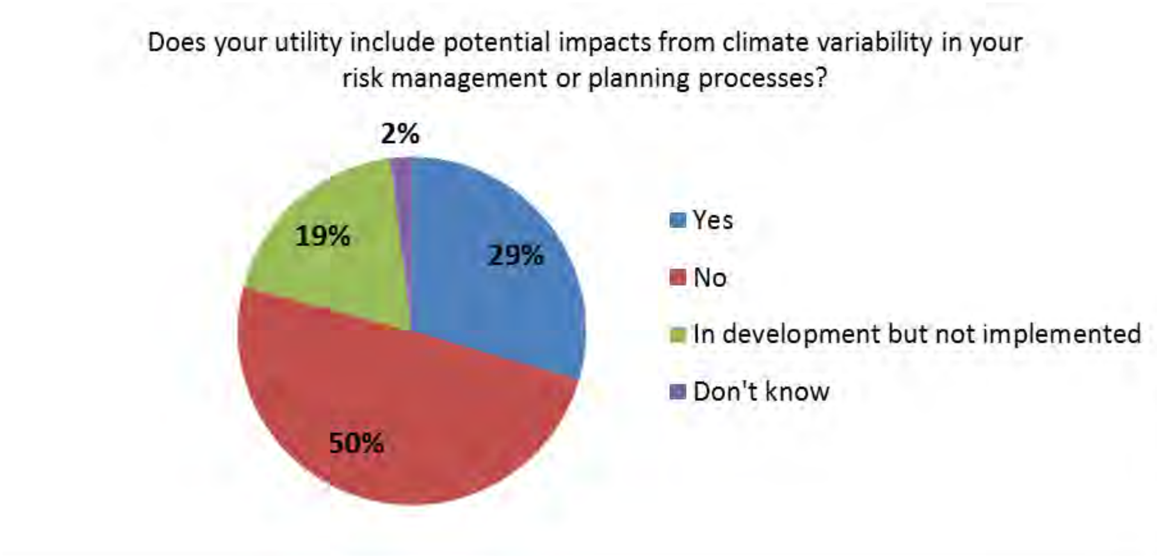


Figure 1-44. Responses from utility employees on their utility's action to include climate variability in its management or planning processes (n=791) (AWWA, 2014).

3.6. Water Research Foundation Forecasting the Future

3.6.1. Methods

A 2012 report from the WRF identifies top trends that will affect the water industry over the next 10 to 20 years (Brueck et al., 2012). The researchers implemented a survey to identify trends in four broad categories:

- Environmental
- Technical
- Economic/Business
- Social/Political

Each of these four broad categories included key topic areas detailing a total of 40 future trends. The report summarizes the results of a survey through which 17 utilities in North America and abroad (the majority were North American) ranked the trends to identify their top five trend areas for the water sector. The respondents ranged in size from mid-sized regional service providers to large metropolitan area utilities. Respondents ranked each issue according to its importance for the water sector and for the individual utility. This approach enabled the researchers to identify trends that concern individual utilities that may not be a concern in the water industry as a whole.

Following the survey, the researchers refined the ranking of trends through a scenario modeling activity during a Futures workshop in Montreal, Canada. The researchers used the results from the survey and the workshop to identify the top 10 trends for the water sector.

3.6.2. Findings

The results of the initial survey of 17 participating utilities are presented in Figure 1-45, which shows the nine top-rated trends for the industry as a whole as well as for individual participating utilities. These nine trends scored a value of 20 or higher on both the water sector scale and individual utility scale. Similar to other surveys discussed above, this survey found that aging water and wastewater infrastructure ranked at the top of the list. Water availability, financial/economic concerns, regulatory changes calling for higher water quality, and an aging workforce also ranked high on this list of future trends. Five of these trends originate from the Economic/Business category, while two trends come from each of the Environmental and Societal/Political categories. No trends from the Technological category ranked among the top nine trends.

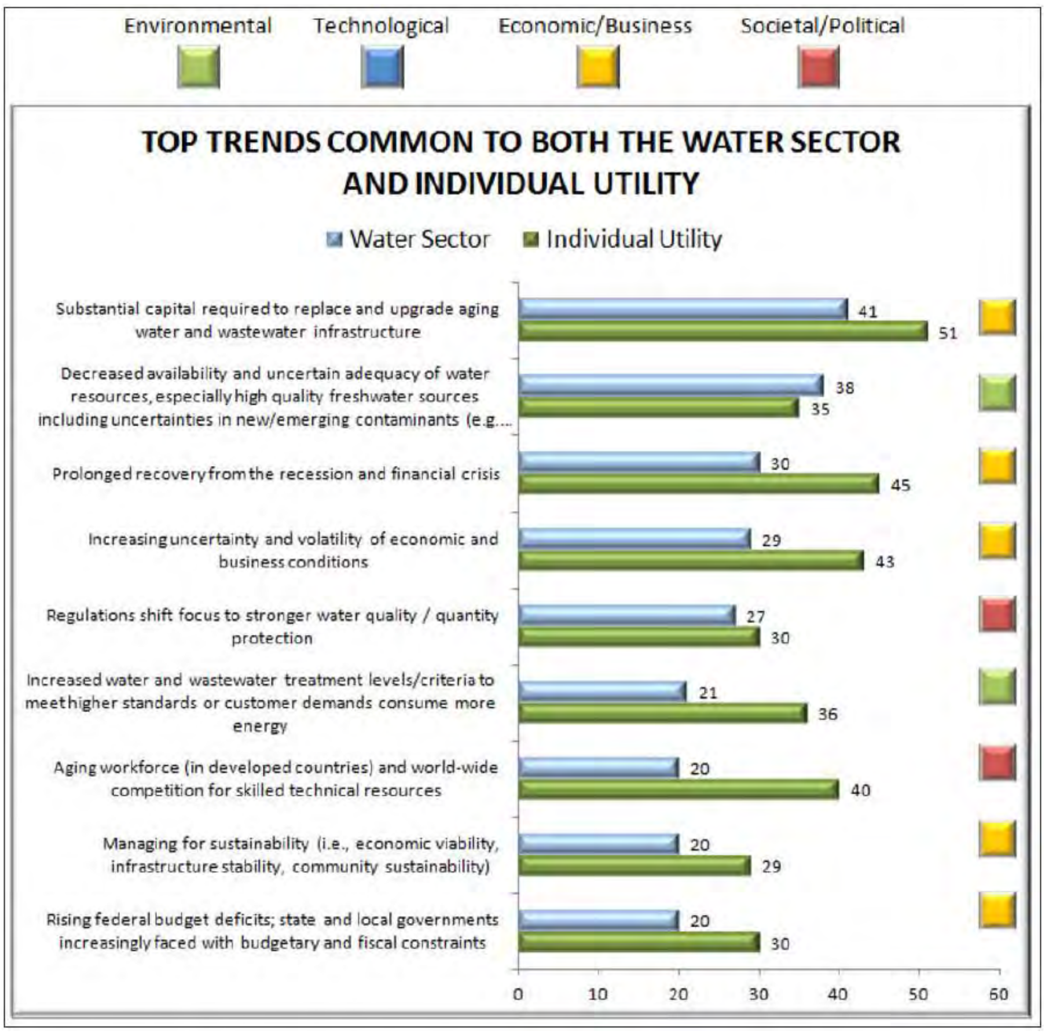


Figure 1-45. Top rated trends common to both the water sector and individual utility (Brueck et al., 2012).

In addition to these nine top trends, six trends received scores with values of 20 or greater for the water industry but not for individual utilities. These additional trends are provided in Figure 1-46.

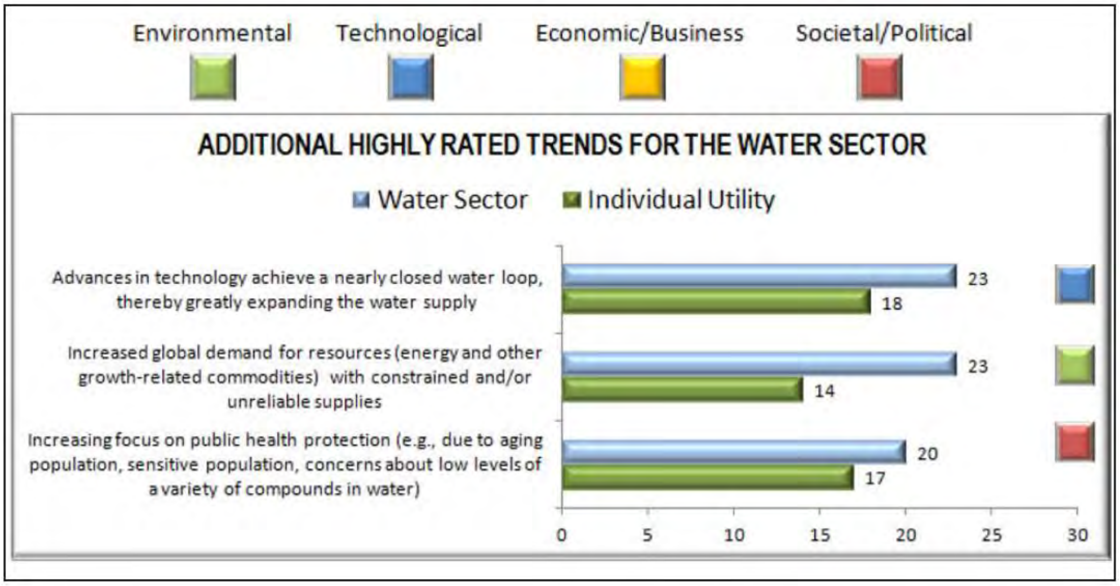


Figure 1-46. Additional highly rated trends for the water sector (Brueck et al., 2012).

Following completion of the survey, participants at a two-day workshop held in Montreal, Canada, discussed and refined the top trends identified in the survey. Using a scenario-based analysis, the workshop participants consolidated overlapping key trends and added new trends. The analysis resulted in the following 10 key trends, which were also validated by WRF subscribers via a web conference:

1. Uncertain economy, financial instability
2. Decreased availability/adequacy of water resources
3. Aging water infrastructure/capital needs
4. Shifting water demands (per capita reduction)
5. Changing workforce, dynamic talent life-cycle
6. Expanding technology application
7. Mass/social media explosion
8. Increasing/expanding regulations
9. Efficiency drivers, resource optimization
10. Climate uncertainty

This revised list identifies the consolidated economic concerns as the top trend, followed by decreasing water availability and aging infrastructure. While vulnerability to climate change did not rank in the original top nine trends, the workshop added climate uncertainty as a key trend. Once again, the issue addressing climate change (in this case "uncertainty"), was included as a trend separate from those addressing issues closely linked with climate vulnerability, such as aging water infrastructure and availability of water resources. The results of this survey and analysis recognize climate uncertainty as one of the top 10 trends, but they do not recognize the link between climate uncertainty and other areas of concern.

3.7. Water Research Foundation Effective Climate Change Communication

A forthcoming report on the results of a WRF survey provides insight on how Americans view climate change, its impacts on drinking water services, and their water utility's role in preparing for climate change. The primary findings of this report are summarized in WRF's publication (Raucher and Raucher, 2014). The researchers conducted a national survey targeting the population of Americans 18 years and older who receive their water from a community water system. The survey respondents consisted of a sample of households that would be representative of the U.S. population. A total of 1,201 participants completed the online survey, based on which the views of Americans were assessed.

Results of the survey indicate that most respondents trust their water utilities as a source of information about climate change (71 percent). Overall, the survey found that respondents overwhelmingly expressed concern that extreme weather events will negatively impact their utility's ability to provide safe drinking water (72 percent). They also expect their water utility to play a role in preparing for extreme weather and climate change. The vast majority of Americans believe that their water utility should account for climate change in future plans (75 percent), and nearly 75 percent of respondents are willing to pay additional monthly fees to ensure that they continue to have a safe, reliable source of drinking water. These results stress that water utility customers rely on their water providers to take a lead role in preparing for the impacts of climate change.

4. Assessment Summary on Adaptation Readiness

The investigation documented in Part I report clearly indicates that the U.S. drinking water and wastewater infrastructure is under stress from a combination of factors including aging water infrastructure, financial resources, population growth, and the newly recognized impacts from climate change. These factors form a "perfect storm" impacting long-term sustainability as well as service functions. The distribution of water, the availability of water resources, and changes in water quality affect how water utilities can and must adapt to create and maintain infrastructure to meet the needs of society. Simultaneously, water utilities must consider traditional and emerging stresses such as increasing pressure from population growth, concentration of populations in urban areas, economic changes, and more stringent regulatory requirements.

Climate change has been an active area of research, debate and concern for well over a quarter of a century. While there is still uncertainty in modeling and analysis of climate change impacts, especially at the local watershed scale, a large body of literature (e.g., IPCC, 2013;

USGCRP, 2014) indicates that changes in precipitation, water quality, and frequency and severity of extreme weather events are will continue to affect water infrastructure. The remainder of this report provides a synthesis of current knowledge and further investigates the degree and nature of climate change in precipitation and its hydrological impacts on watershed hydrology (both in water quantity and water quality). The results show climate change having far-reaching impacts on all aspects of water resources and hence the water infrastructure functions. These effects can affect the U.S. water, air and energy regulatory programs as described in Section 2.4 and detailed in Appendix I-A.

Several nation-wide assessments, including one conducted for this report, show a suite of priority factors water utility managers are facing today. In a holistic view, the climate change interacts with other issues, concerns, and priorities in the water sector, as discussed earlier in this report. These other issues, concerns, and priorities can be distilled down into the following 10 major issues:

- Aging infrastructure. The U.S. EPA's 2011 Drinking Water Infrastructure Needs Survey and Assessment found that the nation's community water systems will need to invest $384.2 billion in the 20-year period of January 1, 2011, through December 31, 2030 in order to continue to provide safe drinking water to their consumers at current population levels (U.S. EPA, 2013a). Based on the Clean Watershed Needs Survey (CWNS) 2008 Report to Congress (U.S. EPA, 2008a) the estimated total POTW construction needs for the nation for the next 20 years is $298.1 billion. The American Society of Civil Engineers (ASCE) has consistently warned that the nation is lagging in its replacement and rehabilitation of water and wastewater infrastructure. Insufficient investments in our infrastructure would result in increasing costs, violations, health concerns, and an inability to meet future demands and growth.
- Population growth and demographic shifts. The U.S. Census Bureau projects an increase in the population of the U.S. from 314 million in 2012 to 420 million in 2060 (U.S. Census Bureau, 2012) and a large spatial variation in population change across the country, with the largest increases generally occurring in areas (e.g., the Southwest) where water use is already the most stressed.
- Public health: Waterborne infectious disease is still a significant concern in the U.S. The state of the water, wastewater, and stormwater infrastructure has a direct bearing on the risk of waterborne disease.
- Economic development. Economic development may result in increased (and more spatially concentrated) water usage, increased wastewater production, increased stormwater runoff and non-point source pollution. Technological innovation and development are essential ingredients to ensure that future growth occurs in a sustainable manner.
- Energy use and production. Global energy demand is increasing, and the production and use of energy are recognized as a major political, economic and environmental factors in shaping our world. There is a strong linkage between the water and energy sectors since water is required to produce and use energy, and energy is used to clean, transport and use water. Most water supply and wastewater systems are dependent upon pumping and

most water and wastewater treatment plant components need sources of energy to perform their functions.

- Regulatory developments: As emerging threats to water quality have appeared over time and the science of drinking water protection has advanced, the regulatory landscape has become more complex. Drinking water utilities must increasingly balance risk-risk tradeoffs: for example, providing adequate protection against waterborne disease outbreaks while minimizing the dangers posed by DBPs. Aspects of the federal regulatory framework for ambient waters and drinking water, and the statutes that authorize them, can be used to help utilities prepare for future variability in water supply and quality and disruptive climate events.
- Groundwater depletion and contamination: Groundwater is an important but limited resource that is susceptible to overuse and contamination. It is part of a hydrologic cycle that interacts with lakes, rivers, creeks, springs, wetlands and oceans. Groundwater quality can be affected by natural processes (e.g., saltwater intrusion, a process that occurs in coastal aquifers due to hydraulic connectivity between the aquifer and the seawater) and anthropogenic (human) activities (e.g., resource extraction, carbon sequestration).
- Non-point-source contamination: Non-point sources of pollution remain a significant threat to the quality of surface water and groundwater. A significant portion of non-point-source pollution is agriculture, with its use of fertilizer, pesticides, and salt-containing irrigation water. These can contaminate drainage water as it moves from the root zone to the underlying groundwater. The problem can be expected to get worse in the future as agriculture must intensify to keep up with the demands for food, fiber, and energy crops. In urban areas, wastewater outfalls and storm water runoff are important non-point sources.
- Security: Water utilities have historically been concerned with security issues such as accidental pollution spills into their raw water sources, and vandalism or other criminal activities resulting in damage to equipment. The twenty-first century has brought an increasing concern over intentional acts directed at water and wastewater utilities.

Worth to note, various assessments described in the preceding sections are difficult to compare directly because of the differences in the timing of the assessments, the range of issues ranked by respondents, and the scope of each study. Three key issues, however, are consistently ranked as top concerns on the assessments: 1) Aging infrastructure; 2) Economic stresses, uncertainty, or instability; and 3) Water supply availability. Climate change, while identified as a concern in several surveys, was not among the highest-ranked issues in any of the survey results. A part of the reason is that in formulation of the questions, none of the assessments framed climate change as being related to the resiliency of water infrastructure. Rather these assessments categorized climate change, climate resiliency, and/or climate risk as independent factors separately from other key concerns, when they all could and should be addressed together.

When the results are further analyzed, climate change is attributed to many top concerns that utilities have on infrastructure sustainability. Key priorities identified in these surveys, including water infrastructure, water availability/drought, affordability, groundwater management and overuse, storm water management, water quality, and emergency preparedness for storms/hurricanes, are all related to the concept of infrastructure sustainability in the face of climate change. Another important factor is the actionable science and the explicit nature of long-term climate change effects. Unless these climate-related impacts are quantified, it is difficult for water utilities to rate climate change as a top priority when other priorities wait for actions and investment. The actionable science question was raised high in the EPA's first national workshop on water infrastructure adaptation to climate changes held in 2009 in Crystal City, Virginia (EPA, 2009d).

It is also important to point out that for practical planning and engineering, the challenges associated with the top ten priority issues cannot be addressed individually or independently from climate. Rather, the intersection of the various trends, risks and stressors, together as a whole present the greatest challenges to maintaining a modern and fully functional water resources infrastructure. Integrating the impacts of climate change into the master plans for water infrastructure construction, repair, and maintenance offers an opportunity to address many of the concerns identified in this report, such as water availability, water quality, cost control, and resilience in the face of extreme weather events, and ultimately to achieve the desired water infrastructure sustainability.

These factors are at the center of national infrastructure adaptation research. The climate change impacts and many of the issues identified in the Part One report can be addressed systematically by adaptive planning for effective climate change adaptation. Tools and procedures for adaptation are discussed and case studies are described in the remainder of this report in Parts II, III, and IV.

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Appendix 1-A

Water and Air Laws and Regulations Relevant to Climate Change Adaptation for Water

1. Safe Drinking Water Act and Regulations

1.1. Total coliform rule and the revised total coliform rule

The Total Coliform Rule (54 FR 27544; U.S. EPA, 1989a) set an MCLG and MCL for total coliforms, which serve as an indicator of potential bacterial contamination, and established a monitoring regimen. This rule is currently still in effect. However, under the SDWA requirement for EPA to review and revise, if appropriate, existing regulations every 6 years, the agency published its decision in July 2003 to revise the TCR. The Revised Total Coliform Rule, or RTCR (78 FR 10269, U.S. EPA, 2013e), takes effect in April 2016. The rule will replace the MCLG and MCL for total coliforms with new standards for *E. coli*, which is a more specific indicator of fecal contamination and potentially harmful pathogens. The revisions create a treatment technique requirement for coliforms. When a water system exceeds a specified frequency of total coliform occurrence or exceeds the *E. coli* MCL, it must conduct an assessment to check for sanitary defects and take corrective action to address any problems that are identified. (A sanitary defect is defined by the RTCR as a ‘‘defect that could provide a pathway of entry for microbial contamination into the distribution system or that is indicative of a failure or imminent failure of a barrier that is already in place.”). The rule establishes monitoring frequency based on compliance monitoring results and system performance. These criteria in turn reward well-operated water systems with reduced monitoring regimens, and increase monitoring for high-risk water systems and seasonal systems. As discussed in Section 2.1.1 of the main text, higher risks of bacterial contamination of drinking water may occur under conditions of climate change due to higher water temperatures and increased frequency of sewer and treatment plant overflows.

1.2. Disinfectant / disinfection by-products rules

In the U.S., chlorine and chloramines are most often used for treatment because they are very effective disinfectants, and residual concentrations can be measured and maintained in the water distribution system. Some utilities (primarily in the U.S. and Europe) use ozone and chlorine dioxide as oxidizing agents for primary disinfection prior to the addition of chlorine or chloramines for residual disinfection. While disinfectants are effective in controlling many microorganisms, they can react with naturally occurring organic matter (NOM) and inorganic matter in the treated and/or distributed water to form potentially harmful disinfection by-products (DBPs). To minimize the formation of DBPs, EPA has promulgated regulations that specify maximum residual disinfectant levels (MRDLs) for chlorine, chloramines, and chlorine dioxide. The Disinfectant/Disinfection By-Products Rules (DBPRs) updated the MCL for total trihalomethanes (TTHMs) and established MCLs for five haloacetic acids (HAA5). In order to meet these requirements, utilities may need to modify their disinfection process or remove disinfection by-product (DBP) precursor materials from water prior to disinfection by applying appropriate treatment techniques (Panguluri et al., 2006).

As shown in the Part II, III and IV reports, climate change can induce significant changes in NOM and total organic carbon (TOC) in source water. The case studies and modeling analyses conclusively point to the risk of DBP regulation violations. For adaptation, a framework for monitoring-modeling and engineering adaptation analysis has been established and presented in this report.

Section 2.1.2 of the main text discussed the potential effects of sea level rise due to climate change. Salt water intrusion in groundwater supplies and more extensive tidal impacts on river supplies can result in higher concentrations of salts, such as bromide and iodide, in source waters. Disinfection of such water can result in higher concentrations of disinfection byproducts, including brominated and iodinated byproducts with harmful health effects.

Higher water temperatures under future climate scenarios could result in different NOM reactivity to disinfectants and thus different DBP-formation potential. Under such circumstances, current standards and treatment may not adequately address future risks to public health from DBPs. This possibility is not assessed in this report, but is indicated in published studies (e.g., Towler et al., 2011; Whitehead et al., 2009).

1.3. Surface water treatment rules

The Surface Water Treatment Rule (SWTR) (54 FR 27486; U.S. EPA, 1989b) established standards for protection against waterborne pathogens, specifically including *Giardia lamblia*, viruses, and *Legionella*. This major regulation was designed to protect customers of the approximately 14,500 public water systems that use surface water, or groundwater under the direct influence of surface water, from microbial contaminants. The SWTR specifies criteria for meeting these standards, and criteria for avoiding filtration. Specifically, the SWTR requires all impacted systems to disinfect their water (as described below). It also requires all such systems to filter their water, unless (1) the system has an effective watershed control program; (2) it complies with the TCR and MCL for TTHM; (3) it uses a good quality source water, meeting standards for coliforms and turbidity (opaqueness); and (4) it meets stringent disinfection conditions.

The SWTR and associated EPA guidance establish pertinent CT values for disinfection inactivation ("C" stands for disinfectant concentration in milligrams/liter; "T" for time of disinfectant contact with the water in minutes) that will enable a system to meet pathogen reduction standards. CT values are provided for *Giardia* and enteric viruses by disinfectant type (e.g., chlorine, chloramines, ozone, or chlorine dioxide), water pH, and water temperature. The regulation also requires a system using surface water to maintain a minimum detectable disinfectant residual at the entrance to the distribution system and a detectable disinfectant residual for at least 95 percent of the sample sites throughout the distribution system. The rule specifies the monitoring frequency and locations for determining these disinfection residuals and (for unfiltered systems) testing source water quality.

The SWTR has been strengthened by three subsequent rules, the Interim Enhanced SWTR (63 FR 69478, U.S. EPA, 1989b), Long-Term 1 Enhanced SWTR (67 FR 1812; U.S. EPA, 2002b), and Long-Term 2 Enhanced SWTR (LT2ESWTR) (71 FR 6135; U.S. EPA, 2006a). These three rules collectively increase the stringency of turbidity standards, require systems to monitor the turbidity levels leaving each individual filter, require periodic on-site reviews of water sources, facilities, equipment, operation, and maintenance (sanitary surveys) by the state, and require the system either to cover all finished drinking water storage facilities (e.g., reservoirs) or treat the water in those facilities, as well as adding other new requirements. The primary purpose of these new requirements is to control *Cryptosporidium*. Another purpose is to ensure that utilities do not compromise pathogen control while complying with DBPR requirements. Under these three rules, a system must provide sufficient water treatment to reduce *Cryptosporidium* by at least 99 percent (or 2-log reduction). However, because of a concern that systems drawing water from a poor quality source might be exposing the public to a greater pathogen risk than is reasonable even under conditions of 2-log reduction, the LT2ESWTR specifies an average density of *Cryptosporidium* oocysts that triggers requirements to provide additional *Cryptosporidium* treatment. The required level of additional treatment depends upon the average *Cryptosporidium* density.

As noted in Section 2.1.1 of the main text, climate change can induce changes in surface water quality including total organic carbon (TOC), NOM, turbidity, micronutrients (e.g., nitrogen and phosphorus), and potentially also biological contaminants such as microcystin. Such changes may make it more challenging for systems to meet the requirements of the rules described above. Flooding or drought also may affect water supply. For instance, flooding may increase sediment loading into reservoirs which may increase turbidity levels and could significantly reduce the useful life of a storage reservoir or may require sediment removal. During a drought, pollutants accumulate on land surface and on other surfaces, such as pavement and structures. These pollutants may be rapidly flushed as large loads of pollutants into surface water bodies during high precipitation events that may follow the drought conditions (Walker et al., 1991). Higher intensity precipitation events may overwhelm storage capacity, and, if there are fewer precipitation events, the result may be reduced water supply. Reduction in snowpack or drought also reduces water supply levels. These outcomes could trigger additional challenges, such as lower reservoir levels.

1.4. Lead and Copper rules

Lead and copper contamination is introduced primarily through corrosion of plumbing materials, including water system pipes, indoor plumbing, and faucets. Less commonly, it can be found in source water. Given the potential introduction of contamination within the residence, monitoring for these contaminants occurs at the customer’s tap. If lead or copper levels exceed specific thresholds, action must be taken to eliminate factors contributing to corrosion. The source water will be tested to confirm the presence of lead and copper. The water system must monitor for water quality parameters that affect corrosion rates, such as temperature, pH, conductivity, and chemicals used during treatment. Remediation ranges from replacement of plumbing fixtures to adding treatment, and, if these measures are unsuccessful, removal of the lead service lines owned by the water system.

Climate change may affect compliance with the LCR in two ways. One is the effect of temperature on pipe corrosion. The relationship is not entirely straightforward. Higher temperatures increase the rate of the corrosion reaction, but the effect may be mitigated or inhibited by other factors, which include biological activity, physical properties of the solution, thermodynamic and physical properties of corrosion scale, chemical rates, and temperature variability (McNeill and Edwards, 2002). Certain conditions related to pH, alkalinity, and dissolved inorganic carbonate levels in the water can cause lead to dissolve from pipe material (U.S. EPA, 2014d). If the water temperature in the pipes increases, corrosion may increase lead and/or copper levels. Secondly, treatment undertaken to mitigate climate change effects may indirectly affect the lead and copper action levels. Treatment to address one public health risk may have unintended consequences on the chemical or biological composition of the water and contribute to other risks. Treatment installed to meet the DBPRs, for example, may affect compliance with the LCR: e.g., the use of chloramine as a residual disinfectant can affect the chemical properties of the water, which subsequently can increase lead and copper corrosion. Likewise, changes in water treatment can increase concentrations of inorganic contaminants, which can increase corrosivity, potentially causing higher levels of lead in the drinking water.

1.5. Ground water rule

The Ground Water Rule (GWR) (71 FR 65574; U.S. EPA, 2006b) was promulgated to provide increased protection from microbial pathogens. It applies to all public water systems that use groundwater not under the direct influence of surface water, or approximately 1,500 systems (U.S. EPA, 2013b). (Systems that use groundwater under the direct influence of surface water must instead comply with the SWTR.)

Under the GWR, states use a risk-based methodology to determine which groundwater systems are vulnerable to fecal contamination and which may contain viruses or bacteria that are harmful to humans. This determination may be made by a variety of means, including direct monitoring of the source water (usually the well), periodic on-site sanitary surveys by a trained inspector to identify significant deficiencies in key operational areas, and an examination of the site's hydrology. Vulnerable water systems must take corrective action such as providing an alternate water source, eliminating the contamination source, correcting all significant deficiencies found during a sanitary survey, and/or providing treatment that reliably achieves at least a 4-log (99.99 percent) virus removal or inactivation of viruses. Systems providing "4-log treatment" must conduct regular compliance monitoring to ensure that the treatment technology meets the standard. For water systems without this treatment, if a distribution system sample collected under the TCR is total-coliform positive, the water system must conduct source water monitoring within 24 hours, unless the state can determine that the positive sample was due to a deficiency in the distribution system and not the source. Additional monitoring is required if the source water samples indicate the presence of fecal contamination. A state also may require the water system to take immediate corrective action. Under the rule, a system may use *E. coli*, enterococci, or coliphage for source water monitoring; the rule approves specific analytical methods for each of the three. The rule specifies when, where, and how often a system must monitor; the frequency of required on-site sanitary surveys; minimum disinfectant requirements; and other provisions.

1.6. Chemical phase rules

EPA established MCLs and MCLGs for removal of 65 chemical contaminants under what are known as the Chemical Phase Rules. These regulations apply to three contaminant groups: Inorganic Chemicals (IOCs), Synthetic Organic Chemicals (SOCs), and Volatile Organic Chemicals (VOCs). The Chemical Phase Rules provide public health protection through the reduction of chronic risks from cancer, organ damage; and circulatory, nervous, and reproductive system disorders. They also help to reduce the occurrence of methemoglobinemia or "blue baby syndrome" from ingestion of elevated levels of nitrate or nitrite (U.S. EPA, 2012d).

Changes in temperature and precipitation could lead to increased concentrations of contaminants covered by these Rules: for instance, as noted in Section 2.3, there may be circumstances where climate change may lead to increased nitrification of source water.

In addition, in cases where drought or source degradation require a water system to seek an alternate water source, any new source must be evaluated to ensure that the system will be able to deliver water that complies with the Chemical Phase Rules.

1.7. Contaminant candidate list and regulatory determinations

EPA is required by SDWA, as amended, to periodically publish a list of microbial and chemical contaminants that are not regulated as drinking water contaminants but are known or considered likely to occur in water systems and thus are candidates for regulation (74 FR 51850; U.S. EPA, 2009c). The third and most recent Candidate Contaminant List (CCL 3) included 104 chemical contaminants and contaminant groups, as well as 12 microbial contaminants: adenovirus, caliciviruses, enterovirus, Hepatitis A virus, Mycobacterium avium, *Campylobacter jejuni, Escherichia coli* (0157), *Helicobacter pylori, Legionella pneumophila, Naegleria fowleri, Salmonella enterica,* and *Shigella sonnei* (74 FR 51850; U.S. EPA, 2009c). In May 2012, EPA requested nominations of chemical and microbial contaminants for possible inclusion on the next iteration of the list, CCL 4 (77 FR 27057; U.S. EPA, 2012e).

EPA is also required by SDWA, as amended, to make regulatory determinations (as to whether or not regulation is warranted, and if so to begin developing the regulation) for at least five contaminants from each list. Regulatory determinations for select contaminants from CCL 3 are expected to be published in the 2014-2015 timeframe. In determining whether to regulate a contaminant, EPA evaluates the threat it poses to public health (including the health of sensitive subpopulations such as children, the elderly, and immunocompromised) and its known or likely occurrence in drinking water or source water. If a national regulation of a contaminant is not warranted, EPA may choose to take some other action, such as issuing guidance to assist states in setting standards to address local contamination concerns. If circumstances warrant, EPA does not need to wait for a new CCL cycle to begin to evaluate and initiate regulation on an emerging contaminant; regulations can be promulgated “off-cycle.” The CCL and Regulatory Determinations programs provide a flexible mechanism to identify and respond to emerging threats to drinking water quality as climatic conditions change over time.

1.8. Underground injection control

The capture and injection of CO_2 produced by human activities for storage via long-term geologic sequestration is one of a portfolio of options that are expected to reduce CO_2 emissions to the atmosphere from large stationary sources of GHG emissions. Geologic sequestration that may occur from future carbon pollution stationary-source standards under the authority of the CAA must be performed in a manner that safeguards underground sources of drinking water as required by the SDWA. In November 2010, EPA finalized “Federal Requirements Under the Underground Injection Control for Carbon Dioxide Geologic Sequestration Wells” (U.S. EPA, 2011) under the authority of SDWA’s Underground Injection Control (UIC) Program. These requirements, also known as the Class VI Rule, are designed to protect underground sources of drinking water from CO_2-injection related activities. The Class VI Rule builds on existing UIC Program requirements, with extensive tailored requirements that address carbon dioxide injection for long-term storage to ensure that wells used for geologic sequestration are appropriately sited, constructed, tested, monitored, funded, and closed. The Rule also affords owners or operators the injection depth flexibility to address injection in various geologic settings in the U.S. in which geologic sequestration may occur, including very deep formations and oil and gas fields that are transitioned for use as CO_2 storage sites.

UIC program also regulates injection of production water, reclaimed water, or storm water into underground formation for storage and later retrieval. The practice, known as aquifer storage and recovery (ASR), can be used to reduce the water supply vulnerability due to climate-induced water availability problem and strong seasonable variations. However, ASR is known to associate with groundwater quality concerns. The holding aquifer can be contaminated from micro-contaminants from injected water, such as personal care products, and from remobilization of indigenous contaminants (e.g., As) in the formation materials.

2. Clean Water Act and Regulations

The Clean Water Act (CWA) is the principal law governing the physical, chemical, and biological condition of waters of the United States (33 U.S.C. Section 1251(a); CWA Section 101(a)). Enacted in 1948 as the Federal Water Pollution Control Act, the CWA was revised by amendments in 1972. The 1972 amendments created a framework for regulating pollutant discharge to the nation's waters for implementation at federal and state level. Although additional amendments enacted in 1977, 1981, and 1987 modified some provisions, the basic elements of the 1972 amendments remain in effect today.

The overall goal of the CWA is to restore and maintain the chemical, physical, and biological integrity of the waters of the United States. A broad set of regulatory, financial, and technical assistance programs have been established to meet this goal and other CWA mandates. Key federal and state water quality based pollution control programs mandated by the CWA include:

- Water quality standards (WQS) programs that establish acceptable surface water conditions and goals;
- Monitoring and assessment programs that inventory and report on the condition of surface waters and attainment of water quality standards;
- National Pollutant Discharge Elimination System (NPDES) permit programs that regulate pollutant discharges from point sources such as wastewater outfalls and stormwater runoff;
- Total Maximum Daily Load (TMDL) programs that maintain lists of impaired waters and develop pollutant budgets (i.e., TMDLs) for impaired waters;
- Clean Water State Revolving Fund (CWSRF) programs that finance water infrastructure projects that improve water quality; and
- Section 319 Nonpoint Source Management Programs fund projects that reduce or prevent polluted runoff from nonpoint sources such agricultural runoff.

The primary relevance of the CWA to climate change is the regulatory and non-regulatory mechanisms it offers for managing climate change impacts to surface waters rather than climate change mitigation (i.e., reduction of GHG emissions) (Craig, 2010). Recognizing the fundamental link between climate and aquatic ecosystem conditions, EPA and states have already begun to incorporate climate change considerations in CWA program planning and implementation (U.S. EPA, 2012f). This section outlines key CWA sections that relate to water infrastructure and their relevance to climate change adaptation.

2.1. Water quality standards

Section 303(c) of the CWA sets forth requirements for establishing WQS for U.S. waters. In general, a WQS must specify:

- The designated uses of a water body (e.g., public water supply, recreation, wildlife protection/propagation, etc.);
- The water quality criteria necessary to protect those designated uses (i.e., numeric standards or narrative statements describing desired chemical, physical, or biological conditions); and
- Anti-degradation provisions that outline policies for protecting existing uses and preventing degradation when conditions are better than minimum criteria.

States are assigned primary responsibility for WQS development with oversight from EPA. The standards established by a state serve as a foundation for other water quality management strategies and decisions, including those affecting stormwater and wastewater operations such as NPDES permitting and TMDL development.

WQS can be used to address climate change impacts in several ways. New WQS may be established as climate-driven pollutant loading issues emerge and existing WQS can be updated to reflect current climate change concepts and data. WQS revisions may include updates to each of the three WQS components (designated uses, numeric/narrative criteria, anti-degradation provisions). For example, existing water temperature criteria may be updated to reflect actual and expected climate-driven shifts in stream thermal regimes. In addition, EPA has pointed to anti-degradation policy updates as a means to protect designated uses that are particularly susceptible to climate change (U.S. EPA, 2012f). New and revised WQS can have cascading effects on stormwater and wastewater dischargers, including modifications to NPDES permits, discussed further in the following section.

2.2. NPDES permitting

CWA Section 402 established the NPDES permit program to regulate pollutant discharges to surface waters from point sources, defined as any discrete conveyance of pollutants such as pipes, ditches, or tunnels. NPDES programs are administered by authorized states or EPA and issue permits that specify allowable pollutant quantities, discharge monitoring requirements, and other provisions that must be adhered to by the permittee. NPDES permits are used to manage pollution from three major wastewater and stormwater system types:

- Separate sanitary sewer systems that collect and treat domestic sewage;
- Municipal separate storm sewer systems (MS4s) that collect and discharge stormwater from roads, sidewalks, parking lots, etc.; and

- Combined sewer systems that collect and treat both domestic sewage and stormwater.

NPDES permits for separate sanitary sewer and combined sewer systems typically include provisions to report, minimize, and prevent SSOs and CSOs. SSOs and CSOs can occur during periods of heavy rainfall, resulting in discharge of raw sewage to surface waters and degraded water body health. Regions projected to receive more frequent and intense storm events are at-risk for increased SSO or CSO discharges. NPDES permitting offers a regulatory means for controlling the SSO and CSO events.

In 2012, the *NPDES Permit Writers' Manual* (U.S. EPA, 2010c) was updated with passages to call attention to climate change considerations when setting effluent limitations for NPDES permits. These revisions reflect a shift from the use of historic data alone to incorporating projected future conditions as well. For example, permit writers often use a critical low flow magnitude to calculate effluent limits. Critical flows have traditionally been based on historic flow data. Because past observations may not be reflective of future conditions, permit writers will now likely consider climate change projections more regularly when calculating critical flows. NPDES permits must also incorporate any new or revised WQS implemented in response to climate change. For example, if water temperature criteria are established for a stream to mitigate the effects of climate-driven temperature changes on stream biota, these criteria will be used by permit writers when determining thermal limits for dischargers.

2.3. TMDL development

Section 303(d) of the CWA requires states to develop a list of impaired waters (those waters not meeting applicable water quality standards) and to develop one or more TMDLs for each impaired water body. A TMDL is the maximum quantity of a pollutant that a water body can receive while still meeting water quality standards. A TMDL also allocates that pollutant load between pollutant sources, with point sources receiving a wasteload allocation (WLA) and nonpoint sources receiving a load allocation (LA). The WLAs established by a TMDL can require revisions to discharge limits and other provisions in NPDES permits for wastewater and stormwater systems.

Climate change has the potential to increase the number of water body impairments and TMDLs required due to increased stress placed on aquatic ecosystems and/or as a result of modified WQS. Future climate change can also be explicitly considered as part of the TMDL development process. TMDLs are typically calculated using historic data on stream/river flows, pollutant loads, and ecological health. Climate change can be integrated into TMDL calculations by evaluating pollutant loads and impacts under a range of projected climatic shifts. The use of climate change projections may result in WLAs and LAs that differ from those calculated if static climate conditions were assumed. Furthermore, climate change may be factored into decisions on the specific water quality target used to determine the TMDL. Although water quality targets are usually equivalent to criteria set forth in water quality standards, alternative targets may be used where water quality standards have not been updated to reflect climate change impacts. Finally, because TMDLs follow an adaptive management approach, existing TMDLs may be revisited and revised to incorporate actual and expected climate change data.

2.4. CWSRF and NPS program funding

The 1987 CWA amendments introduced two important sources for financing clean water projects, the CWSRF program and the Section 319 Nonpoint Source (NPS) program. The CWSRF program provides federal dollars to states for administering low-cost loans and grants to a wide range of water quality improvement projects, including wastewater and stormwater infrastructure upgrades. Section 319 NPS program funds are allocated to state grant programs that focus exclusively on nonpoint source pollution control projects, such as implementation of Best Management Practices (BMPs).

The CWSRF and Section 319 NPS program both have the potential to serve as key funding sources for projects that increase the resiliency of wastewater and stormwater infrastructure to climate change. For example, the CWSRF can fund infrastructure upgrades to prevent SSOs or CSO during large rainfall events. The CWSRF also sets aside a portion of funds for green infrastructure projects in the Green Project Reserve (GPR). The GPR and Section 319 grants can fund stormwater BMPs that prevent runoff from entering sewer systems such as bioretention basins, constructed wetlands, and pervious pavement.

3. Clean Air Act

A comprehensive response to climate change includes both adaptation and mitigation. Under the Clean Air Act, EPA has enacted regulatory actions to control air pollutant emissions including GHG. This section provides an overview of EPA's regulatory efforts that also have implications for water resources management and water infrastructure adaptations. A complete analysis of the impact of regulatory programs on water resources from the Nation's energy productions is provided in an EPA companion report (EPA, 2014o).

3.1. Greenhouse gas regulations under the Clean Air Act

On December 7, 2009, the EPA Administrator signed an Endangerment Finding and a Cause or Contribute Finding for GHG under section 202(a) of the CAA (U.S. EPA, 2009a). Six well-mixed GHGs in the atmosphere were found to threaten public health and welfare. Additionally, emissions of these gases from new motor vehicles were found to contribute to GHG pollution (which, again, threatens public health and welfare).

In response to the fiscal year (FY) 2008 Consolidated Appropriations Act (U.S. Congress, 2007), EPA established the Greenhouse Gas Reporting Program (GHGRP) (U.S. EPA, 2009b), which requires reporting of GHG data and other relevant information from fossil fuel suppliers, industrial gas suppliers, direct GHG emitters, and manufacturers of heavy-duty and off-road vehicles and engines. The regulations do not require control of GHG. Rather, the purpose of the regulations was to collect accurate and timely GHG data to inform future policy decisions. Entities emitting 25,000 metric tons or more per year of GHGs are required to submit annual reports to EPA. GHG emissions reporting under GHGRP began to phase in with the 2010 reporting year. Currently, 41 source categories are required to report GHG emissions under GHGRP. In January 2012, EPA made the first year of GHGRP reporting data available to the public through its interactive Data Publication Tool, called Facility Level Information on GreenHouse gases Tool (FLIGHT) (U.S. EPA, 2012a). EPA will continue to update the tool and release additional data each reporting year.

3.2. Transportation and mobile source greenhouse gas regulations

In 2010, EPA established the first regulatory limits for GHG emissions in the U.S. as part of a joint regulatory effort between EPA and U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA). The regulation established GHG emissions standards and corporate average fuel economy standards for model year 2012 through 2016 passenger cars, light-duty trucks, and medium-duty passenger vehicles (U.S. EPA, 2010a). The EPA GHG standards require these vehicles to meet an estimated combined average emissions level of 250 grams of carbon dioxide (CO_2) per mile in model year 2016. This standard would be equivalent to 35.5 miles per gallon (mpg) if the automotive industry were to meet this CO_2 level exclusively through fuel economy improvements. In 2012, EPA extended this program to the 2017 through 2025 model years (U.S. EPA, 2012b). The final standards are projected to result in an average industry fleet-wide level of 163 grams/mile of carbon dioxide (CO_2) in model year 2025, which would be equivalent to 54.5 miles per gallon (mpg) if achieved exclusively through fuel economy improvements.

In 2011, EPA and NHTSA established a first-ever program to reduce GHG emissions and improve the fuel efficiency of heavy-duty trucks and buses in the U.S. (U.S. EPA, 2011). The regulations included CO_2 emissions standards for combination tractors (semi-trucks), vocational vehicles (trucks and buses), heavy-duty pickup trucks, and vans.

3.3. Stationary source greenhouse gas regulations

EPA has also published a set of regulations under the CAA for stationary source GHG mitigation. In 2010, EPA issued the Greenhouse Gas Tailoring Rule to address GHG emissions from stationary sources under CAA permitting programs (U.S. EPA, 2010b). These regulations set thresholds for GHG emissions that define when permits under the New Source Review, Prevention of Significant Deterioration (PSD), and Title V Operating Permit programs are required for new and existing industrial facilities. This final rule "tailors" the requirements of these CAA permitting programs to limit which facilities will be required to obtain PSD and title V permits. Facilities responsible for nearly 70 percent of the national GHG emissions from stationary sources will be subject to permitting requirements under this rule. This includes the nation's largest stationary GHG emitters—electric power plants, refineries, and cement production facilities. These regulations do not cover emissions from small farms, restaurants, and all but the very largest commercial facilities.

In 2012, EPA proposed the Carbon Pollution Standard for New Power Plants (U.S. EPA, 2012c), which set national limits on the amount of CO_2 that could be emitted from new power plants. In early 2014, EPA withdrew the proposed regulations (U.S. EPA, 2014a) and issued a new proposal to establish national CO_2 emission standards (U.S. EPA, 2014b). If adopted, this program will establish new national limits on the amount of carbon pollution emitted by future fossil fuel-fired electric utility generating units (EGUs). For purposes of this rule, fossil fuel-fired EGUs include utility boilers, integrated gasification combined cycle (IGCC) units and certain natural gas-fired stationary combustion turbine EGUs that generate electricity for sale and are larger than 25 megawatts (MW). Under this program, new natural-gas-fired combustion turbines would need to meet an output-based standard of 1,000 pounds of CO_2 per megawatt-hour (lb CO_2/MWh gross) for large plants (>850 mmBTU/hr) or 1,100 lb CO_2/MWh-gross for smaller plants (≤850 mmBtu/hr). Fossil fuel-fired utility boilers and IGCC units would need to meet an output-based standard of 1,100 lb CO_2/MWh-gross over a 12-operating month period, or an option to meet a standard of 1,000-1,050 lb CO_2/MWh-gross over 7-year period. The optional standard with a 7-year compliance period allows sources to phase in the use of partial carbon capture and sequestration (CCS). The owner/operator can then use some or all of the initial 7-year compliance period to optimize the combined sewer system (CSS).

Nearly all (95 percent) of the natural gas combined cycle (NGCC) units built since 2005 are at or below 1,000 lb CO_2/MWh-gross, so it is anticipated that new NGCC units would be able to meet the proposed standards without additional CO_2 emission controls. New power plants that are designed to use coal or petroleum coke would need to incorporate technology such as CSS with geological storage to reduce CO_2 emissions sufficiently to meet the proposed standards.

In June 2014, EPA also proposed new regulations to reduce carbon pollution from existing power plants by 30 percent by 2030 when compared to 2005 carbon emissions (U.S. EPA, 2014c). The regulation would establish state goals to reduce the carbon intensity of the covered fossil-fuel fired power plants in any given state. EPA identified four measures available to significantly reduce carbon intensity from the power sector:

- Improving efficiency at existing coal-fired power plants
- Increasing utilization of existing natural gas fired power plants
- Expanding the use of wind, solar, or other low- or zero-emitting alternatives, and
- Increasing energy efficiency in homes and businesses.

By looking at the mix of power sources and the ability of each state to take advantage of any of the four carbon pollution reduction measures, EPA calculated goals for each state. The proposed state goals were based upon a consistent national formula and calculated using specific information about the state’s or its region’s individual power profile. The result of the equation is the state goal. Each state goal is a rate – a pollution-to-power ratio – for the future carbon intensity of covered existing fossil-fuel-fired power plants in that state. States can meet their goal using any measures available to them—they do not have to use all the measures EPA identified, and they can use other approaches that will work to bring down the carbon intensity rate. The proposed regulations also include regulatory flexibility that would allow states to work individually to develop plans to reduce carbon-intensity of power generation or to collaborate with other states to develop multi-state plans.

3.4. Water resources impacts from energy and air-related programs

A recent EPA report (EPA, 2014o) describes the impact of traditional and alternative energy production on water resources in the context of air and fuel programs. The intensity of water use via consumptive water loss for the major forms of thermoelectric generation in the U.S. were assessed from detailed engineering analyses. Note that the lower values within the ranges for nuclear and coal systems represent older single-pass (i.e., no cooling tower with direct discharge of cooling water) systems that are being phased out of use due to EPA regulations limiting water discharge temperatures. With respect to general trends, transitioning electric generation from coal-fired power plants to plants with IGCC/CO_2-capture represents an opportunity to reduce water use intensity by approximately 50 percent per plant that is transitioned. Transitioning from coal or natural gas-fired boilers (Rankine cycle) to NGCC represents an opportunity to reduce water intensity by approximately 75 percent per plant that is transitioned (EPA, 2014o). In these areas, reducing the carbon intensity of electric power generation is expected to provide significant opportunities to simultaneously reduce water use. Reductions in water use would include efficiency improvements, shifting to increased use of renewable or zero-carbon-emission alternatives, and shifting to types of thermoelectric generation that offer both reduced carbon-intensity and reduced water consumption.

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Appendix I-B

Results or ranking matrix distributed to utility directors at 2008 Five Cities Plus Conference

Background: Executive directors (or a designee) for wastewater utilities at six municipalities in the Midwest attended the **Five Cities Plus Conference** in Columbus Ohio on June 6, 2008 and completed the matrix ranking exercise. The six participants represented the Cities of Cincinnati, Columbus, Fort Wright, Indianapolis, Louisville and St. Louis.

Results: Nine of 20 issues received above-average scores and are shaded below. The extreme high and low rankings are also identified. With a total of 28 points (maximum possible = 30), the prospect of declining state or federal aid emerged as the single *highest* priority concern of these six regional wastewater utilities. Conversely, tied with 8 points each (minimum possible = 6), the two *lowest* priority concerns of these six regional wastewater utilities were: [i] prospect of privatization and [ii] regional conflicts over water use.

Specific Issue Affecting Your WW Utility Operation Over Next 50 Years	Line Score	Very Serious [5]	[4]	Somewhat Serious [3]	[2]	Not Serious [1]
[01] Aging water system infrastructure	27	✓✓✓✓	✓	✓		
[02] Climate change	17		✓	✓✓✓	✓✓	
[03] CSOs and/or SSOs	27	✓✓✓✓	✓	✓		
[04] Decline in local revenue stream	26	✓✓✓	✓✓	✓		
[05] Decline in state or federal aid	**28**	✓✓✓✓	✓✓			
[06] Emergency plans for storms/hurricane	16		✓	✓✓	✓✓✓	
[07] Endangered species	11		✓	✓		✓✓✓✓
[08] Inadequate treatment capacity	16		✓✓		✓✓✓✓	
[09] Increased cost of energy	26	✓✓	✓✓✓✓			
[10] Infiltration and Inflow (I/I)	23	✓✓	✓	✓✓✓		
[11] Lack of skilled work force	23	✓	✓✓✓	✓✓		
[12] Lack of asset management plan	19	✓	✓	✓✓	✓✓	
[13] Prospect of privatization	**8**				✓✓	✓✓✓✓
[14] Nutrients and pharmaceuticals	24	✓	✓✓✓✓	✓		
[15] Outdated technology/equipment	18		✓✓	✓✓	✓✓	
[16] Reduced flow in receiving water body	13		✓	✓	✓✓	✓✓

[17] Regional conflicts over water use	**8**			✓		✓✓✓✓✓
[18] Stringent government regulations	22	✓	✓✓✓	✓	✓	
[19] Vulnerability to cyber attacks	14			✓✓✓	✓✓	✓
[20] Vulnerability to physical attacks	15			✓✓✓✓	✓	✓
Total Column Tally Count	120	23	30	29	21	17
Total Column Score	381	115	120	87	42	17

Notes: [1] The average line score for all 20 issues is (381)/(20) = 19.05
[2] Issues that scored above average (i.e., line score > 19.05) are highlighted above.
[3] A complete list of ranked results is presented in Table 4.5
[4] Issue #21 "Other" received no votes and was eliminated from further consideration.

Appendix I-C

One-line questionnaire for drinking water industry

WINS: Water Infrastructure National Survey (AMWA-Drinking Water)

1. Motivation

****
This survey is about the Nation's DRINKING WATER infrastructure.
A printed version of this survey accompanied the email with the hot link to this site.
After reviewing the printed version, the on-line version can be completed in 30 minutes.
****

The University of Cincinnati, with support from USEPA's Office of Research and Development, is conducting a national assessment to identify and analyze the most important factors that may affect the performance of public and private water and wastewater systems in the US over the next 50 years. This information will be used, in part, to help USEPA define and prioritize directions for innovative research on sustainable urban water infrastructure.

Factors affecting your drinking water infrastructure might include, among other things, climate change, population growth, economic pressures, funding shortfalls, institutional changes and regulatory requirements.

We believe the best way to identify these and other factors is with feedback from the members of the Association of Metropolitan Water Agencies (AMWA) who deal with these issues every day.

Please take a moment to complete this ANONYMOUS survey to help us understand which issues are most important and which deserve research priority as you develop plans for renovating, restoring, replacing and expanding your water resources infrastructure in the years ahead.

"Exact" answers are not required; in many cases an order-of-magnitude approximation is acceptable. Some questions can be left blank, if you choose.

You can save your responses and return to the survey at a later time. The survey will remain open until August 31, 2008.

Be assured that there is no way to trace any particular response back to any participating utility. Pooled results from this anonymous survey will be shared with the AMWA executive office by October 1, 2008.

++

[Last revision on July 8, 2008]

++

2. Utility Profile

1. What is the approximate size of your service area (sq mi)?

	0 to 10	10 to 100	100 to 1,000	1,000 to 10,000	over 10,000
in 2008	○	○	○	○	○
in 2028	○	○	○	○	○

2. Approximately, how many meter connections do you have in 2008?

Number of Connections

3. Approximately, how many people do you serve in 2008?

Number of People

Page 1

WINS: Water Infrastructure National Survey (AMWA-Drinking Water)

4. Approximately, what percentage growth in the number of "people served" do you expect in the next 20 years?

	less than 0	0 to 10	10 to 50	50 to 100	greater than 100
Percentage Growth	◯	◯	◯	◯	◯

5. Approximately, what percentage of your service population is wholesale?

	0 to 20	20+ to 40	40+ to 60	60+ to 80	80+ to 100
in 2008	◯	◯	◯	◯	◯
in 2028	◯	◯	◯	◯	◯

6. How many people do you employ?

	0 to 9	10 to 99	100 to 499	500 to 999	over 1,000
in 2008	◯	◯	◯	◯	◯
in 2028	◯	◯	◯	◯	◯

7. What is your system-wide AVERAGE DAILY flow (MGD)?

in Summer 2008

in Summer 2028

in Winter 2008

in Winter 2028

8. What is your system-wide MAXIMUM DAILY flow (MGD)?

in Summer 2008

in Summer 2028

in Winter 2008

in Winter 2028

9. What is your primary source of water?

	surface water	ground water	sea water	unknown	other
in 2008	◯	◯	◯	◯	◯
in 2028	◯	◯	◯	◯	◯

If "other" please specify

10. Approximately, what is the average annual temperature (F) in your region?

	less than 40	40 to 50	50 to 60	60 to 70	greater than 70
Average Temp (F)	◯	◯	◯	◯	◯

11. Approximately, what is the average annual precipitation (inches) in your region?

	less than 10	10 to 25	25 to 40	40 to 55	greater than 55
Average Precip (in)	◯	◯	◯	◯	◯

3. Current Infrastructure and Operation (Excluding Wholesale Business)

1. How many water treatment plants do you operate?

	1	2	3	4	5 or more
Number of WTP	◯	◯	◯	◯	◯

WINS: Water Infrastructure National Survey (AMWA-Drinking Water)

2. What is the total design capacity of all the treatment plants in your drinking water system (MGD)?

3. What types of drinking water treatment unit processes do you utilize? (Check all that apply)

- [ ] Bank Filtration
- [ ] Contact Tank
- [ ] Diatomaceous Earth Filtration
- [ ] Filtration
- [ ] Flocculation
- [ ] Granular Activated Carbon (GAC)
- [ ] Microfiltration/Ultrafiltration (MF/UF)
- [ ] Nanofiltration
- [ ] Ozone Chamber
- [ ] Presedimentation Basin
- [ ] Rapid Mix
- [ ] Settling Basin
- [ ] Slow Sand Filtration
- [ ] UV Disinfection

Other (please specify)

4. How many pumping stations do you have in your drinking water distribution system?

5. How many storage tanks for finished water do you have in your drinking water distribution system?

6. What is the total capacity of all storage tanks for finished water in your distribution system (MG)?

7. Approximately, how many miles of pipe do you have in your drinking water system?

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WINS: Water Infrastructure National Survey (AMWA-Drinking Water)

8. Approximately, what percentage of the miles of pipe in your water distribution system is constructed with the following materials (numbers should total to 100):

Asbestos Cement

Cast Iron

Ductile Iron

Concrete

Steel

Polyvinyl Chloride (PVC)

High Density Polyethylene (HDP)

Other

9. Considering all the miles of pipe in your water distribution system, approximately what percentage is greater than 50 years old?

	0 to 15	16 to 30	31 to 45	46 to 60	greater than 60
Percentage	◯	◯	◯	◯	◯

10. Considering all the miles of pipe in your water distribution system, what is the approximate annual breakage rate (breaks per mile per year)?

	less than 0.1	0.1 to 0.25	0.25 to 0.5	0.5 to 1.0	greater than 1.0
Break/mile/year	◯	◯	◯	◯	◯

11. Considering all the miles of pipe in your water distribution system, approximately what percentage is replaced each year?

	0.0 to 0.5	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	greater than 2.0
Percentage	◯	◯	◯	◯	◯

12. Approximately what percentage of your finished water is unaccounted for?

	0 to 5	5 to 10	10 to 15	15 to 20	greater than 20
Percentage	◯	◯	◯	◯	◯

13. This question pertains to finished water after it has been drawn from the distribution system for some initial use. Approximately, what percentage of this "grey" water is subsequently reclaimed and reused in your service area?

	0	0.1 to 5	5 to 10	10 to 20	over 20
in 2008	◯	◯	◯	◯	◯
in 2028	◯	◯	◯	◯	◯

14. On a scale of 1 (poor condition; frequent problems) to 10 (excellent condition; no problems), indicate the average overall system-wide condition and performance of your pumping stations:

	1 (poor)	2	3	4	5	6	7	8	9	10 (excellent)
Pumping Stations	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

If you assigned a score < 10, please indicate the nature of the problem(s).

WINS: Water Infrastructure National Survey (AMWA-Drinking Water)

15. On a scale of 1 (poor condition; frequent problems) to 10 (excellent condition; no problems), indicate the average overall system-wide condition and performance of your water distribution system (pipe lines only):

	1 (poor)	2	3	4	5	6	7	8	9	10 (excellent)
Distribution System	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

If you assigned a score < 10, please indicate the nature of the problem(s).

16. On a scale of 1 (poor condition; frequent problems) to 10 (excellent condition; no problems), indicate the average overall system-wide condition and performance of your water storage tanks:

	1 (poor)	2	3	4	5	6	7	8	9	10 (excellent)
Storage Tanks	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

If you assigned a score < 10, please indicate the nature of the problem(s).

17. On a scale of 1 (poor condition; frequent problems) to 10 (excellent condition; no problems), indicate the average overall system-wide condition and performance of your drinking water treatment plants:

	1 (poor)	2	3	4	5	6	7	8	9	10 (excellent)
Drinking Water Treatment Plants	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

If you assigned a score < 10, please indicate the nature of the problem(s).

18. Excluding "routine" pipe repairs, indicate the approximate year of the last major upgrade to your facilities (e.g., WTP, storage tank, major transmission line, etc)

	prior to 1990	1990 to 1994	1995 to 1999	2000 to 2004	since 2005
Time Period	◯	◯	◯	◯	◯

19. Have you requested VOLUNTARY water conservation in the past 10 years?

- ◯ Yes
- ◯ No
- ◯ Unsure

20. Have you imposed MANDATORY water conservation in the past 10 years?

- ◯ Yes
- ◯ No
- ◯ Unsure

WINS: Water Infrastructure National Survey (AMWA-Drinking Water)

21. Have you issued a boil water directive in the past 10 years?

- Yes
- No
- Unsure

22. Are you using a formal asset management program in your drinking water treatment, storage and distribution operations?

- Yes
- No
- Unsure

4. Agents of Change

1. Listed below are six very general categories for issues that may affect the operation of your utility and perhaps require changes in your drinking water infrastructure over the next 40 years. These changes might include upgrades, expansions, replacements, repairs, rehabilitation or possibly downsizing and decommissioning. Please rank the six categories in their relative order of importance according to their anticipated impact on the operation of your infrastructure.

	1 (most important)	2	3	4	5	6 (least important)
Climate Change	◯	◯	◯	◯	◯	◯
Economic Constraints	◯	◯	◯	◯	◯	◯
Environmental Regs	◯	◯	◯	◯	◯	◯
Institutional Change	◯	◯	◯	◯	◯	◯
Lack of Federal Funds	◯	◯	◯	◯	◯	◯
Population Growth	◯	◯	◯	◯	◯	◯

2. Please use this space to elaborate on your rankings and/or to add other factors not mentioned in Question 1. Additional space for other comments is included at the end of this survey.

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WINS: Water Infrastructure National Survey (AMWA-Drinking Water)

3. Listed below are ten specific problems which may adversely affect the operation of your drinking water utility over the next 50 years. Please rank the ten problems according to the seriousness of their anticipated impact on the operation and sustainability of your drinking water utility.

	1 (most serious)	2	3	4	5	6	7	8	9	10 (least serious)
Aging Water System Infrastructure	○	○	○	○	○	○	○	○	○	○
Decline in Revenue Stream	○	○	○	○	○	○	○	○	○	○
Impaired Source Water Quality	○	○	○	○	○	○	○	○	○	○
Inadequate Treatment Capacity	○	○	○	○	○	○	○	○	○	○
Increased Cost of Energy	○	○	○	○	○	○	○	○	○	○
Lack of Skilled Work Force	○	○	○	○	○	○	○	○	○	○
Outdated Treatment Technology	○	○	○	○	○	○	○	○	○	○
Reduced Source Water Supply	○	○	○	○	○	○	○	○	○	○
Stringent Government Regulations	○	○	○	○	○	○	○	○	○	○
Vulnerable to Cyber and Physical Attacks	○	○	○	○	○	○	○	○	○	○

4. Please use the space below to elaborate on your rankings and/or to add other factors not mentioned in Question 3. Additional space for other comments is included at the end of this survey.

5. Which scenario most closely fits your drinking water utility and its operation over the next 40 years ("size" refers to customer base, annual revenue, areal coverage, utility assets, employee pool, etc):

- ○ Utility size is likely to increase.
- ○ Utility size is likely to remain unchanged.
- ○ Utility size is likely to decrease.
- ○ Unsure about future utility size.

Use this space to elaborate on your answer (optional):

5. Thinking Ahead

WINS: Water Infrastructure National Survey (AMWA-Drinking Water)

1. Do you have an infrastructure master plan?

- ◯ Yes
- ◯ No
- ◯ Unsure

6. Master Plan

1. What is your planning horizon (in years)

	1 to 5 yrs	5 to 10 yrs	10 to 20 yrs	20 to 30 yrs	beyond 30 yrs
Time Horizon	◯	◯	◯	◯	◯

2. When was your current infrastructure master plan prepared?

	prior to 1990	1990 to 1994	1995 to 1999	2000 to 2004	since 2005
Time Period	◯	◯	◯	◯	◯

3. What is the single largest challenge facing successful implementation of your master plan?

4. Is your infrastructure master plan available to the public?

- ◯ Yes, the complete plan is available.
- ◯ Yes, but only a summary is available.
- ◯ No, it is not available.
- ◯ Unsure.

7. Next Steps

1. Please use this space to add any other comments that you think are important regarding the performance and sustainability of your drinking water infrastructure.

2. Would you be willing to participate in a short follow-up survey about your water infrastructure?

- ◯ Yes (you then will be asked to provide contact information)
- ◯ No (you then will be directed to the end of the survey)

8. Contact Information

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WINS: Water Infrastructure National Survey (AMWA-Drinking Water)

1. You arrived on this page because you opted to participate in a short follow-up survey, to be distributed within the next 12 months.

Please provide the contact information requested below.

Be assured, the anonymity of your previous responses in this survey will be preserved.

Your contact information will not be linked with or traceable to any responses you have provided.

Your contact information will be treated as confidential data and will not be shared with anyone under any circumstances.

If you decide not to provide any contact information, simply return to Question 2 in Section 7 and select "No".

==

Name:

Company:

Address:

Address 2:

City/Town:

State:

ZIP/Postal Code:

Country:

Email Address:

Phone Number:

9. Thank You !

This is the last page of the national DRINKING WATER infrastructure survey.

You can return any time before August 31, 2008 to modify/update your responses.
(Just use the hot link provided in the email from AMWA).

Your participation is vital to the success of this national assessment.

Results of this anonymous survey will be provided to the AMWA Executive Office by October 1, 2008.

To exit from the survey, please clink the "Done" button below.

Appendix I-D

One-line questionnaire for wastewater industry

WINS: Water Infrastructure National Survey (NACWA)

1. Motivation

****

This survey is about the Nation's WASTEWATER infrastructure.
A printed version of this survey accompanied the email with the hot link to this site.
After reviewing the printed version, the on-line version can be completed in 30 minutes.

****

The University of Cincinnati, with support from USEPA's Office of Research and Development, is conducting a national assessment to identify and analyze the most important factors that may affect the performance of public and private water and wastewater systems in the US over the next 50 years. This information will be used, in part, to help USEPA define and prioritize directions for innovative research on sustainable urban water infrastructure.

Factors affecting your wastewater infrastructure might include, among other things, climate change, population growth, economic pressures, funding shortfalls, institutional changes and regulatory requirements.

We believe the best way to identify these and other factors is with feedback from the members of the National Association of Clean Water Agencies (NACWA) who deal with these issues every day.

Please take a moment to complete this ANONYMOUS survey to help us understand which issues are most important and which deserve research priority as you develop plans for renovating, restoring, replacing and expanding your water resources infrastructure in the years ahead.

"Exact" answers are not required; in many cases an order-of-magnitude approximation is acceptable. Some questions can be left blank, if you choose.

You can save your responses and return to the survey at a later time. The survey will remain open until June 30, 2008.

Be assured that there is no way to trace any particular response back to any participating utility. Pooled results from this anonymous survey will be shared with the NACWA executive office by October 1, 2008.

++

[Last revision on June 2, 2008]

++

2. Utility Profile

1. What is the approximate size of your service area (sq mi)?

	0 to 10	10 to 100	100 to 1,000	1,000 to 10,000	over 10,000
in 2008	◯	◯	◯	◯	◯
in 2028	◯	◯	◯	◯	◯

2. Approximately, how many service connections do you have in your collection system in 2008?

Number of Connections

3. Approximately, how many people do you serve in 2008?

Number of People

WINS: Water Infrastructure National Survey (NACWA)

4. Approximately, what percentage growth in the number of "people served" do you expect in the next 20 years?

	less than 0	0 to 10	10 to 50	50 to 100	greater than 100
Percentage Growth	◯	◯	◯	◯	◯

5. How many people do you employ?

	0 to 9	10 to 99	100 to 499	500 to 999	over 1,000
in 2008	◯	◯	◯	◯	◯
in 2028	◯	◯	◯	◯	◯

6. What is your system-wide AVERAGE DAILY flow (MGD)?

in Summer 2008 ____

in Summer 2028 ____

in Winter 2008 ____

in Winter 2028 ____

7. What is your system-wide MAXIMUM DAILY flow? (MGD)

in Summer 2008 ____

in Summer 2028 ____

in Winter 2008 ____

in Winter 2028 ____

8. Approximately, what is the average annual temperature (F) in your region?

	less than 40	40 to 50	50 to 60	60 to 70	greater than 70
Average Temp (F)	◯	◯	◯	◯	◯

9. Approximately, what is average annual precipitation (inches) in your region?

	less than 10	10 to 25	25 to 40	40 to 55	greater than 55
Average Precip (in)	◯	◯	◯	◯	◯

3. Current Infrastructure and Operation

1. How many wastewater treatment plants do you operate?

____

2. What is the total design capacity of all the treatment plants in your wastewater system (MGD)?

____

WINS: Water Infrastructure National Survey (NACWA)

3. What types of treatment unit processes do you utilize? (Check all that apply)

- [ ] Activated Sludge
- [ ] Adsorption
- [ ] Aerated Lagoons
- [ ] Anaerobic Digestors
- [ ] Chemical Precipitation
- [ ] Disinfection
- [ ] Filtration
- [ ] Flotation
- [ ] Gas Stripping
- [ ] Nutrient Removal
- [ ] Ozone Chamber
- [ ] Rotating Biological Contactors
- [ ] Screening
- [ ] Sedimentation
- [ ] Stabilization Ponds
- [ ] Trickling Filter
- [ ] UV Light

Other (please specify)

4. How many pumping stations do you operate in your wastewater collection and treatment system?

5. Approximately, how many miles of pipe do you have in your collection system?

WINS: Water Infrastructure National Survey (NACWA)

6. Approximately, what percentage of the miles of pipe in your wastewater collection system is constructed with the following materials? (numbers should total to 100):

Asbestos Cement

Cast Iron

Ductile Iron

Concrete

Steel

Polyvinyl Chloride (PVC)

High Density Polyethylene (HDP)

Other

7. Considering all the miles of pipe in your collection system, approximately what percentage is greater than 50 years old?

	0 to 15	16 to 30	31 to 45	46 to 60	greater than 60
Percentage	◯	◯	◯	◯	◯

8. Considering all the miles of pipe in your collection system, what is the approximate annual breakage rate (breaks per mile per year)?

	less than 0.1	0.1 to 0.25	0.25 to 0.5	0.5 to 1.0	greater than 1.0
Break/mile/year	◯	◯	◯	◯	◯

9. Considering all the miles of pipe in your collection system, approximately what percentage is replaced each year?

	0.0 to 0.5	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	greater than 2.0
Percentage	◯	◯	◯	◯	◯

10. Approximately, what percentage of your system-wide wastewater stream is infiltration and inflow (I/I)?

	0 to 5	5 to 10	10 to 20	20 to 30	greater than 30
Percentage	◯	◯	◯	◯	◯

11. Approximately, what percentage of your wastewater infrastructure assets (pumps, pipes, plants, etc) is inspected each year?

	0 to 5	5 to 10	10 to 20	20 to 30	greater than 30
Percentage	◯	◯	◯	◯	◯

12. On a scale of 1 (poor condition; frequent problems) to 10 (excellent condition; no problems), indicate the average overall system-wide condition and performance of your pumping stations:

	1 (poor)	2	3	4	5	6	7	8	9	10 (excellent)
Pumping Stations	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

If you assigned a score < 10, please indicate the nature of the problem(s).

WINS: Water Infrastructure National Survey (NACWA)

13. On a scale of 1 (poor condition; frequent problems) to 10 (excellent condition; no problems), indicate the average overall system-wide condition and performance of your wastewater collection lines:

	1 (poor)	2	3	4	5	6	7	8	9	10 (excellent)
Collection Lines	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

If you assigned a score < 10, please indicate the nature of the problem(s).

14. On a scale of 1 (poor condition; frequent problems) to 10 (excellent condition; no problems), indicate the average overall system-wide condition and performance of your wastewater treatment plants:

	1 (poor)	2	3	4	5	6	7	8	9	10 (excellent)
Treatment Plants	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

If you assigned a score < 10, please indicate the nature of the problem(s).

15. Excluding "routine" pipe repairs, indicate the approximate year of the last major upgrade to your facilities (pumping station, major transmission line, WWTP, etc)

	prior to 1990	1990 to 1994	1995 to 1999	2000 to 2004	since 2005
Time Period	◯	◯	◯	◯	◯

16. Does your collection system experience sanitary sewer overflows?

- ◯ Yes
- ◯ No
- ◯ Unsure

17. Does your collection system experience combined sewer overflows?

- ◯ Yes
- ◯ No
- ◯ Unsure

18. Are you using a formal asset management program in your wastewater collection and treatment operations?

- ◯ Yes
- ◯ No
- ◯ Unsure

4. Agents of Change

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1. Listed below are six very general categories for issues that may affect the operation of your utility and perhaps require changes in your wastewater infrastructure over the next 40 years. These changes might include upgrades, expansions, replacements, repairs, rehabilitation or possibly downsizing and decommissioning. Please rank the six categories in their relative order of importance according to their anticipated impact on the operation of your infrastructure.

	1 (most important)	2	3	4	5	6 (least important)
Climate Change	○	○	○	○	○	○
Economic Constraints	○	○	○	○	○	○
Environmental Regs	○	○	○	○	○	○
Institutional Change	○	○	○	○	○	○
Lack of Federal Funds	○	○	○	○	○	○
Population Growth	○	○	○	○	○	○

2. Please use this space to elaborate on your rankings and/or to add other factors not mentioned in Question 1. Additional space for other comments is included at the end of this survey.

3. Listed below are ten specific problems which may adversely affect the operation of your wastewater utility over the next 50 years. Please rank the ten problems according to the seriousness of their anticipated impact on the operation and sustainability of your wastewater utility.

	1 (most serious)	2	3	4	5	6	7	8	9	10 (least serious)
Aging Water System Infrastructure	○	○	○	○	○	○	○	○	○	○
Decline in Local Revenue Stream	○	○	○	○	○	○	○	○	○	○
Decline in State or Federal Aid	○	○	○	○	○	○	○	○	○	○
Inadequate Treatment Capacity	○	○	○	○	○	○	○	○	○	○
Increased Cost of Energy	○	○	○	○	○	○	○	○	○	○
Lack of Skilled Work Force	○	○	○	○	○	○	○	○	○	○
Outdated Treatment Technology	○	○	○	○	○	○	○	○	○	○
Reduced Flow in Receiving Water Body	○	○	○	○	○	○	○	○	○	○
Stringent Government Regulations	○	○	○	○	○	○	○	○	○	○
Vulnerable to Cyber and Physical Attacks	○	○	○	○	○	○	○	○	○	○

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4. Please use this space to elaborate on your rankings and/or to add other factors not mentioned in Question 3. Additional space for other comments is included at the end of this survey.

5. Which scenario most closely fits your wastewater utility and its operation over the next 40 years ("size" refers to customer base, annual revenue, areal coverage, utility assets, employee pool, etc):

- ◯ Utility size is likely to increase.
- ◯ Utility size is likely to remain unchanged.
- ◯ Utility size is likely to decrease.
- ◯ Unsure about future utility size.

Use this space to elaborate on your answer (optional).

5. Thinking Ahead

1. Do you have an infrastructure master plan?

- ◯ Yes
- ◯ No
- ◯ Unsure

6. Master Plan

1. What is your planning horizon (in years)

	1 to 5 yrs	5 to 10 yrs	10 to 20 yrs	20 to 30 yrs	beyond 30 yrs
Time Horizon	◯	◯	◯	◯	◯

2. When was your current infrastructure master plan prepared?

	prior to 1990	1990 to 1994	1995 to 1999	2000 to 2004	since 2005
Time Period	◯	◯	◯	◯	◯

3. What is the single largest challenge facing successful implementation of your master plan?

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4. Is your infrastructure master plan available to the public?

- ◯ Yes, the complete plan is available.
- ◯ Yes, but only a summary is available.
- ◯ No, it is not available.
- ◯ Unsure.

7. Next Steps

1. Please use this space to add any other comments that you think are important regarding the performance of your wastewater infrastructure.

2. Would you be willing to participate in a short follow-up survey about your water infrastructure?

- ◯ Yes (you then will be asked to provide contact information)
- ◯ No (you then will be directed to the end of the survey)

8. Contact Information

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WINS: Water Infrastructure National Survey (NACWA)

1. You arrived on this page because you opted to participate in a short follow-up survey, to be distributed within the next 12 months.

Please provide the contact information requested below.

Be assured, the anonymity of your previous responses in this survey will be preserved.

Your contact information will not be linked with or traceable to any responses you have provided.

Your contact information will be treated as confidential data and will not be shared with anyone under any circumstances.

If you decide not to provide any contact information, simply return to Question 2 in Section 7 and select "No".

==

Name:

Company:

Address:

Address 2:

City/Town:

State:

ZIP/Postal Code:

Country:

Email Address:

Phone Number:

9. Thank You

This is the last page of the national WASTEWATER infrastructure survey.

You can return any time before June 30, 2008 to modify/update your responses.
(Just use the hot link provided in the email from NAWCA).

Your participation is vital to the success of this national assessment.

Results of this anonymous survey will be provided to the NAWCA Executive Office by October 1, 2008.

To exit from the survey, please clink the "Done" button below.

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